Board of Building Standards

CODE COMMITTEE MEETING
AGENDA

DATE:	FEBRUARY 24, 2022
TIME:	1:00 PM
LOCATION:	TRAINING RM 3, 6606 TUSSING RD, REYNOLDSBURG, OHIO, 43068

Call to Order

Approval of Minutes

MIN-1 January 27, 2022 Code Committee Meeting Minutes

Petitions

Recommendations of the Residential Construction Advisory Committee

Old Business

OB-1 Commercial Energy Code Review

New Business

Adjourn

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File Attachments for Item:

MIN-1 January 27, 2022 Code Committee Meeting Minutes

OHIO BOARD OF BUILDING STANDARDS
CODE COMMITTEE MINUTES
JANUARY 27, 2022

The Code Committee met on January 27, 2022 with the following members present: Mr. Denk, Mr. Miller, Mr. Pavlis, Mr. Samuelson, Mr. Stanbery, Mr. Tyler, and Mr. Yankie. Board Chairman, Tim Galvin, was also present.

The following staff members were present: Regina Hanshaw, Debbie Ohler, Robert Johnson, and Jay Richards

Guest present: Jack Wintrow of CISPI
Guests present (virtually via Teams): Eric Lacey (RECA), Nicole Westfall (MEEA), Aaron Dearth (Architect), Corie Anderson (MEEA), Ales, Troy Warnock, Laura Hunt, Ray Reich, and Jeff Mang

CALL TO ORDER

The meeting was called to order by Mr. Denk at 1:07 P.M.

APPROVAL OF MINUTES

Mr. Stanbery made the motion to approve the minutes of the Code Committee meeting held on November 18, 2021. Mr. Miller seconded the motion. The motion passed unanimously.

PETITIONS

No items for consideration

RECOMMENDATIONS OF THE RESIDENTIAL CONSTRUCTION ADVISORY COMMITTEE

At their January 26, 2022 meeting, the RCAC recommended to approve Petition #21-01 from Duane Chubb & Dana Daughters of Gamechanger Fittings LLC which sought to change the referenced OPC edition referenced in the RCO Section 4401.2 to include the updates made effective in August of 2018. Mr. Samuelson made the motion to recommend approval of the petition. Mr. Pavlis seconded the motion. The motion passed unanimously.

OLD BUSINESS

The Committee reviewed the comments that were received from stakeholders on the proposed adoption of the 2016 edition of the ASHRAE 90.1 and the 2018 edition of the IECC and invited the online guests to provide additional comment.

Mr. Lacey of the Responsible Energy Codes Alliance (RECA) was available to answer questions of the committee in response to his written comments in support of moving forward, preferably with the newest energy codes. Mr. Pavlis asked Mr. Lacey about first costs. Mr. Lacey referred the committee to PNNL’s cost effectiveness study.

Aaron Dearth, Architect from Ashland, Ohio, shared his concern about the potential impact of adopting the 2018 IECC on a warehouse building. He calculated that it will add $157,000 to the cost of a new metal building and require significant design changes.

Nicole Westfall of MEEA was available to answer questions of the committee in response to her written comments in support of moving forward with the newest energy codes. She added that it is important to move forward on modern energy codes for new buildings because they will be around for another 50-100 years and it is much more cost effective to build-in energy efficiency when the building is new.

The committee spent considerable time discussing first cost vs. life cycle cost, the lack of product availability and its effect on cost, and the possibility of carving out exceptions for certain types of buildings. Mr. Tyler mentioned that education is key and should be provided well ahead of adoption of any new energy code.

Mr. Miller made a motion to table the energy code discussion until codes and other summary materials can be provided to the committee. The committee will then perform a detailed review of the materials, focusing on the significant changes to the 2016 and 2019 editions of ASHRAE 90.1 and decide which provisions they like and which they think are problematic. Mr. Pavlis seconded the motion. The motion passed unanimously.

NEW BUSINESS

Mr. Jack Wintrow, Regional Representative of the Cast Iron Soil Pipe Institute (CISPI) introduced himself to the Committee and offered his assistance at any time, as needed.

ADJOURN

Mr. Stanbery made the motion to adjourn at 3:35 P.M. Mr. Yankie seconded the motion. The motion passed unanimously.

File Attachments for Item:

OB-1 Commercial Energy Code Review

Significant changes 2010-2013 ASHRAE 90.1 Commercial Provisions

(Sources: ASHRAE 90.1-2013 and PNNL-SA-107200)

Building Envelope

- Modifies daylighting and several other definitions
- Limits the size of vestibules and adds specific vestibule requirements for large spaces [5.4.3.4]
- Increased stringency requirements for roofs, walls, below grade walls, slab-on-grade floors [Tables 5.5-4 and 5.5-5]
- Lowers fenestration U-factors about 18% [Tables 5.5-4 and 5.5-5]
- Limits skylight area to 3%, except to 6% if daylighting criteria are met [5.5.4.2.2]

Mechanical

- Increased equipment efficiencies for air conditioners, condensing units, heat pumps, water-chillers, boilers, cooling towers, refrigerators, and freezers [6.4.1 & Tables 6.8.1]
- Reduces occupancy threshold for demand-controlled ventilation from 40 people/1000 sq ft to 25 people/1000 sq ft [6.4.3.8]
- Adds vestibule heating controls [6.4.3.9]
- Adds direct digital control (DDC) and graphical display requirements [6.4.3.10 & Table 6.4.3.10.1]
- Adds control requirements for preheat coils [6.5.2.5]
- Adds requirements for fan efficiency and controls [6.5.3]
- Adds requirements for boiler turndown ratio and efficiency [6.5.4.1]
- Reduces system size and outdoor air thresholds for energy recovery [6.5.6]
- Adds requirements for walk-in coolers, freezers and refrigerated display cases [6.4.5 & 6.5.11]
- Adds requirements for Computer room HVAC systems and introduces the Power usage Effectiveness (PUE) [6.6]

Service Water Heating

- Increases efficiency of water-heating equipment 7.5.3 & Table 7.8]

Power

- Increases the spaces where and reduces the threshold for when plug receptacle shutoff control is required [8.4.2]
- Requires electrical energy monitoring and reporting for total electrical, HVAC systems, lighting, and receptacles [8.4.3]
- Requires separate electrical energy monitoring for buildings with tenants [8.4.3.1]
- Adds specific control requirements for guestroom switched receptacles [9.4.1.3]

Lighting

- Requires the use of certain lighting controls in more space types [9.4.1]
- Increases and clarifies requirements for daylighting and daylighting controls [9.4.1.1]
- Updates and reduces the interior and exterior lighting power densities [Table 9.5.1]
- Adds specific requirements for guest room and task lighting controls [9.4.1.3]
- Adds functional testing requirements for occupant sensors, automatic time switches, and daylight controls [9.4.3]

Other Equipment

- Adds requirements for the efficiency of general-purpose motors having power rating greater than 200 hp, but no more than 500 hp [10.4.1]
- Adds power limitations for elevator cab lighting [10.4.3.1]

- Requires escalators and moving walks to slow to minimum permitted speed when not conveying passengers [10.4.4]
- Requires whole-building energy monitoring and reporting [10.4.5.1]

Energy Cost Budget Method (ECB)

- Allows credit for on-site renewable energy but limits the credit to 5% of the calculated energy cost budget [11.4.3.1]

Appendix C (Envelope tradeoff)

- Completely revamps the methodology for the building envelope trade-off option allowed in Section 5.6

Performance Rating Method (Appendix G)- an above code program

- Numerous clarifications are added for modeling

ASHRAE 90.1-2019

The 2019 edition includes various modifications and clarifications to improve internal consistency and to standardize the structure and language of the document.

Significant changes to requirements include the following

Administration and Enforcement

- New commissioning requirements in accordance with ASHRAE/IES Standard 202 [4.2.5 and Appendix H]

Building Envelope

- Combined categories of “nonmetal framed” and “metal framed” products for vertical fenestration [Tables 5.5-0 through 5.5-8]
- Upgraded minimum criteria for SHGC and U-factor across all climate zones [Tables 5.5-0 through 5.5-8]
- Revised air leakage section to clarify compliance [5.4.3 and 5.9]
- Refined exceptions related to vestibules, added new option and associated criteria for using air curtains [5.4.3.3]

Mechanical

- New requirements to allow the option of using ASHRAE Standard 90.4 instead of ASHRAE Standard 90.1 in computer rooms that have an IT equipment load larger than 10 kW [6.6.1]
- Added pump definitions [3.2], requirements [10.4.7], and efficiency tables [10.8.6] to the standard for the first time
- New equipment efficiency requirement tables and changes to existing tables [Tables 6.8.1-1 to 6.8.1-20]
- Replaced fan efficiency grade (FEG) efficiency metric with fan energy index (FEI) [6.5.3.1.3]
- New requirements for reporting fan power for ceiling fans and updated requirements for fan motor selections to increase design options for load-matching variable-speed fan applications [6.5.3.1.2]
- New energy recovery requirements for high-rise residential building [3.2 and 6.5.6]
- New requirement for condenser heat recovery for acute care inpatient hospitals [6.5.6.3]

Lighting

- Modified lighting power allowances for Space-by-Space Method and the Building Area Method [Tables 9.6.1 and 9.5.1]
- New simplified method for lighting for contractors and designers of renovated office buildings and retail buildings up to 25,000 ft2 (2300 m2). [9.3 and Table 9.3.1-1]
- Updated lighting control requirements for parking garages to account for the use of LEDs [9.4.1.2]
- Updated daylight responsive requirements, added definition for “continuous dimming” based on NEMA LSD-64-2014 [3.2 and 9.4.1.1]
- Clarified side-lighting requirements and associated exceptions [9.4.1.1]

Energy Cost Budget (ECB) Method (Section 11)

- Numerous changes to ensure continuity
- Set baseline for on-site electricity generation systems [11.4.3.1 and 11.4.3.2]

Performance Rating Method (Appendix G)

- Clarified Appendix G rules and corresponding baseline efficiency requirement when combining multiple thermal zones into a single thermal block
- New explicit heating and cooling COPs without fan for baseline packaged cooling equipment
- New rules for modeling impact of automatic receptacle controls [Table G3.1 #12]
- Set more specific baseline rules for infiltration modeling
- Clarified how plant and coil sizing should be performed
- Updated building performance factors

Both Compliance Paths

- Clearer, more specific rules for treatment of renewables [G2.4.1]
- New updates to rules for lighting modeling

Significant changes 2012→2015 IECC Commercial Provisions

(Sources: PNNL-SA-107200 and ESL-TR-14-11-02 Texas A&M Energy Systems Laboratory)

Definitions

- Adds or modifies definitions of “Air Curtain”, “Alteration”, “Approved Agency”, “Boiler, Modulating”, “Boiler System”, “Bubble Point”, “Circulating Hot Water System”, “Computer Room”, “Condensing Unit”, “Conditioned Space”, “Continuous Insulation”, “Daylight Responsive Control”, “Daylight Zone”, “Fan Efficiency Grade”, “Fenestration”, “Floor Area, Net”, “General Purpose Electric Motor”, “Greenhouse”, “Hight Speed Door”, “Historic Building”, “Liner System” , “Low Sloped Roof”, “Low-voltage Dry-Type Distribution Transformer”, “Occupant Sensor Control”, “Opaque Door”, “Powered Roof/Wall Ventilator”, “Radiant Heating System”, “Refrigerant Dew Point”, “Refrigerated Warehouse Cooler”, “Refrigerated Warehouse Freezer”, “Refrigeration System”, “Repair”, “Reroofing”, “Roof Recover”, “Roof Replacement”, “Rooftop Monitor”, “Saturated Condensing Temperature”, “Small Electric Motor”, “Time-Switch Control”, “Variable Refrigerant Flow System”, “Walk-in Cooler”, “Walk-in Freezer”, “Wall, Above-grade”, “Wall, Below-Grade”, “Water Heater”

Building Envelope

- Adds an exception for greenhouses [C402.1.1]
- Increased stringency for roof insulation installed entirely above roof deck [Table C402.1.3]
- Increased stringency for SHGC of vertical fenestration [C402.4.3]
- Expanded requirements to calculate U-factors of walls with cold-formed steel, aged roof reflectance and provisions for rooms containing fuel burning appliances [C402.5]
- Mandatory skylight threshold reduced from 10K to 2.5K square feet [C402.4.2]

Mechanical

- Improved efficiency requirements for HVAC equipment performance [Table C403.2.3(1)-C403.2.3(10)]
- Added efficiency requirements for air-conditioning units serving computer rooms [Table C403.2.3(9)]
- Elaborated and added provisions for HVAC system controls which include: requirement for zone isolation [C403.2.4.4]; and requirement of economizer fault detection [C403.2.4.7]
- Added specifications for hot water boiler outdoor temperature setback control [C403.2.5]
- Updated provisions for energy recovery ventilation systems whose requirements are now based on the number of hour’s ventilations systems operate [C403.2.7]
- Introduced specifications for kitchen exhaust systems [C403.2.8]
- Updated requirements for duct and plenum insulation and sealing [C403.2.9]
- Introduced fan efficiency requirements [C403.2.12.3]
- Added specifications for commercial refrigeration equipment [C403.2.15 and C403.5]
- Updated provisions for air and water economizers, which include added requirements for the efficient operation of these systems [C403.3]
- Updated provisions for complex mechanical systems serving multiple zones, which include updated specifications for fan controls, heat rejection equipment and hot gas bypass limitations [C403.4]

Service Water Heating

- Added performance efficiencies for certain categories of service hot water systems [Table C404.2]
- Revises and clarifies the requirements for insulation of piping [C404.4]

- Added information for implementation of efficient heated water supply piping, heated water circulating and temperature maintenance system, demand recirculation controls, drain water heat recovery systems and energy requirements of portable spas [C404.5]
- Improved specifications for energy consumption of pools and permanent spas [C404.9]
- Added commissioning requirements for hot water systems [C404.11]

Lighting and Power

- Additional provisions for lighting controls, which include the added requirement of occupant sensor controls [C405.2.1]
- New exterior and warehouse lighting control requirements [C405.2.1.2]
- Revised daylighting zone controls [C405.2.3]
- New Hotel/motel sleeping and guest suite lighting controls [C405.2.4 #3]
- Updated lighting power densities for different building area types [Tables C405.4.2]
- Specifies non-tradable components of exterior lighting [C405.5.1]
- Requires a separate meter for each Group R-2 dwelling unit [C405.6]
- Adds federal minimum efficiency requirements for electric transformers [C405.7]
- Adds federal minimum efficiency requirements for electric motors [C405.8]
- Regulates elevator cab luminaires, ventilation fans, and controls [C405.9.1]
- Requires automatic speed control and a variable frequency regenerative drive for escalators [C405.9.2]

Other Equipment

Additional Efficiency Package Options

- Adds new options for more efficient HVAC equipment performance, for reduced lighting power densities, for enhanced digital lighting controls, for dedicated outdoor air systems, and for reduced energy use in service water systems [C406.1]

Total Building Performance

- No significant changes made to this section

Commissioning

- Adds commissioning requirements and documentation submittal requirements for lighting control systems including occupant sensor controls, time control switches, and daylight responsive controls [C408.3.1]

Existing Buildings

- Moved all existing building requirements from Chapter [CE] 1 to a new Chapter [CE] 5
- Historic buildings now partially covered [C501.6]
- Replacement fenestration covered [C401.2.1]
- Requires full upgrade of roofing insulation when re-roofing [C503.1]
- Roof replacement exempt from air barrier requirements [C503.1 Exception 6]

Significant changes 2015-2018 IECC Commercial Provisions

[Sources: IECC 2018 and PNNL-SA-127543]

- Made several editorial changes to eliminate the use of the word “Accessible” (if not associated with the IBC Chapter 11 meaning of “Accessible”).
- Clarifies that commissioning is mandatory for all mechanical and hot water heating systems
- Adds additional as-built energy code documentation and owner training requirements for all buildings (typically part of the commissioning documents) …these documents must be submitted to the owner within 90 days of receipt of the Certificate of Occupancy
- Enhanced the section for required energy code inspections

Definitions

- Adds or modifies definitions of “Access (to)”, “Air Barrier”, “Captive Key Override”, “Computer Room”, “Demand Recirculation Water System”, “Group R”, “IEC Design H Motor”, “IEC Design N Motor”, “Isolation Devices”, “Luminaire-level Lighting Controls”, “NEMA Design A Motor”, “NEMA Design B Motor”, “NEMA Design C Motor”, “Networked Guestroom Control System”, “Ready Access (to)”, and “Voltage Drop”

Building Envelope

- Increased stringency requirements for heated slabs [Tables C402.1.3 and C402.1.4]
- Adds maximum U-values for garage door glazing [Table C402.1.4]
- Requires 2 staggered layers of insulation board when continuous roof insulation is installed. Also provides a new exceptions for around roof drains [C402.2.1]
- Clarifies requirements for mass walls and mass floors [C402.2.2 and C402.2.3]
- Restores section on below-grade walls [C402.2.5]
- Adds a section on airspaces [C402.2.7]
- Decreases the SHGC for fenestration in Climates zones 4 and 5 [Table C402.4]
- Raises the allowable skylight area from 5% to 6% with daylight controls [C402.4.1.2]
- Clarified topics such as sliding doors [Table C402.5.2], rooms containing fuel-burning appliances [C402.5.3], loading dock weather seals [C402.5.6]

Mechanical

- Section 403 (Building Mechanical Systems) reorganized for ease of use
- Clarifies that HVAC equipment shall not be oversized [C403.3.1]
- Eliminates outdated federal equipment efficiencies for air conditioners, heat pumps, furnaces, boilers, chillers, cooling towers, and computer room AC [Tables C403.3.2(1) - C403.3.2(10)]
- Clarified that control must be “configured to” meet the requirements, not just be “capable of” meeting the requirements [throughout]
- Clarifies that many controls requirements are “Mandatory” [throughout]
- Adds HVAC control requirements for heated or cooled vestibules [C403.4.1.4]
- Adds pump flow control requirements for chilled and hot water hydronic piping distribution systems [C403.4.3.3.2 and C403.4.4]
- Adds exceptions to economizer requirements [C403.5]
- Adds a section requiring VAV with zone controls for multiple-zone systems [C403.6.1]
- Adds control requirements for parallel-flow fan-powered VAV air terminals [C403.6.7]
- Increases the threshold design airflow rate at which energy recovery is required [Table C403.7.4(2)]
- New HVAC set point and fan control requirements for hotel and motels (Group R-1) with greater than 50 guest rooms [C403.7.6]

- Provides an allowable hp exception for fans less than or equal to 5 hp [C403.8.1]
- Prescribes motor fan speed controls for heat-rejection devices [C403.9]
- Adds federal efficiency requirements for walk-in coolers and freezers to be in effect in 2020 [C403.10.2.1]

Service Water Heating

- Increased federal water heater efficiencies [Table C404.2]

Lighting

- Adds a section for "open plan office areas" and requires occupant sensor controls [C405.2.1.3]
- Adds exceptions for lighting controls for dwelling units [C405.2.4 #3] and patient rooms [C 405.2.4 #2]
- Interior and exterior lighting power allowance have been modified (reduced) to reflect new lighting levels in the IES lighting handbook and to recognize LED technology [Tables C405.3.2(1), C405.3.2(2), and C405.4.2(2)]
- Lighting control requirements have been modified to add additional controls in some space types and options to others to allow easier application of advanced controls [C405.2]
    - Reduce exterior lighting power by 30% during periods of inactivity or after business hours [C405.2.6.3]
- Adds a requirement that 90% of permanently installed dwelling unit lighting fixtures use high efficacy lamps [C405.1]

Power

- Limits the combined voltage drop of feeder conductors and branch circuits to 5% [C405.9]

Other Equipment

- Updates electric motor terminology, adds exceptions, and adds efficiency tables consistent with federal regulations [C405.7]
- Adds an exception to allow a variable voltage drive in lieu of automatic speed control for escalators that are not conveying passengers [C405.8.2]

Additional Efficiency Package Options

- Adds options for enhanced envelope performance as determined by UA analysis [C406.8]
- Adds options for reduced air infiltration as determined by whole building air leakage testing [C406.9]

Total Building Performance

- Limits the amount of credit allowed for on-site renewable energy [C407.3]
- Limits the amount of credit allowed for renewable energy purchased from off-site sources [C407.3]

Commissioning

- Requires that building operations and maintenance documents be provided to the owner
- Requires a completed "Commissioning Compliance Checklist" with the "Preliminary Commissioning Report"

Existing Buildings

- Provides exceptions for Changes in Space Conditioning and for Changes of Occupancy

Significant changes 2018-2021 IECC Commercial Provisions

[Sources: IECC 2021]

- Changes climate zone maps resulting in 15 Ohio counties moving from Climate Zone 5 to Climate Zone 4
- Requires an insulation certificate identifying the installed R-value of insulation when the insulation of the manufacturer is not readily observable upon inspection
- Requires that a Thermal Envelope Certificate be posted in an approved location
- Clarifies and relocates all “Mandatory” and “Prescriptive” labels to a table

Definitions

- Adds or modifies definitions of “Biogas”, “Biomass”, “Data Center”, “Data Center Systems”, “Direct Digital Control”, “Enthalpy Recovery Ratio”, “Embedded Fan”, “Fan Array”, “Fan Energy Index (FEI)”, “Fan Nameplate Electrical Input Power”, “Fan System Electrical Input Power”, “Fault Detection and Diagnostics (FDD) System”, “Information Technology Equipment (ITE)”, “Internal Curtain System”, “Large Diameter Ceiling Fan”, “On-Site Renewable Energy”, “Renewable Energy Resources”, “Testing Unit Enclosure Area”, “Thermal Distribution Efficiency (TDE)”, “Vegetative Roof”, “Visible Transmittance, Annual”, and “Wall, Above-Grade”

Building Envelope

- Increased envelope stringency and clarity for conditioned greenhouses [C402.1.1.1]
- Allows certain electric equipment buildings up to 1200 ft^2 to be exempt from envelope requirements [C402.1.2]
- Recognizes and provides guidance for layered cavity insulation [C402.1.3]
- Increased stringency requirements for attic insulation, above-grade and below-grade walls, and unheated slabs [Tables C402.1.3 and C402.1.4]
- Clarifies U-factor and R-factor insulation requirements at roofs, particularly tapered above-deck insulation [C402.1.4.1 & C402.2.1]
- Adds limit of maximum of 25% glazing area for garage door [Table C402.1.4, note i]
- Increases stringency of U-values and SHGC for fenestration in CZ 4 and CZ 5 [Table C402.4]
- Clarifies skylight requirements [C402.4.2]
- Removes R-values for doors and prescribes maximum U-factors and glazing area for non-swinging doors [C402.4.5]
- Requires either air barrier inspection and commissioning or enclosure testing to verify envelope performance of buildings and provides testing methodologies [C402.5]
- Requires HVAC interlock with operable openings that are greater than 40 ft^2 and provides a few exceptions (separately zoned commercial kitchens, warehouses, and outside vestibule doors) [C402.5.11]

Mechanical

- Exempts data center systems from control and economizer requirements [C403.1]
- Requires that data center systems comply with ASHRAE 90.4 (with a few modifications) [C403.1.2]
- Requires large HVAC systems (serving $\geq$100,000 ft^2) in new buildings to provide a fault detection and diagnostics system [C403.2.3]
- Updates HVAC equipment efficiency tables (some efficiencies to go into effect on January 1, 2023) for air conditioners, heat pumps, furnaces, boilers, chillers, cooling towers, condensers, and computer room AC [Tables C403.3.2(1) - C403.3.2(16)]
- Clarifies heat pump control requirements [C403.4.1.1]

- Clarifies that automatic stop controls are also required for HVAC systems [C403.4.2.3]
- Requires two-position valve for hydronic heat pump systems to be automatic and interlocked [C403.4.3.3.3]
- Adds a Variable Refrigerant Flow (VRF) exception to economizer requirements [C403.5]
- Requires Demand Control Ventilation (DCV) whenever economizers are required [C403.7.1]
- Increases number of enclosed parking garages that will require detection and controls [C403.7.2]
- Prescribes specific enthalpy recovery ratios for dwelling unit energy recovery systems [C403.7.4.1]
- Differentiates control requirements for hotel and motels (Group R-1) based upon occupancy status of rooms and changes time-out time from 30 minutes to 20 minutes [C403.7.6]
- Requires fans and fan arrays to have a Fan Energy Index (FEI) certified IAW AMCA 208 [C403.8.3]
- Prescribes minimum efficiencies of low-capacity residential-type fans [C403.8.5]
- Recognizes Large-diameter ceiling fans [C403.9]
- Adds performance requirements for commercial refrigerators, freezers, walk-in coolers, walk-in refrigerators and refrigeration equipment [C403.11]
- Clarifies insulation requirements for underground ducts [C403.12.1]
- Prescribes control system operation for operable opening interlocks [C403.14]

Service Water Heating

- Increases minimum efficiency for large (1 M Btu/h input) individual water heating equipment to 92% [C404.2.1]

Lighting

- Clarifies what is meant by "general lighting" [C405.1]
- Requires corridor lighting to be reduced to minimum levels (no more than 50% full power) when unoccupied [C405.2.1.1 & C405.2.1.4]
- Adds a section for "warehouse storage areas" and requires occupant sensor controls [C405.2.1.2]
- Clarifies intent of light reduction control requirements [C405.2.3]
- Adds additional control requirements for the secondary side lit daylight zone [C405.2.4.2]
- Adds control requirements for parking lot luminaires [C405.2.7.3]
- Adds control requirements for parking garage lighting [C405.2.8]
- Clarifies lighting power allowance calculations, especially for projects that involve only a portion of a building and for exterior lighting [C405.3.2 & C405.5.2]]
- Interior and exterior lighting power allowance have been modified to reflect new lighting levels in the IES lighting handbook and to recognize LED technology [Tables C405.3.2(1), C405.3.2(2), and C405.4.2(2)]
- Recognizes the high energy use of plant growth lighting and requires 95% of permanent luminaires to have a minimum photon efficiency of 1.6 m mol/J [C405.4]

Power

- Limits the combined voltage drop of customer-owned service conductors, feeder conductors and branch circuits to 5% [C405.10]
- Requires automatic receptacle control of at least 50% of 125V, 15 and 20 amp receptacles in offices, conference rooms, copy/print rooms, breakrooms, classrooms, and modular workstations and 25% of branch circuit feeders for modular furniture not shown on plans [C405.11]
- Requires new buildings with $\geq$ 25,000 ft^2 to be provided with an energy monitoring system [C405.12]

Other Equipment

- Requires that escalators be designed to recover more electrical energy than is consumed when resisting overspeed in the down direction [C405.9.2.1]

Additional Efficiency Requirements [C406]

- Requires at least 10 credits by adding additional energy efficient features to the building. The credits are determined from newly added tables arranged by occupancy classification [C406.1]
- Modifies more efficient HVAC option [C406.2]
- Modifies reduced lighting power option [C406.3]
- Modifies the basic renewable energy option [C406.5]
- Adds options for energy monitoring systems, if not otherwise required [C406.10]
- Adds options for fault detection system, if not otherwise required [C406.11]
- Adds options for efficient kitchen equipment [C406.12]

Total Building Performance

- Provides a new table that outlines the code requirements that must be met when using the Total Building Performance method [Table C407.2]

Commissioning

- Allows an “approved agency” or a qualified commissioning professional to perform the commissioning activities [C408.3.1]

Existing Buildings

- Reorganizes and clarifies requirements
- Clarifies that commissioning is required for new lighting and power systems [C502.3.6]

PNNL-25032

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Cost-Effectiveness of ASHRAE Standard 90.1-2013 for the State of Ohio

December 2015

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Cost-Effectiveness of ASHRAE Standard 90.1-2013 for the State of Ohio

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Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
BTO	Building Technologies Office
DOE	U.S. Department of Energy
EIA	Energy Information Administration
FEMP	Federal Energy Management Program
HVAC	Heating, Ventilating, and Air-Conditioning
LCC	Life-Cycle Cost
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
UPV	Uniform Present Value
SWH	Service Water Heating

Highlights

Moving to the ASHRAE Standard 90.1-2013 (ASHRAE 2013) edition from Standard 90.1-2010 (ASHRAE 2010) is cost-effective for the State of Ohio. The table below shows the state-wide economic impact of upgrading to Standard 90.1-2013 in terms of the annual energy cost savings in dollars per square foot, additional construction cost per square foot required by the upgrade, and life-cycle cost (LCC) per square foot. These results are weighted averages for all building types in all climate zones in the state, based on weightings shown in Table 4. The methodology used for this analysis is consistent with the methodology used in the national cost-effectiveness analysis[1]. Additional results and details on the methodology are presented in the following sections.

Average Savings, Construction Cost and LCC (Weighted by Climate Zone and Building Type)	
Annual Cost Savings, $/ft^2	$0.144
Added Construction Cost, $/ft^2	($0.018)
Publicly-owned scenario LCC Savings, $/ft^2	$2.38
Privately-owned scenario LCC Savings, $/ft^2	$1.97

The report provides analysis of two LCC scenarios:

- **Scenario 1**, representing publicly-owned buildings, considers initial costs, energy costs, maintenance costs, and replacement costs—without borrowing or taxes.
- **Scenario 2**, representing privately-owned buildings, adds borrowing costs and tax impacts.

Figure 1 compares annual energy cost savings, first cost for the upgrade, and net annualized LCC savings. The net annualized LCC savings per square foot is the annual energy savings plus the annualized value of first cost savings under scenario 1. Figure 2 shows overall state weighted net LCC results for both scenarios. When net LCC is positive, the updated code edition is considered cost-effective.

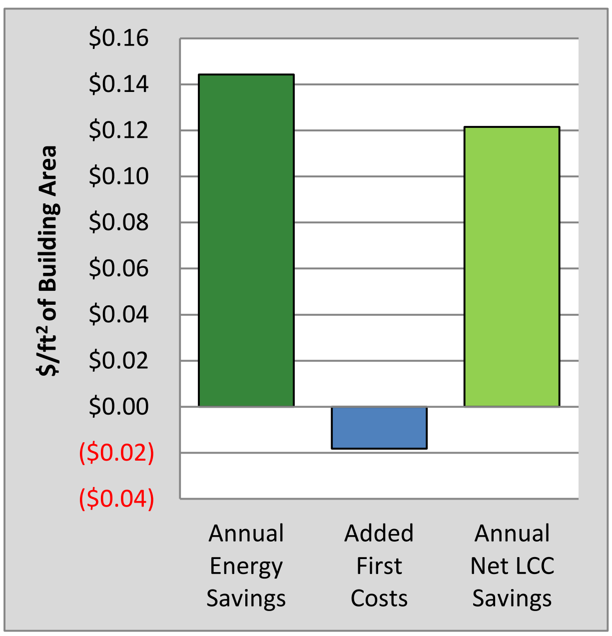

Figure 1. State-wide Weighted Costs and Savings

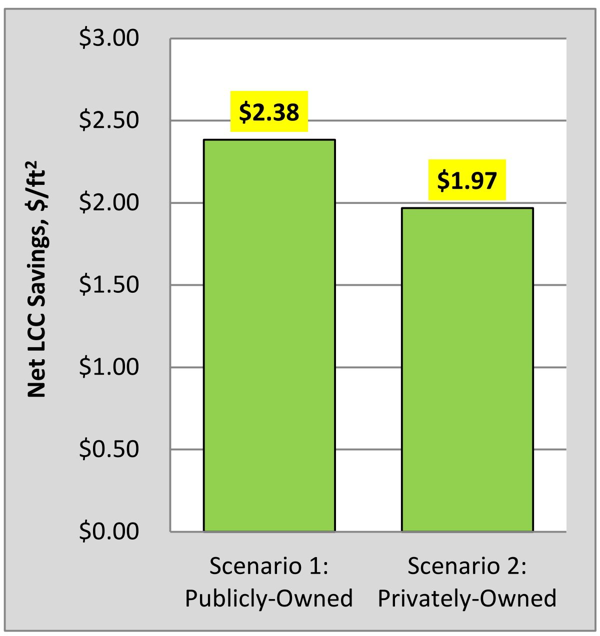

Figure 2. Overall Net Life-Cycle Cost Savings

[1] National cost-effectiveness report: https://www.energycodes.gov/development/commercial/cost_effectiveness.

Cost-Effectiveness Results for ASHRAE Standard 90.1-2013 in Ohio

This section summarizes the cost-effectiveness analysis results. Life-Cycle Cost (LCC) savings is the primary measure DOE uses to assess the economic impact of building energy codes. Savings are computed for two scenarios:

- **Scenario 1 (publicly-owned)** includes costs for initial equipment and construction, energy, maintenance and replacement and does not include loans or taxes.
- **Scenario 2 (privately-owned)** includes the same costs as scenario 1, plus the initial investment is financed through a loan amortized over 30 years with corresponding federal and state corporate income tax deductions for interest and depreciation.

Both scenarios include the residual value of equipment with remaining useful life at the end of the 30 years. Totals for building types, climate zones, and the state overall are averages based on Table 4 weightings. Factors such as inflation and discount rates are different between the two scenarios, as described in the Cost-Effectiveness Methodology section.

LCC is affected by many variables, including the applicability of individual measures in the code, measure costs, measure lives, replacement costs, state cost adjustment, energy prices, and so on. The LCC could be negative for a building type in a climate zone based on the interaction of these variables, but the code is considered cost-effective as long as the weighted state-wide LCC is positive.

Table 1 shows that the value today of the total LCC savings over 30 years for buildings in scenario 1 averages $2.38 per square foot for Standard 90.1-2013.

Table 1. LCC Savings for Ohio, Scenario 1 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$0.37	$33.98	$2.45	$1.02	$1.56	$0.77	$5.98
5A	$0.71	$0.05	$2.88	$0.91	$1.31	$0.58	$1.91
State Average	$0.67	$11.69	$2.84	$0.92	$1.32	$0.63	**$2.38**

Table 2 shows that the LCC savings over 30 years averages $1.97 per square foot for scenario 2.

Table 2. LCC Savings for Ohio, Scenario 2 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$0.81	$22.38	$1.90	$1.30	$1.47	$0.74	$4.29
5A	$0.96	$0.20	$2.23	$1.21	$1.30	$0.63	$1.66
State Average	$0.94	$7.81	$2.20	$1.22	$1.30	$0.66	**$1.97**

Energy Cost Savings

Table 3 shows that the primary benefit of Standard 90.1-2013—annual energy cost savings—averages $0.144 per square foot for both scenarios.

Table 3. Annual Energy Cost Savings for Ohio ($\$/ft^2$)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$0.098	$0.024	$0.175	$0.152	$0.099	$0.049	$0.124
5A	$0.088	$0.032	$0.182	$0.148	$0.104	$0.053	$0.147
State Average	$0.089	$0.029	$0.181	$0.149	$0.104	$0.052	**$0.144**

Construction Weighting of Results

Energy and economic impacts were determined and reported separately for each building type and climate zone. Cost-effectiveness results are also reported as averages for all prototypes and climate zones in the state. To determine these averages, results were combined across the different building types and climate zones using weighting factors shown in Table 4. These weighting factors are based on the floor area of new construction and major renovations for the six analyzed building prototypes in state-specific climate zones. The weighting factors were developed from construction start data from 2003 to 2007 based on an approach developed by Jarnagin and Bandyopadhyay (McGraw Hill Construction 2007, Jarnagin and Bandyopadhyay 2010).

Table 4. Construction Weights by Building Type

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	1.6%	1.6%	4.6%	2.4%	0.1%	1.3%	11.6%
5A	13.0%	3.0%	47.4%	16.6%	4.2%	4.1%	88.4%
State Average	14.6%	4.6%	52.0%	19.1%	4.3%	5.4%	100.0%

Incremental Construction Cost

Cost estimates were developed for the differences between Standard 90.1-2010 and Standard 90.1-2013 as implemented in the six prototype models. Costs for the initial construction include material, labor, commissioning, construction equipment, overhead and profit. These costs were developed using a commercial cost estimation firm, engineering design consultants and RS Means 2012 and 2014 cost data (RS Means 2012a,b,c, 2014a,b,c; Hart et al. 2015). The costs were developed at the national level and then adjusted for local conditions using a state construction cost index (Means 2014c). Table 5 shows incremental initial cost for individual building types in state-specific climate zones and weighted average costs by climate zone and building type for moving to Standard 90.1-2013 from Standard 90.1-2010.

The incremental cost is negative for some building types and climate zones because of fewer lighting fixtures, or due to the downsizing of heating, ventilating, and air-conditioning (HVAC) equipment.

- Fewer light fixtures are required when the allowed lighting power is reduced.
- Smaller equipment sizes can result from the lowering of heating and cooling loads due to other efficiency measures, such as more wall insulation.

The national cost-effectiveness report contains detailed descriptions of how costs were developed for individual efficiency upgrades (Hart et al. 2015). Where cost is negative it represents a reduction in first costs and a savings that is included in the net LCC savings.

Table 5. Incremental Construction Cost for Ohio ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$2.316	($33.360)	($0.288)	$2.196	$0.630	$0.363	($3.854)
5A	$1.663	$0.707	($0.511)	$2.218	$0.896	$0.653	$0.486
State Average	$1.733	($10.975)	($0.491)	$2.215	$0.889	$0.583	**($0.018)**

Simple Payback

Simple payback is the total incremental first cost divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. Simple payback is not used as a measure of cost-effectiveness as it does not account for the time value of money, the value of energy cost savings that occur after payback is achieved, or any replacement costs that occur after the initial investment. However, it is included in the analysis for states who wish to use this information. Table 6 shows simple payback results in years for both scenarios.

Table 6. Simple Payback for Ohio (Years)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	23.7	Immediate	Immediate	14.4	6.2	7.1	Immediate
5A	18.8	24.4	Immediate	15.0	8.4	11.9	7.4
State Average	19.3	Immediate	Immediate	14.9	8.3	10.7	Immediate

Overview of the Cost-Effectiveness Methodology

This analysis was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy's (DOE) Building Energy Codes Program. DOE supports the development and implementation of energy efficient and cost-effective residential and commercial building energy codes. These codes help adopting states and localities establish minimum requirements for energy-efficient building design and construction, as well as ensure significant energy savings and avoided greenhouse gas emissions. LCC savings is the primary measure DOE uses to assess the cost-effectiveness of building energy codes.

Cost-Effectiveness

DOE uses standard economic LCC cost-effectiveness analysis methods in comparing Standard 90.1-2013 and Standard 90.1-2010. A detailed cost-effectiveness methodology was used as described in detail in the national report (Hart et al. 2015). Under this methodology, two metrics are used:

- **LCC Savings:** LCC is the calculation of the present value of costs over a 30-year period including initial equipment and construction costs, energy savings, maintenance and replacement costs, and residual value of components at the end of the 30-year period. A separate LCC is determined for Standard 90.1-2010 and for Standard 90.1-2013. The LCC savings is the Standard 90.1-2010 LCC minus the Standard 90.1-2013 LCC.
- **Simple Payback:** While not a true cost-effectiveness metric, simple payback is also calculated. Simple payback is the number of years required for accumulated annual energy cost savings to exceed the incremental first costs of a new code.

Two cost scenarios are analyzed:

- **Scenario 1** includes the costs and savings listed above without borrowing or tax impacts.
- **Scenario 2** incudes the same costs as scenario 1 plus financing of the incremental first costs through increased borrowing with tax impacts including mortgage interest and depreciation deductions. Corporate tax rates are applied. Economic analysis factors such as discount rates are also different, as described in Table 8.

The cost-effectiveness analysis compares the cost for new buildings meeting Standard 90.1-2013 compared to new buildings meeting Standard 90.1-2010. The analysis includes energy savings estimates from building energy simulations and LCC and simple payback calculations using standard economic analysis parameters. The analysis builds on work documented in *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis* (Halverson et al. 2014), and the cost-effectiveness analysis documented in *National Cost-effectiveness of ANSI/ASHRAE/IES Standard 90.1-2013* (Hart et al. 2015).

Building Prototypes and Energy Modeling

The cost-effectiveness analysis uses six building types represented by six prototype building energy models. These six are a subset of 16 prototype building energy models and represent 80% of commercial floor space. These models provide coverage of the significant changes in ASHRAE Standard 90.1 from 2010 to 2013 and are used to show the impacts of the changes on energy savings. The prototypes represent common construction practice and include the primary conventional HVAC systems most commonly used in commercial buildings. More information on the prototype buildings and savings analysis can be found at: www.energycodes.gov/development/commercial/90.1_models.

Each prototype building is analyzed for each of the climate zones found within the state. Using the U.S. DOE EnergyPlus™ software, the six building prototypes summarized in Table 7 are simulated with characteristics meeting the requirements of Standard 90.1-2010 and then modified to meet the requirements of the next edition of the code (Standard 90.1-2013). The energy use and cost are then compared between the two sets of models.

Table 7. Building Prototypes

Building Prototype	Floor Area (ft²)	Number of Floors
Small Office	5,500	1
Large Office	498,640	13
Stand-Alone Retail	24,690	1
Primary School	73,970	1
Small Hotel	43,210	4
Mid-Rise Apartment	33,740	4

Climate Zones

Climate zones are defined in ASHRAE Standard 90.1 and include eight primary climate zones, the hottest being climate zone 1 and the coldest being climate zone 8. Letters A, B, and C are applied in some cases to denote the level of moisture, with A indicating moist or humid, B indicating dry, and C indicating marine. Figure 3 shows the national climate zones. For this state analysis, savings are analyzed for each climate zone in the state using weather data from a selected city within the climate zone and state, or where necessary, a city in an adjoining state with more robust weather data.

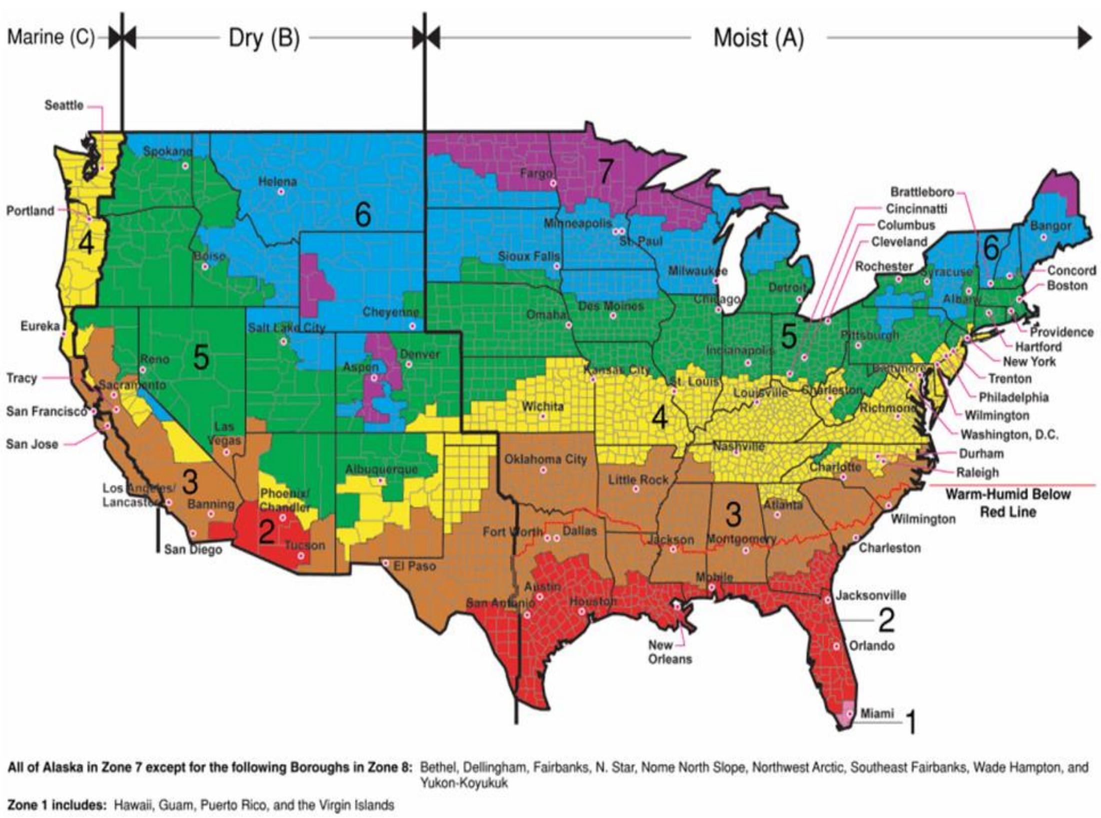

Figure 3. National Climate Zones

Cost-Effectiveness Method and Parameters

The DOE cost-effectiveness methodology accounts for the benefits of energy-efficient building construction over a multi-year analysis period, balancing initial costs against longer term energy savings. DOE evaluates energy codes and code proposals based on LCC analysis over a multi-year study period, accounting for energy savings, incremental investment for energy efficiency measures, and other economic impacts. The value of future savings and costs are discounted to a present value, with improvements deemed cost-effective when the *net LCC savings* (present value of savings minus cost) is positive.

The U.S. DOE Building Energy Codes Program uses an LCC analysis similar to the method used for many federal building projects, as well as other public and private building projects (Fuller and Petersen 1995). The LCC analysis method consists of identifying costs (and revenues if any) and in what year they occur; then determining their value in today’s dollars (known as the present value). This method uses economic relationships about the time value of money (money today is normally worth more than money tomorrow, which is why we pay interest on a loan and earn interest on savings). Future costs are discounted to the present based on a discount rate. The discount rate may reflect the interest rate at which money can be borrowed for projects with the same level of risk or the interest rate that can be earned on other conventional investments with similar risk.

The LCC for both scenarios includes incremental initial costs, repairs, maintenance and replacements. Scenario 2 also includes loan costs and tax impacts including mortgage interest and depreciation deductions. The residual value of equipment (or other component such as roof membrane) that has remaining useful life at end of the 30-year study period is also included for both scenarios. The residual value is calculated by multiplying the initial cost of the component by the years of useful life remaining for the component at year 30 divided by the total useful life, a simplified approach included in the Federal Energy Management Program (FEMP) LCC method (Fuller and Petersen 1995). A component will have zero residual value at year 30 only if it has a 30-year life, or if it has a shorter than 30-year life that divides exactly into 30 years (for example, a 15-year life).

The financial and economic parameters used for the LCC calculations are shown in Table 8.

Table 8. LCC Economic Parameters

Economic Parameter	Scenario 1	Scenario 2
Study Period – Years[1]	30	30
Nominal Discount Rate[2]	3.10%	5.50%
Real Discount Rate[2]	3.00%	3.53%
Effective Inflation Rate[3]	0.10%	1.90%
Electricity Prices[4] (per kWh)	$0.0980	$0.0980
Natural Gas Prices[4] (per therm)	$0.6022	$0.6022
Energy Price Escalation Factors[5]	*Uniform present value factors*	*Uniform present value factors*
Electricity Price UPV[5]	20.68	17.71
Natural Gas Price UPV[5]	23.60	20.21
Loan Interest Rate[6]	NA	5.50%
Federal Corporate Tax Rate[7]	NA	34.00%
State Corporate Tax Rate[8]	NA	0.00%
Combined Income Tax Impact[9]	NA	34.00%
State and Average Local Sales Tax[10]	7.11%	7.11%
State Construction Cost Index[11]	0.950	0.950

[1] A 30-year study period captures most building components useful lives and is a commonly used study period for building project economic analysis. This period is consistent with previous and related national 90.1 cost-effectiveness analysis (Hart et al. 2015). It is also consistent with the cost-effectiveness analysis that was done for the residential energy code as described in multiple state reports and a summary report (DOE 2012). The federal building LCC method uses 25 years and the ASHRAE Standard 90.1 development process uses up to 40 years for building envelope code improvement analysis. Because of the time value of money, results are typically similar for any study periods of 20 years or more.
[2] The scenario 1 real and nominal discount rates are from the National Institute of Standards and Technology (NIST) 2014 annual LCC update for the federal LCC method (Rushing et al. 2014). The scenario 2 nominal discount rate is assumed to be the marginal cost of capital, which is set equal to the loan interest rate (see footnote 6). The real discount rate for scenario 2 is calculated from the nominal discount rate and inflation.
[3] The scenario 1 effective inflation rate is from the NIST 2014 annual LCC update for the federal LCC method (Rushing et al. 2014). The scenario 2 inflation rate is the Producer Price Index for non-residential construction, June 1984 to June 2014 (Bureau of Labor Statistics 2015).
[4] Scenario 1 and 2 electricity and natural gas prices are state average annual prices for 2014 from the United States Energy Information Administration (EIA) *Electricity Power Monthly* (EIA 2015a) and *Natural Gas Monthly* (EIA 2015b).
[5] Scenario 1 energy price escalation rates are from the NIST 2014 annual update for the FEMP LCC method (Rushing et al. 2014). The NIST uniform present value (UPV) factors are multiplied by the first year annual energy cost to determine the present value of 30 years of energy costs and are based on a series of different annual escalation rates for 30 years. Scenario 2 UPV factors are based on NIST UPVs with an adjustment made for the scenario difference in discount rates.
[6] The loan interest rate is estimated from multiple online sources listed in the references (Commercial Loan Direct 2015; Watts 2015).
[7] The highest federal marginal corporate income tax rate is assumed to apply.
[8] The highest marginal state corporate income tax rate is assumed to apply from the Federation of Tax Administrators (FTA 2015).
[9] The combined tax impact is based on state tax being a deduction for federal tax, and is applied to depreciation and loan interest.
[10] The combined state and average local sales tax is included in material costs in the cost estimate (Tax Foundation 2015).
[11] The state construction cost index based on weighted city indices from the state (Means 2014c).

Detailed Energy Use and Cost

On the following pages, specific detailed results for Ohio are included:

- Table 9 shows the average energy rates used.
- Table 10 shows the per square foot energy costs for Standard 90.1-2010 and Standard 90.1-2013 and the cost savings from Standard 90.1-2013.
- Table 11 shows the per square foot energy use for Standard 90.1-2010 and Standard 90.1-2013 and the energy use savings from Standard 90.1-2013.
- Tables 12.A and 12.B show the energy end use by energy type for each climate zone in the state.

Table 9. Energy Rates for Ohio, Average $ per unit

Electricity	$0.0980	kWh
Gas	$0.6022	Therm

Source: Energy Information Administration, annual average prices for 2014 (EIA 2015a,b)

Table 10. Energy Cost Saving Results in Ohio, $ per Square Foot

Climate Zone:	4A				5A			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office								
Electricity	$0.912	$0.815	$0.096	10.5%	$0.893	$0.806	$0.087	9.7%
Gas	$0.005	$0.003	$0.001	20.0%	$0.005	$0.004	$0.001	20.0%
Totals	$0.917	$0.819	$0.098	10.7%	$0.899	$0.810	$0.088	9.8%
Large Office								
Electricity	$1.879	$1.846	$0.033	1.8%	$1.881	$1.840	$0.041	2.2%
Gas	$0.045	$0.053	-$0.009	-20.0%	$0.045	$0.053	-$0.009	-20.0%
Totals	$1.923	$1.899	$0.024	1.2%	$1.925	$1.893	$0.032	1.7%
Stand-Alone Retail								
Electricity	$1.193	$1.036	$0.156	13.1%	$1.161	$1.000	$0.161	13.9%
Gas	$0.073	$0.055	$0.018	24.7%	$0.075	$0.054	$0.021	28.0%
Totals	$1.266	$1.091	$0.175	13.8%	$1.236	$1.053	$0.182	14.7%
Primary School								
Electricity	$1.207	$1.061	$0.146	12.1%	$1.180	$1.040	$0.141	11.9%
Gas	$0.108	$0.102	$0.006	5.6%	$0.112	$0.106	$0.007	6.3%
Totals	$1.315	$1.163	$0.152	11.6%	$1.293	$1.145	$0.148	11.4%
Small Hotel								
Electricity	$1.147	$1.047	$0.099	8.6%	$1.137	$1.032	$0.104	9.1%
Gas	$0.146	$0.146	-$0.001	-0.7%	$0.152	$0.152	$0.000	0.0%
Totals	$1.292	$1.194	$0.099	7.7%	$1.288	$1.184	$0.104	8.1%
Mid-Rise Apartment								
Electricity	$1.154	$1.109	$0.045	3.9%	$1.157	$1.111	$0.046	4.0%
Gas	$0.052	$0.048	$0.005	9.6%	$0.053	$0.046	$0.007	13.2%
Totals	$1.206	$1.156	$0.049	4.1%	$1.210	$1.158	$0.053	4.4%

Table 11. Energy Use Saving Results in Ohio, Energy Use per Square Foot

Climate Zone:	4A				5A			
Code:	90.1-2010	90.1-2013	Savings		90.1-2010	90.1-2013	Savings	
Small Office								
Electricity, kWh/ft^2	9.302	8.318	0.984	10.6%	9.115	8.227	0.888	9.7%
Gas, therm/ft^2	0.008	0.006	0.002	25.0%	0.009	0.007	0.002	22.2%
Totals, kBtu/ft^2	32.563	28.969	3.594	11.0%	31.989	28.735	3.254	10.2%
Large Office								
Electricity, kWh/ft^2	19.172	18.838	0.334	1.7%	19.193	18.772	0.421	2.2%
Gas, therm/ft^2	0.074	0.088	-0.014	-18.9%	0.074	0.089	-0.015	-20.3%
Totals, kBtu/ft^2	72.849	73.124	-0.275	-0.4%	72.903	72.950	-0.048	-0.1%
Stand-Alone Retail								
Electricity, kWh/ft^2	12.170	10.576	1.594	13.1%	11.845	10.200	1.646	13.9%
Gas, therm/ft^2	0.121	0.091	0.031	25.6%	0.124	0.089	0.035	28.2%
Totals, kBtu/ft^2	53.662	45.167	8.494	15.8%	52.841	43.738	9.103	17.2%
Primary School								
Electricity, kWh/ft^2	12.313	10.824	1.489	12.1%	12.044	10.608	1.436	11.9%
Gas, therm/ft^2	0.179	0.169	0.010	5.6%	0.187	0.175	0.011	5.9%
Totals, kBtu/ft^2	59.970	53.848	6.122	10.2%	59.777	53.728	6.049	10.1%
Small Hotel								
Electricity, kWh/ft^2	11.702	10.688	1.014	8.7%	11.600	10.536	1.065	9.2%
Gas, therm/ft^2	0.242	0.243	-0.001	-0.4%	0.252	0.252	0.000	0.0%
Totals, kBtu/ft^2	64.118	60.747	3.371	5.3%	64.762	61.170	3.592	5.5%
Mid-Rise Apartment								
Electricity, kWh/ft^2	11.772	11.314	0.458	3.9%	11.807	11.339	0.468	4.0%
Gas, therm/ft^2	0.087	0.079	0.008	9.2%	0.088	0.077	0.012	13.6%
Totals, kBtu/ft^2	48.834	46.519	2.315	4.7%	49.148	46.397	2.751	5.6%

Table 12.A. Annual Energy Usage for Buildings in Ohio in Climate Zone 4A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$
ASHRAE 90.1-2010												
Heating, Humidification	0.455	0.008	0.014	0.064	0.000	0.085	0.000	0.118	1.259	0.018	0.000	0.087
Cooling	0.998	0.000	2.686	0.000	1.557	0.000	1.974	0.000	1.781	0.000	1.119	0.000
Fans, Pumps, Heat Recovery	1.145	0.000	1.581	0.000	2.748	0.000	1.958	0.000	1.801	0.000	1.759	0.000
Lighting, Interior & Exterior	3.310	0.000	2.490	0.000	5.675	0.000	3.136	0.000	3.061	0.000	1.439	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.148	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.036	0.097	0.015	0.000	0.131	3.245	0.000
Total	9.302	0.008	19.172	0.074	12.170	0.121	12.313	0.179	11.702	0.242	11.772	0.087
ASHRAE 90.1-2013												
Heating, Humidification	0.367	0.006	0.016	0.078	0.000	0.055	0.000	0.107	1.327	0.019	0.000	0.079
Cooling	0.712	0.000	2.601	0.000	1.374	0.000	1.665	0.000	1.517	0.000	0.931	0.000
Fans, Pumps, Heat Recovery	0.986	0.000	1.558	0.000	2.175	0.000	1.672	0.000	1.785	0.000	1.691	0.000
Lighting, Interior & Exterior	2.906	0.000	2.275	0.000	4.841	0.000	2.768	0.000	2.474	0.000	1.242	0.000
Plugs, Refrigeration, Other	2.438	0.000	12.388	0.000	2.186	0.000	4.622	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.036	0.097	0.015	0.000	0.131	3.243	0.000
Total	8.318	0.006	18.838	0.088	10.576	0.091	10.824	0.169	10.688	0.243	11.314	0.079
Total Savings	0.984	0.002	0.334	-0.014	1.594	0.031	1.489	0.010	1.014	-0.001	0.458	0.008

Table 12.B. Annual Energy Usage for Buildings in Ohio in Climate Zone 5A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr
ASHRAE 90.1-2010												
Heating, Humidification	0.457	0.009	0.826	0.063	0.000	0.087	0.000	0.124	1.319	0.020	0.000	0.088
Cooling	0.860	0.000	1.932	0.000	1.296	0.000	1.791	0.000	1.623	0.000	0.982	0.000
Fans, Pumps, Heat Recovery	1.095	0.000	1.544	0.000	2.699	0.000	1.870	0.000	1.798	0.000	1.747	0.000
Lighting, Interior & Exterior	3.311	0.000	2.490	0.000	5.661	0.000	3.138	0.000	3.060	0.000	1.438	0.000
Plugs, Refrigeration, Other	2.484	0.000	12.401	0.000	2.190	0.000	5.148	0.046	3.799	0.092	4.210	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.140	3.430	0.000
Total	9.115		19.193	0.074	11.845	0.124	12.044	0.187	11.600	0.252	11.807	0.088
ASHRAE 90.1-2013												
Heating, Humidification	0.373		0.833	0.078	0.000	0.052	0.000	0.113	1.326	0.020	0.000	0.077
Cooling	0.634	0.000	1.763	0.000	1.141	0.000	1.508	0.000	1.371	0.000	0.806	0.000
Fans, Pumps, Heat Recovery	0.965	0.000	1.513	0.000	2.041	0.000	1.608	0.000	1.781	0.000	1.657	0.000
Lighting, Interior & Exterior	2.906	0.000	2.275	0.000	4.831	0.000	2.772	0.000	2.472	0.000	1.241	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.622	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.140	3.427	0.000
Total	8.227		18.772	0.089	10.200	0.089	10.608	0.175	10.536	0.252	11.339	0.077
Total Savings	0.888	0.002	0.421	-0.015	1.646	0.035	1.436	0.011	1.065	0.000	0.468	0.012

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The U.S. Department of Energy (DOE) provides estimates of energy and cost savings from code adoption at the National, Climate Zone, and State levels. For more information on how these estimates were developed, visit the DOE Building Energy Codes website: www.energycodes.gov/development/commercial

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ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Qualitative Analysis

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August 2014

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Executive Summary

Section 304(b) of the Energy Conservation and Production Act (ECPA), as amended, requires the Secretary of Energy to make a determination each time a revised version of ASHRAE Standard 90.1 is published with respect to whether the revised standard would improve energy efficiency in commercial buildings. When the U.S. Department of Energy (DOE) issues an affirmative determination on Standard 90.1, states are statutorily required to certify within two years that they have reviewed and updated the commercial provisions of their building energy code, with respect to energy efficiency, to meet or exceed the revised standard.

To meet these statutory requirements, the DOE Building Energy Codes Program (BECP) and Pacific Northwest National Laboratory (PNNL) conduct two types of analysis in a determination of energy savings for a revised Standard 90.1:

- **Qualitative Analysis**: This is a detailed textual analysis that identifies all the changes made to the previous edition of Standard 90.1 and categorizes the changes as having a positive, negative, or neutral impact on energy efficiency in commercial buildings. In the qualitative analysis, no attempt is made to estimate a numerical impact using whole building simulation. Three steps are typically undertaken in the qualitative analysis: identify all changes made to Standard 90.1, characterize the impact of each change on the energy efficiency of Standard 90.1, and identify those changes that can be incorporated into the subsequent quantitative analysis.
- **Quantitative Analysis**: This analysis uses the results of the qualitative analysis to identify which changes should be incorporated into the building simulation models to estimate the energy impact resulting from the changes to Standard 90.1.

This report provides the qualitative analysis of all addenda to ANSI/ASHRAE/IES[1] Standard 90.1-2010 (referred to as Standard 90.1-2010 or 2010 edition) that were included in ANSI/ASHRAE/IES Standard 90.1-2013 (referred to as Standard 90.1-2013 or 2013 edition). All addenda in creating Standard 90.1-2013 were evaluated for their projected impact on energy efficiency. Each addendum was characterized as having a positive, neutral, or negative impact on overall building energy efficiency.

The textual analysis indicated that 52 of a total of 110 changes have positive impact on energy efficiency, including 8 changes evaluated as having a major positive impact and 44 changes with a minor positive impact on energy efficiency. Of the remaining changes, 53 were neutral (had neither a positive or negative impact on energy efficiency). These include editorial changes, changes to reference standards, changes to alternative compliance paths, and other changes to the text of the standard that may improve the usability of the standard, but do not generally affect the energy efficiency of a building. Five changes were identified as having a minor negative impact on energy efficiency.

The eight addenda that have major positive impacts on energy efficiency are as follows:

1. Addendum 90.1-2010m – adds control requirements for lighting alterations.
2. Addendum 90.1-2010u – applies new efficiency requirements to individual fans.

[1] American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers/Illuminating Engineering Society of North America

3. Addendum 90.1-2010am – reduces energy usage for large boilers.
4. Addendum 90.1-2010aq – reduces fan energy usage and improves economizer effectiveness.
5. Addendum 90.1-2010bb – increases stringency of building envelope requirements.
6. Addendum 90.1-2010bq – adds new efficiency requirements for commercial refrigeration.
7. Addendum 90.1-2010by – requires more lighting controls in more spaces and reduces time to reduction or shutoff.
8. Addendum 90.1-2010co – decreases lighting power density in most building types.

The five addenda that have negative impacts on energy efficiency are as follows:

1. Addendum 90.1-2010j – reduces energy efficiency ratio for evaporatively cooled air conditioners.
2. Addendum 90.1-2010da – relaxes air leakage requirements for high-speed doors.
3. Addendum 90.1-2010db – relaxes the U-factor requirement for residential steel joist floors in Climate Zone 3.
4. Addendum 90.1-2010de – relaxes economizer requirements for computer rooms.
5. Addendum 90.1-2010dq – eliminates sizing requirements for pipes above 24" in diameter.

Addenda characterized as resulting in negative energy saving impacts are judged to be relatively minor, indicting no significant energy impact.

The 44 addenda that are rated as minor positives are discussed in Section 4. A comparison of the number of major positives and minor positives (a total of 52 positives) to the number of minor negatives (5) indicates that the overall impact on the standard is positive.

Acronyms and Abbreviations

AHRI	Air Conditioning, Heating, and Refrigeration Institute
AHU	air handling unit
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ATC	acceptance test code
BECP	Building Energy Codes Program
bhp	brake horsepower
BOD	Board of Directors
Btu	British thermal unit(s)
Btu/h	British thermal unit(s) per hour
cfm	cubic feet per minute
CFR	Code of Federal Regulations
COP	coefficient of performance
CRRC	Cool Roof Rating Council
CSA	Canadian Standards Association
CTI	Cooling Tower Institute
DDC	direct digital control(s)
DOE	U.S. Department of Energy
DX	direct expansion
ECB	energy cost budget
ECPA	Energy Conservation and Production Act
EER	energy efficiency ratio
EPAct 2005	Energy Policy Act of 2005
EPCA	Energy Policy and Conservation Act
FC	filled cavity
FEG	fan efficiency grade
gpm	gallon(s) per minute
HERS	home energy rating systems
hp	horsepower
HSPF	heating season performance factor
HVAC	heating, ventilation, and air-conditioning
HVACR	heating, ventilation, air-conditioning, and refrigeration
IEC	International Electrotechnical Commission
IEER	Integrated Energy Efficiency Ratio
IES	Illuminating Engineering Society of North America
IESNA	Illuminating Engineering Society of North America
IPLV	integrated partial load value
LPD	lighting power density

LSG	light-to-solar-gain ratio
NAECA	National Appliance Energy Conservation Act
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NFRC	National Fenestration Rating Council
NR	not required
PNNL	Pacific Northwest National Laboratory
OA	outdoor air
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
PUE	power utilization effectiveness
RH	relative humidity
SDHV	small duct high velocity
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SPVAC	single package vertical air conditioner
SPVHP	single package vertical heat pump
SWH	service water heating
VAV	variable air volume
VRF	variable refrigerant flow
VSD	variable speed drive
VT	visible transmittance
WWR	window-to-wall ratio
w.c.	water column

Contents

Tables

Figures

1.0 Introduction

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for the Building Energy Efficiency Standards Program (42 U.S.C. 6831 et seq.). Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA[1] 90.1-1989 (Standard 90.1-1989 or 1989 edition), or any successor to that code, is revised, the Secretary must make a determination, not later than 12 months after such revision, whether the revised code would improve energy efficiency in commercial buildings and must publish notice of such determination in the Federal Register (42 U.S.C. 6833 (b)(2)(A)). The Secretary may determine that the revision of Standard 90.1-1989, or any successor thereof, improves the level of energy efficiency in commercial buildings. If so, then not later than 2 years after the date of the publication of such affirmative determination, each State is required to certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency with respect to the revised or successor code (42 U.S.C. 6833(b)(2)(B)(i)). The State must include in its certification a demonstration that the provisions of its commercial building code, regarding energy efficiency, meet or exceed the revised standard (42 U.S.C. 6833(b)(2)(B)(i)).

If the Secretary makes a determination that the revised standard will not improve energy efficiency in commercial buildings, State commercial codes shall meet or exceed the last revised standard for which the Secretary has made a positive determination (42 U.S.C. 6833(b)(2)(B)(ii)). ECPA also requires the Secretary to permit extensions of the deadlines for the State certification if a State can demonstrate that it has made a good faith effort to comply with the requirements of Section 304(c) of ECPA and that it has made significant progress in doing so (42 U.S.C. 6833(c)).

On October 9, 2011, DOE issued an affirmative determination of energy savings for Standard 90.1-2010, which concluded that Standard 90.1-2010 would achieve greater energy efficiency in buildings subject to the code, than Standard 90.1-2007. (76 FR 64904). Consequently, DOE has determined that Standard 90.1-2010 represents the baseline to which Standard 90.1-2013 requirements are compared for the purpose of a determination of energy savings for Standard 90.1-2013. To meet these statutory requirements, the DOE Building Energy Codes Program (BECP) and Pacific Northwest National Laboratory (PNNL) conduct two types of analysis in a determination of energy savings for a revised Standard 90.1[2]:

- **Qualitative Analysis**: This is a detailed textual analysis that identifies all the changes made to the previous edition of Standard 90.1 and categorizes the changes as having a positive, negative, or neutral impact on energy efficiency in commercial buildings. In the qualitative analysis, no attempt is made to estimate a numerical impact using whole building simulation. Three steps are typically undertaken in the qualitative analysis: identify all changes made to Standard 90.1, characterize the impact of each change on the energy efficiency of Standard 90.1, and identify those changes that can be incorporated into the subsequent quantitative analysis.
- **Quantitative Analysis**: This analysis uses the results of the qualitative analysis to identify which changes should be incorporated into the building simulation models to estimate the energy impact resulting from the changes to Standard 90.1.

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[1] American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers/Illuminating Engineering Society of North America

[2] Standard 90.1-2010 Determination available at http://www.energycodes.gov/regulations/determinations

In support of the U.S. Department of Energy's (DOE's) Determination of Energy Savings for ANSI/ASHRAE/IES Standard 90.1-2013 (referred to as ASHRAE Standard 90.1-2013, Standard 90.1-2013, 90.1-2013, or 2013 edition) (ASHRAE 2013b), Pacific Northwest National Laboratory (PNNL) prepared this qualitative assessment analysis of the relative energy use for commercial buildings designed to meet requirements found in Standard 90.1-2013 compared to meeting requirements found in ANSI/ASHRAE/IES[1] Standard 90.1-2010 (referred to as ASHRAE Standard 90.1-2010, Standard 90.1-2010, 90.1-2010, or 2010 edition) (ASHRAE 2010b). ASHRAE processes changes to Standard 90.1 in the form of individual addenda, with each addendum representing a single change or set of changes related topically or chronologically. Addenda may range from a few words changed for clarification to complete replacement of a series of requirements tables.

The ensuing sections of this document describe the addenda to Standard 90.1-2010 that are included in Standard 90.1-2013, and impacts of the specific addenda and impacts on various sections of Standard 90.1-2013.

Review Under the Information Quality Act

This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. Though this report does not constitute "influential" information, as that term is defined in DOE's information quality guidelines or the Office of Management and Budget's Information Quality Bulletin for Peer Review (Bulletin), the current report builds upon methods of analysis that have been subjected to peer review and public dissemination. In addition, this work has been subject to internal peer review, and external review through the public comment process as part of the DOE Determination for Standard 90.1-2013.

[1] American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers/Illuminating Engineering Society of North America

2.0 Addenda Included in Standard 90.1-2013

Standard 90.1-2013 incorporates ASHRAE Standard 90.1-2010 and all approved addenda. Table 2.1 lists all 110 addenda processed by ASHRAE for inclusion in Standard 90.1-2013. All addenda were applied to Standard 90.1-2010 to create the 2013 edition. The addenda included in Standard 90.1-2013 may also be found in the published supplements to Standard 90.1-2010 on the ASHRAE website (ASHRAE 2012, ASHRAE 2013a).

The following list is taken from Appendix F to ASHRAE Standard 90.1-2013. Table 2.1 lists each addendum and describes the way in which the text is affected by the change, as well as ASHRAE, IES, and ANSI approval dates. Table 2.1 is a copy of Appendix F to Standard 90.1-2013 with minor edits to define some of the acronyms used in Appendix F and to make the format of the descriptions the same. The description of addendum 90.1-2010j was also modified in this table, as it was a repeat of the description of addendum 90.1-2010k. The section affected for addendum 90.1-2010bo was also modified to indicate that this addendum is associated with the Service Water Heating section and not Heating, Ventilating, and Air-Conditioning section.

The table numbers called out in Table 2.1 refer to Standard 90.1-2010. In Standard 90.1-2013, tables have been renumbered from a format of “Table (Section Number)(Letter)” to “Table(Section Number)-(Number).” Thus, for example, Table 6.8.1A in Standard 90.1-2010 is now Table 6.8.1-1 in Standard 90.1-2013. These table numbers have been corrected in Sections 4 and 5 in this document to match the table numbers in the 2013 edition of Standard 90.1.

The first eight addenda listed in Table 2.1were originally developed as addenda to Standard 90.1-2007 and are listed prior to addenda that were developed solely to Standard 90.1-2010. In later tables in this document, addenda are listed strictly in order of their addendum designation.

Table 2.1. Complete List of Addenda Processed for ASHRAE Standard 90.1-2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
bb (formerly addendum bb to 90.1-2007)	5.Building Envelope, Appendix A	This addendum modifies the building envelope requirements for opaque assemblies and fenestration in tables 5.5.1 through 5.5.8 and the associated text in section 5.5.4.5. It also updates the National Fenestration Rating Council (NFRC) 301 reference and modifies two metal building roof assemblies in Table A2.3.	3/23/2012	4/4/2012	3/23/2012	5/11/2012
bz (formerly addendum bz to 90.1-2007))	6. Heating, Ventilating, and Air-Conditioning	This addendum adds a Section 8.4.2 which specifies requirements for installation of basic electrical metering of major end uses (total electrical energy, HVAC systems, interior lighting, exterior lighting and receptacle circuits) to provide basic reporting of energy consumption data to building occupant.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
cg (formerly addendum cg to 90.1-2007))	11.Energy Cost Budget and Appendix G	This addendum modifies the simulation requirements for modeling mandatory automatic daylighting controls as well as automatic lighting controls. It also modifies the simulation requirements for automatic lighting controls in the proposed design, beyond the minimum mandatory requirements. Table G3.2, which provided power adjustment percentages for automatic lighting controls, has been deleted and savings through automatic control devices are now required to be modeled in building simulation through schedule adjustments for the proposed design.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
ci (formerly addendum ci to 90.1-2007))	3.Definitions, 11.Energy Cost Budget and Appendix G	This addendum modifies requirements for the cooling tower in Chapter 11, from two-speed to variable speed. A formula has been specified to calculate the condenser water design supply temperature. Similar revisions have been made to Appendix G for the cooling tower requirements. Definitions for cooling design wet-bulb temperature and heating design wet-bulb temperature have been added to Chapter 3.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
cj (formerly addendum cj to 90.1-2007))	Appendix G	Creates modeling rules for computer rooms in Appendix G	6/26/2012	41086	6/28/2013	7/24/2013
cm (formerly addendum cm to 90.1-2007)	5. Building Envelope	The proposed text clarifies how to interpret the use of dynamic glazing products given the requirements in Addendum bb (envelope requirements).	7/20/2010	7/23/2010	7/24/2010	7/26/2010
dm (previously from 2007)	5. Building Envelope	This addendum modifies Section 5.4.3.4 for vestibules. It adds a size limit for large buildings, exemptions for semiheated spaces and elevator lobbies in parking garages	01/26/13	1/29/2013	2/11/2013	2/12/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
ds (formerly addendum ds to 90.1-2007)	5.Building Envelope	This addendum corrects the definitions of primary sidelighted area, secondary sidelighted area, and sidelighting effective area to use the term “vertical fenestration” instead of “window” to clarify that glazed doors and other fenestration products are included as well as windows. Additionally, the definition of daylight area under rooftop monitors is corrected to include the spread of light beyond the width of the rooftop monitor glazing.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
a	10.Other Equipment and 12.Normative References	This addendum specifies that nominal efficiencies for motors are required to be established in accordance with 10 CFR 431 instead of National Electrical Manufacturers Association (NEMA) Standards. It modifies the footnotes to Tables 10.8A, 10.8B, 10.8 C. The corresponding reference for 10 CFR 431 has also been added.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
b	10.Other Equipment and 12.Normative References	This addendum requires escalators and moving walks to automatically slow when not conveying passengers. The corresponding reference to American Society of Mechanical Engineers (ASME) A17.1/ Canadian Standards Association (CSA) B44 has also been added to the Normative References.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
c	Appendix G	This addendum adds requirements for laboratory exhaust fans to Section G3.1.1, Baseline HVAC System Type and Definition. Lab exhaust fans are required to be modeled as constant horsepower, reflecting constant volume stack discharge with outside air bypass.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
e	Appendix G	This addendum updates language in Section G3.1, part 5 'Building Envelope', to require that existing buildings use the same envelope baseline as new buildings with the exception of fenestration area.	6/27/2012	6/27/2012	6/18/2012	7/26/2012
f	Appendix G	This addendum modifies Section G.3.1, Building Envelope. It specifies the vertical fenestration area for calculating baseline building performance for new buildings and additions.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
g	6. Heating, Ventilating, and Air-Conditioning and 12.Normative References	This addendum adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment. Table 6.8.1L and Table 6.8.1M have been added which specify the energy use limits for refrigerators and freezers. The corresponding references have also been added in Chapter 12.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
h	6. Heating, Ventilating, and Air-Conditioning.	This addendum modifies the minimum efficiency standards for water to air heat pumps (water loop, ground water and ground loop). The proposed cooling energy efficiency ratios (EERs) and heating coefficients of performance (COPs) are more stringent than the present values. This addendum also removes the small duct high velocity product class from Table 6.8.1B.	6/25/2011	6/29/2011	6/30/2011	6/30/2011

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
i	6. Heating, Ventilating, and Air-Conditioning.	This addendum increases the minimum efficiency standards for single package vertical air conditioners (SPVAC) and single package vertical heat pumps (SPVHP). It also creates a new product class for SPVAC and SPVHP used in space constrained applications. This new product class only applies to non-weatherized products with cooling capacities <36,000 Btu/h and intended to replace an existing AC.	01/26/13	1/29/2013	2/11/2013	2/12/2013
j	6. Heating, Ventilating, and Air-Conditioning.	Modifies the minimum efficiency requirements of evaporatively cooled units, of size category 240,000 Btu/h to 760,000 Btu/h and heating type-other, in Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013). The value is reduced to account for increased pressure drop in such system types. The product class, small duct high velocity, has been eliminated.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
k	8. Power and 12. Normative References	This addendum modifies notes to Table 8.1 and specifies that nominal efficiencies would be established in accordance with the 10 CFR 431 test procedure for low-voltage dry-type transformers. The corresponding references have also been added in Chapter 12.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
l	6. Heating, Ventilating, and Air-Conditioning.	This addendum fixes the mistake with 90.1-2010 fan power limitations, which required the user to perform calculations for fan brake horsepower (bhp) even if the simplified nameplate hp option was being used.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
m	9.Lighting	This addendum adds some control requirements for lighting alterations, for interior and exterior applications. It adds a section for submittals and includes loading docks as a tradable surface. It modifies the provisions for additional interior lighting power, which would now be calculated on the basis of controlled wattage.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
n	10.Other Equipment	This addendum clarifies that the total lumens/watt for the entire elevator cab is required to meet the efficiency requirement and it is not required for each individual light source.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
o	5.Building Envelope and 3.Definitions	This addendum adds the definition for sectional garage doors. It also modifies Section 5.4.3.2 (d), fenestration air leakage provisions for doors, to include requirements for glazed sectional garage doors.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
p	5.Building Envelope and 12.Normative References	This addendum modifies Section 5.5.3.1 and requires roof solar reflectance and thermal emittance testing to be in accordance with Cool Roof Rating Council (CRRC)-1 Standard. It also modifies Section 12 by adding the reference for CRRC.	1/21/2012	1/23/2012	1/18/2012	1/26/2012

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
q	5. Building Envelope, 3.Definitions and 12.Normative References	This addendum modifies Section 5.8.2.2, by clarifying the requirements for labeling of fenestration and door products. The corresponding references to NFRC in Chapter 12 have also been updated.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
r	Appendix G and 12.Normative References	This addendum clarifies the requirements related to temperature and humidity control in Appendix G and relocates all related wording to the Schedules section of Table3.1. Additionally, clarity is provided for modeling systems that provide occupant thermal comfort via means other than other than directly controlling the air dry-bulb and wet-bulb temperature (i.e. radiant cooling/heating, elevated air speed, etc.). It permits the use of ASHRAE Standard 55 for calculation of PMV-PPD. This addendum also updates the Normative References by including a reference to ASHRAE Standard 55-2010.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
s	6. Heating, Ventilating, and Air-Conditioning.	This addendum modifies the requirement for the static pressure sensor location and the control requirements for set point reset for systems with direct digital control (DDC) of individual zones. Ensures that savings from previously required static pressure reset will be realized.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
u	6. Heating, Ventilating, and Air-Conditioning.	This addendum adds new definition as Fan Efficiency Grade (FEG) and requires each fan has a FEG of 67 or higher as defined by Air Movement and Control Association (AMCA) 205-10 (Energy Efficiency Classification for Fans)	01/26/13	1/29/2013	2/11/2013	2/12/2013
v	8.Power	This addendum clarifies the requirement for controlled receptacles in open offices. It also requires the automatically controlled receptacles to be appropriately identified for the users benefit.	01/26/13	1/29/2013	2/11/2013	2/28/2013
w	3.Definitions, 11.Energy Cost Budget Method and Appendix G.	This addendum adds definitions for on-site renewable energy and purchased energy. It clarifies the process for accounting for on-site renewable energy and purchased energy as well as calculating the annual energy costs in the energy cost budget (ECB) approach and Appendix G.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
y	3.Definitions and 10.Other Equipment	This addendum revises the definitions of general purpose electric motors (subtype I &II) based on information from NEMA. It also updates the standard to include the new federal energy efficiency standards used in HVAC equipment, to be in effect from 2015. It adds Table 10.8D, which specifies minimum average full-load efficiency for Polyphase Small Electric Motors; and Table 10.8E, which specifies minimum average full-load efficiency for Capacitor-Start Capacitor-Run and Capacitor-Start Induction-Run Small Electric Motors.	1/21/2012	1/23/2012	1/18/2012	1/26/2012

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
z	6. Heating, Ventilating, and Air-Conditioning.	This addendum relocates the requirements for water economizers into the main economizer section, Section 6.5.1.5.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
aa	6. Heating, Ventilating, and Air-Conditioning.	Prior to this addendum certain controls requirements were only required when the controls were provided by a DDC system. This addendum eliminates that contingency for set point overlap restrictions, humidification and dehumidification controls, variable air volume (VAV) fan control set point reset, multiple-zone VAV system ventilation optimization control, hydronic system design and control, and instead specifies how the system must perform. This will in effect require DDC for systems where these controls are needed.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
ad	12.Normative References	Adds reference to specific addenda to Air Conditioning, Heating, and Refrigeration Institute (AHRI) standards 340/360 and 1230 being referenced	6/27/2012	6/27/2012	6/18/2012	6/28/2012
ae	12.Normative References	Adds reference to specific addenda to AHRI standards 210/240 and 550/590 being referenced	7/26/2013	7/30/2013	7/29/2013	8/28/2013
af	6. Heating, Ventilating, and Air-Conditioning	Modifies heat rejection equipment (cooling tower) requirements to require variable speed drives (VSDs) on fans, operate all fans at the same speed instead of sequencing them, and require that systems with multiple condenser water pumps operate those pumps in parallel at reduced flow.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ag	Appendix G	Establishes a method for gaining credit in Appendix G for buildings that undergo whole building air leakage testing to demonstrate that they have an air-tight building.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ah	Appendix G	Sets system sizing requirements in appendix G for humid climates based on humidity ratio instead of Supply Air Temperature Differential. Sets baseline system dehumidification requirements.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
ai	Appendix G	Modifies Appendix G to account for 3 prescriptive addenda that were incorporated in to standard 90.1-2010, but did not make it into Appendix G in time for publication. Updates economizer requirements to match addendum cy, establishes baseline transformer efficiency requirements to match addendum o, and establishes path A for centrifugal chiller baselines from addendum m.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
aj	6. Heating, Ventilating, and Air-Conditioning	Requires fractional horsepower motors >= 1/22 hp to EC motors or minimum 70% efficient in accordance with 10 CFR 431. Also requires adjustable speed or other method to balance airflow.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
al	Appendix G	Establishes a consistent fuel source for space heating for baseline systems based on climate zone. Establishes a consistent fuel source for service water heating based on building type.	6/26/2013	6/26/2013	6/28/2013	7/24/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
am	6. Heating, Ventilating, and Air-Conditioning	Establishes minimum turndown for boilers and boiler plants with of at least 1,000,000 Btu/h.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
an	Appendix C	Rewrites entire Appendix C to use a simulation based approach for envelope trade-offs.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ap	6. Heating, Ventilating, and Air-Conditioning	Adds Power Utilization Effectiveness (PUE) as an alternative compliance methodology for data centers.	1/26/2013	1/29/2013	2/11/2013	5/3/2013
aq	6. Heating, Ventilating, and Air-Conditioning and 11.Energy Cost Budget	This addendum makes changes to the requirements for fan control for both constant volume and VAV units including extending the fan part load power requirements down to ¼ hp. In addition it defines the requirements for integrated economizer control and defines direct expansion (DX) unit capacity staging requirements	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ar	6. Heating, Ventilating, and Air-Conditioning	Adds mandatory and prescriptive requirements for walk-in coolers and freezers and refrigerated display cases.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
as	6. Heating, Ventilating, and Air-Conditioning	Avoidance of simultaneous heating and cooling at air handling unit (AHU). Requires humidifiers mounted in the airstream to have an automatic control valve shutting off preheat when humidification is not required, and insulation on the humidification system dispersion tube surface.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
at	3. Definitions, 5.Building Envelope, and 9. Lighting	Deletes the term clerestory and instead adds roof monitor and clarifies the definition. Changes the references in Chapters 5 and 9 from clerestory to roof monitor.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
au	6. Heating, Ventilating, and Air-Conditioning	This addendum modifies Table 6.5.3.1.1B which addresses fan power limitation pressure drop adjustment credits. Deductions are added for systems without any central heating or cooling as well as systems with electric resistance heating. Sound attenuation credit is modified to be available only when there are background noise criteria requirements.	01/26/13	1/29/2013	2/11/2013	2/12/2013
av	6. Heating, Ventilating, and Air-Conditioning	This addendum modifies Section 6.5.1, exception k, applicable to Tier IV data centers, in an attempt to make economizer exceptions more strict and in agreement with ASHRAE TC 9.9	6/26/2013	6/26/2013	6/28/2013	7/24/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
aw	11. Energy Cost Budget and Appendix G	This addendum updates the reference year for ASHRAE Standard 140 and exempts software used for ECB and Appendix G compliance from having to meet certain sections of ASHRAE Standard 140	01/26/13	1/29/2013	2/11/2013	2/12/2013
ax	Appendix G	Table G3.1, Part 14 of Appendix G is modified to exclude the condition that permits a building surface, shaded by an adjacent structure, to be simulated as north facing if the simulation program is incapable of simulating shading by adjacent structures.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ay	3. Definitions, 9. Lighting	This addendum modifies daylighting requirements. It modifies definitions for daylight area under skylights, daylight area under roof monitors, primary sidelight area, and secondary sidelight area. It modifies the thresholds for applying automatic daylighting control for sidelighting and toplighting, to a wattage basis and provides characteristics for the required photo controls. It modifies Table 9.6.2 to include continuous dimming in secondary sidelighted areas, which is now based on a W level rather than area of the space. It eliminates the need for effective aperture calculation.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
az	6. Heating, Ventilating, and Air-Conditioning	This addendum increases the minimum efficiency of open circuit axial fan cooling towers. An additional requirement has been added which states that the minimum efficiency requirements for all types of cooling towers also applies to accessories that affect the thermal performance of the unit. An additional footnote clarifies that the certification requirements do not apply to field erected cooling towers.	01/26/13	1/29/2013	2/11/2013	2/12/2013
ba	6. Heating, Ventilating, and Air-Conditioning	Adds requirements for door switches to disable or reset mechanical heating or cooling when doors are left open.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
bc	9. Lighting	Modifies requirements for automatic lighting control for guestroom type spaces. Exceptions to this requirement are lighting and switched receptacles controlled by captive key systems.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
bd	9. Lighting	This addenda adds more specific requirements for the functional testing of lighting controls, specifically, occupancy sensors, automatic time switches and daylight controls.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
be	9. Lighting	Minor revisions to Section 9.7.2.2, which addresses the scope of the operating and maintenance manuals required for lighting equipment and controls.	01/26/13	1/29/2013	2/11/2013	2/12/2013
bf	8. Power	This addendum addresses Section 8.4.2 on automatic receptacle control and increases the spaces where plug shutoff control is required. It also clarifies the application of this requirement for furniture systems, states a labeling requirement to distinguish controlled and uncontrolled receptacles and restricts the use of plug-in devices to comply with this requirement.	7/26/2013	7/30/2013	7/29/2013	8/28/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
bg	5.Building Envelope	Requirements for low-E storm window retrofits.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bh	9. Lighting	Modifies Table 9.6.1 Space-By-Space Lighting Power Density allowance	7/26/2013	7/30/2013	8/12/2013	9/4/13
bi	6. Heating, Ventilating, and Air-Conditioning	Increase seasonal energy efficiency ratio (SEER) and heating season performance factor (HSPF) for air-cooled commercial air conditioners and heat pumps below 65,000 Btu/h. Effective 1/1/2015	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bj	6. Heating, Ventilating, and Air-Conditioning.	Re-establishes the product class for Small Duct High Velocity (SDHV) air conditioners and heat pumps. Adds efficiency requirements for systems at <65.000 Btu/h.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bk	6. Heating, Ventilating, and Air-Conditioning	Increases cooling efficiency for packaged terminal air conditioners (PTACs)	01/26/13	1/29/2013	2/11/2013	2/12/2013
bl	11.Energy Cost Budget and Appendix G	Provide rules for removing fan energy from efficiency metrics when modeling in ECB or Appendix G.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bn	8. Power and 10. Other Equipment	Establishes electric and fuel metering requirements	7/26/2013	7/30/2013	7/29/13	9/4/13
bo	7. Service Water Heating	Requires buildings with service water heating (SWH) capacity >= 1million Btu/h to have average efficiency of at least 90%. Updates Table 7.8 to reflect federal requirements for electric water heaters. Updates the reference standard for swimming pool water heaters to ASHRAE Standard 146.	7/26/2013	7/30/2013	7/29/13	9/4/13
bp	6. Heating, Ventilating, and Air-Conditioning	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G for evaporative condensers with ammonia refrigerants	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bq	6. Heating, Ventilating, and Air-Conditioning	Improve efficiency of commercial refrigeration systems	01/26/13	1/29/2013	2/11/2013	2/12/2013
br	10. Other Equipment	Updates motor efficiency tables	6/26/2013	6/26/2013	6/28/2013	7/1/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
bs	6. Heating, Ventilating, and Air-Conditioning	Reduce occupancy threshold for demand controlled ventilation from greater than 40 people per 1000 ft^2 to equal to or greater than 25 people per 1000 ft^2 with exemptions for certain occupancies.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bt	6. Heating, Ventilating, and Air-Conditioning	Reduces the threshold at which energy recovery is required. Relaxed in some climate zones.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
bv	9. Lighting	Reduces the threshold at which skylights and daylighting controls are required for high bay spaces.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bw	5.Building Envelope	Modifies orientation requirements and adds solar heat gain coefficient (SHGC) tradeoff	7/26/2013	7/30/2013	7/29/2013	8/28/2013
bx	9. Lighting	Clarification of exceptions to occupancy sensor requirements	01/26/13	1/29/2013	2/11/2013	2/12/2013
by	9.Lighting	Improves and enhances lighting controls requirements. Establishes table of lighting controls applicable to each space type. Corrects daylighting threshold.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ca	5.Building Envelope	Adds control requirements for heating systems in vestibules	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cb	6. Heating, Ventilating, and Air-Conditioning	This addendum requires night setback 10°F heating and 5°F cooling and removes exception for systems less than 10,000 cfm min for optimum start	7/26/2013	7/30/2013	7/29/2013	8/28/2013
cc	6. Heating, Ventilating, and Air-Conditioning	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G for evaporative condensers with R-507A	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cd	6. Heating, Ventilating, and Air-Conditioning	Provides definition for piping to include all accessories in series with pipe such as pumps, valves, strainers, air separators, etc. This is meant to clarify that these accessories need to be insulated.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ce	Appendix G	Establishes a baseline system type for retail occupancies less than 3 stories in Appendix G	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cf	Appendix G	Establishes baseline window-to-wall ratio (WWR) in Appendix G for strip malls.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ch	6. Heating, Ventilating, and Air-Conditioning	Improved air and water cooled chiller efficiencies in Table 6.8.1C. Exempts water cooled positive displacement chillers with leaving condenser temperature ≥ 115°F (typically heat reclaim chillers).	6/26/2013	6/26/2013	6/28/2013	7/1/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
ck	6. Heating, Ventilating, and Air-Conditioning	Requires VAV dual maximum damper position when DDC system is present	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cl	6. Heating, Ventilating, and Air-Conditioning	Table 6.8.1A and B. Improves integrated energy efficiency ratio (IEER) requirements for air-cooled air conditioners and heat pumps and EER requirements for water and evaporatively cooled air conditioners and heat pumps.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cn	Appendix G	Establishes modeling rules for laboratories with 100% outdoor air (OA) in Appendix G	6/26/2013	6/26/2013	6/28/2013	7/1/2013
co	9.Lighting	Comprehensive update of lighting power densities (LPDs) in Table 9.5.1 - Building Area Method	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cp	5.Building Envelope	Corrects non-residential U-factor and R-value requirements for steel joist floors in CZ3	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cr	9.Lighting	Makes a number of adjustments to Table 9.6.1 Space-by-space LPD	7/26/2013	7/30/2013	7/29/2013	7/31/2013
ct	Appendix G	Identifies heated only storage systems 9 and 10 in Appendix G as being assigned one system per thermal zone.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cv	Appendix G	Establishes baseline system types in Appendix G for Assembly occupancies.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cy	6. Heating, Ventilating, and Air-Conditioning	More stringent energy recovery for 24/7 occupancies	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cz	6. Heating, Ventilating, and Air-Conditioning	Increases boiler efficiency for residential sized (National Appliance Energy Conservation Act (NAECA) covered) equipment, <3,000 Btu/h	7/26/2013	7/30/2013	7/29/2013	7/31/2013
da	5.Building Envelope	Relaxes air leakage requirements for high-speed doors for vehicle access and material transport	7/26/2013	7/30/2013	7/29/2013	8/28/2013
db	5.Building Envelope	Corrects residential U-factor and R-value requirements for steel joist floors in CZ3	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dc	9. Lighting	Clarifies automatic lighting and switched receptacle control in guest rooms as applied to individual spaces.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dd	5.Building Envelope	Clarifies roof insulation requirements, differentiating between roof recovering (on top of existing roof covering) and replacement of roof covering.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
de	6. Heating, Ventilating, and Air-Conditioning	Relaxes design requirements for waterside economizers for computer rooms	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dg	5.Building Envelope	Updates reference to ANSI/CRRC-l Standard 2012 (cool roof ratings)	7/26/2013	7/30/2013	7/29/2013	7/31/2013
di	6. Heating, Ventilating, and Air-Conditioning	Establishes limits on using electric or fossil fuel to humidify or dehumidify between 30% and 60% relative humidity (RH) except certain applications. Requires deadband on humidity controls.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dj	9.Lighting	Additional lighting power allowance for electrical/mechanical rooms provided there is separate control for additional lighting.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dk	9.Lighting	Eliminates the exemption for wattage used in spaces where lighting is specifically designed for those with age-related eye conditions or other medical conditions related to the eye, where special lighting or light levels might be needed.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
dl	9.Lighting	Modifies hotel and motel guest room lighting power density.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
dn	6. Heating, Ventilating, and Air-Conditioning	Reduces the limits on hot gas bypass as a means of cooling capacity control.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
do	6. Heating, Ventilating, and Air-Conditioning	Update references to AHRI 550, AMCA 500, ANSI Z21.10.3 & Z21.47, ASHRAE 90.1 & 62.1, NEMA MG 1, & National Fire Protection Association (NFPA) 70 &96	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dp	6. Heating, Ventilating and Air Conditioning	Corrects the definition of walk-in-cooler to be consistent with federal requirements.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dq	6. Heating, Ventilating, and Air-Conditioning	Deletes sizing requirements for pipes >24"	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dr	5.Building Envelope	Clarifies definition of building entrances to exclude electrical room, mechanical rooms, and other utility service entrances.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dt	9.Lighting	Added exceptions for control of exterior lighting integral to signage. Requires certain types of exterior lighting exempt from LPD requirements to be separately controlled.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Table 2.1 (continued)

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD Approval	IES BOD Approval	ANSI Approval
dv	6. Heating, Ventilating, and Air-Conditioning	Establishes chiller and boiler fluid flow isolation requirements so there is no flow through the equipment when not in use.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dw	6. Heating, Ventilating, and Air-Conditioning	Revises high limit shutoff for air economizers. Add sensor accuracy requirements.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

3.0 Impacts of Addenda in Standard 90.1-2013

Each addendum in Table 2.1 was examined to subjectively evaluate its impact on overall building energy efficiency. Many of the addenda are editorial, clarification of the text, or related to alternative compliance paths of Standard 90.1, and have been determined to have no direct impact on energy efficiency. Other addenda have been determined to have significant positive or negative impacts on energy efficiency. The most common type of positive impact on energy efficiency occurs when a requirement is changed to a higher level of performance. The reverse change, from a higher level of performance to a lower level, is less common. However, there are addenda where exceptions are introduced for various requirements, and the addition of an exception or expansion of an exception could be considered a negative impact on energy efficiency.

Table 3.1 assesses the energy efficiency impact of each addendum. Addenda are ranked in terms of impact on building energy efficiency as follows: "major +" (significant positive impact), "minor +" (minor positive impact), "neutral" (no impact), "major –" (significant negative impact), or "minor –" (minor negative impact). A rationale for the ranking is provided for each addendum as well. Each rating considers the addendum's impact on all compliance paths where the addendum has an effect. The addenda are listed in alphabetical order in Table 3.1.

There are five addenda in Table 3.1that are listed as "neutral – adopts Federal standards" or "neutral – implements Federal standards". These addenda are Addenda 90.1-2010g, 90.1-2010y, 90.1-2010ar, 90.1-2010br, and 90.1-2010cz. Both Standard 90.1-2010 and Standard 90.1-2013 contain specific tables of HVAC, motors, transformers, and service water heating equipment efficiency requirements. Standard 90.1-2013 added efficiency tables for commercial refrigerators and freezers and prescriptive requirements for walk-in coolers and freezers. Most, but not all, of these equipment classes have minimum federal efficiency standards applied to them.

The overlap between federal efficiency standards and the requirements shown in ASHRAE Standard 90.1 as a model standard result in specific complications for an analysis used to inform a DOE determination of energy savings. In some instances, a revised edition of Standard 90.1 will adopt an existing federal efficiency standard into its tabulated efficiency requirement, typically with the same effective date as provided by the federal standard. Because that mandated equipment efficiency will be enforced as a manufacturing standard regardless of whether it is represented in Standard 90.1, the inclusion of the requirement in the ASHRAE standard is assumed to have no real energy impact. To address this issue, such addenda are listed as neutral in PNNL's qualitative analysis.

Table 3.1. Impact Assessment of Addenda for ASHRAE Standard 90.1-2013

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
1	a	90.1-2010a	10. Other Equipment and 12. Normative References	Specifies that nominal efficiencies for motors are required to be established in accordance with 10 CFR 431 instead of NEMA Standards. Modifies the footnotes to Tables 10.8A, 10.8B, 10.8 C (now Tables 10.8-1, 10.8-2, and 10.8-3 in Standard 90.1-2013). The corresponding reference for 10 CFR 431 has also been added.	Neutral (simply specifies alternate rating standard)
2	b	90.1-2010b	10. Other Equipment and 12. Normative References	Requires escalators and moving walks to automatically slow when not conveying passengers. The corresponding reference to ASME A17.1/CSA B44 has also been added to the Normative References.	Minor + (reduces escalator and moving walkway energy usage)
3	c	90.1-2010c	Appendix G	Adds requirements for laboratory exhaust fans to section G3.1.1, Baseline HVAC System Type and Definition. Lab exhaust fans are required to be modeled as constant horsepower, reflecting constant volume stack discharge with outside air bypass.	Neutral (whole building performance tradeoff method only)
4	e	90.1-2010e	Appendix G	Updates language in Section G3.1, part 5 'Building Envelope', to require that existing buildings use the same envelope baseline as new buildings with the exception of fenestration area.	Neutral (whole building performance tradeoff method only)
5	f	90.1-2010f	Appendix G	Modifies Section G.3.1, Building Envelope. Specifies the vertical fenestration area for calculating baseline building performance for new buildings and additions.	Neutral (whole building performance tradeoff method only)
6	g	90.1-2010g	6. Heating, Ventilating, and Air-Conditioning and 12.Normative References	Adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment. Table 6.8.1L and Table 6.8.1M (now Tables 6.8.1-12 and 6.8.1-13 in Standard 90.1-2013) have been added which specify the energy use limits for refrigerators and freezers. The corresponding references have also been added in Chapter 12.	Neutral (adopts Federal standards)
7	h	90.1-2010h	6. Heating, Ventilating, and Air-Conditioning.	Modifies the minimum efficiency standards for water-to-air heat pumps (water loop, ground water and ground loop). The proposed cooling EERs and heating COPs are more stringent than the present values. Also removes the small duct high velocity heat pump product class from Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013).	Minor + (increases stringency of existing requirements)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
8	i	90.1-2010i	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions	Increases the minimum efficiency standards for SPVAC and SPVHP. Also creates a new product class for SPVAC and SPVHP used in space constrained applications. This new product class only applies to non-weatherized products with cooling capacities <36,000 Btu/h and intended to replace an existing AC.	Minor + (increases stringency of existing requirements)
9	j	90.1-2010j	6. Heating, Ventilating, and Air-Conditioning.	Modifies the minimum efficiency requirements for evaporatively cooled air conditioners greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h and heating type-other, in Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013). The value is reduced to account for increased pressure drop in such system types. The product class, small duct high velocity air conditioner, has been eliminated.	Minor - (but this is due to correction of an error)
10	k	90.1-2010k	8. Power and 12. Normative References	Modifies notes to Table 8.1 and specifies that nominal efficiencies would be established in accordance with the 10 CFR 431 test procedure for low-voltage dry-type transformers. The corresponding references have also been added in Chapter 12.	Neutral (simply specifies alternative rating standard)
11	l	90.1-2010l	6. Heating, Ventilating, and Air-Conditioning.	Fixes the mistake with 90.1-2010 fan power limitations that required the user to perform calculations for fan bhp even if the simplified nameplate hp option was being used.	Neutral (editorial correction)
12	m	90.1-2010m	9. Lighting	Adds some control requirements for lighting alterations, for interior and exterior applications. Adds a section for submittals and includes loading docks as a tradable surface. Modifies the provisions for additional interior lighting power, which would now be calculated on the basis of controlled wattage.	Major + (adds control requirements for lighting alterations)
13	n	90.1-2010n	10. Other Equipment	Clarifies that the total lumens/watt for the entire elevator cab is required to meet the efficiency requirement and that each individual light source is not required to meet the lumens/watt value.	Neutral (clarification only)
14	o	90.1-2010o	5. Building Envelope and 3.Definitions	Adds the definition for sectional garage doors. Also modifies Section 5.4.3.2 (d), fenestration air leakage provisions for doors, to include requirements for glazed sectional garage doors.	Minor + (reduces air leakage in glazed sectional garage doors)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
15	p	90.1-2010p	5. Building Envelope and 12. Normative References	Modifies Section 5.5.3.1 and requires roof solar reflectance and thermal emittance testing to be in accordance with CRRC-1 Standard. Also modifies Section 12 by adding the reference for CRRC.	Neutral (simply specifies an alternative rating standard)
16	q	90.1-2010q	5. Building Envelope, 3. Definitions and 12. Normative References	Modifies Section 3 by changing the definition of dynamic glazing to include glazing systems or infill as well as shading systems between glazing layers and chromogenic glazing. Also modifies Section 5.8.2.2, by clarifying the requirements for labeling of fenestration and door products. The corresponding references to NFRC in Chapter 12 have also been updated.	Neutral (clarification only)
17	r	90.1-2010r	Appendix G and 12. Normative References	Clarifies the requirements related to temperature and humidity control in Appendix G and relocates all related wording to the Schedules section of Table3.1. Additionally, clarity is provided for modeling systems that provide occupant thermal comfort via means other than other than directly controlling the air dry-bulb and wet-bulb temperature (i.e. radiant cooling/heating, elevated air speed, etc.). Permits the use of ASHRAE Standard 55 for calculation of PMV-PPD. Also updates the Normative References by including a reference to ASHRAE Standard 55-2010.	Neutral (whole building performance tradeoff method only)
18	s	90.1-2010s	6. Heating, Ventilating, and Air-Conditioning.	Modifies the requirement for the static pressure sensor location and the control requirements for setpoint reset for systems with DDC of individual zones. Ensures that savings from previously required static pressure reset will be realized.	Minor + (ensures savings from static pressure reset achieved)
19	u	90.1-2010u	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions and 12. Normative References	Adds new definition as Fan Efficiency Grade (FEG) and requires each fan has a FEG of 67 or higher as defined by AMCA205-10 (Energy Efficiency Classification for Fans)	Major + (applies new requirements to individual fans)
20	v	90.1-2010v	8. Power	Clarifies the requirement for controlled receptacles in open offices applications by changing the requirement to the workstations themselves. Also requires the automatically controlled receptacles to be appropriately identified for the users benefit.	Neutral (clarification only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
21	w	90.1-2010w	3. Definitions, 11. Energy Cost Budget Method and Appendix G.	Adds definitions for on-site renewable energy and purchased energy. Clarifies the process for accounting for on-site renewable energy and purchased energy as well as calculating the annual energy costs in the ECB approach and Appendix G.	Neutral (whole building performance tradeoff method only)
22	y	90.1-2010y	3. Definitions and 10. Other Equipment	Revises the definitions of general purpose electric motors (subtype I &II) based on information from NEMA. Also updates the standard to include the new federal energy efficiency standards used in HVAC equipment, to be in effect from 2015. Adds Table 10.8D (now Table 10.8-4 in Standard 90.1-2013) which specifies minimum average full-load efficiency for Polyphase Small Electric Motors; and Table 10.8E (now Table 10.8-5 in Standard 90.1-2013) which specifies minimum average full-load efficiency for Capacitor-Start Capacitor-Run and Capacitor-Start Induction-Run Small Electric Motors.	Neutral (adopts Federal standards)
23	z	90.1-2010z	6. Heating, Ventilating, and Air-Conditioning.	Relocates the requirements for water economizers into the main economizer section, Section 6.5.1.5.	Neutral (editorial only)
24	aa	90.1-2010aa	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions	Eliminates the contingency on DDC system existence for setpoint overlap restrictions, humidification and dehumidification controls, VAV fan control setpoint reset, multiple-zone VAV system ventilation optimization control, hydronic system differential pressure reset by valve position. Instead specifies for what system types or sizes DDC is required in new buildings and alterations. Also specifies minimal functional requirements for DDC systems. (Prior to this addendum certain controls requirements were only required when the controls were provided by a DDC system.)	Minor + (requires additional HVAC controls)
25	ad	90.1-2010ad	12. Normative References (related to 6. Heating, Ventilating, and Air-Conditioning)	Adds reference to specific addenda to AHRI standards 340/360 and 1230 being referenced.	Neutral (updates references only)
26	ae	90.1-2010ae	12. Normative References (related to 6. Heating, Ventilating, and Air-Conditioning)	Adds reference to specific addenda to AHRI standards 210/240 and 550/590 being referenced.	Neutral (updates references only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
27	af	90.1-2010af	6. Heating, Ventilating, and Air-Conditioning	Modifies heat rejection equipment (cooling tower) requirements to require that VSD controlled fans operate all fans at the same speed instead of sequencing them, and require that open-circuit towers with multiple cells operate all cells in parallel down to 50% of design flow.	Minor + (reduces cooling tower energy usage)
28	ag	90.1-2010ag	Appendix G and 12. Normative References	Establishes a method for gaining credit in Appendix G for buildings that undergo whole building air leakage testing to demonstrate that they have an air-tight building.	Neutral (whole building performance tradeoff method only)
29	ah	90.1-2010ah	Appendix G	Sets system sizing requirements in Appendix G for humid climates based on humidity ratio instead of supply air temperature differential. Sets baseline system dehumidification requirements.	Neutral (whole building performance tradeoff method only)
30	ai	90.1-2010ai	Appendix G	Modifies Appendix G to account for 3 prescriptive addenda that were incorporated in to standard 90.1-2010, but did not make it into Appendix G in time for publication. Updates economizer requirements to match addendum cy, establishes baseline transformer efficiency requirements to match addendum o, and establishes path A for centrifugal chiller baselines from addendum m.	Neutral (whole building performance tradeoff method only)
31	aj	90.1-2010aj	6. Heating, Ventilating, and Air-Conditioning	Requires fractional horsepower motors ≥1/12 hp to be electronically-commutated motors or have a minimum 70% efficiency in accordance with 10 CFR 431. Also requires adjustable speed or other method to balance airflow.	Minor + (reduces fractional horsepower motor energy usage)
32	al	90.1-2010al	Appendix G	Establishes a consistent fuel source for space heating for baseline systems based on climate zone. Establishes a consistent fuel source for service water heating based on building type.	Neutral (whole building performance tradeoff method only)
33	am	90.1-2010am	6. Heating, Ventilating, and Air-Conditioning	Establishes minimum turndown for boilers and boiler plants with design input power of at least 1,000,000 Btu/h.	Major + (reduces energy usage for large boilers)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
34	an	90.1-2010an	Appendix C	Rewrites entire Appendix C to use a simulation based approach for envelope tradeoffs.	Neutral (alternative compliance method only)
5	ap	90.1-2010ap	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions.	Adds PUE as an alternative compliance methodology for data centers.	Neutral (alternative compliance method only)
36	aq	90.1-2010aq	6. Heating, Ventilating, and Air-Conditioning and 11.Energy Cost Budget	Expands the requirements for fan speed control for both chilled water and unitary direct expansion systems. In addition enhances the requirements for integrated economizer control and defines DX unit capacity staging requirements.	Major + (reduces fan energy usage)
37	ar	90.1-2010ar	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions	Adds mandatory and prescriptive requirements for walk-in coolers and freezers and refrigerated display cases	Neutral (adopts Federal standards)
38	as	90.1-2010as	6. Heating, Ventilating, and Air-Conditioning	Requires humidifiers mounted in the airstream to have an automatic control valve shutting off preheat when humidification is not required, and insulation on the humidification system dispersion tube surface. (Avoidance of simultaneous heating and cooling at AHU.)	Minor + (reduces humidification energy usage)
39	at	90.1-2010at	3. Definitions, 5. Building Envelope, and 9. Lighting	Deletes the term clerestory and instead adds roof monitor and clarifies the definition. Changes the references in Chapters 5 and 9 from clerestory to roof monitor.	Neutral (clarification only)
40	au	90.1-2010au	6. Heating, Ventilating, and Air-Conditioning	Modifies Table 6.5.3.1.1B which addresses fan power limitation pressure drop adjustment credits. Deductions from allowed fan power are added for systems without any central heating or cooling as well as systems with electric resistance heating. Sound attenuation credit is modified to be available only when there are background noise criteria requirements.	Minor + (restricts sound attenuation credit and adds deductions for certain systems)
41	av	90.1-2010av	6. Heating, Ventilating, and Air-Conditioning	Modifies Section 6.5.1, exception k, applicable to Tier IV data centers, to make economizer exceptions more stringent and in agreement with ASHRAE TC 9.9.	Minor + (makes economizer exceptions more stringent)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
42	aw	90.1-2010aw	11. Energy Cost Budget and Appendix G	Updates the reference year for ASHRAE Standard 140 and exempts software used for ECB and Appendix G compliance from having to meet certain sections of ASHRAE Standard 140.	Neutral (whole building performance tradeoff method only)
43	ax	90.1-2010ax	Appendix G	Modifies Table G3.1, Part 14 of Appendix G to exclude the condition that permits a building surface, shaded by an adjacent structure, to be simulated as north facing if the simulation program is incapable of simulating shading by adjacent structures.	Neutral (whole building performance tradeoff method only)
44	ay	90.1-2010ay	3. Definitions and 9. Lighting	Modifies daylighting requirements. Modifies definitions for daylight area under skylights, daylight area under roof monitors, primary sidelight area, and secondary sidelight area. Changes the criterion for applying automatic daylighting control for sidelighting and toplighting to a controlled lighting power basis and provides characteristics for the required photo controls. Adds control requirements for secondary sidelighted areas. Modifies Table 9.6.2 to include continuous dimming in secondary sidelighted areas, which is now based on an installed wattage rather than area of the space. Eliminates the need for effective aperture calculation.	Minor + (requires additional controls)
45	az	90.1-2010az	6. Heating, Ventilating, and Air-Conditioning	Increases the minimum efficiency of open circuit axial fan cooling towers. An additional requirement has been added for all types of cooling towers which states that the minimum efficiency requirements applies to the tower including the capacity effect of accessories which affect thermal performance. An additional footnote clarifies that the certification requirements do not apply to field erected cooling towers.	Minor + (increase efficiency of cooling towers)
46	ba	90.1-2010ba	6. Heating, Ventilating, and Air-Conditioning	Adds requirements for door switches to disable or reset mechanical heating or cooling when doors without automatic door closers are left open.	Minor + (reduces heating and cooling when doors are left open)

3.8

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
47	bb	90.1-2010bb	3. Definitions, 5. Building Envelope, 11. Energy Cost Budget Method, and Appendix A	Modifies the building envelope requirements for opaque assemblies and fenestration in tables 5.5.1 through 5.5.8. Adds and modifies text in Section 5. Adds new visible transmittance (VT) requirement through Section 5.5.4.5. Also updates the NFRC 301 reference, references in Section 11 and modifies two metal building roof assemblies in Table A2.3.	Major + (increases stringency of building envelope requirements)
48	bc	90.1-2010bc	9. Lighting	Modifies requirements for automatic lighting control for guestroom type spaces. Exceptions to this requirement are lighting and switched receptacles controlled by captive key systems.	Minor + (requires automatic control of lighting and switched receptacles in hotel rooms)
49	bd	90.1-2010bd	9. Lighting	Adds more specific requirements for the functional testing of lighting controls, specifically, occupancy sensors, automatic time switches and daylight controls.	Minor + (improves functional testing of lighting controls)
50	be	90.1-2010be	9. Lighting	Makes minor revisions to Section 9.7.2.2, which addresses the scope of the operating and maintenance manuals required for lighting equipment and controls.	Neutral (clarification only)
51	bf	90.1-2010bf	8. Power	Addresses Section 8.4.2 on automatic receptacle control and increases the spaces where plug shutoff control is required. Clarifies the application of this requirement for furniture systems, lowers the threshold for turn off from 30 to 20 minutes, states a labeling requirement to distinguish controlled and uncontrolled receptacles and restricts the use of plug-in devices to comply with this requirement.	Minor + (reduces plug loads)
52	bg	90.1-2010bg	5. Building Envelope	Adds low-E requirements for storm window retrofits.	Minor + (requires low-E storm windows in retrofits)
53	bh	90.1-2010bh	9. Lighting	Modifies Table 9.6.1 Space-By-Space Lighting Power Density allowance.	Minor + (overall, LPDs go down)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
54	bi	90.1-2010bi	6. Heating, Ventilating, and Air-Conditioning	Increase SEER and HSPF for air-cooled three-phase commercial air conditioners and heat pumps below 65,000 Btu/h. Effective 1/1/2015.	Minor + (increases stringency of existing requirements)
55	bj	90.1-2010bj	6. Heating, Ventilating, and Air-Conditioning.	Re-establishes the product class for SDHV air conditioners and heat pumps. Adds efficiency requirements for systems at <65.000 Btu/h below level of current federal standards.	Neutral (re-establishes efficiency requirements that do not meet the level of federal standards)
56	bk	90.1-2010bk	6. Heating, Ventilating, and Air-Conditioning	Increases cooling efficiency for PTACs.	Minor + (increases stringency of existing requirements)
57	bl	90.1-2010bl	11. Energy Cost Budget and Appendix G	Provides rules for removing fan energy from efficiency metrics when modeling in ECB or Appendix G.	Neutral (whole building performance tradeoff method only)
58	bn	90.1-2010bn	8. Power and 10. Other Equipment	Establishes electric and fuel metering requirements.	Neutral (metering by itself does not save energy)
59	bo	90.1-2010bo	7. Service Water Heating	Requires buildings with service water heating (SWH) capacity ≥ 1 million Btu/h to have average thermal efficiency of at least 90%. Updates Table 7.8 to reflect federal requirements for electric water heaters. Updates the reference standard for swimming pool water heaters to ASHRAE Standard 146.	Minor + (requires large new gas SWH systems to have higher average efficiency)
60	bp	90.1-2010bp	6. Heating, Ventilating, and Air-Conditioning and 12. Normative References	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with ammonia refrigerants	Minor + (adds efficiency requirements for new products)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
61	bq	90.1-2010bq	6. Heating, Ventilating, and Air-Conditioning and 3. Definitions	Adds prescriptive requirements for the efficiency and improved control of commercial refrigeration systems.	Major + (adds new efficiency requirements for commercial refrigeration)
62	br	90.1-2010br	10. Other Equipment	Updates motor efficiency tables to match Federal rulemaking.	Neutral (implements Federal standards)
63	bs	90.1-2010bs	6. Heating, Ventilating, and Air-Conditioning	Reduces occupancy threshold for demand controlled ventilation from greater than 40 people per 1000 ft^2 to equal to or greater than 25 people per 1000 ft^2 with exemptions for certain occupancies.	Minor + (reduces ventilation energy usage)
64	bt	90.1-2010bt	6. Heating, Ventilating, and Air-Conditioning	Reduces the system size and outdoor air thresholds at which energy recovery is required. Relaxed in some climate zones.	Minor + (expands the use of exhaust air energy recovery to lower percent outdoor air)
65	bv	90.1-2010bv	5. Building Envelope	Reduces the area threshold at which skylights and daylighting controls are required.	Minor + (reduces lighting energy usage)
66	bw	90.1-2010bw	5. Building Envelope and 11. Energy Cost Budget Method	Modifies orientation requirements and adds SHGC tradeoff.	Minor + (provides more design flexibility leading to higher compliance with prescriptive path)
67	bx	90.1-2010bx	9. Lighting	Clarifies exceptions to occupancy sensor requirements.	Neutral (clarification only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
68	by	90.1-2010by	9. Lighting	Significantly modifies the way requirements are presented in Section 9. Requires the use of certain lighting controls in more space types. Reduces the amount of time after occupants vacate a space for lights to be automatically reduced or shut off. Establishes table of lighting controls applicable to each space type.	Major + (requires more controls in more spaces and reduces time to reduction or shutoff)
69	bz	2007 90.1bz	8. Power	Adds a Section 8.4.2 which specifies requirements for installation of basic electrical metering of major end uses (total electrical energy, HVAC Systems, interior lighting, exterior lighting and receptacle circuits) to provide basic reporting of energy consumption data to building occupant.	Neutral (metering by itself does not save energy)
70	ca	90.1-2010ca	6. Heating, Ventilating, and Air-Conditioning	Adds control requirements for heating systems in vestibules.	Minor + (reduces vestibule heating energy usage)
71	cb	90.1-2010cb	6. Heating, Ventilating, and Air-Conditioning	Revises night setback requirements to a reset of 10°F heating & 5°F cooling and removes exceptions for climate zones. Changes optimum start requirement from > 10,000 cfm to any DDC system and adds a requirement that outside air temperature be used in optimum algorithms.	Minor + (expands heating and cooling setbacks)
72	cc	90.1-2010cc	6. Heating, Ventilating, and Air-Conditioning	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with R-507A.	Minor + (adds efficiency requirements for new products)
73	cd	90.1-2010cd	6. Heating, Ventilating, and Air-Conditioning and 7. Service Water Heating and 3. Definitions	Provides definition for piping to include all accessories in series with pipe such as pumps, valves, strainers, air separators, etc. This is meant to clarify that these accessories need to be insulated.	Neutral (editorial only)
74	ce	90.1-2010ce	Appendix G	Establishes a baseline system type for retail occupancies less than 3 stories in Appendix G.	Neutral (whole building performance tradeoff method only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
75	cf	90.1-2010cf	Appendix G	Establishes baseline WWR in Appendix G for strip malls.	Neutral (whole building performance tradeoff method only)
76	cg	90.1-2010cg	11. Energy Cost Budget and Appendix G	Modifies the simulation requirements for modeling mandatory automatic daylighting controls as well as automatic lighting controls. Also modifies the simulation requirements for automatic lighting controls in the proposed design, beyond the minimum mandatory requirements. Table G3.2, which provided power adjustment percentages for automatic lighting controls, has been deleted and savings through automatic control devices are now required to be modeled in building simulation through schedule adjustments for the proposed design or by lighting power adjustments defined in Table 9.6.3.	Neutral (whole building performance tradeoff method only)
77	ch	90.1-2010ch	6. Heating, Ventilating, and Air-Conditioning	Increases air- and water-cooled chiller efficiencies in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). Exempts water-cooled positive displacement chillers with leaving condenser temperature ≥ 115°F (typically heat reclaim chillers).	Minor + (increases stringency of existing requirements)
78	ci	90.1-2010ci	3. Definitions, 11. Energy Cost Budget and Appendix G	Modifies requirements for the cooling tower fans in Chapter 11baseline simulations, from two-speed to variable speed. A formula has been specified to calculate the condenser water design supply temperature. Similar revisions have been made to Appendix G for the cooling tower requirements. Definitions for cooling design wet-bulb temperature and evaporation design wet-bulb temperature have been added to Chapter 3.	Neutral (whole building performance tradeoff method only)
79	cj	90.1-2010cj	Appendix G	Creates modeling rules for computer rooms in Appendix G.	Neutral (whole building performance tradeoff method only)
80	ck	90.1-2010ck	6. Heating, Ventilating, and Air-Conditioning	Requires VAV dual maximum damper position when DDC system is present and clarifies dual maximum sequence.	Minor + (requires dual maximum control for VAV zones with DDC

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
81	cl	90.1-2010cl	6. Heating, Ventilating, and Air-Conditioning	Increases IEER requirements for air-cooled air conditioners and heat pumps and EER requirements for water and evaporatively cooled air conditioners and heat pumps in Tables 6.8.1A and B (now Tables 6.8.1-1 and 6.8.1-2 in Standard 90.1-2013).	Minor + (increases stringency of existing requirements)
82	cm	90.1-2010cm	5. Building Envelope	Clarifies how to interpret the use of dynamic glazing products given the requirements in Addendum bb (envelope requirements).	Neutral (clarification only)
83	cn	90.1-2010cn	Appendix G	Establishes modeling rules for laboratories with 100% OA in Appendix G.	Neutral (whole building performance tradeoff method only)
84	co	90.1-2010co	9. Lighting	Comprehensive update of LPDs in Table 9.5.1 - Building Area Method.	Major + (decreases LPD in most building types)
85	cp	90.1-2010cp	5. Building Envelope	Corrects non-residential U-factor and R-value requirements for steel joist floors in CZ3.	Minor + (increases R-value requirements for steel joist floors)
86	cr	90.1-2010cr	9. Lighting and 12. Normative References	Makes a number of adjustments to Table 9.6.1, Space-by-space LPD.	Minor + (plus on retail outweighs some negatives on other building types)
87	ct	90.1-2010ct	Appendix G	Identifies heated only storage systems 9 and 10 in Appendix G as being assigned one system per thermal zone.	Neutral (whole building performance tradeoff method only)
88	cv	90.1-2010cv	Appendix G	Establishes baseline system types in Appendix G for Assembly occupancies.	Neutral (whole building performance tradeoff method only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
89	cy	90.1-2010cy	6. Heating, Ventilating, and Air-Conditioning	Reduces the design supply fan air flow rate for which energy recovery is required for systems that operate more than 8000 hours per year.	Minor + (applies energy recovery requirements to smaller fan systems)
90	cz	90.1-2010cz	6. Heating, Ventilating, and Air-Conditioning	Increases boiler efficiency for residential sized (NAECA covered) equipment, <3,000 Btu/h.	Neutral (adopts Federal standards)
91	da	90.1-2010da	5. Building Envelope	Relaxes air leakage requirements for high-speed doors for vehicle access and material transport.	Minor - (relaxes air leakage requirements for high-speed doors)
92	db	90.1-2010db	5. Building Envelope	Corrects residential U-factor and R-value requirements for steel joist floors in CZ3.	Minor - (relaxes steel joist floor requirements in CZ3)
93	dc	90.1-2010dc	9. Lighting	Clarifies automatic lighting and switched receptacle control in guest rooms as applied to individual spaces.	Neutral (clarification only)
94	dd	90.1-2010dd	5. Building Envelope and 3. Definitions	Clarifies roof insulation requirements, differentiating between roof recovering (on top of existing roof covering) and replacement of roof covering.	Neutral (clarification only)
95	de	90.1-2010de	6. Heating, Ventilating, and Air-Conditioning	Relaxes design requirements for waterside economizers for computer rooms.	Minor - (relaxes economizer requirements for computer rooms)
96	dg	90.1-2010dg	12. Normative References (related to 5. Building Envelope)	Updates reference to ANSI/CRRC-l Standard 2012 (cool roof ratings).	Neutral (updates references only)
97	di	90.1-2010di	6. Heating, Ventilating, and Air-Conditioning	Establishes limits on using electric or fossil fuel to humidify or dehumidify between 30% and 60% RH except certain applications. Requires deadband on humidity controls.	Minor + (reduces humidification energy usage)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
98	dj	90.1-2010dj	9. Lighting	Additional lighting power allowance for electrical/mechanical rooms made available to match 2010 level provided there is separate control for the additional lighting.	Neutral (tradeoff of additional lighting power for additional control)
99	dk	90.1-2010dk	9. Lighting	Eliminates the exemption for wattage used in spaces where lighting is specifically designed for those with age-related eye conditions or other medical conditions related to the eye, where special lighting or light levels might be needed.	Minor + (trades blanket exemption for more targeted LPD increases)
100	dl	90.1-2010dl	9. Lighting	Modifies hotel and motel guest room lighting power density.	Minor + (new average LPD less than previous requirements)
101	dm	90.1-2010dm	5. Building Envelope	Modifies section 5.4.3.4 for vestibules. Adds a size limit for large buildings, exemptions for semiheated spaces and elevator lobbies in parking garages.	Minor + (reduces vestibule energy usage)
102	dn	90.1-2010dn	6. Heating, Ventilating, and Air-Conditioning	Reduces the limits on hot gas bypass as a means of cooling capacity control.	Minor + (reduces hot gas bypass)
103	do	90.1-2010do	12. Normative References (related to 6. Heating, Ventilating, and Air-Conditioning)	Updates references to AHRI 550, AMCA 500, ANSI Z21.10.3 & Z21.47, ASHRAE 90.1 & 62.1, NEMA MG 1, & NFPA 70 & 96.	Neutral (updates references only)
104	dp	90.1-2010dp	3. Definitions (related to 6. Heating, Ventilating, and Air-Conditioning)	Corrects the definition of walk-in-cooler to be consistent with federal requirements.	Neutral (editorial only)
105	dq	90.1-2010dq	6. Heating, Ventilating, and Air-Conditioning	Deletes sizing requirements for pipes >24 inches in diameter	Minor - (eliminates sizing requirements for pipes above 24" in diameter)
106	dr	90.1-2010dr	3. Definitions (related to 5. Building Envelope)	Clarifies definition of building entrances to exclude electrical room, mechanical rooms, and other utility service entrances.	Neutral (clarification only)

Table 3.1 (continued)

Number	Addendum Letter	Full Name of Addendum	Section Affected in 90.1-2010	Description of Changes	Impact on Energy Efficiency (justification)
107	ds	90.1-2010ds	5. Building Envelope and 3. Definitions	Revises the definitions of primary sidelighted area, secondary sidelighted area, and sidelighting effective area to use the term "vertical fenestration" instead of "window" to clarify that glazed doors and other fenestration products are included as well as windows. Additionally, the definition of daylight area under rooftop monitors is corrected to include the spread of light beyond the width of the rooftop monitor glazing.	Neutral (editorial only)
108	dt	90.1-2010dt	9. Lighting	Adds exceptions for control of exterior lighting integral to signage. Requires certain types of exterior lighting exempt from LPD requirements to be separately controlled.	Minor + (expansion of requirement to all signage may outweigh addition of exception)
109	dv	90.1-2010dv	6. Heating, Ventilating, and Air-Conditioning	Establishes chiller and boiler fluid flow isolation requirements so there is no flow through the equipment when not in use.	Minor + (reduces off hour chiller and boiler energy use)
110	dw	90.1-2010dw	6. Heating, Ventilating, and Air-Conditioning	Revises high limit shutoff for air economizers. Add sensor accuracy requirements.	Minor + (adds sensor accuracy requirements)

<u>KEY</u>: The following terms are used to characterize the effect of individual addenda on energy efficiency (as contained in the above table): Major + indicates that an addendum is anticipated to significantly improve energy efficiency; Minor + indicates that an addendum may improve energy efficiency in specific applications, Neutral indicates that an addenda is not anticipated to impact energy efficiency; and Minor – indicates that an addendum may increase energy use in certain applications.

Table 3.2 summarizes the overall impacts of addenda included in Standard 90.1-2013.

Table 3.2. Summary of Addenda Impact

Major Negative	Minor Negative	Neutral	Minor Positive	Major Positive	Total
None	5	53	44	8	110

The results of the textual analysis indicate that less than half of the changes (53 of the total of 110 listed) were considered neutral for the purpose of the determination. These include editorial changes, changes to reference standards, changes to alternative compliance paths, and other changes to the text of the standard that may improve the usability of the standard, but do not generally improve or degrade the energy efficiency of a building. Based on the analysis, the sum of the major positive and minor positive addenda (52) greatly overwhelms the number of minor negative addenda (5). Of those five addenda with negative impacts, none were determined to have a major impact, leading to the conclusion that the overall impact of the addenda on the standard is positive.

The eight major positive impacts on energy efficiency include the following:

1. Addendum 90.1-2010m – adds control requirements for lighting alterations.
2. Addendum 90.1-2010u – applies new efficiency requirements to individual fans.
3. Addendum 90.1-2010aq – reduces fan energy usage and improves economizer effectiveness.
4. Addendum 90.1-2010am – reduces large boiler energy usage.
5. Addendum 90.1-2010bb – increases stringency of building envelope requirements.
6. Addendum 90.1-2010bq – adds new efficiency requirements for commercial refrigeration.
7. Addendum 90.1-2010by – requires more lighting controls in more space and reduces time to reduction or shutoff.
8. Addendum 90.1-2010co – decreases LPD in most building types.

Many of these “major positive” addenda are self-descriptive. The high-level themes of the major positive addenda tend be:

- Better lighting, daylighting, and controls (90.1-2010m, 90.1-2010by, and 90.1-2010co)
- Better mechanical systems and application to more systems (90.1-2010u, 90.1-2010aq, and 90.1-2010bq)
- Better building envelope (90.1-2010bb)

The five negative impacts on energy efficiency include the following:

1. Addendum 90.1-2010j – reduces EER for evaporatively cooled air conditioners.
2. Addendum 90.1-2010da – relaxes air leakage requirements for high-speed doors.
3. Addendum 90.1-2010db – relaxes the U-factor requirement for residential steel joist floors in Climate Zone 3.
4. Addendum 90.1-2010de – relaxes economizer requirements for computer rooms.
5. Addendum 90.1-2010dq – eliminates sizing requirements for pipes above 24 inches in diameter.

None of these negative energy impacts is judged to be major. Addendum 90.1-2010j is described in its preamble as "fixing an error"; however, the fixed value does reduce efficiency. Addendum 90.1-2010da provides new requirements for high-speed doors that would have been required to meet tighter requirements for other non-swinging doors. Addendum 90.1-2010db raises the U-factor requirement for residential steel joist floors in Climate Zone 3. Addendum 90.1-2010de provides reduced economizer requirements for computer rooms compared to what was required in Standard 90.1-2010. Addendum 90.1-2010dq eliminates any requirements for piping over 24-inches in diameter, although such piping is likely to be uncommon in buildings covered by Standard 90.1.

Table 3.3 shows the results of the textual analysis on a section-by-section basis. This indicates the impact that different technical areas of the standard have on the efficiency improvements of the standard as a whole. Some addenda affect multiple sections. Addenda are listed by the primary technical section they address. Thus, an addendum that modifies the lighting requirements and a definition related to lighting is listed only in the lighting section. Any addendum that modifies only definitions or references would be listed under the technical section related to the definitions being modified. Any addendum that modifies multiple technical sections (for example, Building Envelope and Lighting) would be credited to each section. The overall addenda count noted at the bottom of Table 3.3 matches the 110 addenda processed for Standard 90.1-2013, as reported in Table 2.1, Table 3.1, and Table 3.2, and in the text of this document, but are not totals of the impacted sections listed in the table as some addenda impact multiple sections.

Table 3.3. Results of Textual Analysis by Section of Standard 90.1-2013

Section of Standard	Total Number of Changes Attributed to Section	Number of Positive (Energy Saving) Changes	Number of Neutral (No Energy Saving) Changes	Number of Negative (Energy Increasing) Changes
Title, (1) Purpose, and (2) Scope	0	0	0	0
(3) Definitions, Abbreviations and Acronyms*	*	*	*	*
(4) Administration and Enforcement	0	0	0	0
(5) Envelope and Normative Appendices	18	7	9	2
(6) HVAC Equipment and Systems	46	31	12	3
(7) Service Water Heating	2	1	1	0
(8) Power	5	1	4	0
(9) Lighting	16	11	5	0
(10) Other Equipment	6	1	5	0
(11) Energy Cost Budget	6	1***	5	0
Appendix G Performance Rating Method	20	0	20	0
Normative and Informative References*	*	*	*	*
Overall Addenda Count**	110	52	53	5

*Changes to Definitions, Abbreviations, and Acronyms or Normative and Informative References are included in the relevant technical section.

** The overall addenda count is not a sum of the values in the table because several addenda affect multiple sections in the standard.

***The single addendum that is a positive change for the whole building sections (Section 11 Energy Cost Budget Method) is addendum 90.1-2010bw, which is rated as minor positive impact due to the impact it has on Section 3 Building Envelope, and not due to its impact on Section 11 Energy Cost Budget Method.

The number of positive and negative addenda for the six prescriptive sections (Building Envelope; Heating, Ventilating, and Air-Conditioning; Service Water Heating; Power; Lighting; and Other) is captured in Figure 3.1. Note that neutral addenda are ignored in this graphic representation, and that some addenda are attributed to more than one technical section.

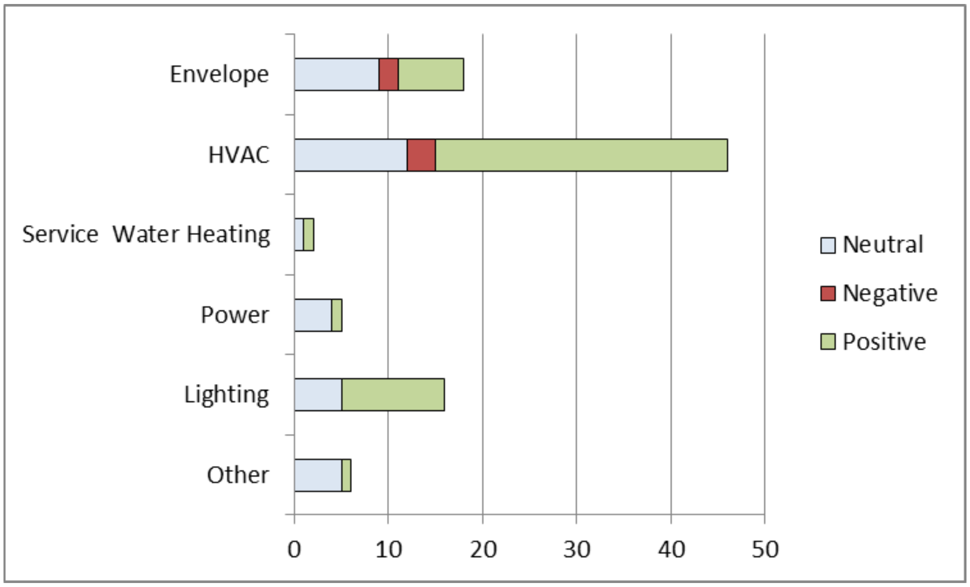

Figure 3.1. Technical Section Addenda Count by Energy Efficiency Impact

4.0 Detailed Discussion of Impacts of Addenda on Various Sections of Standard 90.1-2013

Standard 90.1-2013 contains 12 normative sections and 5 normative appendices that are considered part of the standard. Standard 90.1-2013 also contains two informative appendices that provide additional information relevant to use of the standard, but that are not considered part of Standard 90.1-2010. DOE's evaluation of Standard 90.1-2013 focuses on the normative sections and appendices. This chapter examines each normative section and its associated appendices to identify the changes associated with each section and to assess the impact of those changes on various compliance paths allowed for that section.

Sections 5 through 9 of Standard 90.1-2013 are the heart of the technical requirements. For Sections 5 through 9, Standard 90.1-2013 offers multiple compliance paths. Each section has mandatory requirements that must be met for all buildings. Each section may also have one or more sets of prescriptive requirements that must be met for all buildings unless a tradeoff option is used. Sections 5, 6, and 9 have specific tradeoff options for use within these sections. For example, Section 5 allows tradeoffs between window overhangs and solar heat gain coefficient, Section 6 between economizers and cooling efficiency, and Section 9 between lighting power and lighting controls. Section 6 also has a simple system approach that combines mandatory and prescriptive requirements for certain buildings and HVAC systems. Section 11 provides an overall whole building tradeoff option for Standard 90.1-2013 based on equal energy cost between a baseline building and the proposed design.

Some addenda affect more than one section. Addenda are listed in each technical section that they impact. In some cases, addenda are discussed for multiple sections. For example, addendum 90.1-2010bw impacts both the Building Envelope and Energy Cost Budget Method sections and is therefore discussed under both sections.

4.1 Changes to Title, Section 1 Purpose, and Section 2 Scope

No changes were made to the Title, Purpose, and Scope during the creation of Standard 90.1-2013.

4.2 Changes to Section 3, Definitions, Abbreviations, and Acronyms

Changes made to Section 3, Definitions, Abbreviations, and Acronyms, during the creation of Standard 90.1-2013 are included in the technical section most appropriate to the definition. For example, addendum 90.1-2010dr revises the definition of "building entrance" and is therefore discussed under Section 5, Building Envelope.

4.3 Changes to Section 4, Administration and Enforcement

No changes were made to Section 4, Administration and Enforcement, during the creation of Standard 90.1-2013.

4.4 Changes to Section 5, Building Envelope and Normative Appendices A–D

A total of 18 addenda were made to Section 5, Building Envelope, and the associated Normative Appendices A‑D during the creation of Standard 90.1-2013. Several addenda also modified definitions (Section 3) and normative references (Section 12), but are discussed under Building Envelope. One addendum (90.1-2010bw) updates Section 3, Building Envelope, and Section 11, Energy Cost Budget Method, and is discussed in both locations. One addendum (90.1-2010at) updates Section 3, Building Envelope, and Section 9, Lighting, and is discussed in both locations.

Addendum 90.1-2010o

Sections(s) Modified: 5. Building Envelope and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds the definition for "sectional garage doors." Also modifies Section 5.4.3.2 (d), fenestration air leakage provisions for doors, to include requirements for glazed sectional garage doors.

Discussion: Addendum 90.1-2010o adds a new definition of "sectional garage door" to Section 3 and modifies Section 5.4.3.2(d) to include glazed sectional garage doors to the category of doors having an air leakage requirement of 0.4 cfm/ft^2.

Impact: Given that these doors would likely have fallen into a category with a higher air leakage requirement, this addendum is considered a minor positive in terms of energy efficiency.

Addendum 90.1-2010p

Sections(s) Modified: 5. Building Envelope and 12. Normative References

Short Description: Modifies Section 5.5.3.1 and requires roof solar reflectance and thermal emittance testing to be in accordance with CRRC-1 Standard. Also modifies Section 12 by adding the reference for CRRC.

Discussion: Addendum 90.1-2010q replaces four ASTM references for roof solar reflectance and emittance with a reference to the Cool Roof Rating Council ANSI/CRRC-1 Standard-2010, "Cool Roof Rating Council – ANSI/CRRC-1 Standard" (CRRC 2010). Editorial changes are made to the Roof Solar Reflectance and Thermal Emittance section of Standard 90.1 to incorporate this change.

Impact: Because this addendum simply changes a rating standard, it is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010q

Sections(s) Modified: 5. Building Envelope, 3. Definitions, Abbreviations, and Acronyms, and 12. Normative References

Short Description: Modifies Section 5.8.2.2 by clarifying the requirements for labeling of fenestration and door products. The corresponding references to NFRC in Chapter 12 have also been updated.

Discussion: Addendum 90.1-2010q modifies the definition of "dynamic glazing" to match the definition used by the NFRC. The addendum also modifies requirements for labeling of fenestration and doors to specifically mention site-built fenestration as a product requiring a label or signed certificate. The labeling requirements for doors are also folded into the labeling requirements for windows. The addendum also updates the four NFRC reference standards—100, 200, 300, and 400—from the 2004 version to the 2010 version (NFRC 2010a, NFRC 2010b, NFRC 2010c, and NFRC 2010e).

Impact: Given that this addendum is primarily a clarification, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010an

Sections(s) Modified: Appendix C

Short Description: Rewrites entire Appendix C to use a simulation-based approach for envelope tradeoffs.

Discussion: Appendix C of Standard 90.1 is the building envelope tradeoff methodology specified in Section 5.6 of Standard 90.1, hence the inclusion of this addendum in the Building Envelope section. Addendum 90.1-2010an completely replaces the existing regression equation-based tradeoff methodology with a new whole building simulation approach. Given that it is a complete replacement, detailed discussion of changes is not provided in this document.

Impact: Because this addendum simply changes the building envelope tradeoff methodology, it is considered neutral, with no impact on energy efficiency.

Addendum 90.1-2010at

Sections(s) Modified: 5.Building Envelope, 9. Lighting, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Deletes the term “clerestory” and adds “roof monitor” and clarifies the definition. Changes the references in Chapters 5 and 9 from clerestory to roof monitor.

Discussion: In Section 3, Addendum 90.1-2010at deletes the terms “clerestory” and “rooftop monitor” and adds the term “roof monitor.” The terms “fenestration,” “daylit area,” and “toplighting” are edited to use the term “roof monitor.” The addendum also makes minor changes to the daylight area width under roof monitors. Figure 3.2 in Standard 90.1-2010 for the daylight area under roof monitors is also replaced. In Sections 5 and 9, the addendum edits two sections to use the term “roof monitor”—Exception d to Section 5.5.4.2.3 and Section 9.4.1.5.

Impact: Given that the addendum is editorial, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bb

Sections(s) Modified: 5. Building Envelope and 3. Definitions, Acronyms, and Abbreviations, Appendix A, and 11. Energy Cost Budget Method

Short Description: Modifies the building envelope requirements for opaque assemblies and fenestration in Tables 5.5.1 through 5.5.8 and associated text. Also updates the NFRC 301 reference (NFRC 2010d) and modifies two metal building roof assemblies in Table A2.3.

Discussion: Addendum 90.1-2010bb is a complex addendum that modifies a number of sections impacting building envelope requirements and definitions. A high-level summary of the addendum is provided below:

> Section 3 – Modifies definitions for “continuous insulation,” “north-oriented,” and “vertical fenestration,” and moves definitions of “entrance door,” “fixed,” “operable,” “metal framing,” “metal framing, entrance door,” “metal framing, fixed,” “metal framing, operable,” and “nonmetal framing” from table footnotes to Section 3. Adds VT, FC (filled cavity), and LSG (light-to-solar-gain ratio) to Section 3.

Section 5 – Tables 5.5-1 through 5.5-8, the tables of prescriptive criteria for the building envelope, have been updated. For opaque elements, minimum insulation levels have increased for most assemblies in most climates. For vertical fenestration, the new criteria call for double-glazing with low-E in most climates, with triple-glazing in Alaska (to reduce energy consumption for space heating, which most often occurs during morning warm-up when lights and equipment are off and before sunrise), and good solar control (to reduce energy consumption for space cooling, which occurs primarily during daytime occupied hours). Also, a minimum VT/SHGC ratio has been added to enable good daylighting with minimum solar gain, while not restricting triple- and quadruple-glazing. The skylight criterion has been simplified for greater consistency with the 2009 International Energy Conservation Code. Also, see the text below for new footnotes added for fenestration U-factor criteria in Climate Zone 1 areas other than Miami and Hawaii and for floor insulation criteria in cold climates.[1]

The addendum also changes seven subsections of Section 5.

1. Section 5.5.3.1, the high albedo roof alternative was updated to reflect new roof insulation values in Table 5-5.
2. Section 5.5.3.2, the location of the applicable text of the Table 5.5 footnote for the insulation in masonry cores (sometimes called the perlite exception) was moved from Appendix A (Section A3.1.3.1) to Section 5. This is where it was located in the 1999 and 2001 editions of the standard.
3. Section 5.5.3.4, a steel-joist floor and wood-framed floor exception was added to account for increased insulation levels that occur in floors (similar to the single-rafter roof exception).
4. Section 5.5.4.2, the area references were deleted as they are already specified in Table 5.5 and an exception was added to allow the skylight area to be increased to 6% where skylights are designed and utilized as part of a daylighting scheme.
5. Section 5.5.4.3, one exception was added to allow the skylight U-factor to be increased where skylights are designed and utilized as part of a daylighting scheme. Also, more stringent U-factors are specified for vertical fenestration in areas of Climate Zone 1 with higher cooling design temperatures (e.g., Saudi Arabia).
6. Section 5.5.4.4, an exception was added to allow a modification of the SHGC criteria for vertical fenestration that faces north to account for the reduced solar heat gain on the north side of buildings in cold climates.
7. Section 5.5.4.5, text was added to refer to the table criteria for VT/SHGC.

The addendum also modifies Part 5. Building Envelope of Table 11.3.1 of the Energy Cost Budget Method section to correctly reference the new building envelope requirements tables.

Appendix A – Updates Appendices A2.3 (metal building roofs), A3.1 (mass walls), A3.2 (metal building walls), and A9 for metal building roof insulation.

Impact: Overall, due to the changes made to the building envelope requirements tables, this addendum is rated as a major positive in terms of energy efficiency.

[1] See Tables 5.5-1 through 5.5-8 in Addenda 90.1_2010_bb in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010. "Energy Standard for Buildings Except Low-Rise Residential Buildings" (ASHRAE 2013a), for the final envelope requirements associated with addendum 90.1-2010bb. For a comparison of the differences between Standard 90.1-2010 and Standard 90.1-2013, see the table in Appendix A.

Addendum 90.1-2010bg

Sections(s) Modified: 5. Building Envelope

Short Description: Adds requirements for low-E storm window retrofits.

Discussion: Addendum 90.1-2010bg updates the existing exception for storm window retrofits by requiring any storm window or glazed panel to have a low-emissivity coating unless the existing glazing already has a low-emissivity coating.

Impact: This addendum is rated as a minor positive because in some cases it will require the installation of low-E storm windows.

Addendum 90.1-2010bv

Sections(s) Modified: 5. Building Envelope

Short Description: Reduces the area threshold at which skylights and daylighting controls are required.

Discussion: Addendum 90.1-2010bv addresses toplighting requirements and daylighting controls. This addendum reduces the space area threshold, adds single-story buildings, and expands the list of spaces where daylight would not adversely affect operation of the space (such as a movie theater seating area where daylight is not appropriate). The existing requirement states that in enclosed spaces larger than 5000 ft^2 and with ceiling heights greater than 15 feet (4.57 m), a minimum skylight fenestration area must be provided. This addendum reduces the enclosed space area threshold from 5000 to 2500 ft^2 (465 to 232 m^2), which brings in more high-ceiling spaces and spaces in single-story buildings that were previously not required to install skylights.

Impact: Based on the reduced threshold for which skylights and daylighting controls are required, which should reduce energy usage, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010bw

Sections(s) Modified: 5. Building Envelope and 11. Energy Cost Budget Method

Short Description: Modifies orientation requirements and adds SHGC tradeoff.

Discussion: Addendum 90.1-2010bw modifies existing fenestration orientation requirements. The addendum removes the existing requirement that the area of fenestration with south orientation must be greater than or equal to both the area of fenestration with east orientation and the area of fenestration with west orientation. The addendum then replaces this requirement with two new requirements that consider both the orientation and SHGC of fenestration in various orientations. The two new requirements are (in words):

a. Western oriented fenestration area must be less than ¼ of the total fenestration area and eastern oriented fenestration must be less than ¼ of total fenestration area.
b. Western solar aperture (area times SHGC) must less than or equal to ¼ of the total solar aperture and eastern solar aperture must less than or equal to ¼ of the total solar aperture.

The addendum also removes direction to use the northern orientation in the Southern Hemisphere, as the southern orientation is no longer part of the requirement. The addendum also adds two new exceptions. The first new exception is for buildings where the west-oriented and east-oriented vertical fenestration area (as defined in Section 5.5.4.5) does not exceed 20% of the gross wall area for each of those façades, and SHGC on those facades is no greater than 90% of the criteria in Tables 5.5-1 through 5.5-8. The second exception is buildings in Climate Zone 8. The addendum also changes how fenestration orientation is dealt with in whole building tradeoffs. Specifically, this addendum applies the approach currently used in the Performance Rating Method to the Energy Cost Budget Method. This approach requires simulating the building in all four cardinal orientations and then averaging the results.

Impact: The overall impact of this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cm

Sections(s) Modified: 5. Building Envelope

Short Description: Clarifies how to interpret the use of dynamic glazing products given the requirements in addendum bb (envelope requirements).

Discussion: Addendum 90.1-2010cm adds mention of the new terms "VT/SHGC" and "LSG" used in addendum 90.1-2010bb to Section 5.5.4.1 and adds a new exception to Section 5.5.4.5 that describes how VT/SHGC should be calculated for dynamic glazing.

Impact: This addendum is primarily clarification and as such is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cp

Sections(s) Modified: 5. Building Envelope

Short Description: Corrects non-residential U-factor and R-value requirements for steel joist floors in Climate Zone 3.

Discussion: Addendum 90.1-2010cp changes the non-residential U-factor for steel joist floors in Climate Zone 3 from U-0.052 to U-0.038 and changes the corresponding R-value requirements from R-19 to R-30.

Impact: This addendum is rated as a minor positive because U-factor requirements decrease.

Addendum 90.1-2010da

Sections(s) Modified: 5. Building Envelope

Short Description: Relaxes air leakage requirements for high-speed doors for vehicle access and material transport.

Discussion: Addendum 90.1-2010da provides a separate and higher air leakage rate for high-speed non-swinging doors. The addendum also clarifies which requirement covers upward acting non-swinging glazed doors. The addendum also adds a new exception for all types of fenestration and doors that are part of a building that has achieved a measured whole building air leakage rate of 0.4 cfm/ft^2.

Impact: Overall, this addendum is a minor negative in terms of energy efficiency due to the allowance of higher leakage rates for high-speed doors.

Addendum 90.1-2010db

Sections(s) Modified: 5. Building Envelope

Short Description: Corrects residential U-factor and R-value requirements for steel joist floors in Climate Zone 3.

Discussion: Addendum 90.1-2010db modifies the residential U-factor and R-value requirements for steel joist floors in Climate Zone 3. The modification raises the U-factor from U-0.032 to U-0.038 and lowers the R-value from R-38 to R-30.

Impact: While this modification is described in the foreword to the addendum as "addresses an error," it does represent a weakening of Standard 90.1 and therefore is a minor negative in terms of energy efficiency.

<u>Addendum 90.1-2010dd</u>

Sections(s) Modified: 5. Building Envelope and 3. Definitions, Abbreviations, and Acronyms

Short Description: Clarifies roof insulation requirements, differentiating between roof recovering (on top of existing roof covering) and replacement of roof covering.

Discussion: Addendum 90.1-2010dd defines two new terms: "roof covering" and "roof recovering." In addition, the term "roof recovering" is added to the list of envelope alterations not subject to Standard 90.1. the addendum also modifies the existing exception that replacement of a roof covering is not subject to Standard 90.1 if there is insulation below the deck to remove the idea that the exception only applies if roof sheathing or roof insulation is not exposed and to add the concept of insulation integral to roof deck.

Impact: This addendum is considered a clarification only and therefore it is rated as neutral (no impact) in terms of energy efficiency.

<u>Addendum 90.1-2010dg</u>

Sections(s) Modified: 12. Normative References (related to 5. Building Envelope)

Short Description: Updates reference to ANSI/CRRC-l Standard 2012 (cool roof ratings).

Discussion: While addendum 90.1-2010ae only modifies Section 12. Normative References, the normative references it modifies is directly related to building envelope. Addendum 90.1-2010dg simply updates the reference year of ANSI/CRRC-1 Standard, "Cool Roof Rating Council – ANSI/CRRC-1 Standard" (CRRC 2012), from 2010 to 2012.

Impact: Because the change is only to a reference standard, the addendum is rated as neutral (no impact) in terms of energy efficiency.

<u>Addendum 90.1-2010dm</u>

Sections(s) Modified: 5. Building Envelope

Short Description: Modifies Section 5.4.3.4 for vestibules. Adds a size limit for large buildings, exemptions for semiheated spaces and elevator lobbies in parking garages.

Discussion: Addendum 90.1-2010dm modifies the existing vestibule requirements in Section 5.4.3.4 in four ways: 1) a size limit is put on vestibule floor area, with no more than the greater of 50 ft^2 or 2% of the gross conditioned floor area for that level of the building; 2) editorial changes are made to two of the vestibule requirement exceptions; 3) the term "gross conditioned floor area" is substituted for "area" in three exceptions; and 4) a new section addressing vestibules in spaces with a gross conditioned floor area of 40,000 ft^2 or more and with automatic, electrically-driven, self-closing devices, which are required to have a minimum distance between interior and exterior doors of 16 feet.

Impact: The size limit on vestibules is the most significant change and this change is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010dr

Sections(s) Modified: 3. Definitions, Abbreviations, and Acronyms (Related to 5. Building Envelope)

Short Description: Clarifies definition of “building entrances” to exclude electrical rooms, mechanical rooms, and other utility service entrances.

Discussion: Addendum 90.1-2010dr addresses a definition used in Section 5 Building Envelope. Addendum 90.1-2010dr revises the definition of “building entrance” by replacing “turnstile” with “revolving door,” clarifying that the entrance can be used to exit the building as well as gain access to the building, and clarifies that the term “building entrance” does not include doors used to directly enter mechanical, electrical, and other utility service equipment rooms.

Impact: This addendum is primarily clarification and such is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ds

Sections(s) Modified: 5. Building Envelope and 3. Definitions, Abbreviations, and Acronyms

Short Description: Corrects the definitions of “primary sidelighted area,” “secondary sidelighted area,” and “sidelighting effective area” to use the term “vertical fenestration” instead of “window” to clarify that glazed doors and other fenestration products are included as well as windows. Additionally, the definition of “daylight area” under rooftop monitors is corrected to include the spread of light beyond the width of the rooftop monitor glazing.

Discussion: Addendum 90.1-2010ds modifies four definitions in Section 3—“daylight area,” “primary sidelighted area,” “secondary sidelighted area,” and “sidelighting effective aperture” —by referring to “vertical fenestration” as opposed to “windows.” Additionally, the term “clerestory” is used in definitions where needed. The addendum also updates Section 9.4.1.4, Automatic Daylighting Controls for Toplighting, to specifically mention clerestories.

Impact: Given that this addendum is primarily editorial, it is rated neutral (no impact) in terms of energy efficiency.

4.5 Changes to Section 6, Heating, Ventilating, and Air-Conditioning

A total of 45 addenda were made to Section 6, Heating, Ventilating, and Air-Conditioning, during the creation of Standard 90.1-2013. Several addenda also modify definitions (Section 3) or normative references (Section 12) but are discussed in this section as the definitions or references modified are related to Section 6, Heating, Ventilating, and Air-Conditioning. One addendum (90.1-2010cd) also modifies Section 7, Service Water Heating, and is therefore discussed in both locations.

One major restructuring of Section 6 was that the equipment efficiency tables in Section 6.8.1 were renumbered from Table 6.8.1A to 6.8.1K to a new format of Table 6.8.1-1 to 6.8.1-11. The tables called out in this document correspond to the new table numbers used in Standard 90.1-2013.

Addendum 90.1-2010g

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 12. Normative References

Short Description: Adds efficiency requirements for commercial refrigerators, freezers, and refrigeration equipment. Table 6.8.1L and Table 6.8.1M (now Tables 6.8.1-12 and 6.8.1-13 in Standard

90.1-2013), which specify the energy use limits for refrigerators and freezers, have been added. The corresponding references have also been added in Section 12.

Discussion: Section 136(c) of the Energy Policy Act of 2005 (EPAct 2005) amended the Energy Policy and Conservation Act (EPCA) to prescribe energy conservation standards for self-contained equipment consisting of refrigerators with solid doors, refrigerators with transparent doors, freezers with solid doors, freezers with transparent doors, refrigerator/freezers with solid doors, and refrigerators with transparent doors designed for pull-down temperature applications (42 U.S.C. 6313(c)(1–3)). These standards became effective on January 1, 2010. Section 136(c) of EPAct 2005 also amended EPCA to mandate that DOE sets standards for the following additional categories of equipment: ice-cream freezers; self-contained commercial refrigerators, freezers, and refrigerator-freezers without doors; and remote condensing commercial refrigerators, freezers, and refrigerator-freezers (42 U.S.C. 6313(c)(4)(A)). DOE published the final rule prescribing these standards on January 9, 2009 (74 FR 1092). The energy conservation standards established in the final rule are applicable to products manufactured on or after January 1, 2012. Addendum 90.1-2010g adopts both EPAct 2005 requirements and the new rulemaking requirements.

Impact: Given that this addendum is simply adopting federal requirements, no additional savings are attributed to this addendum.

Addendum 90.1-2010h

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Modifies the minimum efficiency standards for water-to-air heat pumps (water loop, ground water and ground loop). The proposed cooling EERs and heating COPs are more stringent than the present values. Also removes the small duct high velocity heat pump product class from Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013).

Discussion: Addendum 90.1-2010h improves the minimum energy efficiency standards for water-to-air heat pumps (water loop, ground water and ground loop) listed in Table 6.8.1B of Standard 90.1-2010 (now Table 6.8.1-2 in Standard 90.1-2013). Table 4.1 shows the minimum efficiency for water-to-air heat pumps as required by Standard 90.1-2010 (before addendum h) and by addendum h. Note that the small duct high velocity product class is reestablished with a higher air conditioning efficiency requirement in addendum bj.

Table 4.1. Water to Air Heat Pump Efficiency Improvements

			Minimum Efficiency	
Equipment Type	Size Category	Rating Condition	STD 90.1-2010	Addendum h
Water to Air: Water Loop (cooling mode)	<17,000 Btu/h	86 °F entering water	11.2 EER	12.2 EER
	≥17,000 Btu/h and <65,000 Btu/h	86 °F entering water	12.0 EER	13.0 EER
	≥65,000 Btu/h and <135,000 Btu/h	86 °F entering water	12.0 EER	13.0 EER
Water to Air: Ground Water (cooling mode)	<135,000 Btu/h	59 °F entering water	16.2 EER	18.0 EER
Brine to Air: Ground Loop (cooling mode)	<135,000 Btu/h	77 °F entering fluid	13.4 EER	14.1 EER
Water to Air: Water Loop (heating mode)	<135,000 Btu/h (cooling capacity)	68 °F entering water	4.2 COP	4.3 COP
Water to Air: Ground Water (heating mode)	<135,000 Btu/h (cooling capacity)	50 °F entering water	3.6 COP	3.7 COP
Brine to Air: Ground Loop (heating mode)	<135,000 Btu/h (cooling capacity)	32 °F entering fluid	3.1 COP	3.2 COP

Impact: Overall, this addendum is considered to be a minor positive because addendum h does improve the performance of water to air heat pumps. This addendum is not considered a major positive because the use of water to air heat pumps is not that common.

Addendum 90.1-2010i

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 3. Definitions, Abbreviations, and Acronyms

Short Description: Increases the minimum efficiency standards for SPVAC and SPVHP. Also creates a new product class for SPVAC and SPVHP used in space-constrained applications. This new product class only applies to non-weatherized products with cooling capacities <36,000 Btu/h and intended to replace an existing AC.

Discussion: Addendum 90.1-2010i adds a new definition for non-weatherized space-constrained single-package vertical unit that addresses both air conditioners and heat pumps. This addendum also updates existing requirements for SPVAC and SPVHP in Table 6.8.1D (now Table 6.8.1-4 in Standard 90.1-2013) by increasing SPVAC and SPVHP cooling mode EERs from approximately 9 EER (depending on size of unit) to 10 EER and by increasing SPVHP heating mode COP from 2.9 to 3.0 COP for larger units. This addendum also implements new requirements for a "space constrained" SPVAC and SPVHP units.

Impact: The result of this addendum should be a minor positive improvement in efficiency.

Addendum 90.1-2010j

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Modifies the minimum efficiency requirements of for evaporatively cooled air conditioners units, of size category greater than or equal to 240,000 Btu/h and less than to 760,000 Btu/h and heating type-other, in Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013). The value is reduced to account for increased pressure drop in such system types. The product class, small duct high velocity air conditioner, has been eliminated.

Discussion: Addendum 90.1-2010j removes the category of small duct high velocity (air cooled) unitary air conditioners from Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013). The addendum also changes the required minimum efficiency for air conditioners, evaporatively cooled with a size category of greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h and all other heating section type from 12.2 to 11.7 EER as of 6/1/2011. The addendum also removes a footnote related to the term "IPLV" (integrated partial load value) because the standard no longer uses that term. Note that a small duct high velocity product class is reestablished with a higher air conditioning efficiency requirement in addendum bj.

Impact: Overall, due to the reduction in the EER value, this addendum is rated as a minor negative in terms of energy efficiency, although it is noted that the foreword to this addendum describes this change as fixing an error.

Addendum 90.1-2010l

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Fixes the mistake with 90.1-2010 fan power limitations that required the user to perform calculations for fan bhp even if the simplified nameplate hp option was being used.

Discussion: Addendum 90.1-2010l adds a new exception to the Motor Nameplate Horsepower (Section 6.5.3.1.2) requirements that allows motors to meet the requirements of Section 6.5.3.1.1, Option 1 instead of the requirement of Section 6.5.3.1.2.

Impact: Review of these sections indicates that 6.5.3.1.2 essentially duplicates the nameplate horsepower limits in 6.5.3.1.1, indicating that this addendum should be rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010s

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Modifies the requirement for the static pressure sensor location and the control requirements for setpoint reset for systems with DDC of individual zones. This ensures that savings from previously required static pressure reset will be realized.

Discussion: Addendum 90.1-2010s modifies the requirement for the static pressure sensor location and the control requirements for setpoint reset for systems with DDC of individual zones in Section 6. Specifically, the addendum changes the static sensor setpoint locations are changed from one-third of the total design fan static pressure to 1.2 inches w.c. An editorial change is made to specifically list an existing exception as an exception. New requirements are added to the Setpoint Reset section that controls must 1) monitor zone damper positions; 2) automatically detect zones that may be excessively driving reset logic; and 3) readily allow the operator to remove the zone(s) from the reset algorithm. Using a fixed setpoint may require sensors to be located closer to the zones and be set at a lower static pressure for high static pressure systems. The requirement to detect and allow removal of errant zones from the sequence avoids bad zones driving the system to full fan speed when unnecessary.

Impact: The addendum is intended to ensure that savings from previously required static pressure reset will be realized. The fixed setpoint of 1.2-inches is likely to be less than one-third of the total static pressure in many systems, resulting in a reduction in fan power. Based on this intent, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010u

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning, 3. Definitions, Abbreviations, and Acronyms, and 12. Normative References.

Short Description: Adds new definition of “Fan Efficiency Grade (FEG)” and requires that each fan have a FEG of 67 or higher as defined by AMCA 205-12, “Energy Efficiency Classification for Fans.”

Discussion: Addendum 90.1-2010u adds new definitions for “fan efficiency grade” and “power roof/wall ventilators (PRV).” This addendum also modifies the text of Section 6.5.3.1 to require that all fans have a fan efficiency grade of 67 or higher. This addendum also adds AMCA 205-12 “Energy Efficiency Classification for Fans,” as a normative reference. As pointed out in the foreword to this addendum, “fan power limits have been in Standard 90.1 for some time. These place restrictions on the design of systems and the amount of fan energy utilized. However the standard has not had a requirement for minimum fan efficiency.”

Impact: Given that this requirement is adding a new minimum requirement for fan efficiency and that fans are extremely common in commercial and high-rise multi-family residential buildings, this addendum is considered a major positive in terms of energy efficiency, especially for smaller systems with lower pressure drops that easily meet the fan power limitations.

Addendum 90.1-2010z

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Relocates the requirements for water economizers into the main economizer section, Section 6.5.1.5.

Discussion: Addendum 90.1-2010z edits the wording of the Humidification subsection of Section 6 to clarify that it applies to economizers. The only change is that the title of the section is changed from "Humidification" to "Economizer Humidification System Impact" and the section is moved to be part of the overall economizer requirements.

Impact: Given that this change is simply editorial, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010aa

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 3. Definitions, Abbreviations, and Acronyms

Short Description: Eliminates the contingency on DDC system existence for setpoint overlap restrictions, humidification and dehumidification controls, VAV fan control setpoint reset, multiple-zone VAV system ventilation optimization control, and hydronic system differential pressure reset by valve position. Instead specifies for what system types or sizes DDC is required in new buildings and alterations. Also specifies minimal functional requirements for DDC systems. (Prior to this addendum certain controls requirements were only required when the controls were provided by a DDC system.)

Discussion: Addendum 90.1-2010aa adds the acronym "DDC" for "direct digital control" to Section 3, Definitions, Abbreviations, and Acronyms. The addendum also adds a new section for direct digital control with three parts: 1) DDC applications that require DDC for 3 new building situations and 5 existing building situations; 2) new requirements for DDC controls to have four capabilities – monitor zone and system demand for 5 parameters, transfer zone and system demand information to appropriate controllers, automatically detect those zones and systems that may be excessively driving the reset logic and generate an alarm to the system operator, and allow operator to remove zones from the reset algorithm (addendum 90.1 2010s also required the last two items for VAV static pressure reset—placing these requirements in a mandatory DDC section expands their scope to all resets, including chilled water and supply air); and 3) a requirement for DDC trending and graphically displaying input and output. With the clarity added for when DDC is required, it is possible to eliminate the contingency on DDC system existence for setpoint overlap restrictions, humidification and dehumidification controls, VAV fan control setpoint reset, multiple-zone VAV system ventilation optimization control, and hydronic system differential pressure reset by valve position.

Impact: While this addendum contains new requirements for DDC in 8 common situations, it is rated as a minor positive in terms of energy efficiency because DDC is standard practice in most of these situations anyway and two of VAV reset requirements were already required.

Addendum 90.1-2010ad

Sections(s) Modified: 12. Normative References

Short Description: Adds reference to specific addenda to AHRI standards 340/360 and 1230 being referenced.

Discussion: Addendum 90.1-2010ad updates two references associated with Section 6, Heating, Ventilation, and Air-Conditioning. The reference to AHRI Standard 340/360-2007 (AHRI 2007) is updated to the same version with addenda 1 and 2, "Performance Rating of Commercial and Industrial

Unitary Air Air-Conditioning and Heat Pump Equipment." The reference to AHRI Standard 1230-2010, "Performance Rating of Variable Refrigerant Flow (VRF) Multi-split Air-Conditioning and Heat Pump Equipment" (AHRI 2010), is updated to the same version with addendum 1.

Addenda 1 and 2 for AHRI Standard 340/360-2007 are described in the document as follows: (the text is quoted from AHRI Standard 340/360-2007 but reformatted for this document):

> "Addendum 1 - The certification program scope, on the inside front cover, has been revised. New provisions have been added to the footnotes of Tables 5 and 6 to specify the tolerances associated with external static pressure for all units, and the leaving air dry-bulb temperature on variable air volume (VAV) units, respectively. The following tolerance has been added to the footnote of Table 5 of ANSI/AHRI Standard 340/360-2007: The tolerance for external static pressure (averaged during the run time) for all equipment is -0 in H2O [0 Pa], +0.05 in H2O [12.5 Pa]. The following tolerance has been added to the footnote of Table 6 of ANSI/AHRI Standard 340/360-2007: The tolerance for the leaving air dry-bulb temperature on VAV units is ±0.3 °F [±0.2 °C]."

> "Addendum 2 - The language in Section 6.2.2 associated with units using discrete step fan control and variable air volume units has been revised. An external static equation has been added to the footnotes of Table 6. The following equation has been added to the footnote of Table 6 of ANSI/AHRI Standard 340/360-2007:

$$ExternalStatic = FullLoadExternalStatic \times \left(\frac{PartLoadCFM}{FullLoadCFM}\right)^2$$

Addendum 1 for AHRI Standard 1230- 2010 is described in the document as follows: (the text is quoted from AHRI Standard 340/360-2007 but reformatted for this document):

"Addendum 1 - The changes include:

> 3.25 Tested Combination. A sample basic model comprised of units that are production units, or are representative of production units, of the basic model being tested. The Tested Combination shall have the following features:

> a. The basic model of a variable refrigerant flow system (―VRF system‖) used as a Tested Combination shall consist of an outdoor unit (an outdoor unit can include multiple outdoor units that have been folded into a single refrigeration system, with a specific model number) that is matched with between 2 and ~~5~~ 12 indoor units. ~~(for systems with nominal cooling capacities greater than 150,000 Btu/h [43,846 W], the number of indoor units may be as high as 8 to be able to test non-ducted indoor unit combinations)~~

> b. The indoor units shall:

>> b.1 Represent the highest sales model family as determined by type of indoor unit e.g. ceiling cassette, wall-mounted, ceiling concealed. etc~~. If 5 are insufficient to reach capacity another model family can be used for testing.~~"

Impact: Review of the addendum to these two AHRI standards indicates that the changes are minor and that this addendum should be considered simply an update of reference standards. Therefore, addendum 90.1-2010ad is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ae

Sections(s) Modified: 12. Normative References

Short Description: Adds reference to specific addenda to AHRI standards 210/240 and 550/590 being referenced.

Discussion: Addendum 90.1-2010ae modifies two references associated with Section 6, Heating, Ventilation, and Air-Conditioning. The two references are AHRI 210/240-2008, "Unitary Air Conditioning and Air-Source Heat Pump Equipment" (AHRI 2008), and AHRI 550/590-2011 "Water-Chilling Packages Using the Vapor Compression Cycle" (AHRI 2011). The modifications are to require addenda 1 and 2 for AHRI 210/240 and to update from the 2003 version to the 2011 version of AHRI 550/590. The modifications to AHRI 210/240 for addenda 1 and 2 are described in the published document as follows (the text is quoted from AHRI 210/240-2008 with addenda 1 and 2 but reformatted for this document):

> "Addendum 1 - The Integrated Part-Load Values (IPLV) methodology has been removed from the standard. This includes the deletion of: Section 3.6 Integrated Part Load Value (IPLV) Definition (page 2); "and in multiples of 0.1 for IPLV" from Section 6.1.2 (page 5); The Part Load Conditions line and Note 2 of Table 12 (page 21); Section 6.2 Part Load Ratings (pages 21-22); "plus the IPLV (where applicable)" from Section 6.4 (page 22); and Appendix E. The corresponding Table E1 has also been removed (pages 122-125)."

> "Addendum 2 - The Integrated Energy Efficiency Ratio (IEER) methodology has been added to the standard for water-cooled and evaporatively-cooled products. It is not intended for air-cooled products which should be rated with SEER. This includes: The addition of 3.4.2 definition of IEER (page 2); The addition of "and in multiples of 0.1 for IEER" to Section 6.1.2 (page 5); The addition of Part-Load IEER Conditions to Test Conditions to Table 12 (page 21); The reinstatement of Note 2 in Table 12 (page 21); New Section 6.2 Part Load Ratings (pages 22-26). This new Section 6.2 is duplicated from Section 6.2 from AHRI Standard 340/360-2007 (AHRI 2007) with addenda 1 and 2.; The addition of "plus the IEER (where applicable)," to Section 6.4 (page 26); The addition of "except IEER which shall not be less than 90% of Published Ratings." to Section 6.5 (page 26); and the addition of "3. Integrated Energy Efficiency Ratio, IEER," to Section 7.1.b (page 27)."

Impact: The main change associated with addenda 1 and 2 is the substitution of the IEER for IPLV where appropriate. This change, along with the update to the version year for AHRI 550/590, is considered neutral, with no impact on energy efficiency.

Addendum 90.1-2010af

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Modifies heat rejection equipment (cooling tower) requirements to require multi-speed or variable speed fans and that VSD-controlled fans operate all fans at the same speed instead of sequencing them, and require that open-circuit towers with multiple cells operate all cells in parallel down to 50% of design flow

Discussion: Addendum 90.1-2010af makes four specific changes to Section 6. First, this addendum adds a requirement (in Section 6.5.5.4 of Standard 90.1-2013) for open circuit towers to have parallel operation and modulate condenser water flow down to 50% flow or the low flow of the smallest condenser water pump as a means to save energy. Second, this addendum requires that multiple cell heat rejection equipment with variable speed fan drives operate the maximum number of fans and to control all fans to the same fan speed to minimize energy use and that the minimum speed be as low as allowed by the fan-drive system manufacturer. Third, this addendum adds "dry coolers" as an example of a common heat rejection device. Fourth, this addendum eliminates an exception to the fan speed control requirements that allowed up to one-third of the fans on a unit with multiple fans to be exempt as long as the lead fans complied with the requirement. Energy is generally saved by this addendum by reducing fan energy use at part load.

Impact: Overall, this addendum is evaluated as having a minor positive in terms of energy efficiency.

Addendum 90.1-2010aj

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Requires fractional horsepower motors ≥1/12 hp to be electronically commutated motors or have a minimum 70% efficiency in accordance with 10 CFR 431. Also requires adjustable speed or other method to balance airflow.

Discussion: Addendum 90.1-2010aj adds a new set of requirements for fractional horsepower motors in Section 6.5.3.5 of Standard 90.1-2013 that includes both a 70% minimum efficiency and adjustable speed or other method to balance airflow. It is particularly applicable to fan powered boxes or fan coil units where electronically commutated motors can be used.

Impact: This addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010am

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Establishes minimum turndown for boilers and boiler plants with design input power of at least 1,000,000 Btu/h.

Discussion: Addendum 90.1-2010am requires that boiler systems with design input of at least 1,000,000 Btu/h shall comply with the turndown ratio specified in the second column of Table 4.2.

Table 4.2. Addendum 2010 90.190.1-2010am Boiler Turndown Requirements

Boiler System Design Input (Btu/h)	Minimum Turndown Ratio	Implied Minimum Burner Capacity (Percent of Maximum)
≥ 1,000,000 and less than or equal to 5,000,000	3 to 1	33.3%
> 5,000,000 and less than or equal to 10,000,000	4 to 1	25%
> 10,000,000	5 to 1	20%

Turndown ratio is a measure of the modulation capabilities of the boiler burner. The third column of Table 4.2 shows implied minimum burner capacity that the system must be able to achieve, with larger boilers being required to achieve higher turndown ratios. When boilers turn down, efficiency is improved because there is a larger ratio of heat exchange surface to firing rate, so stack temperatures can be reduced at part load.

Impact: Given that these requirements were not in Standard 90.1 before and that boilers are fairly commonly used in commercial buildings, addendum am is estimated to be a major positive in terms of energy efficiency.

Addendum 90.1-2010ap

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds Power Utilization Effectiveness (PUE) as an alternative compliance methodology for data centers.

Discussion: Addendum 90.1-2010ap adds five new definitions to Section 3: “computer room energy,” “IT equipment energy,” “power usage effectiveness,” and two subcategories of “power usage effectiveness” or PUE: PUE_0 relates to peak demand and PUE_1 relates to annual energy use. The addendum also adds an alternative compliance path for computer room systems (in Section 6.6 of Standard 90.1-2013) that utilizes the power usage effectiveness concept. Computer rooms shown to use less demand or energy than either PUE target are deemed to meet code requirements.

Impact: Given that this is an alternative compliance path only, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010aq

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 11. Energy Cost Budget

Short Description: Expands the requirements for fan speed control for both chilled water and unitary direct expansion systems. In addition enhances the requirements for integrated economizer control and defines DX unit capacity staging requirements.

Discussion: Addendum 90.1-2010aq changes the requirements for fan control for both constant-volume and VAV units, including extending the fan part-load power requirements down to 1/4 hp (0.20 kW). In addition, it more clearly defines the requirements for integrated economizer control and defines DX unit capacity staging requirements (in Section 6.5.1.3). This addendum removes Section 6.4.3.10, Single Zone Variable Air Volume Controls, in its entirety and replaces it with a new Section 6.5.3.2.1, Fan Airflow Control. This addendum also changes Table 11.3.2A (now Table 11.3.2-1 in Standard 90.1-2013) for coordination between Section 6 and Section 11. Generally, the addendum saves energy by requiring multi-speed or variable speed fans for smaller units and adds a requirement for staging DX cooling systems. It clarifies how economizer integration is to be achieved with DX units, improving economizer operation.

Requirements that go into effect during the 2013 edition of the standard are shown in Table 4.3.

Table 4.3. Addendum 90.1-2010aq Fan Speed Control and Staging Requirements

Cooling type	Control Type	Capacity (Btu/h)	Fan Control (minimum speed)	Fan motor size (hp)	Capacity Staging
DX Cooling	Direct zone temperature	≥65,000	2-speed (66%)	any	2-stages
DX Cooling	Other control including VAV	≥65,000	variable (50%)	any	3-stages
		≥240,000	variable (50%)	any	4-stages
Chilled water and evaporative	Any	Any	variable (50%)	≥ 1/4	N/A

Impact: Overall, this addendum is rated a major positive in terms of energy efficiency for reducing fan energy.

Addendum 90.1-2010ar

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds mandatory and prescriptive requirements for walk-in coolers and freezers and refrigerated display cases.

Discussion: Addendum 90.1-2010ar adds definitions and requirements for walk-in coolers and freezers. In Section 3, this addendum adds six new definitions—“condensing unit,” “low-temperature refrigeration system,” “medium-temperature refrigeration system,” “saturated condensing temperature,” “walk-in cooler,” and “walk-in freezer”—and one new acronym, HVACR (heating, ventilation, air-conditioning, and refrigeration). This addendum adds refrigeration systems to those systems that must meet new building, addition, or alteration requirements for mechanical systems (Section 6.1). This addendum adds new requirements for walk-in coolers and freezers in Section 6.4.5 and new requirements for refrigeration systems in new Section 6.5.10.

Impact: All of these requirements are based on new federal standards and therefore this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010as

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Requires humidifiers mounted in the airstream to have an automatic control valve shutting off preheat when humidification is not required, and insulation on the humidification system dispersion tube surface. This avoids simultaneous heating and cooling at the air handling unit.

Discussion: Addendum 90.1-2010as addresses simultaneous heating and cooling in zone controls, hydronic systems, dehumidification systems, and humidification systems. The existing wording does not limit simultaneous heating and cooling in some air-handling equipment serving multiple zones. This addendum is intended to limit some of these cases. An existing requirement for humidifier preheat is merged into the section on humidification. A new requirement for insulation on humidification system dispersion tube hot surfaces in the airstreams of ducts or air-handling units is added. A new requirement for preheat coil controls is added.

Impact: The overall effect of this addendum should be to reduce energy usage during humidification and that leads to this addendum being rated a minor positive in terms of energy efficiency.

Addendum 90.1-2010au

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Modifies Table 6.5.3.1.1B, which addresses fan power limitation pressure drop adjustment credits. Deductions from allowed fan power are added for systems without any central heating or cooling as well as systems with electric resistance heating. Sound attenuation credit is modified to be available only when there are background noise criteria requirements.

Discussion: Addendum 90.1-2010au modifies Table 6.5.3.1.1B by limiting the existing 0.15 inches w.c. adjustment credit for sound attenuation systems to “fans serving spaces with design background noise goals below NC35” and by imposing three new deductions for systems without central cooling devices, systems without central heating devices, and systems with electric resistance heating. Given that the addendum limits the use of the credit and imposes three additional deductions from allowed static pressure, the end result should be that fan systems should use less energy.

Impact: Given the number of other potential adjustments, this addendum is considered to be a minor positive in terms of energy efficiency.

Addendum 90.1-2010av

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Modifies Section 6.5.1, exception k, applicable to Tier IV data centers, to make economizer exceptions stricter and in agreement with ASHRAE TC 9.9.

Discussion: Addendum 90.1-2010av modifies exception k to Section 6.5.1 by removing the words "mechanical cooling" in front of the word "design." The intent of the addendum was to close a loophole that would potentially allow a data center that merely had a cooling design goal equal to that of Tier IV data center to use the exception. With the removal of the words "mechanical cooling," the wording of exception k now reads "those spaces having a design of Tier IV as defined by ANSI/TIA 942," with the implication that the data center must be a Tier IV data in its entirety.

Impact: With that interpretation of the addendum, Addendum 90.1-2010av is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010az

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increases the minimum efficiency of open circuit axial fan cooling towers. An additional requirement has been added for all types of cooling towers, which states that the minimum efficiency requirements apply to the tower, including the capacity effect of accessories that influence thermal performance. An additional footnote clarifies that the certification requirements do not apply to field erected cooling towers.

Discussion: Addendum 90.1-2010az increases the minimum efficiency of open circuit axial fan cooling towers from 38.2 gpm/hp to 40.2 gpm/hp, at rated conditions. Additionally, a note "f" is added to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013), clarifying that the required minimum efficiency rating for all types of cooling towers applies to models with options and accessories that affect the thermal performance of the whole unit, not just the base model.

Impact: Overall, this addendum is a minor positive because it increases open circuit axial fan cooling tower efficiency and includes the impact of accessories into the efficiency metric.

Addendum 90.1-2010ba

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Adds requirements for door switches to disable or reset mechanical heating or cooling when doors without automatic door closers are left open.

Discussion: Addendum 90.1-2010ba adds a new Section 6.5.10, Door Switches, in Standard 90.1-2013. This new section requires that any conditioned space with a door that opens to the outdoors be provided with controls that disable mechanical heating and cooling or reset the heating and cooling setpoints when the door is open. The intent is to reduce unnecessary heating or cooling of additional outside air if a door is left open. There is an exception for doors with automatic closers.

Impact: Given that this addendum will definitely save energy when doors are left open, but that doors are not routinely left open, this addendum is considered to a minor positive in terms of energy efficiency.

Addendum 90.1-2010bi

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increase SEER and HSPF for air-cooled commercial three-phase air conditioners and heat pumps below 65,000 Btu/h. Effective January 1, 2015.

Discussion: Addendum 90.1-2010bi increases the minimum efficiency of air-cooled three-phase commercial air conditioners and the cooling mode for heat pumps with cooling capacity less than 65,000 Btu/h from SEER 13 to SEER 14 effective 1/1/2015. The addendum also increases the HSPF for heat pumps below 65,000 Btu/h from 7.7 to 8.2 effective January 1, 2015. These changes are not applicable to single-phase single package units which are regulated by NAECA.

Impact: Both of these changes increase requirements and will trigger a DOE review of these standards, and as such the addendum is rated as minor positive in terms of energy efficiency.

Addendum 90.1-2010bj

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning.

Short Description: Reestablishes the product class for Small Duct High Velocity (SDHV) air conditioners and heat pumps. Adds efficiency requirements for systems <65, 000 Btu/h.

Discussion: Addendum 90.1-2010bj reestablishes the product class for small-duct high-velocity air conditioners and heat pumps, which was deleted in Standard 90.1-2010. The minimum energy efficiency levels shown in 90.1-2013 are 11 SEER for air conditioners and 11 SEER/6.8 HSPF for heat pumps, which are identical to the efficiencies established by DOE for single-phase residential SDHV products. (Note that addenda 90.1-2010j and 90.1-2010h previously deleted this product group from 90.1's tables.) The DOE standards for commercial SDHV air conditioners, which are 13.0 SEER, and SDHV heat pumps, which are 13.0 SEER and 7.7 HSPF, were established for the overall equipment category of small commercial package air-conditioning and heating equipment by EISA 2007, as noted in the ASHRAE 2010 products rule.[1]

Impact: Given that the ASHRAE 90.1-2013 requirements for SDHV are set below federal levels and are therefore unenforceable, the impact of this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bk

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increases cooling efficiency for PTACs.

Discussion: Addendum 90.1-2010bk raises the minimum energy efficiency requirements for standard-size PTACs to the same level as the package terminal heat pumps (PTHPs) reflected in the federal energy efficiencies established by DOE effective in October 2012. DOE's rulemaking sets the minimum EER for PTACs at a lower level than PTHPs. This addendum revises the equation for calculating the EER of PTACs (equation below) effective as of January 1, 2015.

$$EER = 14.0 - 0.3 \times Capacity/1{,}000$$

[1] See http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/ashrae_90_1_2010_final_rule.pdf for the ASHRAE 2010 Products Rule.

Impact: Because addendum 90.1-2010bk increases the required efficiency for a DOE-regulated product and thereby starts DOE's regulatory review and revision cycle, this addendum is estimated to be a minor positive in terms of energy efficiency.

Addendum 90.1-2010bp

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 12. Normative References

Short Description: Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with ammonia refrigerants.

Discussion: Addendum 90.1-2010bp adds minimum efficiencies for evaporative condensers used in ammonia-based refrigeration systems. Specifically, new requirements are added to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for propeller or axial fan evaporative condensers and for centrifugal fan evaporative condensers. Also, the now required test procedure Cooling Tower Institute (CTI) Acceptance Test Code ATC-106(11), "Acceptance Test Code for Mechanical Draft Evaporative Vapor Condensers," is added to Section 12, Normative References. In addition, the revision date for CTI ATC - 105S was updated from the 1996 version to the 2011 version and the version date for CTI Std-201 was updated from the 2009 version to 2011 version. Finally, the mention of "R-22 test fluid" as part of the rating conditions for air-cooled condensers was deleted as the test standard (AHRI 460) now applies to all refrigerants.

Impact: The addition of new requirements for evaporative condensers is the major change focus of this addendum; however, the application is only to ammonia-based refrigeration systems that are a small share of the refrigeration market, so based on this change, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010bq

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds prescriptive requirements for the efficiency of commercial refrigeration systems.

Discussion: Addendum 90.1-2010bq adds new definitions for "bubble point," "refrigerant dew point," low-temperature refrigeration system," and "medium temperature refrigeration system." The addendum also adds the acronym "HVACR" for "heating, ventilating, air conditioning, and refrigerating." The addendum adds a new requirement that walk-in freezers have temperature-based defrost termination control with a time limit default. The addendum also adds a new Section 6.4.6 in Standard 90.1-2013 for refrigerated display cases that contains four requirements: 1) refrigerated display cases must meet the minimum equipment efficiencies found in Tables 6.8.1A to 6.8.1M; 2) lighting in refrigerated display cases must be controlled by automatic time switches or motion sensor controls; 3) all low-temperature display cases must incorporate temperature-based defrost controls with a time-limit default; and 4) anti-sweat heaters must have anti-sweat heater controls.

The addendum also replaces the phrase "remote condensers not in a condensing unit" with "remote condensing unit" and adds ammonia refrigerant systems to the systems exempted from new Section 6.5.10. The addendum also makes it clear that new Section 6.5.11.1 (in Standard 90.1-2013) is focused on condensers serving refrigeration systems and adds instructions for calculating the saturated condensing temperature for blend refrigerants. The addendum also adds two new requirements that condensers serving refrigeration systems use some form of continuous variable speed control and that multiple fan condensers be controlled in unison. The addendum also moves an existing requirement for minimum condensing temperature setpoint from one section to another.

The addendum also adds a new section on compressor systems (Section 6.5.11.2 of Standard 90.1-2013) that includes three new requirements: 1) compressors must have control systems that use floating suction pressure control logic; 2) liquid sub-cooling must be provided for certain sizes of low-temperature compressor systems, and 3) all compressors with internal or external crankcase heaters must provide a means to cycle the heaters off during operation.

Impact: Overall, the addendum provides a variety of new requirements for walk-in coolers and freezers, refrigerated display cases, condensers, and compressor systems, leading to the conclusion that this addendum will save energy. Because these systems are relatively common in the commercial sector, this addendum is considered to be a major positive in terms of energy efficiency.

Addendum 90.1-2010bs

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Reduces occupancy threshold for demand controlled ventilation from greater than 40 people per 1000 ft^2 to equal to or greater than 25 people per 1000 ft^2 with exemptions for certain occupancies.

Discussion: Addendum 90.1-2010bs updates existing requirements for ventilation controls for high-occupancy areas by reducing the occupancy threshold from >40 people per 1000 ft^2 to ≥25 people per 1000 ft^2. This addendum also modifies an existing exception to this requirement by reducing the maximum size of exempted systems from 1200 to 750 cfm. An existing exemption for spaces where supply airflow rate minus makeup or outgoing transfer air was less than 1200 cfm was transformed into an exemption for spaces where 75% of space design outdoor airflow is required for makeup air that is exhausted or transfer air. Finally, a new exception was added for spaces with occupancy categories defined by ASHRAE Standard 62.1-2007 (ASHRAE 2007) as correctional cells, daycare sickrooms, science labs, barbers, beauty and nail salons, and bowling alleys.

Impact: The main feature of this addendum is the lowering of the occupancy threshold for demand controlled ventilation, and based on that change, this addendum is rated a minor positive in terms of energy efficiency.

Addendum 90.1-2010bt

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Reduces the threshold at which energy recovery is required. The threshold is relaxed in some climate zones.

Discussion: This addendum relaxes requirements for systems utilizing 70% or greater outdoor air in Climate Zones 3B, 3C, 4B, 4C, and 5B, but also adds new requirements for systems utilizing 30% or less outdoor air in Climate Zones 1A, 2A, 3A, 4A, 5A, 6A, 6B, 7, and 8. While there is a relaxation of requirements in mild climates, the relaxation is based on an analysis that shows added fan energy offsets heating and cooling savings in these climates. The requirement is expanded to units with lower outside airflows in hot and cold climate zones. Addendum 90.1-2010bt revised Table 6.5.6.1 in Standard 90.1-2010 (shown below as Table 4.4).

Table 4.4. Addendum 2010 90.190.1-2010bt Energy Recovery Requirements

	% *Outdoor Air* at Full Design Airflow Rate							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and <80%	≥80%
Zone	Design Supply Fan Airflow Rate (cfm)							
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	NR	NR	~~≥5000~~ NR	~~≥5000~~ NR
1B, 2B,5C	NR	NR	NR	NR≥	NR≥	NR≥	≥5000	≥4000
6B	≥28000	≥26500	≥11000	≥5500	≥4500	≥3500	≥2500	≥1500
1A, 2A, 3A, 4A, 5A, 6A	≥26000	≥16000	≥5500	≥4500	≥3500	≥2000	≥1000	≥0
7,8	≥4500	≥4000	≥2500	≥1000	≥0	≥0	≥0	≥0

NR – Not required

Impact: Overall, this change is viewed as a minor positive in terms of energy efficiency.

Addendum 90.1-2010ca

Sections(s) Modified: 6. Heating, Ventilating, and Air Conditioning

Short Description: Adds control requirements for heating systems in vestibules.

Discussion: Addendum 90.1-2010ca adds a requirement that heating systems in vestibules must include automatic controls configured to shut off the heating system when outdoor air temperatures are above 45°F (7°C).Vestibule heating systems shall also be controlled by a thermostat in the vestibule with a setpoint limited to a maximum of 60°F (16°C).

Impact: This addendum adds a new requirement for vestibule heating controls, and as such is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cb

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Revises night setback requirements to a reset of 10°F heating and 5°F cooling and removes exceptions for climate zones. Changes optimum start requirement from units > 10,000 cfm to any DDC system and adds a requirement that outside air temperature be used in optimum algorithms.

Discussion: Addendum 90.1-2010cb makes several changes to the existing setback controls and optimum start controls portions of Section 6. For setback controls, the addendum eliminates the limitation of the heat setback requirement to Climate Zones 2-8, thereby adding the requirement to Climate Zone 1. The addendum changes the requirement from a fixed setback temperature of 55°F to one of 10°F below the occupied heating setpoint. The addendum also eliminates the limitation of cooling setback to Climate Zones 1b, 2b, and 3b, thereby applying the cooling setback to all climate zones. The addendum changes the requirement from a fixed cooling setback temperature of 90°F to one of at least 5°F higher than the occupied cooling setpoint. The addendum also modifies the exception for radiant heating systems by eliminating specific mention of floor and ceiling systems and adding a requirement that the exception applies only to those radiant systems configured with a setback heating setpoint of at least 4°F below the occupied heating setpoint.

For optimum start controls, the addendum eliminates the existing limitation to systems greater than 10,000 cfm (about 25 tons of cooling) with one or more supply fans and adds the requirement that this applies to all systems with setback controls and DDC. The addendum also specifically requires the control algorithms used to consider the outdoor air temperature to avoid spaces not being fully warmed up by occupancy, thereby avoiding optimum start being disabled. The addendum also requires that mass radiant floor slab systems incorporate floor temperature into the optimum start algorithm.

Impact: Overall, the changes listed are likely to require setback and optimum start for more systems, and that would lead to the addendum being rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cc

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with R-507A.

Discussion: Addendum 90.1-2010cc adds new requirements for minimum efficiencies for both axial and centrifugal fan evaporative condensers with R-507A as the test fluid to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013). Because of the numerous halocarbon refrigerants that can be utilized, a footnote has been added to the table clarifying that evaporative condenser models intended for use with halocarbon refrigerants other than R-507A must meet the minimum efficiency requirements listed for R-507A as the test fluid.

Impact: Based on the fact this table adds requirements for new types of equipment, this addendum is rated as a minor positive.

Addendum 90.1-2010cd

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning, 7. Service Water Heating, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Provides definition for piping to include all accessories in series with pipe such as pumps, valves, strainers, air separators, etc. The intent is to clarify that these accessories need to be insulated.

Discussion: Addendum 90.1-2010cd adds a new definition of "piping" to Standard 90.1 and then makes editorial changes to Sections 6 and 7 to change the word "pipe" to "piping" in eight locations.

Impact: This addendum may result in some savings where these accessories may not have been insulated before; however, as the changes are editorial, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ch

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increases air- and water-cooled chiller efficiencies in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). Exempts water-cooled positive displacement chillers with leaving condenser temperature ≥ 115°F (typically heat reclaim chillers).

Discussion: Addendum 90.1ch makes three changes related to chiller requirements in Standard 90.1. First, the requirements for chillers in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013) are updated and the text describing that table is completely updated.[1] Second, the title of AHRI standard governing

[1] See Table 6.81C in addendum 90.1_2010_ch in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, "Energy Standard for Buildings Except Low-Rise Residential Buildings" (ASHRAE 2013a), for the revised table showing both the Standard 90.1-2010 requirements in the columns marked "Effective 1/1/2010" and the new requirements for Standard 90.1-2013 in the columns marked "Effective 1/1/2015".

chillers is updated to match the correct title of the standard and to reference a revised version of the AHRI standard developed solely for SI units. Third, water-cooling positive displacement chilling packages with a condenser leaving fluid above 115°F are exempted from compliance with Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). These packages are typically heat reclaim chillers for which no testing procedures have yet been developed.

Impact: Overall, the main impact of the addendum is the revision of the chiller efficiencies in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). Efficiency requirements for both air-cooled chillers and water-cooled chillers result in higher efficiency, and therefore this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010ck

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Requires VAV dual maximum damper position when DDC system is present and clarifies dual maximum sequence of operations.

Discussion: Addendum 90.1-2010ck requires the use of dual maximum control for VAV zone control when the building has DDC controls. To accomplish this, this addendum establishes a distinction between zones with DDC and those without in the exceptions to Section 6.5.2.1, Zone Controls. Exception (a) now addresses zones without DDC, while exception (b) addresses zones with DDC. A new option is added for exception (b), part 1, which allows the exception if air flow rate in deadband is no more than the airflow rate required to comply with applicable codes or accreditation standards, such as pressure relationships or minimum air change rates. The existing part 3 of exception (b) ("Airflow between dead band and full heating or full cooling shall be modulated") is deleted and two parts are added to exception (b): a new part 3 ("The first stage of heating consists of modulating the zone supply air temperature setpoint up to a maximum setpoint while the airflow is maintained at the dead band flow rate") and a new part 4 ("The second stage of heating consists of modulating the airflow rate from the dead band flow rate up to the heating maximum flow rate"). This control sequence minimizes airflow during mild heating and prevents high discharge temperatures that would increase the ventilation requirements due to a reduction in ventilation effectiveness.

Impact: Because this addendum does improve control of VAV systems with DDC, this addendum is rated a minor positive in terms of energy efficiency.

Addendum 90.1-2010cl

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increases IEER requirements for air-cooled air conditioners and heat pumps and EER requirements for water and evaporatively cooled air conditioners and heat pumps in Table 6.8.1A and B (now Tables 6.8.1-1 and 6.8.1-2 in Standard 90.1-2013).

Discussion: Addendum 90.1-2010cl modifies Tables 6.8.1A and 6.8.1B (now Tables 6.8.1-1 and 6.8.1-2 of Standard 90.1-2013) to update the IEER values for air-cooled and water-cooled air conditioners and heat pumps above 65,000 Btu/h. In Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013), for air-cooled air conditioners, all eight size ranges and heating section types of the appropriate size range acquire more efficient IEER values as of 2016. For water-cooled air conditioners, all eight size ranges and heating section types of the appropriate size range acquire more efficient IEER values as of 2016. For evaporatively cooled air conditioners, editorial changes were made to remove start dates for efficiency requirements that have already come into effect and to remove outdated requirements.[1] In Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013), for air-cooled heat pumps, all six size ranges and heating section types of the appropriate size range acquire more efficient IEER values as of 2016.[2] It should be noted that federal requirements for this equipment are based on EER, so the addition of IEER is separate from federal standards.

Impact: Overall, this addendum represents an increase in efficiency for commonly used HVAC equipment, so it is rated a minor positive in terms of energy efficiency.

Addendum 90.1-2010cy

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Reduces the design supply fan air flow rate for which energy recovery is required for systems that operate more than 8000 hours per year.

Discussion: Addendum 90.1-2010cy modifies the existing exhaust air energy recovery requirements in Section 6.5.6.1 created by addendum 90.1-2010bt by adding a new table of requirements for systems that operate more than 8000 hours per year and by limiting the existing requirements to all systems that operate less than 8000 hours per year.

Impact: Because the new requirements for systems that operate more than 8000 hours per year are considerably more stringent than corresponding requirements for systems that operate less than 8000 hours per year, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cz

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Increases boiler efficiency for residential sized (NAECA covered) equipment, <3,000 Btu/h.

Discussion: Addendum 90.1-2010cz updates the minimum efficiency requirements for gas-fired and oil-fired boilers in Table 6.8.1F (now Table 6.8.1-6 in Standard 90.1-2013). The addendum also adds footnotes that gas-fired boilers shall not be equipped with a constant burning pilot light and that hot-water boilers not equipped with a tankless domestic water heating coil must be equipped with an automatic means of adjusting water temperature in response to changes in inferred heat load. These revisions are done in accordance with Section 303 of the Energy Independence and Security Act of 2007.

Impact: Given that the changes are made in response to federal legislation, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010de

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Relaxes design requirements for waterside economizers for computer rooms.

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[1] See Table 6.81A in addendum 90.1_2010_cl in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, “Energy Standard for Buildings Except Low-Rise Residential Buildings” (ASHRAE 2013a), for the revised table showing both the pre-2016 and post-2016 IEER requirements.

[2] See Table 6.81B in addendum 90.1_2010_cl in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, “Energy Standard for Buildings Except Low-Rise Residential Buildings” (ASHRAE 2013a), for the revised table showing both the pre-2016 and post-2016 IEER requirements.

Discussion: Addendum 90.1-2010de revises the design requirements for waterside economizers used in computer room applications. The revisions include editorial revisions to the text of the exceptions to Section 6.5.1.2.1 and the addition of a new Table 6.5.1.2.1 in Standard 90.1-2013 that is specifically intended for use with water economizers used in computer room applications. The primary change implemented in this addendum is to consider the appropriate dry-bulb and wet-bulb temperatures for using the exceptions on a climate zone by climate zone basis rather than based on a single dry-bulb/wet-bulb combination for evaporative water economizers or a single dry-bulb temperature for dry cooler water economizers. For Climate Zone 1, the exceptions no longer apply. For Climate Zones 2A, 3A, 4A, and 5A, there is no change in requirements for evaporative water economizers, with the exception requiring 100% cooling load met at 40°F dry-bulb/35°F wet-bulb. For the remaining climate zones, the dry-bulb and wet-bulb temperatures are lowered by 5°F to 10°F. For dry cooler water economizers, there is no longer an exception for Climate Zone 1 and the dry-bulb requirements have been lowered from 5°F to 15°F in all other climate zones.

Impact: Overall, this addendum represents a minor negative in terms of energy efficiency.

Addendum 90.1-2010di

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Establishes limits on using electric or fossil fuel to humidify or dehumidify between 30% and 60% RH except certain applications. Requires deadband on humidity controls.

Discussion: Addendum 90.1-2010di addresses the humidification and dehumidification requirements in Standard 90.1. A new requirement is added to Section 6.4.3.7, Humidification and Dehumidification, that requires humidity controls to prevent use of fossil fuel or electricity to produce RH above 30% in the warmest zone or below 60% in the coldest zones served. In conjunction with this change, one exception was modified to allow an exception if required by accreditation standards (as is common in hospitals) and to require that all exempt systems maintain at least a 10% RH deadband. Another exception was added for systems serving zones where humidity levels must be maintained within plus or minus 5%. A series of changes were also made to Section 6.5.2.3, Dehumidification. These include two editorial changes to the requirement and exceptions, as well as four technical changes to the exceptions: 1) the maximum size of the individual fan coil units is reduced from 80,000 to 65,000 Btu/h in exception b; 2) pharmacies are added to the list of special needs spaces in exception d; 3) a requirement is added that certain spaces allowed to reheat for dehumidification control must provide at least 75% of the annual energy needed for reheating or mixing air by site-recovered or site solar energy; and 4) the percentage of recovered or solar energy is increased from 75% to 90% and specifying annual energy in exception e.

Impact: Overall, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010dn

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Reduces the limits on hot gas bypass as a means of cooling capacity control.

Discussion: Addendum 90.1-2010dn revises the existing hot gas bypass requirements by reducing the allowable percent of total capacity significantly (from 50% to 15% for units with a capacity of less than or equal to 240,000 Btu/h and from 25% to 10% for units with a capacity of greater 240,000 Btu/h). The addendum also specifies that hot gas bypass should be limited to these values for VAV units and single-zone VAV units and that hot gas bypass should not be used for constant-volume units.

Impact: Overall, this addendum is rated a minor positive for reducing hot gas bypass, an inefficient form of variable capacity control.

Addendum 90.1-2010do

Sections(s) Modified: 12. Normative References (related to 6. Heating, Ventilating, and Air-Conditioning)

Short Description: Updates references to AHRI 550, AMCA 500, ANSI Z21.10.3 & Z21.47, ASHRAE 90.1 and 62.1, NEMA MG 1, and NFPA 70 and 96.

Discussion: Addendum 90.1-2010do updates references for nine standards referenced in the mechanical sections of Standard 90.1.

Impact: Given that this addendum only updated standards references, this addendum is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010dp

Sections(s) Modified: 3. Definitions, Abbreviations, and Acronyms (related to 6. Heating, Ventilating, and Air-Conditioning)

Short Description: Corrects the definition of “walk-in-cooler” to be consistent with federal requirements.

Discussion: Addendum 90.1-2010dp only updates a definition used in Section 6, Heating, Ventilating and Air-Conditioning. Addendum 90.1-2010dp modifies the definition of “walk-in cooler” to match the federal definition by replacing the word “but” with “and” and adding an “equal to” sign to the “less than 55°F” portion of the definition.

Impact: Given that this addendum updates a definition, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010dq

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Deletes sizing requirements for pipes larger than 24 inches in diameter. .

Discussion: Addendum 90.1-2010dq drops requirements for piping system design maximum flow rates for pipes larger than 24 inches in diameter because the analysis did not extend beyond 24-inch pipes.

Impact: Because there are now no flow rate limits for pipes larger than 24 inches in diameter, this constitutes a very slight weakening of the standard and therefore this addendum is rated a minor negative in terms of energy efficiency.

Addendum 90.1-2010dv

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Establishes chiller and boiler fluid flow isolation requirements so there is no flow through the equipment when not in use.

Discussion: Addendum 90.1-2010dv revises the existing chiller and boiler pump requirements in Standard 90.1. Specifically, the addendum makes it clear that this section applies only to chiller and boiler pumps and makes a number of editorial changes to the section. The addendum does add two new requirements (now in Section 6.5.4.3 of Standard 90.1-2013): When constant speed pumps serve multiple chillers (or boilers), the number of pumps must be no less than the number of chillers (or boilers) and the pumps must be staged off and on with the chillers (or boilers).

Impact: These requirements are intended reduce standby pump, chiller, and boiler energy use. Based on these new requirements, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010dw

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning

Short Description: Revises high-limit shutoff for air economizers. Adds sensor accuracy requirements.

Discussion: Addendum 90.1-2010dw modifies the existing high-limit shutoff control requirements for air economizers in Section 6. Specifically, the addendum deletes the existing table of high-limit shutoff control options, which lists the allowable and prohibited control types for each climate zone, and edits the existing table of high-limit shut-off control settings to show the climate zones for which a particular control type is allowed and the required high-limit setpoint for that control in particular climate zones. Two control types are no longer allowed: "electronic enthalpy" and "dew point and dry-bulb temperature." Both fixed and differential enthalpy control now require a fixed dry-bulb temperature in combination to protect against humidity sensor inaccuracy. A new allowance is made for fixed dry-bulb temperature controls in Climate Zones 1A, 2A, 3A, and 4A. A new footnote to the table requires that devices with selectable rather than adjustable setpoints be capable of being set to within 2°F or 2 Btu/lb of the setpoint listed.

Impact: The addition of dry-bulb to enthalpy control has the main impact on energy use, and based on that change this addendum is rated as a minor positive in terms of energy efficiency.

4.6 Changes to Section 7, Service Water Heating

A total of two addenda were made to Section 7, Service Water Heating, during the creation of Standard 90.1-2013. One addendum (90.1-2010cd) also modifies Section 6, Heating, Ventilating, and Air-Conditioning, and is therefore discussed in both locations.

Addendum 90.1-2010bo

Sections(s) Modified: 7. Service Water Heating

Short Description: Requires buildings with service water heating (SWH) capacity ≥ 1 million Btu/h to have average efficiency of at least 90%. Updates Table 7.8 to reflect federal requirements for electric water heaters. Updates the reference standard for swimming pool water heaters to ASHRAE Standard 146.

Discussion: Addendum 90.1-2010bo adds a new requirement in Section 7.5.3 of Standard 90.1-2013 that new buildings with high capacity service water heating systems (defined as gas systems with a total installed input capacity of 1,000,000 Btu/h) have a minimum thermal efficiency of 90%. This essentially requires gas-condensing service water heaters for at least part of the equipment in large new buildings. The addendum also changes the test procedure for heat pump pool heaters to ASHRAE Standard 146, modifies the performance required for certain oil storage water heaters from 78% to 80% thermal efficiency, and modifies the performance required for electric water heaters to match current federal regulations.

Impact: Overall, the addition of the new requirement for buildings with high capacity systems to use gas-condensing units is judged the most significant change in this addendum. As this change (and the changes to the oil storage water heater requirements) only applies to a subset of building hot water systems, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cd

Sections(s) Modified: 6. Heating, Ventilating, and Air-Conditioning, 7. Service Water Heating, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Provides definition for piping to include all accessories in series with pipe such as pumps, valves, strainers, air separators, etc. This is meant to clarify that these accessories need to be insulated.

Discussion: Addendum 90.1-2010cd adds a new definition of “piping” to Standard 90.1 and then makes editorial changes to Section 6 and Section 7 to change the word “pipe” to “piping” in eight locations.

Impact: This addendum may result in some savings where these accessories may not have been insulated before; however, as the changes are editorial, this addendum is rated as neutral (no impact) in terms of energy efficiency.

4.7 Changes to Section 8, Power

A total of five addenda were made to Section 8, Power, during the creation of Standard 90.1-2013. One addendum (90.1-2010bn) contains changes for Section 8, Power, and Section 10, Other Equipment, and is discussed under both sections. Several addenda also modify definitions (Section 3) or normative references (Section 12), but are discussed in this section as the definitions or references modified are related to Section 8, Power.

Addendum 90.1-2010k

Sections(s) Modified: 8. Power and 12. Normative References

Short Description: Modifies notes to Table 8.1 and specifies that nominal efficiencies would be established in accordance with the 10 CFR 431 test procedure for low-voltage dry-type transformers. The corresponding references have also been added in Chapter 12.

Discussion: Addendum 90.1-2010k modifies the footnotes to Table 8.1 to direct use of 10 CFR 431 instead of NEMA TP1 (NEMA 2002) for low-voltage dry-type transformers. 10 CFR 431 is also added to Chapter 12. (The requirements for low-voltage dry-type transformers are now found in Section 8.4.4 of Standard 90.1-2013).

Impact: Because the only impact is to change the reference standard, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010v

Sections(s) Modified: 8. Power

Short Description: Clarifies the requirement for controlled receptacles in open offices by changing the requirement to the workstations themselves. Also requires the automatically controlled receptacles to be appropriately identified for the user’s benefit.

Discussion: Addendum 90.1-2010v revises the list of required areas to specifically include individual workstations in all space types not otherwise exempted and areas where modular furniture will be used but is not shown on the construction documents. This addendum also requires that the controlled receptacles be appropriately identified so that users can clearly distinguish between controlled and non-controlled receptacles.

Impact: Since this addendum primarily clarifies that the existing requirements include modular furniture, it is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bf

Sections(s) Modified: 8. Power

Short Description: Addresses Section 8.4.2 on automatic receptacle control and increases the spaces where plug shutoff control is required. Clarifies the application of this requirement for furniture systems, states a labeling requirement to distinguish controlled and uncontrolled receptacles, and restricts the use of plug-in devices to comply with this requirement.

Discussion: Addendum 90.1-2010bf modifies existing automatic receptacle control requirements by 1) specifically noting that receptacles must be automatically controlled; 2) specifying receptacles in all private offices, conference rooms, rooms used primarily for printing and copying, break rooms, class rooms, and individual workstations; 3) specifically noting branch feeder circuits installed for modular furniture; 4) reducing the size of an automatically controlled area from 25,000 to 5000 ft^2 and adding a requirement for manual override by occupants; 5) reducing the time allowed for occupancy sensors to turn off receptacles from 30 to 20 minutes after an area is unoccupied; 6) adding a requirement that controlled receptacles be marked to visually differentiate them from uncontrolled receptacles; 7) adding a requirement that plug-in devices not be used to meet the automatic receptacle control requirements; 8) clarifying that 24-hour operation is continuous operation (24 hours/day, 365 days/year) in an exception; and 8) changing the wording of another exception from “automatic shutoff” to “automatic control” for clarity.

Impact: Overall, the addendum should save energy by increasing the types of spaces where automatic receptacle control is required and is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010bn

Sections(s) Modified: 8. Power and 10. Other Equipment

Short Description: Establishes electric and fuel metering requirements.

Discussion: Addendum 90.1-2010bn implements additional whole building energy monitoring in Standard 90.1. There were existing electrical energy monitoring requirements in Section 8.4.3 in Standard 90.1-2013 due to addendum 90.1-2010bz and these requirements are expanded in addendum 90.1-2010bn. This addendum modifies the existing requirements by specifying that the provision only applies to new buildings and by providing five exceptions: 1) buildings less than 25,000 ft^2; 2) individual tenant spaces less than 10,000 ft^2; 3) dwelling units; 4) residential buildings with less than 10,000 ft^2 of common area; and 5) critical and equipment branches as defined by NEC Article 517.[1] In addition, existing exceptions for recording and reporting energy usage are modified to match exceptions for monitoring for buildings (to less than 25,000 ft^2) and individual tenant spaces (to less than 10,000 ft^2).

In Section 10, Other Equipment, a new Section 10.4.5 in Standard 90.1-2013 on whole building monitoring of natural gas, fuel oil, propane, steam, chilled water, and hot water is added with a similar list of exceptions to that found in Section 8, except that the critical and equipment branch exception is not included and the exception for hotels, motels, and restaurants is not included, while a new exception for fuel used for on-site emergency equipment is added. A new section on recording and reporting (Section 10.4.5.2 of Standard 90.1-2013) is added with the same exceptions as the monitoring portion of Section 10 (Section 10.4.5.1 of Standard 90.1-2013).

[1] One issue noted with this addendum is that while it adds an exception based on NEC Article 517, NEC Article 517 was not added as a normative reference. This has been reported to the committee and will be addressed in 2016.

Impact: Overall, while the addition of metering requirements through addenda 90.1-2010bn and 90.1-2010bz may have a long-term effect on energy usage if the metered data is used to analyze problems, the addition of monitoring and recording and reporting requirements by themselves does not save energy, so this addendum is therefore rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bz

Sections(s) Modified: 8. Power

Short Description: Adds Section 8.4.2, which specifies requirements for installation of basic electrical metering of major end uses (total electrical energy, HVAC systems, interior lighting, exterior lighting, and receptacle circuits) to provide basic reporting of energy consumption data to building occupant.

Discussion: Addendum 90.1-2010bz (formerly addendum bz to 90.1-2007) was the first of two addenda that significantly expand energy monitoring requirements for Standard 90.1-2013. The other addendum was 90.1-2010bn. Addendum 90.1-2010bz added new monitoring, recording, and reporting requirements for electrical energy to Section 8. These requirements were later modified in addendum 90.1-2010bn.

Impact: While the addition of metering requirements through addenda 90.1-2010bn and 90.1-2010bz may have a long-term effect on energy usage if the metered data is used to analyze problems and correction is conducted to improve energy performance, the addition of monitoring and recording and reporting requirements by themselves does not save energy; therefore, this addendum is rated neutral (no impact) in terms of energy efficiency.

4.8 Changes to Section 9, Lighting

A total of 17 addenda were made to Section 9, Lighting, during the creation of Standard 90.1-2013. One addendum (90.1-2010at) updates Section 3, Building Envelope, and Section 9, Lighting, and is discussed in both locations. One major restructuring of Section 9 was that the tables in Section 9.4.2 were renumbered from Table 9.4.2A to 9.4.2B to a new format of Table 9.4.2-1 to 9.4.2-2. These tables were not modified by addenda, but were renumbered during the course of development of Standard 90.1-2013. Another major restructuring was that a number of sections were deleted, combined, or added in Standard 90.1-2013.

Table 4.5 shows the restructuring in Standard 90.1-2013.

Table 4.5. Restructuring of Section 9 in 90.1-2013

Section Number	Title 90.1-2010	Title 90.1-2013
9.4	Mandatory Provisions	Mandatory Provisions
9.4.1	Lighting Control	Lighting Controls
9.4.1.1	Automatic Lighting Shutoff	Interior Lighting Controls (includes contents of Sections 9.4.1.1, 9.4.1.2, 9.4.1.4, and 9.4.1.5 of Standard 90.1-2010)
9.4.1.2	Space Control	Parking Garage Lighting Controls (former Section 9.4.1.3 of Standard 90.1-2010)
9.4.1.3	Parking Garage Lighting Control	Special Applications (former Section 9.4.1.6 of Standard 90.1-2010)
9.4.1.4	Automatic Daylighting Controls for Primary Sidelighted Areas	Exterior Lighting Controls (former Section 9.4.17 of Standard 90.1-2010)
9.4.1.5	Automatic Daylighting Controls for Toplighted Areas	Not used in Standard 90.1-2013
9.4.1.6	Additional Controls	Not used in Standard 90.1-2013
9.4.1.7	Exterior Lighting Control	Not used in Standard 90.1-2013
9.4.2	Exit Signs (dropped in Standard 90.1-2013)	Exterior Building Lighting Power (former Section 9.4.3 of Standard 90.1-2010)
9.4.3	Exterior Building Lighting Power	Functional Testing (former Section 9.4.4 of in Standard 90.1-2010)
9.4.4	Functional Testing	
9.5	Building Area Method Compliance Path	Building Area Method Compliance Path
9.5.1	Building Area Method	Building Area Method
9.6	Alternative Compliance Path – Space-by-Space Method	Alternative Compliance Path – Space-by-Space Method
9.6.1	Space-by-Space Method	Space-by-Space Method
9.6.2	Additional Interior Lighting Power	Additional Interior Lighting Power
9.6.3	Room Geometry Adjustment	Additional Interior Lighting Power Using Non-Mandatory Controls (new for Standard 90.1-2013)
9.6.4	Not used in Standard 90.1-2010	Room Geometry Adjustment (former Section 9.6.3 in Standard 90.1-2010)
9.7	Submittals	Submittals
9.7.1	General	General
9.7.2	Completion Requirements	Completion Requirements
9.7.2.1	Drawings	Drawings
9.7.2.2	Manuals	Manuals
9.7.2.3	Not used in Standard 90.1-2010	Daylighting Documentation (new for Standard 90.1-2013)

Addendum 90.1-2010m

Sections(s) Modified: 9. Lighting

Short Description: Adds control requirements for lighting alterations, for interior and exterior applications. Adds a section for submittals and includes loading docks as a tradable surface. Modifies the provisions for additional interior lighting power, which is now calculated based on controlled wattage.

Discussion: Addendum 90.1-2010m makes several changes related to lighting:

- Clarifies that changes to existing building lighting must comply with the both the LPD requirements and the specific lighting control requirements.
- Adds specific exterior control requirements to exterior lighting alterations (daylight shutoff and façade/landscape after-hours shutoff).
- Adds the submittal section of the lighting section to the compliance path to ensure that it is clear that compliance with Section 9.7 on submittals is mandatory.
- Adds all nonhuman life forms to the exceptions because, like plants, the lighting needs for humans are not sufficient for the growth and maintenance of animals, which often require different light levels and lighting spectrum.
- Adds the exterior loading area type to Table 9.4.3b (now Table 9.4.2-2 in Standard 90.1-2013) because loading docks are specifically listed as being in the scope of Standard 90.1 (Section 9.1.1b) but they are not listed in Table 9.4.3b (now Table 9.4.2-2 of Standard 90.1-2013) and therefore have no power allowance associated with them.
- Modifies the application of control credits to the appropriate lighting and the specific lighting that is actually controlled.

Impact: Given that this addendum requires lighting controls to renovations and adds loading docks to the external lighting power allowances, it is as a major positive in terms of energy efficiency.

Addendum 90.1-2010at

Sections(s) Modified: 5.Building Envelope, 9. Lighting, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Deletes the term "clerestory" and instead adds "roof monitor" and clarifies the definition. Changes the references in Chapters 5 and 9 from clerestory to roof monitor.

Discussion: In Section 3, addendum 90.1-2010at deletes the terms "clerestory" and "rooftop monitor" and adds the term "roof monitor." The terms "fenestration," "daylit area," and "toplighting" are edited to use the term "roof monitor." The addendum also makes minor changes to the daylight area width under roof monitors. Figure 3.2 for the daylight area under roof monitors is also replaced. In Sections 5 and 9, the addendum edits two sections to use the term "roof monitor"—exception d to Section 5.5.4.2.3 and Section 9.4.1.5 (now part of Section 9.4.1.1 of Standard 90.1-2013).

Impact: Given that the addendum is editorial, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ay

Sections(s) Modified: 9. Lighting and 3. Definitions, Abbreviations, and Acronyms

Short Description: Modifies daylighting requirements. Modifies definitions for daylight area under skylights, daylight area under roof monitors, primary sidelight area, secondary sidelight area. Modifies the thresholds for applying automatic daylighting control for sidelighting and toplighting to a wattage basis and provides characteristics for the required photo controls. Modifies Table 9.6.2 to include continuous dimming in secondary sidelighted areas, which is now based on a wattage level rather than space area. Eliminates the need for effective aperture calculation.

Discussion: Addendum 90.1-2010ay makes a number of changes related to daylighting and daylighting control:

- Changes the thresholds for applying daylighting controls to a wattage-controlled basis, which applies to more spaces in a building for additional energy savings.
- Simplifies the delineation of daylight zones and clarifies area calculations.
- Eliminates the need for effective aperture calculation.

Impact: Because this addendum expands the number of spaces that must utilize daylighting controls, it is rated a minor positive in terms of energy efficiency.

Addendum 90.1-2010bc

Sections(s) Modified: 9. Lighting

Short Description: Modifies requirements for automatic lighting control for guestroom-type spaces. Exceptions to this requirement are lighting and switched receptacles controlled by captive key systems.

Discussion: Addendum 90.1-2010bc adds automatic lighting control to guestroom-type spaces for additional energy savings and also allows captive key systems that provide similar savings control to comply.

Impact: Based on the expansion of lighting and switched receptacle control requirements to guest rooms, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010bd

Sections(s) Modified: 9. Lighting

Short Description: Adds more-specific requirements for the functional testing of lighting controls, specifically, occupancy sensors, automatic time switches, and daylight controls.

Discussion: Addendum 90.1-2010bd adds more-specific requirements to the functional testing of lighting controls for the common controls required by the standard and clarifies the description of entities allowed to perform the testing and verification.

Impact: Based on the addition of new functioning testing requirements for lighting controls, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010be

Sections(s) Modified: 9. Lighting

Short Description: Makes minor revisions to Section 9.7.2.2, which addresses the scope of the operating and maintenance manuals required for lighting equipment and controls.

Discussion: Addendum 90.1-2010be adds the descriptor phrase “including but not limited to lamps, ballasts, and drivers” to the mention of lighting equipment in Section 9.7.2.2, Manuals. The addendum also adds the word “cleaning” after the existing mention of a recommended relamping program.

Impact: Given that this addendum is essentially clarification, the estimated impact is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bh

Sections(s) Modified: 9. Lighting

Short Description: Modifies Table 9.6.1, Space-By-Space Lighting Power Density Allowance.

Discussion: Addendum 90.1-2010bh modifies the space-by-space method interior lighting power allowance table in five ways:

1. LPDs have been adjusted to account for changes to recommended light levels as published in the new IES Lighting Handbook, 10th Edition. Some values have increased while others have decreased.
2. Three new space types have been added in response to user requests: (a) Copy/Print Rooms; (b) Loading Docks, Interior; and (c) Computer Rooms.
3. New space types for Assisted Living Facilities were added, including corridor, dining area, lobby, restroom, chapel, and recreation room. In all cases, these modified LPDs are restricted to those spaces that are used primarily by the residents.
4. Some space types were renamed for consistency.
5. Some table footnotes were added to provide more-specific direction.

Addendum 90.1-2010cr further modified the LPD values to correct and add space types.[1] Of the five sets of changes noted above, those changes associated with items 2 and 3 are entirely new space types for Standard 90.1-2013 and therefore any consideration of the energy impact of these spaces types would depend on what would have been chosen from the available space types in Standard 90.1-2010 in the absence of these new space types. Items 4 and 5 are essentially editorial or clarification. That leaves item 1 as the only set of changes that can be easily evaluated for stringency.

[1] See Table 9.6.1 in addendum by in the Addenda 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, “Energy Standard for Buildings Except Low-Rise Residential Buildings” (ASHRAE 2013a). for the table showing the final LPDs from addenda 90.1-2010 bh, 90.1-2010cr, and 90.1-2010dl. The LPDs generated by these addenda were reformatted in addendum 90.1-2010by.

Table 4.6 and Table 4.7 show the changes made in this addendum that can be compared to existing values in Standard 90.1-2010.

Table 4.6. Addendum 2010 90.190.1-2010bh Space-by-Space Lighting Power Changes

	90.1-2010	Addendum bh	Change
Common Space Types[1]	**LPD**		
	watts/sq.ft		
Audience Seating Area ~~— Permanent~~			
... in an auditorium	0.79	0.63	0.16
… in a gymnasium	0.43	0.65	-0.22
... in a penitentiary	0.43	0.28	0.15
Atrium			
Banking Activity Area	1.38	1.01	0.37
Breakroom (See Lounge/Breakroom)			
Classroom/Lecture Hall/Training Room			
Confinement Cells	1.1	0.81	0.29
Corridor[2]			
… in a hospital	0.89	0.79	0.1
Dining Area			
… in a penitentiary	1.07	0.96	0.11
… in Bar/Lounge or Leisure Dining	1.31	1.07	0.24
Electrical/Mechanical Room	0.95	0.42	0.53
Food Preparation Area	0.99	1.21	-0.22
Guest Room	0.93	0.47	0.46
Laboratory			
… in or as a classroom	1.28	1.43	-0.15
Lobby			
… in a motion picture theater	0.52	0.59	-0.07
Lounge/Breakroom			
… in a healthcare facility	1.07	0.92	0.15
Office			
Pharmacy Area	1.14	1.68	-0.54
Restroom			
Sales Area[4]	1.68	1.59	0.09

Table 4.7. Addendum 2010 90.190.1-2010bh Building Area Lighting Power Changes

	90.1-2010	Addendum bh	Change
Building Type Specific Space Types	**LPD watts/sq.ft**		
Fire Station - Sleeping Quarters	0.25	0.22	0.03
Healthcare Facility			
… in an Imaging Room	1.32	1.51	-0.19
… in a Medical Supply Room	1.27	0.74	0.53
… in a Nurse's Station	0.87	0.71	0.16
… in an Operating Room	1.89	2.48	-0.59
Library			
… in a Reading Area	0.93	1.06	-0.13
Manufacturing Facility			
… in an Equipment Room	0.95	0.74	0.21
Performing Arts Theater - Dressing Room	0.4	0.61	-0.21
Retail Facilities			
… in a Dressing/Fitting Room	0.87	0.71	0.16
Sports Arena - Playing Area			
… for a Class I facility	3.01	3.68	-0.67
… for a Class II facility	1.92	2.4	-0.48
… for a Class III facility	1.2	1.8	-0.6
… for a Class IV facility	0.72	1.2	-0.48
Transportation Facility			
… in a baggage/carousel Area	0.76	0.53	0.23
… at a Terminal Ticket Counter	1.08	0.8	0.28

Impact: The overall savings for the 16 changes to the space-by-space method is 0.09 W/ft^2 based on an unweighted average. The overall savings for the 15 changes for the building-specific space types is -0.12 W/ft^2 based on an unweighted average. This indicates that for the changes that can be quantified in addendum 90.1-2010bh, the impact is slightly negative (-0.03 W/ft^2 for the collection of 31 changes). This is a very small number and therefore further consideration is given of the changes discussed under item 3 above for Assisted Living. These changes were implemented as a replacement to a blanket exemption for Assisted Living facilities in exception g to Section 9.2.2.3 in Standard 90.1-2010. This exception was removed in Standard 90.1-2013 and therefore it is very likely that the values listed for Assisted Living facilities in both the space-by-space and building area tables do represent reductions in energy usage from what would have been installed under Standard 90.1-2013. For this reason, this addendum is rated a minor positive.

Addendum 90.1-2010bx

Sections(s) Modified: 9. Lighting

Short Description: Clarifies exceptions to occupancy sensor requirements.

Discussion: Addendum 90.1-2010bx removes the statement from the exceptions list to Section 9.4.1.2b (now part of Section 9.4.1.1 of Standard 90.1-2013) that “these spaces are not required to be connected to other automatic lighting shutoff controls” because that was not in standard ASHRAE format for how exceptions are written. Section 9.4.1.2b (now part of Section 9.4.1.1 of Standard 90.1-2013) is in fact a requirement for an occupant sensor or timer switch that automatically turns lighting off, and therefore an exception to that requirement would mean that no automatic lighting shutoff control would be required. The addendum also removes an exception for spaces with multi-scene control systems and modifies the text of another exception to clarify that it is the space that is exempted from 9.4.1.2b (now part of Section 9.4.1.1 of Standard 90.1-2013).

Impact: The overall impact of this addendum is rated as neutral (no impact) in terms of energy efficiency, as it is only clarification.

Addendum 90.1-2010by

Sections(s) Modified: 9. Lighting

Short Description: Requires the use of certain lighting controls in more space types. Reduces the amount of time after occupants vacate a space for lights to be automatically reduced or shut off. Establishes table of lighting controls applicable to each space type.

Discussion: Addendum 90.1-2010by completely replaces the interior lighting control requirements in Section 9.4.1 of Standard 90.1. Because this is a complete replacement, a line-by-line comparison is not appropriate. The foreword to the addendum notes that there are three major impacts of this addendum. First, it requires certain lighting controls in more space types and also reduces the times until lights are automatically shut off. Second, it provides a more tabular structure for lighting controls requirements. And third, it corrects errors in wattage thresholds for sidelighting and toplighting daylight responsive controls.[1] This addendum also provides a new format for LPD requirements that were impacted by addenda 90.1-2010bh, 90.1-2010cr, and 90.1-2010dl, as discussed elsewhere in this section.

Impact: Overall, due to the increase of lighting control requirements in more space types, this addendum is rated as a major positive in terms of energy efficiency.

Addendum 90.1-2010co

Sections(s) Modified: 9. Lighting

Short Description: Comprehensive update of LPDs in Table 9.5.1 - Building Area Method.

Discussion: The original and revised LPDs by building area type are shown in Table 4.8, along with the calculated percentage change, with a decrease (negative values) indicating energy savings. As Table 4.8 shows, the majority of changes are negative, with 6 building area types increasing, 4 building area types staying the same, and 23 building area types decreasing. Overall, an unweighted average of the percentage change is about -4%, indicating that addendum co is a major positive in terms of energy efficiency.

[1] See Table 9.6.1 in addendum by in the Addenda 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, “Energy Standard for Buildings Except Low-Rise Residential Buildings” (ASHRAE 2013a), for the control requirements generated by addendum 90.1-2010by. This table also shows the final LPDs from addenda 90.1-2010 bh, 90.1-2010cr, and 90.1-2010dl.

Table 4.8. Addendum 90.1-2010co Building Area Method Light Power Changes

Building Area Type	Standard 90.1-2010	Addendum co	Percentage Change
Automotive facility	0.82	0.80	-2%
Convention center	1.08	1.01	-6%
Courthouse	1.05	1.01	-4%
Dining: bar lounge/leisure	0.99	1.01	2%
Dining: cafeteria/fast food	0.90	0.90	0%
Dining: family	0.89	0.95	7%
Dormitory	0.61	0.57	-7%
Exercise center	0.88	0.84	-5%
Fire station	0.71	0.67	-6%
Gymnasium	1.00	0.94	-6%
Health-care clinic	0.87	0.90	3%
Hospital	1.21	1.05	-13%
Hotel/Motel	1.00	0.87	-13%
Library	1.18	1.19	1%
Manufacturing facility	1.11	1.17	5%
Motel*	0.88	0.87*	-1%
Motion picture theater	0.83	0.76	-8%
Multifamily	0.60	0.51	-15%
Museum	1.06	1.02	-4%
Office	0.90	0.82	-9%
Parking garage	0.25	0.21	-16%
Penitentiary	0.97	0.81	-16%
Performing arts theater	1.39	1.39	0%
Police station	0.96	0.87	-9%
Post office	0.87	0.87	0%
Religious building	1.05	1.00	-5%
Retail	1.40	1.26	-10%
School/university	0.99	0.87	-12%
Sports arena	0.78	0.91	17%
Town hall	0.92	0.89	-3%
Transportation	0.77	0.70	-9%
Warehouse	0.66	0.66	0%
Workshop	1.20	1.19	-1%

* Motel now part of combined hotel/motel.

Impact: Overall, most LPD requirements are reduced across various building types, indicating that this addendum should be rated a major positive.

Addendum 90.1-2010cr

Sections(s) Modified: 9. Lighting and 12. Normative References

Short Description: Adjusts Table 9.6.1, Space-by-space LPD.

Discussion: Addendum 90.1-2010cr revises the requirements for five common space types in Table 9.6.1. The changes are shown in Table 4.9.[1]

[1] See Table 9.6.1 in addendum 90.1_2010_by in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, "Energy Standard for Buildings Except Low-Rise Residential Buildings" (ASHRAE 2013a), for the table showing the final LPDs from addenda 90.1-2010 bh, 90.1-2010cr, and 90.1-2010dl. The LPDs generated by these addenda were reformatted in addendum 90.1-2010by.

Table 4.9. Addendum 90.1-2010cr Space-by-Space Light Power Changes

Space Type	Size Modifier	Standard 90.1-2010LPD	Addendum cr LPD	Percentage Change
Hospital Corridor	NA	0.79	0.99	25%
Dining Area in a facility for the visually impaired (and used primarily by staff)	NA	1.90	2.65	39%
Sales Area	NA	1.59	1.44	-9%
Storage Room	Greater than 50 ft2	0.63	0.63	No change
Storage Room	Less than or equal to 50 ft2	0.63	1.24	97%
Recreation room/common living room in Facility for the Visually Impaired (used primarily by staff)	NA	2.41	2.41	No change

The addendum also adds a new normative reference in ANSI/IES Research Project RP-28-2007, “Lighting and the Visual Environment for Senior Living” (IES 2007). This addendum deals with overall LPDs that were also dealt with in addenda 90.1-2010bh and 90.1-2010by.

Impact: Overall, the impact of this addendum is to allow more lighting power in hospital corridors, staff dining areas in facilities for the visually impaired, and small storage rooms. Balancing this out is the reduction in LPD allowed in sales areas. It is very likely that the reduction in allowed LPD more than balances out the increases in LPD for hospital corridors, staff dining areas in facilities for the visually impaired, and small storage rooms. Therefore, this addendum is considered a minor positive.

Addendum 90.1-2010dc

Sections(s) Modified: 9. Lighting

Short Description: Clarifies automatic lighting and switched receptacle control in guest rooms as applied to individual spaces.

Discussion: Addendum 90.1-2010dc modifies guestroom lighting requirements (including switched receptacles) in Standard 90.1 that were previously modified by addenda 90.1-2010bc and 90.1-2010by by clarifying that each enclosed space should be controlled independently. An exception is added for enclosed spaces where the lighting and switched receptacles are controlled by a captive key system.

Impact: The overall impact of this addendum is rated as neutral (no impact) in terms of energy efficiency, as it is only clarification.

Addendum 90.1-2010dj

Sections(s) Modified: 9. Lighting

Short Description: Allows additional lighting power allowance for electrical/mechanical rooms to increase the level to the same as provided in 90.1-2010, provided there is a separate control for the additional lighting.

Discussion: Addendum 90.1-2010dj adds a footnote to Table 9.6.1 that allows an additional 0.53 W/ft^2 for electrical/mechanical rooms (from the baseline amount of 0.42 W/ft^2) as long as the additional lighting is separately controlled.

Impact: This addendum is essentially a tradeoff of additional LPD for additional controls and as such is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010dk

Sections(s) Modified: 9. Lighting

Short Description: Eliminates the exemption for wattage used in spaces where lighting is specifically designed for those with age-related eye conditions or other medical conditions related to the eye, where special lighting or light levels might be needed.

Discussion: Addendum 90.1-2010dk eliminates an exception for lighting in spaces specifically designed for use by occupants with special lighting needs and also eliminates a requirement that internally illuminated exit signs not exceed 5 W per face. As noted in the foreword to this addendum, addenda 90.1-2010bh and 90.1-2010cr provide new, specific design lighting requirements for spaces occupied by those with special lighting needs. In addition, the 5 W per face requirement for exit signs is now a federal requirement and there is no longer any need for this requirement in Standard 90.1.

Impact: This addendum is rated as a minor positive because it trades the blanket exception for spaces occupied by occupants with special lighting needs for more targeted requirements found in other addenda.

Addendum 90.1-2010dl

Sections(s) Modified: 9. Lighting

Short Description: Modifies hotel and motel guest room LPD.

Discussion: Addendum 90.1-2010dl deletes LPD requirements for hotel guest rooms and highway lodging guest rooms and provides a new requirement for guest rooms. This addendum modifies LPD values that were also modified in addenda 90.1-2010bh and 90.1-2010by.[1] The requirements for guest rooms in Standard 90.1-2010 and in this addendum are shown in Table 4.10.

Table 4.10. Addendum 90.1-2010dl Lighting Power Changes

Space Type	Standard 90.1-2010	Addendum 90.1-2010dl
Hotel Guest Rooms	1.11 W/ft^2	NR
Highway Lodging Guest Rooms	0.75 W/ft^2	NR
Guest Rooms	NR	0.91 W/ft^2

Impact: The new requirement (0.91W/ft^2) is slightly less than the average of the two original requirements (0.93) in Standard 90.1-2010, so this requirement is a minor positive in terms of energy efficiency.

Addendum 90.1-2010dt

Sections(s) Modified: 9. Lighting

Short Description: Adds exceptions for control of exterior lighting integral to signage. Requires certain types of exterior lighting exempt from LPD requirements to be separately controlled.

Discussion: Addendum 90.1-2010dt addresses the exterior lighting and exterior lighting control requirements in Standard 90.1. The addendum removes mention of “advertising signage” and simply

[1] See Table 9.6.1 in addendum 90.1_2010_by in the 2013 Supplement to ANSI/ASHRAE/IES Standard 90.1-2010, “Energy Standard for Buildings Except Low-Rise Residential Buildings” (ASHRAE 2013a), for the control requirements generated by addendum 90.1-2010by. This table also shows the final LPDs from addenda 90.1-2010 bh, 90.1-2010cr, and 90.1-2010dl.

refers to “signage” and makes it clear that lighting that is integral to signage and installed in signage by a manufacturer is exempt from exterior lighting control requirements and also not included in the exterior lighting power allowance. The addendum also moves a number of exterior lighting items such as temporary lighting, specialized signal, and directional lighting and other exterior lighting that would not be typically included in a building permit to separate exception under Exterior Building Lighting Power.

Impact: The impactful change here is the application of the requirement that all signage (and not just advertising signage) be controlled when not needed. For this reason, this addendum is rated as a minor positive in terms of energy efficiency.

4.9 Changes to Section 10, Other Equipment

A total of six addenda were made to Section 10, Other Equipment, during the creation of Standard 90.1-2013. One addendum (90.1-2010bn) also modifies Section 8, Power, and is therefore discussed in both locations. Several addenda also modify definitions (Section 3) or normative references (Section 12) but are discussed in this section as the definitions or references modified are related to Section 10, Other Equipment.

One major restructuring of Section 10 was that the tables in Section 10.8 were renumbered from Table 10.8A to 10.8C to a new format of Table 10.8-1 to 10.8-3. The tables called out in this document correspond to the table numbers used in Standard 90.1-2013.

Addendum 90.1-2010a

Sections(s) Modified: 10. Other Equipment and 12. Normative References

Short Description: Specifies that nominal efficiencies for motors are required to be established in accordance with 10 CFR 431 instead of NEMA Standards (NEMA 2006). Modifies the footnotes to Tables 10.8A, 10.8B, and 10.8C (now Tables 10.8-1, 10.8-2, and 10.8-3 in Standard 90.1-2013). The corresponding reference for 10 CFR 431 has also been added.

Discussion: Addendum 90.1-2010a updates the test procedure references in the tables in Section 10.8 and adds a normative reference in Chapter 12.

Impact: Given that this addendum impacts test procedures and no other changes are made, this addendum is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010b

Sections(s) Modified: 10. Other Equipment and 12. Normative References

Short Description: Requires escalators and moving walks to automatically slow when not conveying passengers. The corresponding reference to ASME A17.1/CSA B44 has also been added to the normative references.

Discussion: Addendum 90.1-2010b adds new requirements in Section 10.4.4 of Standard 90.1-2013 that escalators and moving walks automatically slow down when not conveying passengers and adds a normative reference to ASME A17.102010/CSA B44-10, “Safety Code for Elevators and Escalators,” (ASME/CSA 2010) as the source of information on how this should be done.

Impact: Given that escalators and moving walks are a minor energy user only affecting a small subset of building types, this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010n

Sections(s) Modified: 10. Other Equipment

Short Description: Clarifies that the total lumens per watt for the entire elevator cab is required to meet the efficiency requirement but that each individual light source is not required to meet the lumens per watt value.

Discussion: Addendum 90.1-2010n clarifies that the total lumens per watt for the entire elevator cab is required to meet the efficiency requirement but that it is not required that each individual light source must comply.

Impact: Given the fact that this addendum is simply clarification, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010y

Sections(s) Modified: 10. Other Equipment and 3. Definitions, Abbreviations, and Acronyms

Short Description: Revises the definitions of general purpose electric motors (subtypes I and II) based on information from NEMA. Adds Table 10.8D (now Table 10.8-4 in Standard 90.1-2013), which specifies minimum average full-load efficiency for poly-phase small electric motors; and Table 10.8E (now Table 10.8-5 in Standard 90.1-2013), which specifies minimum average full-load efficiency for capacitor-start capacitor-run and capacitor-start induction-run small electric motors.

Discussion: Addendum 90.1-2010y adds a new acronym for "IEC" (International Electrotechnical Commission), completely replaces existing definitions for "general purpose electric motor (subtype I)" and "general purpose electric motor (subtype II)," and adds a new definition for "small electric motor" to Section 3 and updates Section 10 to use these new terms. The addendum also adds two new tables with requirements for poly-phase small electric motors and capacitor-start capacitor-run and capacitor-start induction-run small electric motors.

Impact: All of the changes made in this addendum are the result of federal energy efficiency standards and therefore the impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bn

Sections(s) Modified: 8. Power and 10. Other Equipment

Short Description: Establishes electric and fuel metering requirements.

Discussion: Addendum 90.1-2010bn implements additional whole building energy monitoring in Standard 90.1. There were existing electrical energy monitoring requirements in Standard 90.1-2013 due to addendum 90.1-2010bz and these requirements are expanded in addendum bn. This addendum modifies the existing requirements by specifying that the provision only applies to new buildings and by providing five exceptions: 1) buildings less than 25,000 ft^2; 2) individual tenant spaces less than 10,000 ft^2; 3) dwelling units; 4) residential buildings with less than 10,000 ft^2 of common area; and 5) critical and equipment branches as defined by NEC Article 517.[1] In addition, existing exceptions for recording and reporting energy usage are modified to match exceptions for monitoring for buildings (to less than 25,000 ft^2) and individual tenant spaces (to less than 10,000 ft^2).

[1] One issue noted with this addendum is that while it adds an exception based on NEC Article 517, NEC Article 517 was not added as a normative reference. This has been reported to the SSPC 90.1 and will be addressed in 2014.

In Section 10, Other Equipment, a new section on whole building monitoring of natural gas, fuel oil, propane, steam, chilled water, and hot water is added with a similar list of exceptions to those found in Section 8, except that the critical and equipment branch exception is not included and the exception for hotels, motels, and restaurants is not included, while a new exception for fuel used for on-site emergency equipment is added. A new section on recording and reporting is added with the same exceptions as the monitoring portion of Section 10.

Impact: Overall, while the addition of metering requirements through addenda 90.1-2010bn and 90.1-2010bz may have a long-term effect on energy usage if the metered data is used to analyze problems, the addition of monitoring and recording and reporting requirements by themselves does not save energy, so this addendum is estimated to be neutral or have no energy impact.

Addendum 90.1-2010br

Sections(s) Modified: 10. Other Equipment

Short Description: Updates motor efficiency tables to match Federal rulemaking.

Discussion: Addendum 90.1-2010br updates motor definitions and motor efficiency tables in line with a DOE rulemaking. In addition, the efficiency requirements for motors that were produced before December 19, 2010, have been removed because they are no longer allowed to be manufactured in or imported to the Unites States.

Impact: Given that this addendum simply implements a federal rulemaking, it is rated neutral (no impact) in terms of energy efficiency.

4.10 Changes to Section 11, Energy Cost Budget Method

A total of six addenda were made to Section 11, Energy Cost Budget Method, during the creation of Standard 90.1-2013. A number of these addenda also modify Normative Appendix G, Performance Rating Method, and are therefore discussed in both locations. One addendum (90.1-2010bw) updates Section 3, Building Envelope, and Section 11, Energy Cost Budget Method, and is discussed in both locations.

One major restructuring of Section 11 was that the tables in Section 11.3.2 were renumbered from Table 11.3.2A to a new format of Table 11.3.2-1. The tables called out in this document correspond to the table numbers used in Standard 90.1-2013.

Addendum 90.1-2010w

Sections(s) Modified: 11. Energy Cost Budget Method, Appendix G. Performance Rating Method, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds definitions for on-site renewable energy and purchased energy. Clarifies the process for accounting for on-site renewable energy and purchased energy as well as calculating the annual energy costs in the ECB approach and Appendix G.

Discussion: Addendum 90.1-2010w clarifies the credit for on-site renewable energy and site recovered energy in Section 11 and Appendix G. Definitions for on-site renewable energy and purchased energy have been added along with clearer guidance on the determination of applicable credits in Section 11 and Appendix G. Credit available for tradeoffs from on-site renewable energy is limited in Section 11 to a maximum of 5% of the calculated energy-cost budget.

Impact: Given that this addendum impacts only one of the whole building tradeoffs in Standard 90.1, the impact is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010aw

Sections(s) Modified: 11. Energy Cost Budget, Appendix G. Performance Rating Method, and 12. Normative References

Short Description: Updates the reference year for ASHRAE Standard 140 and exempts software used for ECB and Appendix G compliance from having to meet certain sections of ASHRAE Standard 140.

Discussion: Addendum 90.1-2010aw excludes testing for Sections 7 and 8 of ASHRAE Standard 140-2011 (ASHRAE 2011) from the existing requirement to test to all of Standard 140-2011. Sections 7 and 8 (titled “Class II Test Procedures” and “Class II Output Requirements,” respectively) are focused on testing of home energy rating systems (HERS) and as low-rise residential buildings such as homes that fall outside the scope of Standard 90.1, there is no need to test software used for Standard 90.1 against these two sections. In addition, the addendum updates the reference year for Standard 140 from 2004 to 2011.

Impact: Because this addendum is just changing the rules of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bl

Sections(s) Modified: 11. Energy Cost Budget and Appendix G. Performance Rating Method

Short Description: Provides rules for removing fan energy from efficiency metrics when modeling in ECB or Appendix G.

Discussion: Addendum 90.1-2010bl adds a methodology for removing the fan energy component of HVAC efficiency ratings when fan energy is included in that rating. This addendum is applied to Section 11, Energy Cost Budget Method, and Appendix G. In Section 11, the change is added to Section 11.3.2 and Tables 11.3.1 and 11.3.2A. In Appendix G, the change is added to Section G3.1.2.1 and Table G3.1, Part 10, HVAC Systems.

Impact: Because this addendum only impacts whole building tradeoffs, the overall impact on energy efficiency is estimated to be neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bw

Sections(s) Modified: 5. Building Envelope and 11. Energy Cost Budget Method

Short Description: Modifies orientation requirements and adds SHGC tradeoff.

Discussion: Addendum 90.1-2010bw modifies existing fenestration orientation requirements by removing the existing requirement that the area of fenestration with south orientation must be greater than or equal to both the area of fenestration with east orientation and the area of fenestration with west orientation and replaces this requirement with two new requirements that consider both the orientation and SHGC of fenestration in various orientations. The two new requirements are (in words):

a. Western oriented fenestration area must be less than one-quarter of the total fenestration area and eastern oriented fenestration must be less than one-quarter of total fenestration area.

b. Western solar aperture (area times SHGC) must less than or equal to one-quarter of the total solar aperture and eastern solar aperture must less than or equal to one-quarter of the total solar aperture.

The addendum also removes direction to use the northern orientation in the Southern Hemisphere as the southern orientation is no longer part of the requirement. The addendum also adds two new exceptions. The first new exception is for buildings where the west-oriented and east-oriented vertical fenestration area (as defined in Section 5.5.4.5) does not exceed 20% of the gross wall area for each of those façades, and SHGC on those facades is no greater than 90% of the criteria in Tables 5.5-1 through 5.5-8. The second exception is buildings in Climate Zone 8. The addendum also changes how fenestration orientation is dealt with whole building tradeoffs by using the same approach in the Energy Cost Budget Method as currently used in the Performance Rating Method, that is, simulating the building in all four cardinal orientations and then averaging the results.

Impact: The overall impact of this addendum is rated as a minor positive in terms of energy efficiency.

Addendum 90.1-2010cg

Sections(s) Modified: 11. Energy Cost Budget and Appendix G. Performance Rating Method

Short Description: Modifies the simulation requirements for modeling mandatory automatic daylighting controls as well as automatic lighting controls. Also modifies the simulation requirements for automatic lighting controls in the proposed design, beyond the minimum mandatory requirements. Table G3.2, which provided power adjustment percentages for automatic lighting controls, has been deleted and savings through automatic control devices are now required to be modeled in building simulation through schedule adjustments for the proposed design or by lighting power adjustments defined in Table 9.6.3.

Discussion: Addendum 90.1-2010cg modifies Section 11 and Appendix G to include changes that were made in Addenda 90.1-2010d, 90.1-2010x, 90.1-2010ab, and 90.1-2010ac that impact Section 11 and Appendix G. All of these changes deal with automatic lighting controls. Specifically, this addendum updates Section 11 by updating Part 6 Lighting of Table 11.3.1 to include a requirement that the proposed design simulated schedules include the impact of mandatory automatic lighting requirements in Section 9.4.1 (with an exception allowing a specific daylighting controls simulation) and that the proposed design may include other automatic lighting controls not required in Section 9.4.1. The budget building design portion of Table 11.3.1 was also modified to distinguish between mandatory and non-mandatory lighting controls in Section 9.4.1. For Appendix G, similar changes were made to Table G3.1 and in addition, Table G3.2 Power Adjustment Percentages for Automatic Lighting Controls was deleted.

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, this addendum is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ci

Sections(s) Modified: 11. Energy Cost Budget, Appendix G. Performance Rating Method, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Modifies requirements for the cooling tower fans in Chapter 11 baseline simulations, from two-speed to variable speed. A formula has been specified to calculate the condenser water design supply temperature. Similar revisions have been made to Appendix G for the cooling tower requirements. Definitions for cooling design wet-bulb temperature and evaporation design wet-bulb temperature have been added to Chapter 3.

Discussion: Addendum 90.1-2010ci modifies the definition of “cooling design wet-bulb temperature” and adds a new definition for “evaporation design wet-bulb temperature.” The addendum specifically specifies an “open circuit” cooling tower shall be simulated in footnote e of Table 11.3.2A (now Table 11.3.2-1 in Standard 90.1-2013) in Section 11. The addendum also updates the design requirements for cooling towers sizing to be based on the “evaporation design wet-bulb temperature.”

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, it is rated neutral (no impact) in terms of energy efficiency.

4.11 Changes to Section 12, Normative References

Changes made to Section 12, Normative References, during the creation of Standard 90.1-2013 are included in the technical section most appropriate to the definition. For example, addendum 90.1-2010b adds new requirements for escalators and moving walks to Section 10, Other Equipment, and adds a normative reference to ASME A17.1-2010/CSA B44-10, "Safety Code for Elevators and Escalators" (ASME/CSA 2010).

4.12 Changes to Informative Appendix E, Informative References

No changes were made solely to Informative Appendix E, Informative References, during the creation of Standard 90.1-2013.

4.13 Changes to Informative Appendix F Addenda Description Information

Informative Appendix F, Addenda Description Information, is simply a list of all addenda to Standard 90.1-2010 processed during the creation of Standard 90.1-2013. Informative Appendix F is completely replaced each time Standard 90.1 is updated.

4.14 Changes to Normative Appendix G, Performance Rating Method

A total of 20 addenda were made to Normative Appendix G, Performance Rating Method, during the creation of Standard 90.1-2013. A number of these addenda also modify Section 11, Energy Cost Budget Method, and are therefore discussed in both locations.

One major restructuring of Appendix G was that the tables in Section G3.1.1 were renumbered from Table G3.1.1A and G3.1.1B to a new format of Table G3.1.1-1 and G3.1.1-2. The tables called out in this document correspond to the new table numbers used in Standard 90.1-2013.

<u>Addendum 90.1-2010c</u>

Sections(s) Modified: Appendix G

Short Description: Adds requirements for laboratory exhaust fans to Section G3.1.1, Baseline HVAC System Type and Definition. Lab exhaust fans are required to be modeled as constant horsepower, reflecting constant volume stack discharge with outside air bypass.

Discussion: Addendum 90.1-2010c requires that lab exhaust fans be modeled as constant horsepower reflecting constant volume stack discharge with outdoor air bypass in the baseline HVAC system in Appendix G.

Impact: Given that this change is only to one of the whole building tradeoff methodologies, this addendum is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010e

Sections(s) Modified: Appendix G

Short Description: Updates language in Section G3.1, Part 5, Building Envelope, to require that existing buildings use the same envelope baseline as new buildings with the exception of fenestration area.

Discussion: Addendum 90.1-2010e modifies Appendix G of Standard 90.1 to create a consistent baseline building envelope for the Performance Rating Method. Standard 90.1-2010 specifies that the baseline building envelope of an existing building reflect the existing conditions rather than the minimum prescriptive requirements of the standard as specified for new buildings and additions. This addendum will provide more consistency in the Performance Rating Method, as all other regulated building components (e.g., mechanical and lighting systems) currently require that the baseline building model be consistent with the standard's prescriptive requirements, regardless of whether the project is new construction or modification to an existing building. With the exception of fenestration area, all other baseline conditions must reflect the standard's prescriptive requirements.

Impact: Given that this change is only to one of the whole building tradeoff methodologies, this addendum is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010f

Sections(s) Modified: Appendix G

Short Description: Modifies Section G.3.1, Building Envelope. Specifies the vertical fenestration area for calculating baseline building performance for new buildings and additions.

Discussion: Addendum 90.1-2010f establishes baseline window-to-wall areas for different building types. Prior to this addendum, the baseline building window area was equal to the proposed building window area, provided the proposed area was below the prescriptive limit (40%). This has several negative consequences. It caused the baseline energy performance to vary in response to the design window area, so that the baseline becomes a moving target. As a result, two similar buildings with very different energy uses due to differences in window area could have the same performance rating. Another outcome of the existing approach is that it does not reward projects that use an integrated design process to optimize window area to balance heating and cooling loads with daylighting energy savings. The baseline includes the same optimized window area, which has frustrated many design teams. This addendum sets the window area to a level that is average for each building type so that the proposed design will reflect the energy implications of window area.

Impact: Given that this change is only to one of the whole building tradeoff methodologies, this addendum is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010r

Sections(s) Modified: Appendix G and 12. Normative References

Short Description: Clarifies the requirements related to temperature and humidity control in Appendix G and relocates all related wording to the Schedules section of Table 2.1. Additionally, clarity is provided for modeling systems that provide occupant thermal comfort via means other than directly controlling the air dry-bulb and wet-bulb temperature (i.e., radiant cooling/heating, elevated air speed, etc.). Permits the use of ASHRAE Standard 55-2010 (ASHARE 2010a) for calculation of PMV-PPD. Also updates the normative references by including a reference to ASHRAE Standard 55-2010.

Discussion: Addendum 90.1-2010r modifies Table G3.1 in two ways: 1) Under Section 1, Design Model, Part b – moving the statement that temperature and humidity control setpoints and schedules and temperature control throttling range be the same for both the proposed and baseline design from this section to 4. Schedules; and 2) adding a new exception to Section 4, Schedule, to allow setpoints and schedules for HVAC systems that automatically provide occupant thermal comfort via means other than direct control of air dry-bulb and wet-bulb temperature to vary between the proposed and baseline design as long as equivalent levels of thermal comfort are provided via the methodologies of ASHRAE Standard 55. The addendum also adds a normative reference to ASHRAE Standard 55.

Impact: Given that this addendum impacts only one of the whole building tradeoff methodologies in Standard 90.1, the impact is rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010w

Sections(s) Modified: 11. Energy Cost Budget Method, Appendix G, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Adds definitions for on-site renewable energy and purchased energy. Clarifies the process for accounting for on-site renewable energy and purchased energy as well as calculating the annual energy costs in the ECB approach and Appendix G.

Discussion: Addendum 90.1-2010w clarifies the credit for on-site renewable energy and site recovered energy in Section 11 and Appendix G. Definitions for on-site renewable energy and purchased energy have been added along with clearer guidance on the determination of applicable credits in Section 11 and Appendix G. Credit available for tradeoffs from on-site renewable energy is limited in Section 11 to a maximum of 5% of the calculated energy-cost budget.

Impact: Given that this addendum impacts only one of the whole building tradeoff methodologies in Standard 90.1, the impact is rated as neutral (none).

Addendum 90.1-2010ag

Sections(s) Modified: Appendix G and 12. Normative References.

Short Description: Establishes a method for gaining credit in Appendix G for buildings that undergo whole building air leakage testing to demonstrate that they are air-tight.

Discussion: Addendum 90.1-2010ag revises Table G3.1 by adding a new Section b under 5. Building Envelope, that requires infiltration modeling assumptions be the same for the proposed design and baseline design, except for buildings where whole-building air leakage testing is performed, the proposed design air leakage rate is to be based on the measured value. This addendum also adds a new Section G3.1.1.4, Modeling Building Envelope Infiltration, to provide more direction for simulating building infiltration. This addendum also adds a new normative reference in ASTM E779-10, "Standard Test Method for Determining Air Leakage Rate by Fan Pressurization." As pointed out in the short description above, this allows credit for some measure of air-tightness beyond the 0.4 cfm/ft^2 assumed for the baseline design.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ah

Sections(s) Modified: Appendix G

Short Description: Sets system sizing requirements in Appendix G for humid climates based on humidity ratio instead of supply air temperature differential. Sets baseline system dehumidification requirements.

Discussion: Addendum 90.1-2010ah sets system sizing requirements for humid climates based on humidity ratios rather than temperature differences. Buildings located in humid climates may require dehumidification and reheat of supply air to maintain space dry-bulb temperatures even when ventilation requirements may be no more than local code and/or Standard 62.1-2007 (ASHRAE 2007). Appendix G baseline building design systems 3 through 8 are "single-path" airflow systems, and unless the requirements for exhaust air energy recovery (Section 6.5.6.1) are met, the baseline building design system may be required to reheat the supply airstream given the dehumidification load.

Because space dehumidification setpoints must be the same between the baseline building design and proposed design, humid climates may result in the baseline building design system having to substantially sub-cool the supply airstream and, in turn, reheat to maintain the space supply air dry-bulb setpoint. In some scenarios, this may result in considerable energy consumption for the baseline building design. The new exception b to Section G3.1.2.9.1 allows the baseline building design supply air to be sized based on the same humidity ratio difference of the proposed design. New Section G3.1.3.18 requires the baseline building design to count only 25% of the total energy used to reheat the supply airstream. The assumption is that 75% of the total energy used to reheat in the baseline building design comes from a recovered source (i.e., condenser heat recovery or exhaust air energy recovery, etc.). By comparison, Section G3.1.3.18 requires design teams to seriously consider limiting or eliminating reheat (by using dedicated outdoor air units, condenser heat recovery, or exhaust air energy recovery, etc.) in the proposed design, because the baseline building design gets 75% of its total reheat energy from a recovered source.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ai

Sections(s) Modified: Appendix G

Short Description: Modifies Appendix G to account for three prescriptive addenda that were incorporated into Standard 90.1-2010, but did not make it into Appendix G in time for publication. Updates economizer requirements to match addendum cy, establishes baseline transformer efficiency requirements to match addendum o, and establishes path A for centrifugal chiller baselines from addendum m.

Discussion: Addendum 90.1-2010ai updates Section 11 and Appendix G to be consistent with three addenda to Standard 90.1-2007. The changes to Section 11.3.2(b) and G3.1.2.1 are in response to addendum m to Standard 90.1-2007, which introduced the two paths for chiller efficiency. The new row for Table G3.1 is in response to addendum o to Standard 90.1-2007, which added new requirements for distribution transformers. The changes to Section G3.1.2.8 and Tables G3.1.2.6A, G3.1.2.6B, and 11.3.2D are in response to addendum 90.1-2007cy.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010al

Sections(s) Modified: Appendix G

Short Description: Establishes a consistent fuel source for space heating for baseline systems based on climate zone. Establishes a consistent fuel source for service water heating based on building type.

Discussion: Addendum 90.1-2010al modifies the baseline building design used in Appendix G. Prior to addendum al, in Appendix G, the choice of space heating energy source (either electricity or fossil fuel) in the proposed design determines the energy source in the baseline building design. Similarly, the choice of service water heating energy source in the proposed design determines the water heating energy source in the baseline building design. This results, for some buildings, in wide variations in baseline energy-cost budgets, depending on whether electricity or fossil fuel is specified for the proposed design. In some cases, the choice of either electricity or fossil fuel in the proposed design provides a much higher baseline energy cost budget than if the alternative energy source were used. This provides an incentive to use one energy source over the other in order to claim greater savings.

To prevent this unintended impact on the energy savings projected using Appendix G, this addendum specifies the energy source for space heating and water heating to be used in the baseline building design, regardless of the type of energy specified for space heating or water heating in the proposed design. The space heating energy source is determined by climate zone, and the water heating energy source is determined by the type of activity that is proposed for that area of the building. (Building area, rather than whole building, is used for water heating in order to accommodate mixed-use buildings.) Electric space heating is specified for the baseline building design for climate zones where electric space heating is most common (Climate Zones 1 through 3a) and fossil fuel space heating is specified in the baseline building design where it is more common (Climate Zones 3b through 8.) Similarly, building areas with low service water heating demand such as offices, where electricity is most often used for water heating, specify electric water heating for the baseline building design, and uses with high service water heating demand such as hotels, where fossil fuels are used more often for service water heating, specify fossil fuel water heating for the baseline building design.

Where fossil fuels are specified using this procedure, the baseline building energy costs will be based on natural gas costs, unless natural gas is not available at the building location, in which case propane is used for energy costs. The choices of space heating and service water heating energy sources were based on the most common energy source found for that application in the most recent (2003) DOE Energy Information Administration's Commercial Buildings Energy Consumption Survey and on current standard practice. The specification of a consistent baseline building energy budget for a particular proposed building, regardless of the energy source chosen for actual installation in the proposed building, should make energy savings determined using Appendix G more consistent and equitable.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010aw

Sections(s) Modified: 11. Energy Cost Budget, Appendix G, and 12. Normative References

Short Description: Updates the reference year for ASHRAE Standard 140 and exempts software used for ECB and Appendix G compliance from having to meet certain sections of ASHRAE Standard 140.

Discussion: Addendum 90.1-2010aw excludes testing for Sections 7 and 8 of ASHRAE Standard 140-2011 (ASHRAE 2011) from the existing requirement to test to all of Standard 140-2011. Sections 7 and 8 (titled "Class II Test Procedures" and "Class II Output Requirements," respectively) are focused on testing of HERS and as low-rise residential buildings such as homes fall outside the scope of Standard 90.1, there is no need to test software used for Standard 90.1 against these two sections. In addition, the addendum updates the reference year for Standard 140 from 2004 to 2011.

Impact: Because this addendum is just changing the rules of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ax

Sections(s) Modified: Appendix G

Short Description: Modifies Table G3.1, part 14 of Appendix G to exclude the condition that permits a building surface, shaded by an adjacent structure, to be simulated as north-facing if the simulation program is incapable of simulating shading by adjacent structures.

Discussion: Addendum 90.1-2010ax requires that all shading by adjacent structures be modeled per G3.1, part 14a.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010bl

Sections(s) Modified: 11. Energy Cost Budget and Appendix G

Short Description: Provides rules for removing fan energy from efficiency metrics when modeling in ECB or Appendix G.

Discussion: Addendum 90.1-2010bl adds a methodology for removing the fan energy component of HVAC efficiency ratings when fan energy is included in that rating. This addendum is applied to Section 11, Energy Cost Budget Method, and Appendix G. In Section 11, the change is added to Section 11.3.2 and Tables 11.3.1 and 11.3.2A. In Appendix G, the change is added to Section G3.1.2.1 and Table G3.1, Part 10, HVAC Systems.

Impact: Because this addendum only impacts whole building tradeoffs, the overall impact on energy efficiency is estimated to be neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ce

Sections(s) Modified: Appendix G

Short Description: Establishes a baseline system type for retail occupancies less than three stories in Appendix G.

Discussion: Addendum 90.1-2010ce establishes package single-zone systems as the baseline HVAC system type for all retail occupancies of two stories or fewer. Prior to this change, large low-rise retail facilities would have VAV reheat baseline systems, which are uncommon in that building type. This change sets a more realistic baseline building HVAC system.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cf

Sections(s) Modified: Appendix G

Short Description: Establishes baseline WWR in Appendix G for strip malls.

Discussion: Addendum 90.1-2010cf updates Appendix G to add a baseline WWR for strip malls. Addendum 90.1-2010f established baseline building WWRs for different building types in Appendix G. Based on limited data available at the time, a value only applicable to standalone retail buildings was established. Since that time, new data have enabled the establishment of a (WWR) for retail strip-mall buildings, which is added in this current addendum.

Impact: Because this addendum is just changing the rules of one of the whole building tradeoffs in Standard 90.1, the overall energy impact of this addendum is neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cg

Sections(s) Modified: 11. Energy Cost Budget and Appendix G

Short Description: Modifies the simulation requirements for modeling mandatory automatic daylighting controls as well as automatic lighting controls. Also modifies the simulation requirements for automatic lighting controls in the proposed design, beyond the minimum mandatory requirements. Table G3.2, which provided power adjustment percentages for automatic lighting controls, has been deleted and savings through automatic control devices are now required to be modeled in building simulation through schedule adjustments for the proposed design or by lighting power adjustments defined in Table 9.6.3.

Discussion: Addendum 90.1-2010cg modifies Section 11 and Appendix G to include changes that were made in addenda 90.1-2010d, 90.1-2010x, 90.1-2010ab, and 90.1-2010ac that impact Section 11 and Appendix G. All of these changes deal with automatic lighting controls. Specifically, this addendum updates Section 11 by updating Part 6, Lighting, of Table 11.3.1 to include a requirement that the proposed design simulated schedules include the impact of mandatory automatic lighting requirements in Section 9.4.1 (with an exception allowing a specific daylighting controls simulation) and that the proposed design may include other automatic lighting controls not required in Section 9.4.1. The budget building design portion of Table 11.3.1 was also modified to distinguish between mandatory and non-mandatory lighting controls in Section 9.4.1. For Appendix G, similar changes were made to Table G3.1 and in addition, Table G3.2, Power Adjustment Percentages for Automatic Lighting Controls, was deleted.

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ci

Sections(s) Modified: 11. Energy Cost Budget, Appendix G. Performance Rating Method, and 3. Definitions, Abbreviations, and Acronyms

Short Description: Modifies requirements for the cooling tower fans in Chapter 11 baseline simulations, from two-speed to variable speed. A formula has been specified to calculate the condenser water design supply temperature. Similar revisions have been made to Appendix G for the cooling tower requirements. Definitions for cooling design wet-bulb temperature and evaporation design wet-bulb temperature have been added to Chapter 3.

Discussion: Addendum 90.1-2010ci modifies the definition of "cooling design wet-bulb temperature" and adds a new definition for "evaporation design wet-bulb temperature." The addendum specifically specifies an "open circuit" cooling tower shall be simulated in footnote e of Table 11.3.2A (now Table 11.3.2-1 in Standard 90.1-2013) in Section 11. The addendum also updates the design requirements for cooling towers sizing to be based on the "evaporation design wet-bulb temperature."

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cj

Sections(s) Modified: Appendix G

Short Description: Creates modeling rules for computer rooms in Appendix G.

Discussion: Addendum 90.1-2010cj creates modeling rules for computer rooms in Appendix G.

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cn

Sections(s) Modified: Appendix G

Short Description: Establishes modeling rules for laboratories with 100% outdoor air in Appendix G.

Discussion: Addendum 90.1-2010cn allows laboratory designs that incorporate strategies to reduce peak airflows and minimum unoccupied airflows to document energy savings associated with reduced outdoor air volumes. Laboratory systems are often required by the rating authority or accreditation standards to be 100% outdoor air.

Currently, the standard requires ventilation rates for the baseline design to be the same as for the proposed design. Rating authorities interpret this to mean that in the case where baseline airflow is greater than in the proposed design, the baseline system is to be modeled as a recirculating air system. To provide credit to proposed design systems that have lower peak design airflow, the baseline is allowed to vary from the proposed. In addition, the current standard requires baseline minimum airflows in laboratory spaces to be the largest of 50% of zone peak airflow, the minimum outdoor airflow rate, or the airflow rate required to comply with applicable codes or accreditation standards.

Where owners install systems and controls that reduce laboratory airflows below these minimum thresholds, the baseline is required to be modeled as a recirculating system, and the proposed design is not credited with savings associated with reduced outdoor air conditioning.

Impact: Given that this addendum only makes changes to the whole building tradeoff methodology sections of Standard 90.1, it is rated neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010ct

Sections(s) Modified: Appendix G

Short Description: Identifies heated-only storage systems 9 and 10 in Appendix G as being assigned one system per thermal zone.

Discussion: Addendum 90.1-2010ct modifies Section G3.1.1, Baseline HVAC System Type and Description, to require that for systems 9 and 10 each thermal block be modeled with its own HVAC system, as opposed to requiring that each floor be modeled with a separate HVAC system.

Impact: Overall, this addendum impacts only the whole building tradeoff methodology in Appendix G and is therefore rated as neutral (no impact) in terms of energy efficiency.

Addendum 90.1-2010cv

Sections(s) Modified: Appendix G

Short Description: Establishes baseline system types in Appendix G for assembly occupancies.

Discussion: Addendum 90.1-2010cv adds two new baseline system types for public assembly building types in Table G3.1.1A (now Standard G3.1.1-1 in Standard 90.1-2013). The addendum also adds a new footnote to the table that defines public assembly building types. The addendum also adds references to the two new system types in 11 locations in Appendix G.

Impact: Overall, this addendum impacts only the whole building tradeoff methodology in Appendix G and is therefore rated as neutral (no impact) in terms of energy efficiency.

5.0 References

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Appendix A. Comparison of Building Envelope Requirements in Standard 90.1-2010 and Standard 90.1-2013

This appendix compares building envelope requirements from Standard 90.1-2010 and addendum 90.1-2010bb. The addendum version published in the 2013 Addenda Supplement to Standard 90.1-2010 (ASHRAE 2013a) contains only a complete replacement version of the building envelope requirements tables and does not identify where changes have been made. The tables below show a side-by-side comparison of the envelope requirements between 90.1-2010 and 90.1-2013 and can be used to identify specific building envelope requirements that have changed.

Abbreviations used in Opaque Envelope tables below:

2010 Requirements in 90.1-2010

bb Requirements in addendum 90.1-2010bb

Table A.1. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Non-Residential Buildings

	Climate Zone															
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
IEAD Roof[1]	0.063	0.048	0.048	0.039	0.048	0.039	0.048	0.032	0.048	0.032	0.048	0.032	0.048	0.028	0.048	0.028
Metal Building Roof	0.065	0.041	0.055	0.041	0.055	0.041	0.055	0.037	0.055	0.037	0.049	0.031	0.049	0.029	0.035	0.026
Attic Roof	0.034	0.027	0.027	0.027	0.027	0.027	0.027	0.021	0.027	0.021	0.027	0.021	0.027	0.017	0.021	0.017
Mass Wall	0.580	0.580	0.151	0.151	0.123	0.123	0.104	0.104	0.090	0.090	0.080	0.080	0.071	0.071	0.071	0.048
Metal Building Wall	0.093	0.094	0.093	0.094	0.084	0.094	0.084	0.060	0.069	0.050	0.069	0.050	0.057	0.044	0.057	0.039
Steel-Frame Wall	0.124	0.124	0.124	0.077	0.084	0.077	0.064	0.064	0.064	0.055	0.064	0.049	0.064	0.049	0.064	0.037
Wood-Frame Wall	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.064	0.064	0.051	0.051	0.051	0.051	0.051	0.036	0.032
Below Ground Wall[2]	1.140	1.140	1.140	1.140	1.140	0.119	1.140	0.119	0.119	0.119	0.119	0.092	0.119	0.063	0.119	0.063
Mass Floor	0.322	0.322	0.107	0.107	0.107	0.074	0.087	0.057	0.074	0.057	0.064	0.051	0.064	0.042	0.057	0.038
Steel-Joist Floor	0.350	0.350	0.052	0.038	0.052	0.052	0.038	0.038	0.038	0.038	0.038	0.032	0.038	0.032	0.032	0.032
Wood-Framed Floor	0.282	0.282	0.051	0.033	0.051	0.033	0.033	0.033	0.033	0.033	0.033	0.027	0.033	0.027	0.033	0.027
Unheated Slab on Grade[3]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.520	0.730	0.520	0.540	0.510	0.520	0.510	0.520	0.434
Heated Slab on Grade[3]	1.020	1.020	1.020	0.900	0.900	0.860	0.860	0.843	0.860	0.688	0.860	0.688	0.843	0.671	0.688	0.671

U-factors are expressed in Btu/h-ft^2-°F.

(1) IEAD: insulation entirely above deck.

(2) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F)

(3) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F)

Table A.2. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Residential Buildings

	Climate Zone															
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
IEAD Roof[1]	0.048	0.039	0.048	0.039	0.048	0.039	0.048	0.032	0.048	0.032	0.048	0.032	0.048	0.028	0.048	0.028
Metal Building Roof	0.065	0.041	0.055	0.041	0.055	0.041	0.055	0.037	0.055	0.037	0.049	0.029	0.049	0.029	0.035	0.026
Attic Roof	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.021	0.027	0.021	0.027	0.021	0.027	0.017	0.021	0.017
Mass Wall	0.151	0.151	0.123	0.123	0.104	0.104	0.090	0.090	0.080	0.080	0.071	0.071	0.071	0.071	0.052	0.048
Metal Building Wall	0.093	0.094	0.093	0.094	0.084	0.072	0.084	0.050	0.069	0.050	0.069	0.050	0.057	0.044	0.057	0.039
Steel-Frame Wall	0.124	0.124	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.055	0.064	0.049	0.042	0.049	0.037	0.037
Wood-Frame Wall	0.089	0.089	0.089	0.089	0.089	0.064	0.064	0.064	0.051	0.051	0.051	0.051	0.051	0.051	0.036	0.032
Below Ground Wall[2]	1.140	1.140	1.140	1.140	1.140	0.119	0.119	0.092	0.119	0.092	0.119	0.063	0.092	0.063	0.075	0.063
Mass Floor	0.322	0.322	0.087	0.087	0.087	0.074	0.074	0.051	0.064	0.051	0.057	0.051	0.051	0.042	0.051	0.038
Steel-Joist Floor	0.350	0.350	0.052	0.038	0.052	0.032	0.038	0.038	0.038	0.038	0.032	0.032	0.032	0.032	0.032	0.032
Wood-Framed Floor	0.282	0.282	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.027	0.033	0.027	0.033	0.027
Unheated Slab on Grade[3]	0.730	0.730	0.730	0.730	0.730	0.540	0.540	0.520	0.540	0.510	0.520	0.434	0.520	0.434	0.510	0.424
Heated Slab on Grade[3]	1.020	1.020	1.020	0.860	0.900	0.860	0.860	0.688	0.860	0.688	0.688	0.671	0.688	0.671	0.688	0.373

U-factors are expressed in Btu/h-ft^2-°F.

(1) IEAD: insulation entirely above deck.

(2) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F).

(3) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F).

Table A.3. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
IEAD Roof[1]	0.218	0.218	0.218	0.173	0.173	0.119	0.173	0.093	0.119	0.063	0.093	0.063	0.093	0.039	0.063	0.039
Metal Building Roof	0.167	0.115	0.097	0.096	0.097	0.096	0.097	0.082	0.083	0.082	0.072	0.060	0.072	0.037	0.065	0.037
Attic Roof	0.081	0.081	0.081	0.053	0.053	0.053	0.053	0.034	0.053	0.034	0.034	0.034	0.034	0.027	0.034	0.027
Mass Wall	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.151	0.151	0.151	0.151	0.123	0.123	0.104	0.104
Metal Building Wall	0.113	0.352	0.113	0.162	0.113	0.162	0.113	0.162	0.113	0.094	0.113	0.094	0.113	0.072	0.113	0.060
Steel-Frame Wall	0.352	0.352	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.084	0.124	0.084	0.124	0.064	0.084	0.064
Wood-Frame Wall	0.292	0.292	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.064	0.089	0.051
Below Ground Wall[2]	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	0.119	1.140	0.119	1.140	0.119
Mass Floor	0.322	0.322	0.322	0.322	0.322	0.137	0.137	0.107	0.137	0.107	0.137	0.087	0.107	0.074	0.087	0.064
Steel-Joist Floor	0.350	0.350	0.069	0.069	0.069	0.052	0.069	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
Wood-Framed Floor	0.282	0.282	0.066	0.066	0.066	0.051	0.066	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.033	0.033
Unheated Slab on Grade[3]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.740	0.540
Heated Slab on Grade[3]	1.020	1.020	1.020	1.020	1.020	1.020	1.020	0.900	1.020	0.900	1.020	0.860	0.900	0.860	0.900	0.860

U-factors are expressed in Btu/h-ft^2-°F.

(1) IEAD: insulation entirely above deck.

(2) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F).

(3) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F).

Table A.4. Addendum 90.1-2010bb Changes to Fenestration Requirements for Nonresidential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.50	0.75	0.40	0.65	0.35	0.40	0.35	0.35	0.32	0.35	0.32	0.35	0.32	0.35	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	0.57	0.70	0.57	0.60	0.50	0.50	0.42	0.45	0.42	0.45	0.42	0.40	0.38	0.40	0.38
Metal Framing (entrance door)	1.20	1.10	1.10	0.83	0.90	0.77	0.85	0.77	0.80	0.77	0.80	0.77	0.80	0.77	0.8	0.77
Metal Framing (all other)/ Operable Metal Framing	1.20	0.65	0.75	0.65	0.65	0.60	0.55	0.50	0.55	0.50	0.55	0.50	0.45	0.40	0.45	0.40
Vertical Fenestration, SHGC																
All framing types	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	0.45	0.45

Table A.5. Addendum 90.1-2010bb Changes to Fenestration Requirements for Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.50	0.75	0.40	0.65	0.35	0.40	0.35	0.35	0.32	0.35	0.32	0.35	0.32	0.35	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	0.57	0.70	0.57	0.60	0.50	0.50	0.42	0.45	0.42	0.45	0.42	0.40	0.38	0.40	0.38
Metal Framing (entrance door)	1.20	1.10	1.10	0.83	0.90	0.77	0.85	0.68	0.80	0.68	0.80	0.68	0.80	0.68	0.80	0.68
Metal Framing (all other)/ Operable Metal Framing	1.20	0.65	0.75	0.65	0.65	0.6	0.55	0.50	0.55	0.50	0.55	0.50	0.45	0.40	0.45	0.40
Vertical Fenestration, SHGC																
All framing types	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	1.00	0.45	1.00	0.45

Table A.6. Addendum 90.1-2010bb Changes to Fenestration Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.93	1.20	0.93	1.20	0.87	1.20	0.51	1.20	0.45	0.65	0.45	0.65	0.32	0.65	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.73	1.20	0.62	0.60	0.51	0.60	0.38	0.60	0.38
Metal Framing (entrance door)	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.81	1.20	0.70	0.90	0.59	0.90	0.44	0.90	0.44
Metal Framing (all other)/ Operable Metal Framing	1.20	1.10	1.20	0.83	1.20	0.77	1.20	0.77	1.20	0.77	0.65	0.77	0.65	0.77	0.65	0.77
Vertical Fenestration, SHGC																
All framing types	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Table A.7. Addendum 90.1-2010bb Changes to Skylight Requirements for Non-Residential Buildings

	Climate Zone															
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
Skylights, U-factor, 0-3% skylight area[1]																
Skylights with curb – glass	1.98	0.75	1.98	0.65	1.17	0.55	1.17	0.50	1.17	0.50	1.17	0.50	1.17	0.50	0.98	0.50
Skylights with curb – plastic	1.90	0.75	1.90	0.65	1.30	0.55	1.30	0.50	1.10	0.50	0.87	0.50	0.87	0.50	0.61	0.50
Skylights without curb – all	1.36	0.75	1.36	0.65	0.69	0.55	0.69	0.50	0.69	0.50	0.69	0.50	0.69	0.50	0.58	0.50
Skylights, SHGC, 0-2% skylight area																
Skylights with curb – glass	0.36	0.35	0.36	0.35	0.39	0.35	0.49	0.40	0.49	0.40	0.49	0.40	0.68	1.00	1.00	1.00
Skylights with curb – plastic	0.34	0.35	0.39	0.35	0.65	0.35	0.65	0.40	0.77	0.40	0.71	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.36	0.35	0.36	0.35	0.39	0.35	0.49	0.40	0.49	0.40	0.49	0.40	0.68	1.00	1.00	1.00
Skylights, SHGC, 2-3% skylight area[1]																
Skylights with curb – glass	0.19	0.35	0.19	0.35	0.19	0.35	0.39	0.35	0.39	0.35	0.49	0.35	0.64	0.35	1.00	0.35
Skylights with curb – plastic	0.27	0.35	0.34	0.35	0.34	0.35	0.34	0.35	0.62	0.35	0.58	0.35	0.71	0.35	1.00	0.35
Skylights without curb – all	0.19	0.35	0.19	0.35	0.19	0.35	0.39	0.35	0.39	0.35	0.49	0.35	0.64	0.35	1.00	0.35

(1) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

Table A.8. Addendum 90.1-2010bb Changes to Skylight Requirements for Residential Buildings

	Climate Zone															
	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**	
	2010	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**	**2010**	**bb**
Skylights, U-factor, 0-3% skylight area[1]																
Skylights with curb – glass	1.98	0.75	1.98	0.65	1.17	0.55	1.17	0.50	1.17	0.50	0.98	0.50	1.17	0.50	0.98	0.50
Skylights with curb – plastic	1.90	0.75	1.90	0.65	1.30	0.55	1.30	0.50	1.10	0.50	0.74	0.50	0.61	0.50	0.61	0.50
Skylights without curb – all	1.36	0.75	1.36	0.65	0.69	0.55	0.69	0.50	0.69	0.50	0.58	0.50	0.69	0.50	0.58	0.50
Skylights, SHGC, 0-2% skylight area																
Skylights with curb – glass	0.19	0.35	0.19	0.35	0.36	0.35	0.36	0.40	0.49	0.40	0.46	0.40	0.64	1.00	1.00	1.00
Skylights with curb – plastic	0.27	0.35	0.27	0.35	0.27	0.35	0.62	0.40	0.77	0.40	0.65	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.19	0.35	0.19	0.35	0.36	0.35	0.36	0.40	0.49	0.40	0.49	0.40	0.64	1.00	1.00	1.00
Skylights, SHGC, 2-3% skylight area[1]																
Skylights with curb – glass	0.16	0.35	0.19	0.35	0.19	0.35	0.19	0.40	0.39	0.40	0.36	0.40	0.64	1.00	1.00	1.00
Skylights with curb – plastic	0.27	0.35	0.27	0.35	0.27	0.35	0.27	0.40	0.62	0.40	0.55	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.19	0.35	0.19	0.35	0.19	0.35	0.19	0.40	0.39	0.40	0.49	0.40	0.64	1.00	1.00	1.00

(1) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

Table A.9. Addendum 90.1-2010bb Changes to Skylight Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Skylights, U-factor, 0-3% skylight area[1]																
Skylights with curb - glass	1.98	1.80	1.98	1.80	1.98	1.70	1.98	1.15	1.98	0.98	1.98	0.85	1.98	0.85	1.30	0.85
Skylights with curb - plastic	1.90	1.80	1.90	1.80	1.90	1.70	1.90	1.15	1.90	0.98	1.90	0.85	1.90	0.85	1.10	0.85
Skylights without curb - all	1.36	1.80	1.36	1.80	1.36	1.70	1.36	1.15	1.36	0.98	1.36	0.85	1.36	0.85	0.81	0.85
Skylights, SHGC, 0-2% skylight area																
Skylights with curb - glass	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights with curb - plastic	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights without curb - all	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights, SHGC, 2-3% skylight area[1]																
Skylights with curb - glass	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights with curb - plastic	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights without curb - all	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

(1) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

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Acronyms

AEO	Annual Energy Outlook
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu	British thermal unit(s)
CBECS	Commercial Building Energy Consumption Survey
COP	coefficient of performance
CRAC	computer room air conditioner
DCV	demand controlled ventilation
DDC	direct digital control
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
ECB	Energy Cost Budget
ECI	energy cost intensity
ECPA	Energy Conservation and Production Act
ERR	enthalpy recovery ratio
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERV	energy recovery ventilator
EUI	energy use intensity
ft^2	square foot(feet)
GWP	Global Warming Potential
HRV	heat recovery ventilator
HVAC	heating, ventilating, and air conditioning
IAM	integrated assessment model
IECC	International Energy Conservation Code
IEER	integrated energy efficiency ratio
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
kft^2	thousand square feet
kWh	thousand Watt-hour
LPD	lighting power density
PBA	principal building activity
PCI	Performance Cost Index
PRM	Performance Rating Method
PNNL	Pacific Northwest National Laboratory
SAT	supply air temperature

SCOP	seasonal coefficient of performance
SC-CO_2	social cost of carbon
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
U.S.C	United State Code
VAV	variable air volume
VRF	variable-refrigerant-flow
VT	visible transmittance
yr	year(s)

Executive Summary

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for DOE to review consensus-based building energy conservation standards. (42 U.S.C. 6831 et seq.) Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA[1] Standard 90.1-1989 (Standard 90.1-1989 or 1989 edition), or any successor to that code, is revised, the Secretary of Energy (Secretary) must make a determination, not later than 12 months after such a revision, whether the revised code would improve energy efficiency in commercial buildings, and must publish a notice of such determination in the *Federal Register*. (42 U.S.C. 6833(b)(2)(A))

Standard 90.1 is developed under ANSI-approved consensus procedures[2], and is under continuous maintenance by a Standing Standard Project Committee (commonly referenced as SSPC 90.1). ASHRAE has an established program for regular publication of addenda, or revisions, including procedures for timely, documented, consensus action on requested changes to the Standard.[3] Standard 90.1-2019 was published in October 2019, triggering the statutorily required DOE review process.

To meet the statutory requirement, DOE conducted an analysis to quantify the expected energy savings associated with Standard 90.1-2019. This report documents the methodology used to conduct the analysis.

Based on the analysis, DOE has preliminarily determined that the 2019 edition of the ANSI/ASHRAE/IES Standard 90.1 would improve overall energy efficiency in buildings subject to the code (compared to the 2016 edition of Standard 90.1).

Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analyses and determinations, is designed to evaluate the impact of the updated Standard on new construction across the U.S., and is based on a combination of *qualitative* and *quantitative* assessments:

- **Qualitative**: The first phase of analysis was a comparative review of the textual requirements of the Standard, examining specific changes (known as "addenda") made between Standard 90.1-2019 and the previous 2016 edition. ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard and then bundles them together to form the next published edition. Addenda with direct impact on energy use were identified and their anticipated impact on energy use was determined.
- **Quantitative**: The second phase of analysis examined the impact of addenda having a direct impact on energy use. The quantitative phase uses whole-building energy simulation and relies upon the established DOE methodology for energy analysis, which is based on 16 representative building types across all U.S. climate zones, as defined by Standard 90.1. Energy use intensities (EUIs) by fuel type and by end-use were developed for each building type and weighted by the relative square footage of construction to estimate the difference between the aggregated national energy use under Standard 90.1-2016, which serves as the baseline, and Standard 90.1-2019.

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IES – Illuminating Engineering Society (previously identified as the Illuminating Engineering Society of North America, IESNA)
[2] See https://www.ansi.org/about_ansi/overview/
3 More information on the development of ANSI/ASHRAE/IES Standard 90.1 is available at http://sspc901.ashraepcs.org/index.php

Results

In creating Standard 90.1-2019, ASHRAE published 88 addenda in total, of which:

- 29 are expected to *decrease* energy use (i.e., increased energy savings);
- none are expected to *increase* energy use (i.e., decreased energy savings), and;
- 59 are expected to have *no direct impact* on energy savings (such as administrative or clarifications or changes to alternative compliance paths).[1]

New commercial buildings meeting the requirements of Standard 90.1-2019 that were analyzed in the quantitative analysis exhibit national savings (compared to Standard 90.1-2016) of approximately the following:

- 4.7 percent *site* energy savings;
- 4.3 percent *source* energy savings;
- 4.3 percent *energy cost* savings, and;
- 4.2 percent *carbon emissions*.

The quantitative analysis relies upon prototype buildings reflecting a mix of typical U.S. building types and construction practices. In creating its prototypes, DOE leverages recent U.S. construction data that is mapped to the commercial building types defined by the Energy Information Administration (EIA) and adapted for use by Standard 90.1. In combination with resulting building type weighting factors, the prototypes represent approximately 75 percent of the total square footage of new commercial construction (Lei et al. 2020).

Site and source EUIs, energy cost indices (ECIs), carbon emissions, and SC-CO_2, which vary by building type, are shown in Table ES.1 and Table ES.2 for Standard 90.1-2016 and Standard 90.1-2019, respectively. Percentage savings aggregated at the national level are shown in Figure ES.1 and Table ES.3, and analogous tables aggregated by climate zone are included in Section 4.2.

[1] Addenda characterized as having *no direct impact* on energy savings are detailed in Appendix A:

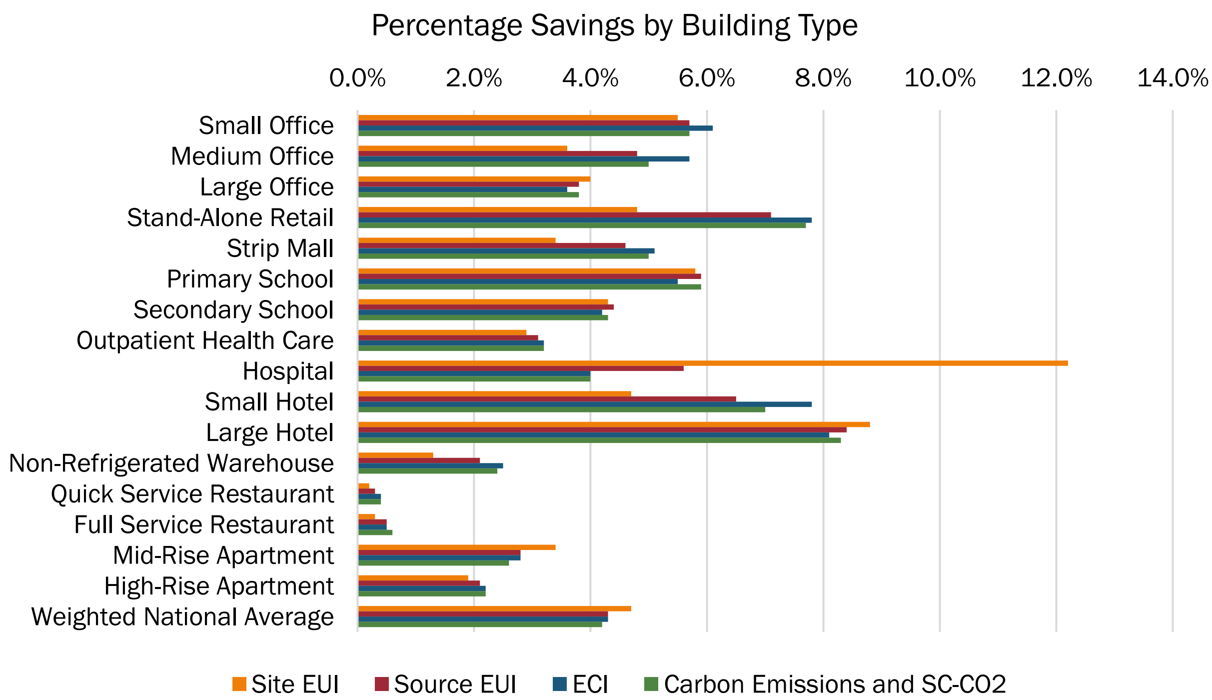

Figure ES.1. Percentage Savings by Building Type from 90.1-2016 to 90.1-2019

Table ES.1. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI (\$/ft^2-yr)	Carbon Emission (tons/kft^2-yr)	SC-CO_2 (\$/kft^2-yr)
Office	Small Office	3.8%	27.1	77.6	$0.82	5.5	$275
	Medium Office	5.0%	30.8	84.2	$0.88	5.9	$296
	Large Office	3.9%	55.4	156.9	$1.65	11.1	$555
Retail	Stand-Alone Retail	10.9%	48.4	114.4	$1.15	7.8	$389
	Strip Mall	3.7%	52.8	133.8	$1.37	9.2	$462
Education	Primary School	4.8%	43.4	107.4	$1.09	7.4	$369
	Secondary School	10.9%	37.2	94.0	$0.96	6.5	$325
Healthcare	Outpatient Health Care	3.4%	107.6	276.3	$2.84	19.1	$958
	Hospital	4.5%	120.0	276.8	$2.77	18.7	$936
Lodging	Small Hotel	1.6%	54.8	118.0	$1.16	7.8	$392
	Large Hotel	4.2%	83.1	177.1	$1.73	11.7	$586
Warehouse	Non-Refrigerated Warehouse	18.6%	15.7	33.2	$0.32	2.2	$110
Food Service	Quick Service Restaurant	0.3%	493.4	863.7	$7.87	53.7	$2,689
	Full Service Restaurant	1.0%	336.5	649.8	$6.14	41.7	$2,090
Apartment	Mid-Rise Apartment	13.7%	37.8	104.4	$1.09	7.3	$367
	High-Rise Apartment	9.6%	41.3	92.0	$0.91	6.2	$308
National		100%	48.6	116.0	$1.17	7.9	$395

Table ES.2. Estimated Energy Use Intensity by Building Type – Standard 90.1-2019

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI (\$/ft^2-yr)	Carbon Emission (tons/kft^2-yr)	SC-CO_2 (\$/kft^2-yr)
Office	Small Office	3.8%	25.6	73.2	$0.77	5.2	$259
	Medium Office	5.0%	29.7	80.2	$0.83	5.6	$281
	Large Office	3.9%	53.2	151.0	$1.59	10.7	$534
Retail	Stand-Alone Retail	10.9%	46.1	106.3	$1.06	7.2	$359
	Strip Mall	3.7%	51.0	127.6	$1.30	8.8	$440
Education	Primary School	4.8%	40.9	101.1	$1.03	6.9	$348
	Secondary School	10.9%	35.6	89.9	$0.92	6.2	$311
Healthcare	Outpatient Health Care	3.4%	104.5	267.7	$2.75	18.5	$927
	Hospital	4.5%	105.4	261.2	$2.66	17.9	$898
Lodging	Small Hotel	1.6%	52.2	110.3	$1.07	7.3	$364
	Large Hotel	4.2%	75.8	162.2	$1.59	10.7	$538
Warehouse	Non-Refrigerated Warehouse	18.6%	15.5	32.5	$0.32	2.1	$107
Food Service	Quick Service Restaurant	0.3%	492.5	860.9	$7.84	53.5	$2,679
	Full Service Restaurant	1.0%	335.5	646.6	$6.11	41.5	$2,079
Apartment	Mid-Rise Apartment	13.7%	36.5	101.5	$1.06	7.1	$358
	High-Rise Apartment	9.6%	40.5	90.1	$0.89	6.0	$302
National		100%	46.3	111.0	$1.12	7.6	$379

Table ES.3. Estimated Percent Energy Savings between 2016 and 2019 Editions of Standard 90.1 – by Building Type

Building Type	Prototype Building	Floor Area Weight (%)	Savings (%) Site EUI	Source EUI	ECI	Carbon Emissions & SC-CO_2
Office	Small Office	3.8%	5.5%	5.7%	6.1%	5.7%
	Medium Office	5.0%	3.6%	4.8%	5.7%	5.0%
	Large Office	3.9%	4.0%	3.8%	3.6%	3.8%
Retail	Stand-Alone Retail	10.9%	4.8%	7.1%	7.8%	7.7%
	Strip Mall	3.7%	3.4%	4.6%	5.1%	5.0%
Education	Primary School	4.8%	5.8%	5.9%	5.5%	5.9%
	Secondary School	10.9%	4.3%	4.4%	4.2%	4.3%
Healthcare	Outpatient Health Care	3.4%	2.9%	3.1%	3.2%	3.2%
	Hospital*	4.5%	12.2%	5.6%	4.0%	4.0%
Lodging	Small Hotel	1.6%	4.7%	6.5%	7.8%	7.0%
	Large Hotel	4.2%	8.8%	8.4%	8.1%	8.3%
Warehouse	Non-Refrigerated Warehouse	18.6%	1.3%	2.1%	2.5%	2.4%
Food Service	Quick Service Restaurant	0.3%	0.2%	0.3%	0.4%	0.4%
	Full Service Restaurant	1.0%	0.3%	0.5%	0.5%	0.6%
Apartment	Mid-Rise Apartment	13.7%	3.4%	2.8%	2.8%	2.6%
	High-Rise Apartment	9.6%	1.9%	2.1%	2.2%	2.2%
National		100%	4.7%	4.3%	4.3%	4.2%

*See Section 4.2 for discussion of Hospital site EUI savings

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1. Introduction

ANSI/ASHRAE/IES[1] Standard 90.1 is recognized by the U.S. Congress as the national model energy code for commercial buildings under the Energy Conservation and Production Act (ECPA), as amended. (42 U.S.C 6833) With each new edition of Standard 90.1, Section 304(b) of ECPA directs the Secretary of Energy (Secretary) to make a *determination* as to whether the update would improve energy efficiency in commercial buildings. Standard 90.1 is developed under ANSI-approved consensus procedures[2] and is under continuous maintenance by a Standing Standard Project Committee (commonly referenced as SSPC 90.1). ASHRAE has an established program for regular publication of addenda, or revisions, including procedures for timely, documented, consensus action on requested changes to the Standard.[3] Standard 90.1-2019 (ASHRAE 2019), the most recent edition, was published in October 2019, triggering the statutorily required U.S. Department of Energy (DOE) review and determination process. A notice of the determination must be published in the Federal Register not later than 12 months after such revision. (42 U.S.C. 6833 (b)(2)(A)) Within two years of publication of the determination, each State is required to certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency with respect to the revised or successor code and to include in its certification, a demonstration that the provisions of its commercial building code, regarding energy efficiency, meet or exceed the revised Standard. (42 U.S.C. 6833(b)(2)(B)(i))

On February 27, 2018, DOE issued an affirmative determination of energy savings for Standard 90.1-2016 (DOE 2017), which concluded that it would achieve greater overall energy efficiency in commercial buildings required to meet the Standard than the previous edition, Standard 90.1-2013 (83 FR 8463). Through this determination, Standard 90.1-2016 became the national model energy code for commercial buildings. Consequently, and consistent with previous determinations, it also then represents the baseline to which future changes are compared, including the current review of Standard 90.1-2019. In performing its determination, DOE recognizes that not all states adopt the national model energy code directly, and many states adopt and update their codes at different rates. Instead of adopting Standard 90.1 directly, many states adopt the International Energy Conservation Code (IECC), which includes the option to comply with Standard 90.1 by reference (ICC 2018). Separately, the DOE Building Energy Codes Program also provides technical assistance supporting states implementing building energy codes, including analysis to quantify state code impacts, tracking the status of state code adoption, and developing a suite of tools to assist states and industry stakeholders in demonstrating compliance with their codes (DOE 2020).

To fulfill its statutory directive, DOE analyzed Standard 90.1-2019 to understand its overall impact on energy efficiency in commercial buildings required to meet the Standard. Section 2 of this report summarizes specific changes (known as 'addenda') made between Standard 90.1-2019 and the previous 2016 edition; Section 3 documents the qualitative and quantitative analysis methodology; Section 4 presents the analysis results. In addition, Appendix A discusses addenda not included in the quantitative analysis. Appendix A also details the modeling strategies for individual addenda included in the quantitative analysis.

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IES – Illuminating Engineering Society (previously identified as the Illuminating Engineering Society of North America, IESNA)

[2] See ANSI Essential Requirements (updated January 2020) at https://share.ansi.org/Shared%20Documents/Standards%20Activities/American%20National%20Standards/Procedures,%20Guides,%20and%20Forms/2020_ANSI_Essential_Requirements.pdf

[3] More information on the development of ANSI/ASHRAE/IES Standard 90.1 is available at http://sspc901.ashraepcs.org/index.php

1.1 Compliance with Standard 90.1

Standard 90.1-2019 includes several paths for compliance in order to provide flexibility to users of the Standard. The prescriptive path, which is widely considered the most traditional, establishes criteria for energy-related characteristics of individual building components, such as minimum insulation levels, maximum lighting power, and controls for heating, ventilating, and air conditioning (HVAC) systems. Some of those requirements are considered "mandatory," meaning that they must be met even when one of the other optional paths is utilized (e.g., performance path). The other optional paths are further described below.

In addition to the prescriptive path, Standard 90.1 includes two optional whole building performance paths. The first, known as the *Energy Cost Budget* (ECB) method, provides flexibility in allowing a designer to "trade-off" compliance. This effectively allows a designer to not meet a given prescriptive requirement if the impact on energy cost is offset by exceeding other prescriptive requirements, as demonstrated through established energy modeling protocols. A building is deemed in compliance when the annual energy cost of the proposed design is no greater than the annual energy cost of the reference building design (baseline). In addition, Standard 90.1-2019 includes a second performance approach, the *Performance Rating Method* (PRM), often referred to by its location in the Standard, Appendix G. PRM is similar to ECB except that it uses a stable baseline that does not increase in stringency with each new edition of the Standard, target building performance factors which must be achieved on a whole-building basis to demonstrate compliance, and it allows credit for design features not credited in ECB. The qualitative assessment in this analysis includes addenda impacting all three paths, and the quantitative analyzes the prescriptive path only. More details are provided in Section 3.

2. Summary of Addenda Included in Standard 90.1-2019

ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard and then bundles them together to form the next published edition. In creating the 2019 edition, ASHRAE published 88 addenda in total (listed in Appendix I of Standard 90.1-2019). Table 2.1 shows the number of addenda included in Standard 90.1-2019 grouped into the primary sections of the Standard they impact. When an addendum impacts multiple sections, it is counted only once in this table towards the section that receives the most substantial impacts.

Table 2.1. Number of Addenda affecting Various Sections in Standard 90.1-2019

Section of 90.1-2019	Number of Addenda
5. Building Envelope	9
6. Heating, Ventilating, and Air Conditioning	32
7. Service Water Heating	1
8. Power	0
9. Lighting	10
10. Other Equipment	1
Performance Compliance (including Sections 4.2.1.1, 11 and Appendices C and G)	23
Others	12
Total	88

More broadly, DOE characterized the individual addenda into three categories to help guide the analysis:

1. are clarifications, administrative, or update references to other documents;
2. modify the prescriptive and mandatory design and construction requirements for the building envelope, HVAC, service water heating (SWH), power, lighting, and other equipment sections of the Standard; or
3. modify the performance path options for compliance (e.g., the ECB, building envelope trade-off option, and PRM sections of Standard 90.1).

While DOE reviews all addenda from a given code cycle, performing a qualitative review to characterize the expect impacts of each, category #2 above—changes which affect the mandatory and prescriptive provisions of the code—represents the subset of addenda which ultimately become the primary focal point of the energy savings analysis. This is discussed further in the following section.

3. Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analyses and determinations, evaluates the expected impact of the updated Standard on new construction, and is based on a combination of qualitative and quantitative assessments.

3.1 Overview

The *qualitative* phase of the analysis made initial assessments as to whether an individual addendum decreased energy use, increased energy use, or did not affect energy use in a direct manner. The *quantitative* phase then used whole-building energy modeling and simulation to quantify the impact of the collection of addenda on overall energy use. The following steps provide a general overview of the process:

Qualitative Analysis:

1. Determine whether each addendum is applicable to the *prescriptive* or *mandatory* requirements of Standard 90.1-2019.

2. Determine whether each addendum that is applicable to the prescriptive path directly impacts energy use.

3. Of the addenda that directly impact energy use, determine whether they increase or decrease energy use.

Quantitative Analysis:

4. Of the addenda that directly impact energy use, determine those that can be reasonably quantified through energy modeling and simulation analysis.

5. Calculate whole-building results and quantify the national impact based on energy use of the addenda in step 4.

Additional detail on each phase of the analysis is provided in Sections 3.2 and 3.3.

3.2 Qualitative Analysis

Expanding upon the steps presented in the previous section, the first and second steps of the qualitative analysis are used to filter out addenda that were deemed to not directly impact energy use (within the context of this analysis). Addenda were excluded if they met either of the following criteria:

1. The addenda are not applicable to the *prescriptive* and *mandatory* requirements of the Standard, meaning they only applied to the performance paths in Standard 90.1: Section 11 (Energy Cost Budget Method), Appendix C (Methodology for Building Envelope Trade-off Option), and Appendix G (Performance Rating Method). The performance paths represent optional alternatives to the prescriptive path, and generally intended to align with the prescriptive path. As the stringency of the prescriptive path is increased, the performance path rules and targets are typically updated to mirror those changes. Therefore, the use of the prescriptive and mandatory requirements effectively represents changes to the entire Standard. Additionally, the purpose of the optional performance paths is to provide design flexibility, which occurs by allowing an almost limitless number of trade-off combinations that comply with the Standard. Analytically, it is not practical or possible to model all these combinations in a manner which can be aggregated to align with the purpose of a national energy savings determination.

2. The addenda affect the prescriptive path but had no impact on energy use, an undetermined impact within the scope of the analysis, or cannot be reasonably quantified through established and accepted methods of energy modeling and simulation analysis. Addenda with no impact include administrative changes or clarifications, changes to rating methods or categorization of equipment (as opposed to required efficiency levels), changes to optional alternatives, exceptions, updates of references to other documents, and text changes that are intended to improve the general usability of Standard 90.1. Addenda with undetermined impact include those related to commissioning and functional testing requirements, and to those whose impact on energy is dependent on site-specific conditions (such as shading from trees or its neighboring buildings). Changes with impacts, which do not become effective within three years from the publication of Standard 90.1-2019 (i.e., until a cutoff date of December 31, 2022), are also considered as having no impact (within the context of this analysis).

The addenda that were considered to not have a direct impact on energy use, as described above, are compiled in Appendix A. The remaining addenda were carried to the next step in the qualitative analysis, which was to make a determination of the anticipated impact on energy use (i.e., whether the addendum will decrease or increase energy use). Section 4.1 presents the results of the qualitative analysis.

3.3 Quantitative Analysis

The quantitative analysis builds on established methods to assess the energy performance of new editions of Standard 90.1. As described in the previous section, whole-building energy models were used to quantify the impact of addenda on energy use. Individual building models were created to represent each unique combination of the mandatory and prescriptive requirements for Standard 90.1-2016 for each of 16 prototype building types in each of 16 climate zones. Each of these 'compliant' models was then duplicated, with the second version amended only to incorporate the new requirements of 90.1-2019. Additional details of the implementation into the prototype building models for each of the 17 addenda are provided in Appendix B:.

The models were simulated using *EnergyPlus Version 9.0* (DOE 2018). Those addenda that were not captured through the quantitative analysis were filtered out and are labeled as such in Table 4.1 in Section 4.1. Addenda were not included in the quantitative analysis when they met one of the following criteria:

1. The addenda impact features are not representative of typical building designs. As explained in Section 3.3.1, the purpose of the prototype models is to represent common design features found in each building type in the United States. Therefore, there are less common features that are not incorporated in the prototypes, such as series energy recovery, swimming pools, exterior lighting (except for uncovered parking, building entrances and exits, and façade lighting that is typically linked with the building), parking garages, and so on. Addenda affecting these features of buildings were not captured via the prototypes in order to preserve representation of the typical building stock.

2. The addenda adopt known standard practices. The systems and their configuration in the prototype models are based on standard practice that has been widely adopted in the United States. When an addendum is to fix a loophole for an uncommon design practice, the uncommon design is not modeled in the prototypes and thus, has no affect within the quantitative analysis.

3. The addenda relate to verification or commissioning. Addenda related to verification, commissioning, and fault-detection generate savings only when there is imperfect operation. Because the models and simulation assume ideal operation, including these addenda would have no impact.

4. The addenda incorporate federal minimum equipment standards. These addenda mirror update to

federal equipment standards and will improve efficiency even in the absence of their replication in Standard 90.1-2019, and therefore, they were left out of the quantitative analysis. Additional discussion is provided in Section 3.3.4.

3.3.1 Building Types and Model Prototypes

The 16 prototype buildings (DOE and PNNL 2020) used in the quantitative analysis largely correspond to a classification scheme established in the 2003 DOE/Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) (EIA 2003). CBECS separates the commercial sector into 29 categories and 51 subcategories using the two variables "principal building activity" (PBA) and "detailed principal building activity" (PBAplus, for more specific activities). DOE relied heavily on these classifications in determining the buildings to be represented by the set of prototype building models. By mapping CBECS observations to each prototype building, DOE also used the CBECS building characteristics data to develop prototypes that could best represent the building stock.

The exception to this is multi-family housing buildings that are not included in CBECS but are covered by Standard 90.1 if more than three stories tall. Consequently, DOE developed mid-rise and high-rise multi-family prototype buildings to add to the 14 prototype buildings identified through the review of CBECS (Thornton et al. 2011).

Table 3.1 lists the broad building category, the prototype building, floor area of the prototype building, and its construction weight relative to the other building types. DOE developed three sizes and form factors characteristic of small, medium, and large office buildings to reflect the wide variation in office building design. Similarly, retail, education, healthcare, lodging, food service, and apartments have two representative prototypes each.

The 16 prototype buildings are representative of the characteristics of new construction in the United States. It is not feasible to simulate all building types and possible permutations of building design. Further, data are simply not available to correctly weight each possible permutation in each U.S. climate zone as a fraction of the national building construction mix. Hence, the quantitative analysis focuses on the use of prototype buildings that reflect a representative mix of typical construction practices. Together with the construction weighting factors (described in Section 3.3.3), the 16 prototypes represent approximately 75% of the total square footage of new commercial construction, including multi-family buildings more than three stories tall, consistent with the scope of Standard 90.1 (Lei et al. 2020).

Table 3.1. Commercial Prototype Building Models

Building Type	Prototype Building	Floor Area (ft^2)	Floor Area (%)
Office	Small Office	5,502	3.8%
	Medium Office	53,628	5.0%
	Large Office	498,588	3.9%
Retail	Stand-Alone Retail	24,692	10.9%
	Strip Mall	22,500	3.7%
Education	Primary School	73,959	4.8%
	Secondary School	210,887	10.9%
Healthcare	Outpatient Health Care	40,946	3.4%
	Hospital	241,501	4.5%
Lodging	Small Hotel	43,202	1.6%
	Large Hotel	122,120	4.2%
Warehouse	Non-Refrigerated Warehouse	52,045	18.6%
Food Service	Quick Service Restaurant	2,501	0.3%
	Full Service Restaurant	5,502	1.0%
Apartment	Mid-Rise Apartment	33,741	13.7%
	High-Rise Apartment	84,360	9.6%
Total			100%

3.3.2 Climate Zones

Building models were analyzed in standardized climate zones described in ASHRAE Standard 169-2013 (ASHRAE 2013). Standard 169-2013 includes nine thermal zones and three moisture regimes. The U.S. climate zones and moisture regimes are shown in Figure 1.

For this analysis, a specific climate location (city) was selected as a representative of each of the 16 climate/moisture zones found in the United States. These are also consistent with representative cities approved by the SSPC 90.1 for setting the criteria for 90.1-2019.

The 16 cities used in the current analysis are as follows:

- 1A: Honolulu, Hawaii (very hot, humid)
- 2A: Tampa, Florida (hot, humid)
- 2B: Tucson, Arizona (hot, dry)
- 3A: Atlanta, Georgia (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Diego, California (warm, marine)
- 4A: New York, New York (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Seattle, Washington (mixed, marine)
- 5A: Buffalo, NY (cool, humid)
- 5B: Denver, Colorado (cool, dry)
- 5C: Port Angeles, Washington (cool, marine)
- 6A: Rochester, Minnesota (cold, humid)
- 6B: Great Falls, Montana (cold, dry)
- 7: International Falls, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic/arctic)

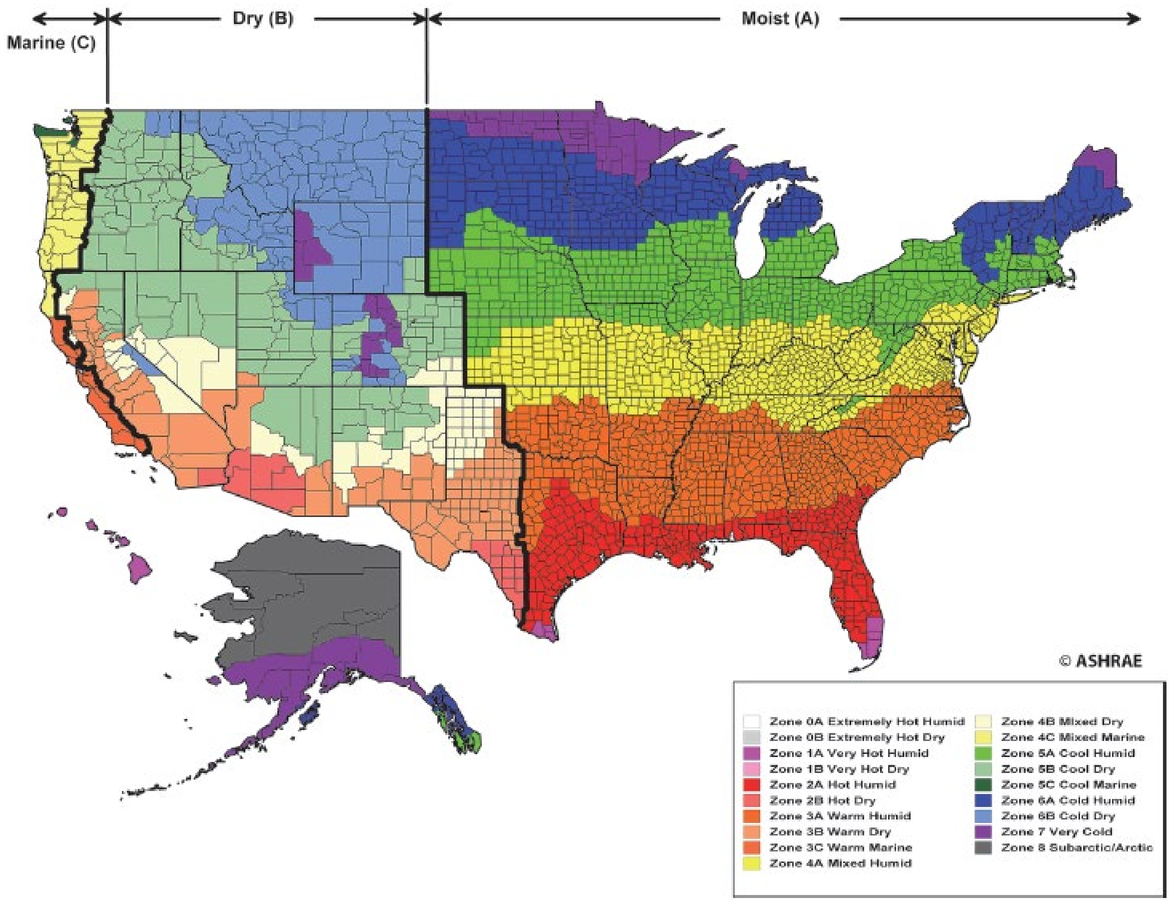

Figure 1. United States Climate Zone Map

3.3.3 Development of Weighting Factors

Weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level were developed from construction data purchased from McGraw Hill. Details of the development are further discussed in a PNNL report (Lei et al. 2020). New construction weights were determined for each building type in each climate zone based on the county-climate zone mapping from ASHRAE Standard 169-2013. Table 3.2 lists the resulting weighting factors by climate and by prototype building used in the analysis. These data are used to develop the relative fractions of new construction floor space represented by prototype building and within the 16 climate zones.

Using the energy use intensity (EUI) statistics from each building simulation and the corresponding relative fractions of new construction floor space, DOE developed floor-space-weighted national EUI statistics by energy type for each building type and standard edition. DOE then summed these energy type-specific EUI estimates to obtain the national site energy EUI by building type and standard edition. DOE also applied national data for average energy prices, average source energy conversion rates to the energy type-specific EUI data, average carbon emission factors, and social cost of carbon (SC-CO_2) to obtain estimates of national source energy EUI, national energy cost intensity (ECI), national carbon emissions, and national SC-CO_2, again by building type and by standard edition.

3.3.4 Treatment of Federal Minimum Equipment Standards

Standard 90.1 contains requirements for specific types of equipment that are regulated by federal efficiency standards for manufacturing and import. Addenda that adopted federal efficiency standards were excluded from the analysis to ensure that savings from energy codes and efficiency standards were not double counted. In the quantitative analysis, this was accomplished by assuming current minimum federal equipment efficiencies (i.e., as published in Standard 90.1-2019 with an effective date no later than December 31, 2022) in both the 2016 and 2019 prototype building models (with offsetting effects), which is consistent with historical DOE determination analyses. Note that the excluded addenda relate to minimum equipment efficiency levels set through the federal appliance and equipment standards rulemaking process, and not revised efficiency levels standards originating in ASHRAE Standard 90.1-2019. If the efficiency improvement is due to a change initiated in Standard 90.1, even those which may subsequently trigger an update in federal regulations, then those addenda are included in the determination savings.

Table 3.2. Relative Construction Volume Weights for 16 Prototype Buildings by Climate Zone (percent)

Building Type	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Weights by Bldg Type
Large Office	0.11	0.54	0.07	0.54	0.26	0.23	1.13	0.00	0.24	0.48	0.15	0.00	0.09	0.00	0.01	0.00	3.86
Medium Office	0.14	0.78	0.19	0.73	0.45	0.16	0.95	0.03	0.17	0.88	0.31	0.00	0.17	0.03	0.02	0.00	5.01
Small Office	0.11	0.77	0.15	0.70	0.27	0.05	0.58	0.03	0.09	0.67	0.21	0.00	0.13	0.02	0.02	0.00	3.80
Stand-Alone Retail	0.29	1.79	0.31	1.78	0.85	0.12	1.92	0.08	0.26	2.37	0.54	0.01	0.49	0.06	0.06	0.01	10.94
Strip Mall	0.16	0.63	0.14	0.70	0.42	0.09	0.66	0.02	0.09	0.61	0.12	0.00	0.06	0.01	0.01	0.00	3.71
Primary School	0.13	0.98	0.12	0.94	0.36	0.04	0.88	0.03	0.12	0.77	0.23	0.00	0.16	0.05	0.02	0.00	4.83
Secondary School	0.26	1.86	0.19	2.16	0.77	0.14	1.98	0.07	0.27	2.18	0.51	0.01	0.37	0.09	0.06	0.01	10.92
Hospital	0.09	0.75	0.11	0.63	0.32	0.10	0.92	0.03	0.13	0.95	0.23	0.01	0.20	0.03	0.03	0.00	4.52
Outpatient Health Care	0.05	0.54	0.09	0.53	0.17	0.04	0.62	0.02	0.10	0.80	0.20	0.00	0.18	0.03	0.03	0.00	3.42
Full Service Restaurant	0.03	0.18	0.03	0.17	0.08	0.01	0.16	0.01	0.02	0.19	0.04	0.00	0.03	0.00	0.00	0.00	0.97
Quick Service Restaurant	0.01	0.07	0.01	0.06	0.02	0.00	0.06	0.00	0.00	0.07	0.02	0.00	0.01	0.00	0.00	0.00	0.33
Large Hotel	0.18	0.71	0.10	0.56	0.55	0.09	0.82	0.02	0.13	0.65	0.19	0.00	0.14	0.04	0.02	0.00	4.22
Small Hotel	0.03	0.30	0.02	0.27	0.11	0.02	0.30	0.01	0.03	0.27	0.10	0.00	0.08	0.03	0.02	0.00	1.59
Non-Refrigerated Warehouse	0.53	3.53	0.63	2.77	2.23	0.18	3.69	0.05	0.54	3.14	0.82	0.00	0.37	0.03	0.04	0.00	18.56
High-Rise Apartment	1.44	1.19	0.08	0.57	0.63	0.29	3.26	0.00	0.49	1.36	0.19	0.00	0.11	0.01	0.00	0.00	9.64
Mid-Rise Apartment	0.36	2.24	0.27	1.78	1.18	0.49	3.02	0.03	0.71	2.22	0.73	0.01	0.57	0.05	0.04	0.00	13.69
Weights by Zone	3.94	16.85	2.52	14.89	8.67	2.06	20.94	0.43	3.39	17.60	4.59	0.05	3.17	0.49	0.38	0.03	100.00

3.4 Comments on Methodology

The goal of this analysis was to determine if the 2019 edition of Standard 90.1 is more energy-efficient relative to the 2016 edition. The approach selected to make this determination has certain limitations. These limitations are outlined below.

State Code Adoption: As discussed in the Introduction (Section 1), states adopt and update their energy codes in a variety of different manners. Some states adopt updated model codes as published while others draft state-level amendments to modify the model code. States also adopt codes at varying rates, with some states updating relatively quickly after a new edition is available, while others may remain on older editions for a longer duration. While these variables are not included in the DOE determination analysis, they ultimately affect the impacts of the model codes as applied across adopting states and localities.

Prototype Representation: Not all the addenda impacting energy use can be captured by the quantitative analysis due to the fixed nature of the prototypes, as explained in Section 3.3.1. Thus, the impact resulting from the quantitative analysis can be considered conservative. At the same time, the impact could be considered generous because the addenda that were included impacted all buildings of a given type (i.e., the weighting factors carried the impact to all buildings of a given type in a climate zone even though some of those buildings may not fit the descriptions of the prototype buildings). For example, the analysis assumes all large office buildings have water-cooled chillers—a property of the Large Office prototype. In reality, some have air-cooled, some have packaged equipment, some have variable refrigerant volume systems, etc. If the water-cooled chiller efficiency improved more than the other systems, the analysis overestimates savings. Whereas, if the efficiency improved less than the other systems, the analysis will have underestimated savings.

Combination of Qualitative & Quantitative Analysis: In any high-level analysis there is a need to balance precision, accuracy and practicality. The approach selected here addresses that by performing both a qualitative and quantitative analysis. The quantitative analysis taken together with the qualitative analysis provides a more robust and defensible determination. If the qualitative analysis determines that a large majority of addenda are expected to decrease energy use, and the quantitative analysis also shows a reduction in energy use from addenda impacting representative building designs, then taken together, the determination can be said to be more robust and reliable.

4. Results

4.1 Qualitative Analysis Results

The qualitative analysis concluded that 29 of the 88 addenda had a direct impact on energy use as defined in Section 3.2 — all 29 of the addenda listed decrease energy use in commercial buildings. The 59 remaining changes were determined to have no direct impact on energy use. A graphical summary of the qualitative analysis results is shown in Figure 2.

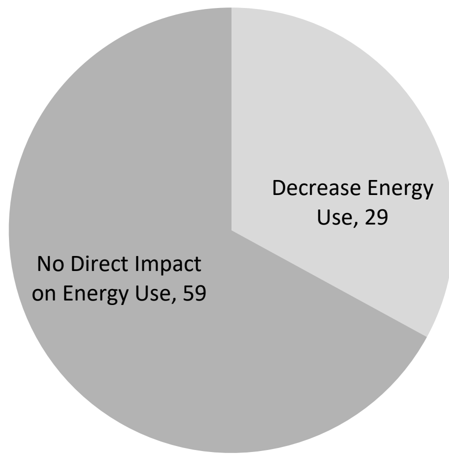

Figure 2. Categorization of Addenda

The 29 addenda with a direct impact are shown in Table 4.1, while the remainder are shown in Appendix A:. Six columns of information are listed for each addendum in Table 4.1:

1. **Addendum**: the letter addendum designation assigned by ASHRAE.
2. **Code Section(s)**: a list of the section numbers in Standard 90.1-2016 that are affected by the addendum.
3. **Description of Change**: a brief description of the change made by the addendum.
4. **Impact on Energy Use**: the anticipated impact of the addendum on energy use.
5. **Included in Quantitative Analysis**: whether the addendum can be included in the forthcoming Quantitative Analysis (see Section 4.2).
6. **Discussion**: how the impact on energy use was determined (and why the addendum was excluded from the quantitative analysis, if applicable).

Addenda characterized as having *no direct impact* on energy savings are detailed in Appendix.

Table 4.1. Addenda Determined to Directly Save Energy by the Qualitative Analysis of Standard 90.1-2019

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
dn	6.5.6	Modifies exceptions to exhaust air energy recovery requirements.	Decreases Energy Use	No	Excluded from quantitative analysis because series energy recovery is not modeled in the prototypes.
a	6.4.3.4.2, 6.4.3.4.3, 6.5.1.1.4	Changes term "ventilation air" to "outdoor air" in multiple locations. Adds an exception to allow systems intended to operate continuously not to install motorized outdoor air damper. Changes return air dampers to require low leakage ratings.	Decreases Energy Use	Yes	Reduces fan energy by allowing systems intended to operate continuously not to install motorized outdoor air damper (less pressure drop), and reduce cooling energy for systems with air economizers because of lower leakage through return air dampers.
g	3.2, 6.4.3.9	Provides definition of "occupied-standby mode" and adds new ventilation air requirements for zones served in occupied-standby mode.	Decreases Energy Use	Yes	Requires thermostat setback and minimum variable air volume (VAV) damper reset to zero during occupied standby model.
h	6.5.6.1	Clarifies that exhaust air ERVs should be sized to meet both heating and cooling design conditions unless one mode is not exempted by existing exceptions.	Decreases Energy Use	Yes	Reduces HVAC energy by requiring adequately sized ERVs.
j	6.4.3.8	Revises exception to demand control ventilation (DCV) requirements to clarify that the exception only applies to systems with ERV required to meet Section 6.5.6.1.	Decreases Energy Use	No	Reduces HVAC energy by preventing a bad design practice of using ERV rather than DCV in climate zones where ERVs are not required and DCV would save more energy. Excluded from quantitative analysis because typical designs, as represented by the established prototypes, do not use this design practice.
k	3.2, 6.4.3.3.5, 9.4.1.3	Revises definition of "networked guest room control system" and aligns HVAC and lighting time-out periods for guest rooms.	Decreases Energy Use	Yes	Reduces timeout period from 30 to 20 minutes to activate occupancy-based temperature and ventilation setback controls for guestrooms.
t	9.4.2	Expands the exterior lighting power density (LPD) application table to cover additional exterior spaces that are not in the exterior LPD table.	Decreases Energy Use	No	Reduces lighting energy. Excluded from quantitative analysis because the exterior areas added to the table are not modeled in the prototypes.
v	6.5.6.3	Adds heat recovery for space conditioning requirement targeted specifically at in-patient hospitals	Decreases Energy Use	Yes	Requires in-patient hospitals with large chillers to recover rejected heat for use in heating water systems.
ai	Too many to list. See Addendum ai	Restructures commissioning and functional testing requirements in all sections of Standard 90.1 to require verification or testing for smaller and simpler buildings and commissioning for larger and more complex buildings.	Decreases Energy Use	No	Excluded from quantitative analysis because the analysis is based on proper operation of controls in the prototypes and would not show savings for improvements from verification, testing, or commissioning.

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
am	6.5.6.4	Adds indoor pool dehumidifier energy recovery requirement.	Decreases Energy Use	No	Reduces HVAC energy. Excluded from quantitative analysis because swimming pools are not modeled in the prototypes.
an	3.2, 10.4.6	Implements federal clean water pump requirements.	Decreases Energy Use	No	Reduces pump energy through improved efficiency. Excluded from quantitative analysis because impacted pumps are federally-regulated. (See Section 3.3.4)
ao	3.2, 6.5.3.1.3, 12	Replaces Fan Energy Grade metric with Fan Energy Index metric	Decreases Energy Use	No	Reduces fan energy through improved fan efficiency. Excluded from quantitative analysis because fan power in the prototypes is set based on the total fan power limit in the Standard, which has not been changed.
ap	6.5.3.5	Revises supply air temperature reset controls	Decreases Energy Use	Yes	Revises supply air temperature reset requirements.
au	6.5.2.1,	Eliminates the requirement that zones with direct digital control (DDC) have air flow rates that are no more than 20% of the zone design peak flow rate.	Decreases Energy Use	Yes	Replaces VAV box minimum setpoint of 20% of the design supply air rate with a setpoint determined using Simplified Procedure in ASHRAE Standard 62.1.
aw	3.2, Tables 5.5-0 through 5.5-8, 12	Revises prescriptive fenestration U and SHGC requirements and makes them material neutral.	Decreases Energy Use	Yes	Improves thermal performance of most fenestration components.
ay	6.5.6.1	Provides separate requirements for nontransient dwelling unit exhaust air energy recovery.	Decreases Energy Use	Yes	Requires more dwelling units to have exhaust air energy recovery.
bb	Table 9.6.1	Changes interior LPD requirements for many space types.	Decreases Energy Use	Yes	Reduces lighting energy with lower LPD.
bd	Table 6.8.1-18	Adds new chiller table for heat pump and heat recovery chillers.	Decreases Energy Use	Yes	Establishes new efficiency requirement for equipment including heat recovery chillers.
be	Table 6.8.1-11, Table 6.8.1-19	Revises computer room air conditioner (CRAC) requirements to clarify these are for floor mounted units and adds a new table for ceiling mounted units.	Decreases Energy Use	Yes	Requires higher efficiency CRAC units.
bo	3.2, Tables 6.8.1.5 and F4	Adds definition of Standby Power Mode Consumption. Increases furnace efficiency requirements.	Decreases Energy Use	No	Reduces heating energy through improved furnace efficiency. Excluded from quantitative analysis because the impacted furnaces are federally-regulated. (See Section 3.3.4)
bp	Tables 6.8.1.6 and F5	Adds a new table F-5 to specify DOE covered residential water boiler efficiency requirements and notes that requirements in Table 6.8.1-6 apply only to products used outside the US. Adds standby mode and improved efficiency as of 1/15/2021.	Decreases Energy Use	No	Excluded from quantitative analysis because the impacted boilers are federally-regulated. (See Section 3.3.4)

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
bq	Table 6.8.1.7	Adds dry cooler efficiency requirements and slightly increases efficiency requirements for evaporative condensers.	Decreases Energy Use	Yes	Requires higher efficiency dry coolers.
br	Table 6.8.1.13 & 12	Combines commercial refrigerator and freezer table with refrigerated casework table into a single table. Increases efficiency requirements.	Decreases Energy Use	No	Excluded from quantitative analysis because the impacted refrigerators and freezers are federally-regulated. (See Section 3.3.4)
cg	Table 9.5.1	Revises LPDs using the Building Area Method.	Decreases Energy Use	Yes	Reduces lighting energy with lower LPD.
cm	6.5.2.1	Makes a similar change to VAV box minimums as Addendum au to 90.1-2016, but in exception 1 to Section 6.5.2.1 where the same 20% requirement still existed.	Decreases Energy Use	Yes	Replaces VAV box minimum setpoint of 20% of the design supply air rate with a setpoint determined using the Simplified Procedure in Standard 62.1. Similar to Addendum au.
cn	6.4.1.1, 6.4.5, Table 6.8.1-20, Table 6.8.1-21, Table 6.8.1-22	Cleans up outdated language regarding walk-in cooler and walk-in freezer requirements, and makes the requirements consistent with current and future federal regulations.	Decreases Energy Use	No	Excluded from quantitative analysis because the impacted walk-in coolers and freezers are federally-regulated. (See Section 3.3.4)
co	12	Adds new normative references and updates existing ones with new effective dates, including several addenda to ASHRAE Standard 62.1-2016, which enable Simplified Ventilation Procedure.	Decreases Energy Use	Yes	Updates to include Addendum f to 62.1-2016, which enables Simplified Ventilation Procedure to be used for VAV box minimum setpoint controls and system ventilation control.
cv	9.4.1.2	Updates the lighting control requirements for parking garages in Section 9.4.1.2.	Decreases Energy Use	No	Reduces lighting energy. Excluded from quantitative analysis because the parking garages are not modeled in the prototypes.
cw	9.4.1.1, Table 9.6.3	Changes the daylight responsive requirements from continuous dimming or stepped control to continuous dimming required for all spaces and adds a definition of continuous dimming.	Decreases Energy Use	Yes	Reduces lighting energy because of more stringent daylighting control requirements.

4.2 Quantitative Analysis Results

The quantitative analysis only includes those addenda that have a direct impact on energy use as described in Section 3.2 and Section 3.3. A graphical summary of the addenda included in the quantitative analysis is shown in Figure 3. The category labeled "Unquantified Energy Impact" includes those addenda that were determined to have a direct impact on energy use but are not be included in the quantitative analysis. Appendix B: describes the implementation of addenda into the prototype models.

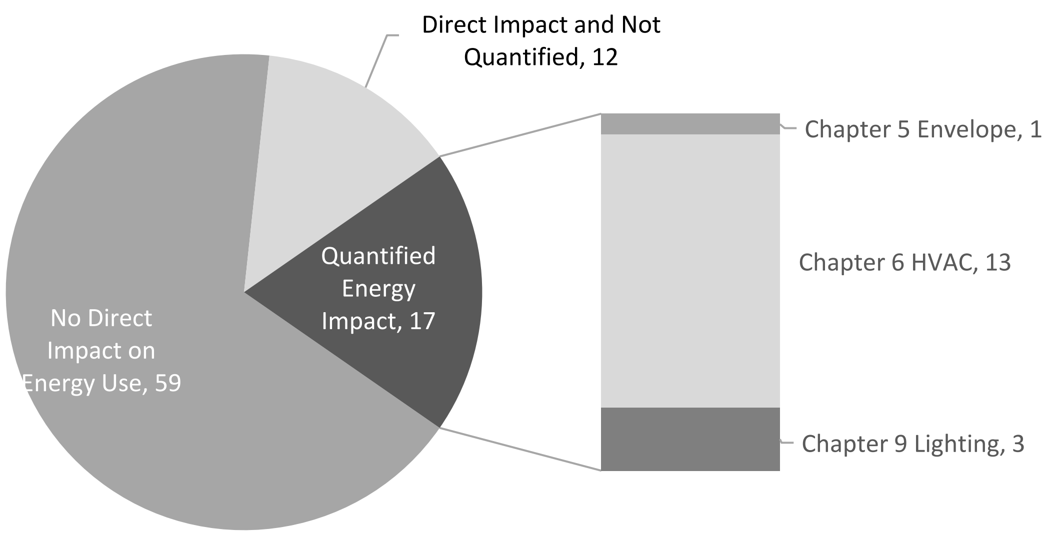

Figure 3. Categorization of Quantified Addenda

Table 4.3 through Table 4.6 show the quantitative analysis results by building type and climate zone for Standard 90.1-2016 and 90.1-2019, respectively. The results were aggregated on a national basis for each Standard, based on the weighting factors discussed in Section 3.3.3. In these tables, site energy refers to the energy consumed at the building site, and source energy (or primary energy) refers to the energy required to generate and deliver energy to the site. To calculate source energy, conversion factors were applied to the electricity and natural gas consumption. The development of these conversion factors is explained below.

The electric energy source conversion factor of 9,957 Btu/kWh was calculated from EIA's Annual Energy Outlook (AEO) 2020 (EIA 2020) Table 2[1] as follows:

- Delivered commercial electricity, 2019: 4.65 quads
- Commercial electricity related losses, 2019: 8.92 quads
- Total commercial electric energy use, 2019: 13.58 quads
- Commercial electric source ratio, U.S. 2019: 2.92
- Source electric energy factor (3413 Btu/kWh site) 9,957 Btu/kWh[2]

[1] Available at https://www.eia.gov/outlooks/aeo/

[2] The final conversion value is calculated using the full seven digit values available in Table 2 of AEO 2020. Other values shown in the text are rounded.

Natural gas EUIs in the prototype buildings were converted to source energy using a factor of 1.088 Btu of source energy per Btu of site natural gas use, based on the 2019 national energy use estimate shown in Table 2 of the AEO 2020 as follows:

- Delivered total natural gas, 2019: 29.39 quads
- Natural gas used in well, field, and pipeline: 2.58 quads
- Total gross natural gas use, 2019: 31.97 quads
- Total natural gas source ratio, U.S. 2019: 1.088 Btu source/Btu site
- Source natural gas energy factor (100,000 Btu/therm site): 108,800 Btu/therm

To calculate the energy cost, DOE relied on national average commercial building energy prices based on EIA statistics for 2019 in Table 3, "Energy Prices by Sector and Source," of the AEO 2020 for commercial sector natural gas and electricity of:

- $0.1052/kWh of electricity
- $7.79 per 1000 cubic feet ($0.752/therm) of natural gas.

DOE recognizes that actual energy costs will vary somewhat by building type within a region, and even more across regions. However, the use of national average figures sufficiently illustrates energy cost savings and the effect on energy efficiency in commercial buildings, as is the purpose of the DOE determination.

Carbon emissions in the quantitative analysis are based on the source energy consumption on a national scale. Carbon emission metrics are provided by the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Equivalencies Calculator[1]. The Greenhouse calculator reports the national marginal carbon emission conversion factor for electricity at 7.07×10^{-4} metric tons carbon dioxide (CO_2)/kWh. For natural gas, the carbon emission conversion factor is 0.0053 metric tons CO_2/therm. Table 4.2 summarizes the carbon emission factors.

Table 4.2. Carbon Emission Factors by Fuel Type

Fuel Source	Carbon Emission Factor
Electricity	7.07×10^{-4} metric tons CO_2/kWh
Natural Gas	0.0053 metric tons CO_2/therm

On January 20, 2021, President Biden issued Executive Order (E.O.) 13990[2], which noted that it is essential that agencies capture the full costs of greenhouse gas emissions as accurately as possible, including by taking global damages into account and that doing so facilitates sound decision-making, recognizes the breadth of climate impacts, and supports the international leadership of the United States on climate issues. To that end, DOE is including estimates of the absolute cost and relative costs savings

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[1] See the EPA webpage at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

[2] Exec. Order No. 13990, 86 Fed. Reg. 7037 (January 20, 2021) https://www.federalregister.gov/documents/2021/01/25/2021-01765/protecting-public-health-and-the-environment-and-restoring-science-to-tackle-the-climate-crisis

of greenhouse gas emissions associated with the building energy use examined in this analysis.

The principal greenhouse gas emission associated with commercial building energy use, as examined in this analysis, is CO_2. DOE estimates the global social benefits of first year CO_2 emission reductions using the SC-CO_2 estimates presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG 2021). These SC-CO_2 estimates are interim values established under E.O. 13990 for use in benefit-cost analyses until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. These SC-CO_2 estimates are the same as those used in the *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (IWG 2016), but are updated to 2020$. An unrounded value of $51.086 (2020$/Metric Ton CO_2) is used in this analysis reflecting a SC-CO_2 present value per metric ton of carbon dioxide emissions avoided in 2020 based on a 3% discount rate and the average global damage estimate from three integrated assessment models (IAMs).

Table 4.7 and Table 4.8 present the estimated percent energy and energy cost savings between the 2016 and 2019 editions of Standard 90.1 by building type and climate zone respectively.

Overall, the analysis indicates that Standard 90.1-2019 will result in increased energy efficiency in commercial buildings. On a weighted national average basis, Standard 90.1-2019 saves 4.7% site energy, 4.3% of source energy, 4.3% of energy cost, and 4.2% of carbon emissions and SC-CO_2. Weighted national average savings results by building type and climate zone are shown in Figure 4 and Figure 5.

Of interest is the large site energy savings found in the Hospital prototype compared to source energy and cost savings. The majority of savings is due to Addendum v which requires acute care hospitals to recover chiller condenser heat to be used to offset space heating. This causes a large reduction in natural gas consumption, and a much smaller increase in electricity consumption required by the heat recovery chiller and pumping system (see Section B.2.5). Since the site-to-source conversion factor for electricity is almost three times that of natural gas and the cost per delivered Btu of electricity is about four times that of natural gas (see Section 4.2), the result is much higher savings for site energy than either of the other two metrics.

Table 4.3. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics				
			Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)	Carbon Emission (tons/kft^2-yr)	SC-CO_2 ($/kft^2-yr)
Office	Small Office	3.8%	27.1	77.6	$0.82	5.5	$275
	Medium Office	5.0%	30.8	84.2	$0.88	5.9	$296
	Large Office	3.9%	55.4	156.9	$1.65	11.1	$555
Retail	Stand-Alone Retail	10.9%	48.4	114.4	$1.15	7.8	$389
	Strip Mall	3.7%	52.8	133.8	$1.37	9.2	$462
Education	Primary School	4.8%	43.4	107.4	$1.09	7.4	$369
	Secondary School	10.9%	37.2	94.0	$0.96	6.5	$325
Healthcare	Outpatient Health Care	3.4%	107.6	276.3	$2.84	19.1	$958
	Hospital	4.5%	120.0	276.8	$2.77	18.7	$936
Lodging	Small Hotel	1.6%	54.8	118.0	$1.16	7.8	$392
	Large Hotel	4.2%	83.1	177.1	$1.73	11.7	$586
Warehouse	Non-Refrigerated Warehouse	18.6%	15.7	33.2	$0.32	2.2	$110
Food Service	Quick Service Restaurant	0.3%	493.4	863.7	$7.87	53.7	$2,689
	Full Service Restaurant	1.0%	336.5	649.8	$6.14	41.7	$2,090
Apartment	Mid-Rise Apartment	13.7%	37.8	104.4	$1.09	7.3	$367
	High-Rise Apartment	9.6%	41.3	92.0	$0.91	6.2	$308
National		100%	48.6	116.0	$1.17	7.9	$395

Table 4.4. Estimated Energy Use Intensity by Building Type – Standard 90.1-2019

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)	Carbon Emission (tons/kft2-yr)	SC-CO2 ($/kft2-yr)
Office	Small Office	3.8%	25.6	73.2	$0.77	5.2	$259
	Medium Office	5.0%	29.7	80.2	$0.83	5.6	$281
	Large Office	3.9%	53.2	151.0	$1.59	10.7	$534
Retail	Stand-Alone Retail	10.9%	46.1	106.3	$1.06	7.2	$359
	Strip Mall	3.7%	51.0	127.6	$1.30	8.8	$440
Education	Primary School	4.8%	40.9	101.1	$1.03	6.9	$348
	Secondary School	10.9%	35.6	89.9	$0.92	6.2	$311
Healthcare	Outpatient Health Care	3.4%	104.5	267.7	$2.75	18.5	$927
	Hospital	4.5%	105.4	261.2	$2.66	17.9	$898
Lodging	Small Hotel	1.6%	52.2	110.3	$1.07	7.3	$364
	Large Hotel	4.2%	75.8	162.2	$1.59	10.7	$538
Warehouse	Non-Refrigerated Warehouse	18.6%	15.5	32.5	$0.32	2.1	$107
Food Service	Quick Service Restaurant	0.3%	492.5	860.9	$7.84	53.5	$2,679
	Full Service Restaurant	1.0%	335.5	646.6	$6.11	41.5	$2,079
Apartment	Mid-Rise Apartment	13.7%	36.5	101.5	$1.06	7.1	$358
	High-Rise Apartment	9.6%	40.5	90.1	$0.89	6.0	$302
National		100%	46.3	111.0	$1.12	7.6	$379

Table 4.5. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2016

Climate Zone	Climate Zone Floor Area Weight %	Whole Building Energy Metrics				
		Site EUI kBtu/ft^2-yr	Source EUI kBtu/ft^2-yr	ECI \$/ft^2-yr	Carbon Emission tons/kft^2-yr	SC-CO_2 \$/kft^2-yr
1A	3.9%	46.5	121.0	$1.25	8.4	$421
2A	16.9%	47.0	122.0	$1.26	8.5	$424
2B	2.5%	43.3	112.9	$1.16	7.8	$393
3A	14.9%	47.3	116.2	$1.18	8.0	$399
3B	8.7%	40.8	103.1	$1.06	7.1	$356
3C	2.1%	41.0	105.5	$1.08	7.3	$366
4A	20.9%	48.0	111.8	$1.12	7.6	$379
4B	0.4%	50.6	121.7	$1.23	8.3	$416
4C	3.4%	42.3	100.4	$1.01	6.8	$342
5A	17.6%	54.9	119.9	$1.18	8.0	$399
5B	4.6%	49.7	115.4	$1.15	7.8	$391
5C	0.1%	54.4	126.3	$1.26	8.5	$428
6A	3.2%	64.2	136.7	$1.33	9.0	$453
6B	0.5%	59.1	130.3	$1.28	8.7	$435
7	0.4%	69.9	147.0	$1.43	9.7	$485
8	0.03%	86.6	165.5	$1.56	10.6	$530
National	100%	48.6	116.0	$1.17	7.9	$395

Table 4.6. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2019

Climate Zone	Climate Zone Floor Area Weight %	Whole Building Energy Metrics: Site EUI kBtu/ft^2-yr	Source EUI kBtu/ft^2-yr	ECI \$/ft^2-yr	Carbon Emission tons/kft^2-yr	$SC\text{-}CO_2$ \$/kft^2-yr
1A	3.9%	44.5	115.9	$1.19	8.0	$403
2A	16.9%	44.5	116.4	$1.20	8.1	$405
2B	2.5%	41.1	107.9	$1.11	7.5	$376
3A	14.9%	44.5	110.1	$1.12	7.6	$379
3B	8.7%	38.8	98.6	$1.01	6.8	$341
3C	2.1%	39.0	101.1	$1.04	7.0	$351
4A	20.9%	46.2	107.7	$1.08	7.3	$365
4B	0.4%	48.3	116.3	$1.18	7.9	$397
4C	3.4%	39.7	95.9	$0.97	6.5	$328
5A	17.6%	53.0	115.3	$1.13	7.7	$384
5B	4.6%	47.2	110.3	$1.11	7.5	$374
5C	0.1%	52.7	122.0	$1.22	8.2	$413
6A	3.2%	61.9	131.5	$1.28	8.7	$435
6B	0.5%	57.2	125.3	$1.23	8.3	$418
7	0.4%	67.4	141.2	$1.37	9.3	$466
8	0.03%	84.1	159.5	$1.50	10.2	$510
National	100%	46.3	111.0	$1.12	7.6	$379

Table 4.7. Estimated Percent Energy Savings between 2016 and 2019 Editions of Standard 90.1 – by Building Type

Building Type	Prototype Building	Floor Area Weight (%)	Savings (%) Site EUI	Source EUI	ECI	Carbon Emissions & SC-CO2
Office	Small Office	3.8%	5.5%	5.7%	6.1%	5.7%
	Medium Office	5.0%	3.6%	4.8%	5.7%	5.0%
	Large Office	3.9%	4.0%	3.8%	3.6%	3.8%
Retail	Stand-Alone Retail	10.9%	4.8%	7.1%	7.8%	7.7%
	Strip Mall	3.7%	3.4%	4.6%	5.1%	5.0%
Education	Primary School	4.8%	5.8%	5.9%	5.5%	5.9%
	Secondary School	10.9%	4.3%	4.4%	4.2%	4.3%
Healthcare	Outpatient Health Care	3.4%	2.9%	3.1%	3.2%	3.2%
	Hospital	4.5%	12.2%	5.6%	4.0%	4.0%
Lodging	Small Hotel	1.6%	4.7%	6.5%	7.8%	7.0%
	Large Hotel	4.2%	8.8%	8.4%	8.1%	8.3%
Warehouse	Non-Refrigerated Warehouse	18.6%	1.3%	2.1%	2.5%	2.4%
Food Service	Quick Service Restaurant	0.3%	0.2%	0.3%	0.4%	0.4%
	Full Service Restaurant	1.0%	0.3%	0.5%	0.5%	0.6%
Apartment	Mid-Rise Apartment	13.7%	3.4%	2.8%	2.8%	2.6%
	High-Rise Apartment	9.6%	1.9%	2.1%	2.2%	2.2%
National		100%	4.7%	4.3%	4.3%	4.2%

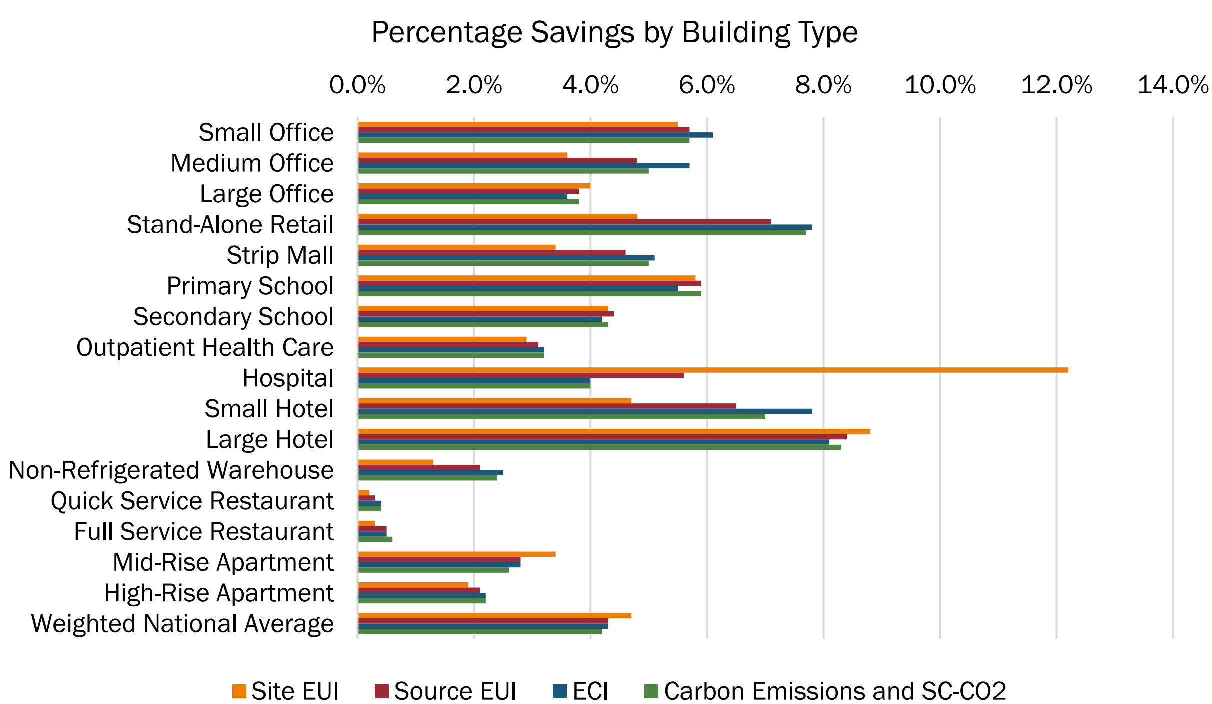

Figure 4. Percentage Savings by Building Type from 90.1-2016 to 90.1-2019

Table 4.8. Estimated Percent Energy Savings between 2016 and 2019 Editions of Standard 90.1 – by Climate Zone

		Savings (%)			
Climate Zone	Climate Zone Floor Area Weight %	Site EUI	Source EUI	ECI	Carbon Emissions & SC-CO2
1A	3.9%	4.3%	4.2%	4.8%	4.2%
2A	16.9%	5.3%	4.6%	4.8%	4.5%
2B	2.5%	5.1%	4.4%	4.3%	4.3%
3A	14.9%	5.9%	5.2%	5.1%	5.1%
3B	8.7%	4.9%	4.4%	4.7%	4.2%
3C	2.1%	4.9%	4.2%	3.7%	4.0%
4A	20.9%	3.8%	3.7%	3.6%	3.7%
4B	0.4%	4.5%	4.4%	4.1%	4.4%
4C	3.4%	6.1%	4.5%	4.0%	4.2%
5A	17.6%	3.5%	3.8%	4.2%	3.9%
5B	4.6%	5.0%	4.4%	3.5%	4.3%
5C	0.1%	3.1%	3.4%	3.2%	3.5%
6A	3.2%	3.6%	3.8%	3.8%	3.9%
6B	0.5%	3.2%	3.8%	3.9%	3.9%
7	0.4%	3.6%	3.9%	4.2%	4.0%
8	0.03%	2.9%	3.6%	3.8%	3.9%
National	100%	4.7%	4.3%	4.3%	4.2%

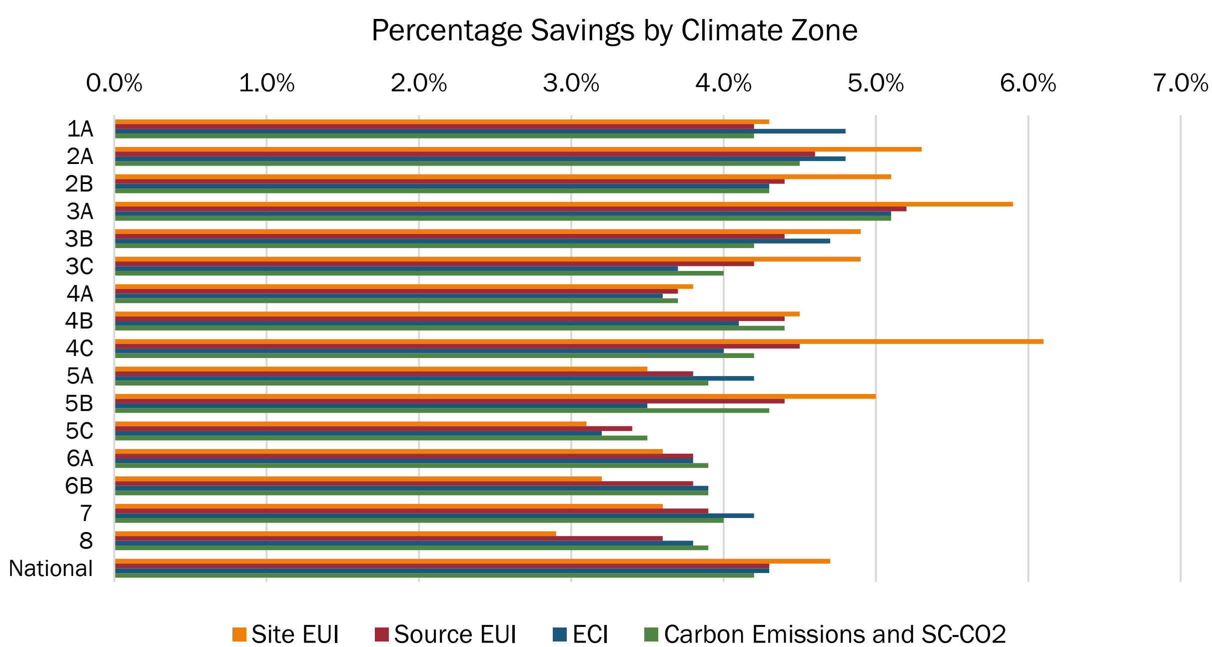

Figure 5. Percentage Savings by Climate Zone from 90.1-2016 to 90.1-2019

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Appendix A: Addenda Not Quantified in Energy Savings Analysis

Addendum	Sections Affected	Description of Change	Discussion
bg	9.3	Adds a simplified building method for interior lighting in offices, schools, and retail buildings, and exterior lighting.	Changed provisions are an alternative to the existing requirements.
b	5.5.3.1.1	Updates reference to ANSI/CRRC S100 “Standard Test Methods for Determining Radiative Properties of Materials.”	References update only.
c	3.2	Adds rooftop monitors to the definition of fixed and operable vertical fenestration.	Clarification only.
d	Table G3.1 1c	Modifies text to make it consistent with other portions of Appendix G for projects undergoing phased permitting.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
e	Table G3.1 11f	Adds direction that service water heater (SWH) piping losses shall not be modeled.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
f	G3.1.2.1	Modifies text to require that the capacity used for selecting the system efficiency is based on the size of the actual zone instead of the size of the zones as combined into a single thermal block.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
l	Table G3.1.2.9	Adds requirements for fan break horsepower for two systems.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
m	Table G3.1 5b	Lowers baseline building performance air leakage and sets an air leakage value to be used in conjunction with the air barrier verification path.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
n	3.2	Removes 10 unused definitions and changes the definition of “unitary cooling equipment” to “unitary air conditioners.”	Clarification only.
o	3.2, 4.2.2.3, 5.5.1, 5.5.2, 5.7, 5.8, 6.7, 7.7, 8.7, 9.7, 10.7,	Revises the submittals section of the envelope and power chapters for consistency across the Standard.	Administrative provisions only.

Addendum	Sections Affected	Description of Change	Discussion
	11.7, G1.3		
p	Table 6.8.1-14	Revises the rating conditions for indoor pool dehumidifiers.	Clarification to rating condition.
q	5.4.3, 5.5, 5.8.3	Clarifies and restructures air leakage requirements for the building envelope.	Clarification only.
r	G3.1.2.6	Specifies air economizer control types for Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
s	4.2.1.1, 11.4.3, G2.4.1	Modifies the Performance Cost Index (PCI) equation to implement a 5% limitation on renewable energy usage and clarifies what types of renewable energy systems are eligible.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
x	4.2	Clarifies compliance paths for new construction, additions, and alterations.	Clarification only.
y	G3.1.2.2	Provides explicit guidance on how to conduct sizing runs for Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
z	11.5, G3.1.2	Modifies the formulas in Section 11 and G3.1.2.1 for removing fan energy from baseline packaged heating and cooling efficiency ratings to cap the system capacity equations in Section 11 to levels allowed in Section 6 and provide a fixed baseline efficiency rating for Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ab	3.2	Modifies definition of "door", "entrance door", "fenestration", and "sectional garage door."	Clarification only.
ac	3.2	Clarifies use of defined terms to include the term with different tense or plurality.	Clarification only.
ad	5, 6, 7, 8, 9, 10, 11, G	Clarifies the requirements for showing compliance using the methods in Sections 5-10, or Section 11, or Appendix G.	Clarification only.
ae	3.2, 6.4.3.6	Clarifies humidification and dehumidification control requirements.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
ag	Table G3.1 12	Accounts for the inclusion of automatic receptacle controls in a proposed building design for spaces that are not required to have them.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ah	9.1.4	Updates the language and terminology of the lighting wattage section to clarify application in modern lighting systems and equipment. Also adds a section specifically to address using DC power over Cat6 structured cable for connection of LED lighting to a remote power supply.	Clarification only.
aj	3.2, 6.4.3, 6.5.1, 6.5.2, 6.5.4	Adds new definition "process application" and uses it throughout the Standard in place of "process load."	Clarification only.
ak	Tables G3.4-1 to G3.4-8	Defines solar heat gain coefficient (SHGC) baseline for buildings in zones where there is no prescriptive maximum SHGC.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
al	Table G3.1 4, Table G3.1 7, G3.1.2.4	Modifies requirements in Appendix G to ensure that the intent of G3.1.1(c) (separate HVAC systems for unusual loads or schedules) is met.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
aq	9.2.2.3, 9.4.1.3, 9.4.4, 9.6.2,	Clarifies lighting control requirements for applications not covered in Section 9.6.2.	Clarification only.
ar	G3.1.2.9, Table G3.1 12, Table G3.5.5, Table G3.5.6, Table G3.6, Table G3.9, Table G3.9.3	Cleans up the modeling requirements for pumps in Appendix G to address unresolved comments to Addendum di to Standard 90.1-2016.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
as	New appendix I	Adds informative appendix Additional Guidance for Verification, Testing, and Commissioning	Change applies to informative appendix and does not change normative requirements.
at	11.5, G1.2.2,	Adds an exception for energy used to refuel or recharge offsite vehicles.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
az	Table G3.1 17	Clarifies how to deal with refrigeration equipment rated under AHRI 1200 in Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
ba	Table G3.1 11	Establishes a methodology for determining the baseline flow rates on projects where service water-heating is demonstrated to be reduced by water conservation measures that reduce the physical volume of service water required, such as with low-flow showerheads.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bf	5.4.3.4, 10.4.5, App E	Allows self-closing doors with air curtains as an alternative to vestibules for particular climate zones and building heights.	Changed provisions are alternative to the existing and unchanged ones.
bh	5.4.3.2, Table 5.8.3.2	Corrects omissions from Addendum q.	Clarification only.
bi	11.4.1.4, 12, C3.1.4, G2.4.4	Updates reference to Standard 140 and makes clarifications regarding application of Standard 140.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bj	6.5.5.1	Adds equipment covered by Tables 6.8.1-9 through 6.8.1-16 to the list of exceptions from heat rejection requirements.	Clarification only.
bk	3.2, 11.4.3.2, G2.4.2	Defines onsite electricity generation systems and clarifies that systems using the performance path must use the same electricity generation systems in the baseline as in the proposed design, except for onsite renewable generation systems.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bl	Table 6.8.1.1	Updates efficiency requirements for Table 6.8.1-1 Electrically Operated Unitary Air Conditioners and Condensing Units.	Change will not be effective within three years from the publication of Standard 90.1-2019.
bm	6.4.1.1, Tables 6.8.1.2 and 6.8.1.17	Removes water, evaporatively, and ground cooled heat pumps from Table 6.8.1.2 and establishes their efficiency requirements in new table 6.8.1.18. Updates efficiency requirements for all heat pumps.	Change will not be effective within three years from the publication of Standard 90.1-2019.
bn	3.2, Tables 6.8.1.4, F1, and F3.	Adds new definitions for CEER, CCOPc, and Off-mode power consumption. Updates efficiency for PTAC, PTHP, SPVAC, SPVHP, and room air conditioners. Updates federally regulated equipment efficiency in Appendix F.	Change will not be effective within three years from the publication of Standard 90.1-2019.
bs	Tables 7.8 and F-2	Updates water heater requirements in Tables F2 and 7.8 to align with new federal requirements.	Change aligns with recent federal rulemaking that impacts the categorizations and performance rating method of service water heaters but not (intended) the stringency of the requirements.
bt	Table 4.2.1.1	Updates Building Performance Factors used to show compliance with Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
bu	G3.1.1, G3.1.3.2, G3.1.3.3, G3.1.3.6, G3.1.3.10, G3.1.3.11, G3.1.3.12, Tables 4.2.1.1, G3.1.1-1, G3.4-1, G3.4-2, G3.4-3, G3.4-4, G3.4-5, G3.4-6, G3.4-7, G3.4-8.	Changes references from spaces to zones, corrects a conflict on heating source, clarifies when separate baseline systems are required, removes redundant footnote in Tables 4.2.1.1, G3.1.1-1, G3.4-1, corrects errors in subsection title headings.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bv	3.2, 6.2.1, 6.6.1, 6.6.6.1, 6.6.1.2, 6.6.1.3, 8.2.1, 8.6.1	Deletes computer room alternative compliance option in Standard 90.1 and instead allows an alternative path of complying with ASHRAE Standard 90.4 for electrical and mechanical components in computer rooms greater than 10 kW.	Changed provisions are alternative to the existing and unchanged ones.
bx	A6.1, Table A6.3.1-1	Adds F-factors for heated slabs that are uninsulated or insulated only under slab.	Additional factors for condition combinations not currently covered and do not change requirements.
bz	3.2, C1.4, C2.7, C3.1.2, C3.3, C3.5.5.1, C3.5.8	Modifies Appendix C Envelope Tradeoff.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ca	Table A3.2.3	Adds U-factors to Table A3.2.3 for use of continuous insulation on metal building walls with double layer cavity insulation	Clarification only.
cc	A9.4.6	Clarifies the limitations of the calculation procedures in A9.4.6.	Clarification only.
ce	6.5.3.1.2	Removes one of three criteria for fan motor selections.	Changed provisions are alternative to the existing and unchanged ones.
cf	6.4.5	Adds vacuum insulating glazing to the list of options for reach-in doors in walk-in coolers and freezers.	Changed provisions are alternative to the existing and unchanged ones.
ch	3.2, 9.4.1.1	Addresses two areas of uncertainty in the definitions of daylighted zones.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
ci	Table 4.2.1.1	Updates the Building Performance Factors that are used for compliance with Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cj	Table 11.5.1, Table G3.1, Table G3.7	Makes three specific changes to the lighting provisions of the Energy Cost Budget Method and the specific changes to the lighting provisions of Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cl	3.2, 11.4.1, 11.4.1.1, 11.4.1.2, 11.4.2, 11.4.5, 11.5.2, 11.7, Table 11.5.1, Table 11.5.2-1, Table 11.5.2-3, Table 11.5.2-5	Makes changes throughout Section 11 to better align with Appendix G providing greater consistency between the two sections.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cq	6.4.1.3 (new)	Adds requirements for large-diameter ceiling fans to be rated in accordance with certain test methods.	Requires fans to be rated, but includes no minimum efficiency requirement.
cs	Appendix E	Makes many edits and updates to Informative References.	References update only.
ct	12	Updates the revision date for Acceptance Test Code for open circuit cooling towers.	References update only.
cu	6.4.1.4, 6.4.7 (new)	Adds 6.4.7 to require that liquid to liquid heat exchangers that fall under the scope of AHRI 400 be rated in accordance with AHRI 400. Deletes Table 6.8.1-8 which included the same rating requirement.	References update only.
cy	9.4.1	Clarifies language in an exception to the sidelighting requirements and adds natural objects to the exception.	Primarily a clarification.

Appendix B: Modeling of Individual Addenda

This appendix details the modeling of the 17 addenda to Standard 90.1-2016 simulated for the quantitative analysis. They are a subset of the addenda listed in Table 4.1 and marked as "Included in Quantitative Analysis". In the cases where individual addenda modify the same section of Standard 90.1, these addenda are discussed together. The procedures for implementing the addenda into the Standard 90.1-2016 and 90.1-2019 prototype models include identifying the changes to the prototypes required by each addendum, developing model inputs to simulate those changes, applying those changes to the prototype models, running the simulations, and extracting and post-processing the results. This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for EnergyPlus. The terms "baseline" and "advanced" are used in some cases to describe the modeling of the addenda. The baseline case is Standard 90.1-2016 and the advanced case is Standard 90.1-2019. In some instances, a new addendum to Standard 90.1-2016 identifies the need for a change to baseline 2016 models. There are generally two reasons why a baseline change was necessary: (1) in the course of modeling an addendum, an opportunity to increase the accuracy of the simulation was identified and (2) to add additional detail to the models so that the impact of a particular addendum could be captured. For example, prior to the simulation of the 2019 Standard, ventilation in the Mid-rise and High-rise Apartment prototypes was changed from through the space air conditioning systems to through an exhaust-driven ventilator. This allows the accurate simulation of Addendum *ay*, which requires residential systems to have heat recovery.

B.1 Building Envelope Addenda

B.1.1 Addendum *aw*: Fenestration U and SHGC

Addendum Description. Addendum *aw* revises the prescriptive U-factor and solar heat gain coefficient (SHGC) requirements in Tables 5.5-0 through 5.5-8 for vertical fenestrations and skylights. It also modifies the vertical fenestration categories from "Nonmetal," "Metal fixed," "Metal operable," and "Metal entrance door" to "Fixed," "Operable," and "Entrance Door." The adjusted categorization is independent of frame material type, provides increased consistency with the International Energy Conservation Code (IECC), and helps facilitate alignment of 90.1 and IECC criteria. The revised SHGC values for operable and vertical fenestrations are slightly lower than those for fixed ones, which is to acknowledge the fact that operable windows have a larger frame-to-glass ratio and therefore lower SHGC values with the same glazing type. The addendum generally reduces U-factor for fixed metal framed windows; however; it also increases the U-factor for non-metal framed windows. Since the predominant framing is metal in commercial construction, the average U-factor is reduced, in turn reducing heat loss and gain for commercial buildings, which provides an overall reduction in both annual and peak heating and cooling loads. SHGC is slightly reduced overall, contributing further to a reduction in cooling load and energy use.

Modeling Strategy. All the prototypes have vertical fenestration (i.e., windows), and four (Stand-alone Retail, Primary School, Secondary School, and Non-refrigerated Warehouse) have skylights, which are all modeled using U-factor and SHGC inputs to WindowMaterial:SimpleGlazingSystem objects in EnergyPlus. To capture the window requirements with different categorizations introduced by this addendum, weighting factors of different window categories as shown in Table B.1 were used to calculate weighted U-factor and SHGC values for each prototype based on recent market data from Ducker.[1] The weighting factors are slightly updated from those used in the previous analyses (Thornton et al. 2011). Although the required minimum ratio of visible transmittance (VT) to SHGC (VT/SHGC) is not changed

[1] Detailed market data from https://www.ducker.com/ were processed by the SSPC90.1 Envelope Subcommittee.

by the addendum, the new SHGC values result in different VT inputs in the prototypes.

Table B.1. Weighting Factors of Different Windows Categorized in 90.1-2016 and 90.1-2019

	Vertical fenestration categories in 90.1-2016			Vertical fenestration categories in 90.1-2019	
Building Prototype	Nonmetal	Metal - Fixed	Metal - Operable	Fixed	Operable
Small Office	2.5%	95.7%	1.8%	96.9%	3.1%
Medium Office	2.5%	95.7%	1.8%	96.9%	3.1%
Large Office	2.5%	95.7%	1.8%	96.9%	3.1%
Stand-alone Retail	2.6%	96.2%	1.2%	97.8%	2.2%
Strip Mall	2.6%	96.2%	1.2%	97.8%	2.2%
Primary School	7.5%	86.6%	5.8%	89.8%	10.2%
Secondary School	7.5%	86.6%	5.8%	89.8%	10.2%
Outpatient Healthcare	3.1%	94.6%	2.3%	95.9%	4.1%
Hospital	3.1%	94.6%	2.3%	95.9%	4.1%
Small Hotel	5.8%	89.7%	4.5%	92.0%	8.0%
Large Hotel	5.8%	89.7%	4.5%	92.0%	8.0%
Non-Refrigerated Warehouse	2.4%	96.1%	1.5%	97.4%	2.6%
Quick Service Restaurant	2.6%	96.2%	1.2%	97.8%	2.2%
Full Service Restaurant	2.6%	96.2%	1.2%	97.8%	2.2%
Mid-Rise Apartment	17.3%	68.7%	14.0%	75.4%	24.6%
High-Rise Apartment	17.3%	68.7%	14.0%	75.4%	24.6%

B.2 Heating, Refrigerating, and Air-Conditioning Addenda

B.2.1 Addendum *a*: Outdoor and Return Dampers

Addendum Description. Addendum *a* makes a few clarification changes such as modifying the term “ventilation air” to “outdoor air.” It also improves energy efficiency by requiring return dampers to meet Table 6.4.3.4.3, which means a lower leakage rate from return air to supply air than Standard 90.1-2016. This improves economizer operation by increasing the outside air entering the system during economizer mode, as leaky return air dampers result in mixing of some return air back into the mixed air, even when dampers are fully closed. In addition, an exception is added to Section 6.4.3.4.2. Without this exception, a system with continuous ventilation intake needs to have an outdoor air damper, which creates a pressure drop. With the exception, such a system without the outdoor air damper would have lower pressure drop and therefore less fan energy consumption.

Modeling Strategy. When air-side economizers are modeled in single-zone unitary systems in the baseline prototypes, their maximum fraction of outdoor over design supply air is modeled to be 70% based on field measurements for unitary systems (Davis et al. 2002), which limits the maximum outdoor air flow during economizer operation. With the lower leakage damper required by the addendum, the improvement in the economizer option is modeled as an increase in the maximum outdoor air fraction from 70% to 75%, which is approximated based on the relationship between damper leakage rates and opening positions of sample products. The savings were only captured for single-zone systems with economizers. In some systems, the design outdoor air flow fraction is already higher than 70% due to zone exhaust or ventilation needs; therefore, the impacts of the addendum on these systems are not modeled. Similarly, for multiple-zone variable air volume (VAV) systems, the modeled maximum outdoor air fraction is already 100%; therefore, the impacts on these are not captured.

Although the added exception to Section 6.4.3.4.2 could theoretically result in a pressure drop reduction for fans with continuous operation, the Fan Power Limitation calculation method is used in the prototypes to calculate the fan pressure drop, which only allows pressure adjustments for devices listed in Table 6.5.3.1-2 Fan Power Limitation Pressure Drop Adjustment. Because the outdoor air dampers are not in the table, the energy savings impacts were not captured.

B.2.2 Addendum *g*: Occupied Standby Controls

Addendum Description. Standard 90.1-2016 Section 9.4.1.1 (see Table 9.6.1) already requires occupancy sensors for lighting control in certain spaces, but the available occupancy status is not required to control heating, ventilating, and air conditioning (HVAC) systems except for hotel/motel guest rooms (see Section 6.3.3.3.5). Standard 62.1-2016, referenced by Standard 90.1-2019, introduced a new definition for occupied-standby mode: when a zone is scheduled to be occupied and an occupant sensor indicates zero population within the zone. It now allows outside air ventilation to be shut off in occupied-standby mode for many occupancy categories including office and conference/meeting spaces (see Note H in Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone in Standard 62.1-2016). Addendum *g* requires zones that already have occupancy sensors and qualify for the occupied-standby mode to automatically enter an occupied standby mode, during which the zones should have a heating and cooling thermostat setback of 1°F and should completely shut off HVAC supply air within the deadband.

Addendum *g* provides energy savings for VAV systems by significantly reducing deadband airflow and thereby reducing fan, cooling, and reheat energy during the occupied-standby mode. Before this addendum, the full minimum amount of air was delivered to empty zones during the occupied-standby mode, resulting in excessive reheat to maintain temperature. Energy is saved by reducing reheat, primary air cooling, and fan use for unneeded airflow. Single-zone, dedicated outdoor air systems (DOAS) and other HVAC systems experience similar savings through shut off of airflow to temporarily unoccupied spaces unless there is a demand for thermal conditioning.

Modeling Strategy. Each thermal zone in the prototypes is mapped to an occupancy category defined in Table 6.2.2.1 in Standard 62.1-2016 and a space type defined in Table 9.6.1 in Standard 90.1-2019. The two were crossed checked to identify the zones that are required to have occupancy sensors for lighting control and their occupancy category qualifies for occupied-standby mode. They include enclosed office, conference/meeting, corridor, and lobby spaces. Because lobby and corridor spaces are not expected to be often in occupied-standby mode, the savings to these were ignored. For prototypes without detailed space type zoning such as the three office prototypes, selected zones were designated to represent the collective impacts on the prototypes.

The occupancy schedules of the impacted zones were adjusted to have a few hours of occupied-standby mode per day as baseline enhancements based on occupancy profile data from literature and engineering judgment. In the advanced models, the thermostat schedules were set to have the setback of 1°F during the standby hours. During occupied-standby mode, the single-zone HVAC systems were modeled with the supply air flow cycling with thermal load and not providing ventilation. For multiple-zone VAV systems, standby mode was modeled with the minimum VAV box damper position and the zone ventilation set to zero that results in system outdoor air flow reduction through the Ventilation Rate Procedure. The impacted prototypes include Small Office, Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, Small Hotel, Mid-Rise Apartment, and High-Rise Apartment.

B.2.3 Addenda *h and ay*: ERV Sizing and Residential Energy Recovery

Addendum Description. Standard 90.1-2016 already has requirements for exhaust air energy recovery for ventilation systems based on the design supply fan airflow rate and the ratio of outdoor airflow rate to fan supply airflow rate at design conditions. Dwelling units are subject to the criteria in Table 6.5.6.1-2 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year. There has been confusion as to whether heating or cooling design should be used for sizing an energy recovery ventilator (ERV).

Addendum *h* clarifies that the ERV equipment should meet the greater enthalpy recovery ratio (ERR) of either heating or cooling, unless one mode is specifically excluded for the climate zone by exception. This addendum is primarily a clarification.

Addendum *ay* provides new requirements for the nontransient dwelling unit (apartment) ERV that are distinct from other commercial buildings. Dwelling unit energy recovery uses different equipment than general commercial spaces and has a different cost effectiveness, so the addenda resulted in the ERV being required in more climate zones than under the commercial requirements. Based on the SSPC 90.1 analysis, climate zone 3C is completely exempt, while the energy recovery device selection is based on heating only in climate zones 4 through 8 and cooling only in climate zones 0 through 2. Climate zones 3A and 3B must meet both heating and cooling requirements. Smaller apartments—less than 500 square feet—are exempt in climate zones 0 through 3 and 4C and 5C.

The ERV provides energy savings by pre-heating or pre-cooling incoming outside air for ventilation using the heat energy in the exhaust air stream. Pre-treatment of the outside air reduces the energy use by the heating and cooling systems. While there is some increase in fan energy use, this is partially offset by reduced exhaust fan operation for ventilation. Overall, in the climate zones where it is required, exhaust air energy recovery will save more heating and cooling energy than the fan energy increase. The addendum specifies an enthalpy recovery ratio of at least 50% at cooling design conditions and at least 60% at heating design conditions. There are several exceptions to these requirements. The addendum increases the number of climate zones and situations where exhaust air energy recovery is required in apartments, dormitories, and residential institutions.

Modeling Strategy. All apartment units modeled in the Mid-Rise Apartment and High-Rise Apartment prototypes meet the definition of nontransient dwelling unit and their sizes are all above 500 square feet. Continuous ventilation of 55 cubic feet per minute (cfm) is provided to each dwelling unit. To better represent the typical design practice, the prototypes were recently modified from supplying ventilation airflow through the unitary air conditioner in the Mid-Rise Apartment and the water source heat pump for the High-Rise Apartment to having a local exhaust-driven ventilator in each unit. In the enhanced models, space conditioning systems cycle with thermal loads. The ventilator fan airflow rate (i.e., the outdoor airflow rate) is 55 cfm. Without an ERV, the fan power of the ventilator is estimated to be 44 Watts per unit, which is modeled with fan efficiency and pressure drop inputs in the simulation model. When an ERV is installed, an additional pressure drop is approximated to result in added fan power of 51 Watts based on a review of residential heat/energy recovery ventilator products.

The baseline prototypes, as shown in Table B.2, are required to have heat recovery ventilators (HRV) or ERVs in colder and dry climate zones. Addendum *ay* now requires all dwelling units to have ERVs except for climate zone 3C, and it also has different minimum ERRs for heating and cooling, as summarized in Table B.2.

EnergyPlus requires inputs in terms of heat recovery effectiveness. In order to convert the ERR values at local design conditions to effectiveness, representative data from equipment manufacturers with both ERR and effectiveness were reviewed. Both Addenda *h* and *ay* specify ERR at the local design condition rather than at an Air Conditioning, Heating, and Refrigeration Institute (AHRI) standard rating condition. Some adjustment factors from rated ERR to that at the local design conditions were derived from the product review, and these were used to calculate climate-specific heat recovery effectiveness inputs as shown in Table B.3.

Table B.2. The Modeled ERVs in the Mid-Rise and High-Rise Apartments for 90.1-2016 and 90.1-2019

Climate zones	90.1-2016 Table 6.5.6.1-2	90.1-2019 Section 6.5.6.1.1		
	Required	Required	Enthalpy recovery ratio (ERR)	
			Cooling	Heating
0A	No	Yes	50%	No minimum
0B	No	Yes	50%	No minimum
1A	No	Yes	50%	No minimum
1B	No	Yes	50%	No minimum
2A	No	Yes	50%	No minimum
2B	No	Yes	50%	No minimum
3A	No	Yes	50%	60%
3B	No	Yes	50%	60%
3C	NR	Exempt	NA	NA
4A	Yes	Yes	No minimum	60%
4B	No	Yes	No minimum	60%
4C	No	Yes	No minimum	60%
5A	Yes	Yes	No minimum	60%
5B	No	Yes	No minimum	60%
5C	No	Yes	No minimum	60%
6A	Yes	Yes	No minimum	60%
6B	Yes*	Yes	No minimum	60%
7	Yes*	Yes	No minimum	60%
8	Yes*	Yes	No minimum	60%

* Even though cooling energy recovery is exempted, the installed HRV for heating will save sensible cooling energy.

Table B.3 Heat Recovery Effectiveness for Standard 90.1-2016 and 90.1-2019 Based on Required Design EER for Mid-Rise and High-Rise Apartment Prototypes

	90.1-2016		90.1-2019			
Climate zones	4A, 5A, 6A	6B, 7, 8	0, 1, 2A, 3A	2B	3B	4 thru 8
Design condition used for sizing ERR	Cooling	Heating	Cooling	Cooling	Cooling	Heating
Required ERR at local design conditions	50%	50%	50%	50%	50%	60%
Sensible Eff. at 100% Heating Air Flow	0.67	0.50	0.67	0.63	0.62	0.60
Latent Eff. at 100% Heating Air Flow	0.45	0.00	0.45	0.38	0.35	0.00
Sensible Eff. at 75% Heating Air Flow	0.70	0.53	0.70	0.67	0.66	0.62
Latent Eff. at 75% Heating Air Flow	0.50	0.00	0.50	0.43	0.40	0.00
Sensible Eff. at 100% Cooling Air Flow	0.66	0.50	0.66	0.62	0.61	0.60
Latent Eff. at 100% Cooling Air Flow	0.41	0.00	0.41	0.33	0.31	0.00
Sensible Eff. at 75% Cooling Air Flow	0.69	0.52	0.69	0.66	0.64	0.62
Latent Eff. at 75% Cooling Air Flow	0.45	0.00	0.45	0.38	0.35	0.00

B.2.4 Addendum *k*: Hotel/Motel HVAC Guest Room Controls

Addendum Description. Standard 90.1-2016 already requires hotel/motel guest rooms to have automatic setback thermostat setpoint and shut off ventilation for rooms that are either rented and unoccupied, or unrented and unoccupied. Addendum *k* clarifies the language by calling out the two modes with the same intent, and the clarification does not have quantifiable energy impacts. The addendum saves a little bit more energy by reducing the time-out period for unoccupied indication from 30 minutes to 20 minutes. Consequently, there will be 10 minutes more per cycle with reduced ventilation and setback heating and cooling, reducing energy use.

Modeling Strategy. The baseline Small Hotel and Large Hotel prototypes were already modeled to meet the control requirements through thermostat and ventilation schedules. The schedules in their advanced models were slightly adjusted to capture the added savings from the reduced time-out period.

B.2.5 Addenda *v* and *bd*: Heat Recovery Chiller and Its Efficiency

Addendum Description. Addendum *v* adds a new code section that requires acute inpatient hospital mechanical systems to include heat recovery for space conditioning in all climate zones except 6B, 5C, 7 and 8. The requirement is limited to hospitals that include spaces that are used on a 24-hour basis and have an installed total design chilled water capacity at design conditions that exceed 300 tons (1,100 kW). The cooling capacity of the heat recovery system is required to be 7% of the total design chilled water capacity at peak design conditions.

Addendum *bd* adds new minimum performance requirements for air- and water-cooled heat pump chillers. The new requirements are split between two categories: cooling-only performance and heating operation. While cooling-only requirements have been defined as being the same as defined in Table

6.8.1-3 less 5% (to take into account the impact of additional hardware needed for heat recovery), the heating performance of these machines is described by three new metrics defined in AHRI Standard 550/590: heating coefficient of performance (COP_H), heat recovery coefficient of performance (COP_{HR}) and simultaneous heating and cooling coefficient of performance (COP_{SHC}).

Modeling Strategy. The only prototype that is targeted by the language in Addendum *v* is the Hospital. As per the addendum description, since the total design chilled water capacity at design conditions exceeds 300 tons in all climate zones, heat recovery chillers were modeled in all Hospital models except in 6B, 5C, 7 and 8.

Different configurations can be employed with a heat recovery chiller, such configurations include "preferential loading" or "sidestream." In the "preferential loading" configuration, the chiller is in parallel with the other chillers, whereas in the "sidestream" configuration, the heat recovery chiller is placed in series, ahead of the other chillers; it pre-cools some of the water returning from the cooling coils. This configuration is typically preferred and hence was chosen for modeling the impact of Addendum *v*.

Heat recovery chillers can have a single or a double condenser bundle. The former allows the chiller to transfer the condenser heat to a hot water loop, whereas the latter allows the chiller to transfer heat to both a hot and a condenser water loop. By having the ability to reject heat to a condenser loop, the chiller heat transferred to the hot water loop can be modulated to not operate above a specific inlet water temperature and/or controlled to meet a setpoint. A double-bundled chiller was modeled to estimate the impact of Addendum *v*.

In EnergyPlus, most chiller objects have heat recovery capabilities whether it is through the condenser bundle or through a dedicated heat recovery bundle (double-bundled chiller). To model such a configuration, that is a "sidestream" double-bundled chiller, heat is recovered from the chiller through a dedicated heat recovery loop which is transferred to the hot water loop using an ideal water heater with (with 100% efficiency, acting as an ideal fluid-to-fluid heat exchanger). The second bundle of the chiller is connected to the condenser water loop.

To benefit from heat recovery, a hot water loop setpoint reset strategy was implemented: 140°F at 20°F outdoor air dry-bulb temperature moving linearly to 120°F at 50°F outdoor air dry-bulb temperature. A reset strategy was also implemented for the chilled water loop: 44°F at 70°F outdoor air dry-bulb moving linearly to 48°F at 55°F outdoor air dry-bulb. Ideally, the heat recovery chiller operation would be controlled based on the desired water temperature leaving the heat recovery bundle, but this strategy is not currently available in EnergyPlus. As a solution, the heat recovery chiller was simulated to provide a maximum water temperature of 120°F and controlled based on the return water temperature and hot water loop load relative to the chiller heat recovery output to minimize excess heat rejection. This control strategy was implemented in an EnergyPlus energy management system (EMS) program.

B.2.6 Addendum *ap*: SAT Reset

Addendum Description. HVAC systems with simultaneous heating and cooling (typically multiple-zone VAV systems) were previously required to provide supply air temperature (SAT) reset except in climate zones 0A through 3A. In these climate zones, several approaches can successfully dehumidify the outside air while still providing SAT reset and reducing reheat energy use. Addendum *ap* extends the requirement for SAT reset to the warm and humid climate zones where it was previously excepted. The dehumidification requirements of addendum *ap* can be met with either a separate outside air cooling coil or alternative approaches including bypassing return air around the cooling coil, a dedicated outside air system, or series heat recovery.

Units smaller than 3000 cfm are excepted from SAT reset in climate zones 0A, 1A and 3A, with units smaller than 10,000 cfm excepted in 2A. There are also requirements that the system is designed to allow simultaneous SAT reset and dehumidification with one of the strategies discussed above.

Supply air temperature reset saves significant heating energy in VAV reheat systems that require minimum airflow for ventilation. That savings is higher in northern climate zones than in climate zones 0A through 3A, which were previously excepted because outside air dehumidification—typically performed with a low dewpoint on the supply air—is required much of the year. Dehumidification can be achieved more efficiently by separately dehumidifying the outside air, as it reduces the total volume of air that must be cooled, significantly reducing cooling energy use in all the warm and humid climate zones and allowing SAT reset that reduces reheat energy use.

Modeling Strategy. Seven prototypes have multiple-zone VAV systems, and only Hospital and Outpatient Healthcare include a few air handling units (AHUs) with active dehumidification control modeled with a zone humidistat that triggers the central cooling coils to reduce the setpoint, increasing latent cooling during dehumidification. These AHUs are not modeled with SAT reset for all climates because its interaction with the dehumidification controls and the energy use cannot be captured using the prototype models without significant custom modeling and testing. All other VAV systems are modeled with SAT reset except for 0A, 1A, 2A, and 3A, which meet the current SAT reset requirements and exceptions in Standard 90.1-2016.

To capture the savings to the AHUs without active dehumidification control, the sample HVAC system designs in the Informative Note in Addendum *ap* were not used. It was found that simply adding outdoor-air-temperature-based SAT reset controls to the VAV AHUs in Climate Zones 0A, 1A, 2A, and 3A was sufficient to estimate savings and did not cause much increase to the indoor humidity level.

B.2.7 Addenda *au*, *cm*, and *co*: DDC VAV Minimum Damper and Simplified Ventilation Procedure

Addendum Description. Addendum *co* reflects the periodic update of Standard 90.1 normative references. It updates many references with new effective dates and adds some new references. One of them (i.e., the Addendum *f* to Standard 62.1-2016, Ventilation for Acceptable Indoor Air Quality), in particular, creates a “Simplified Procedure” to determine system ventilation efficiency. Addenda *au* and *cm* take advantage of the changes in Standard 62.1 to reduce the minimum airflow required in VAV boxes and outdoor air intake of the AHUs; hence, these reduce energy used to condition outdoor air intake and reheat of cooled primary air.

Addenda *au* and *cm* refer to this new minimum primary airflow rate to replace the provision in Standard 90.1 that allows VAV box minimum setpoints to be 20% of the design supply air rate. Outdoor air rates for zones with moderate occupancy density, such as offices, are generally much lower than 20% of the design supply air rate, but designers often need a higher percentage or an oversized VAV box when they follow the system ventilation efficiency specified in Standard 62.1 and its Normative Appendix A Multiple-zone System Ventilation Efficiency. With these addenda, Appendix A in Standard 62.1 becomes an alternative to the Simplified Procedure, by which designers no longer need to calculate what minimum rates are required using the multiple spaces equations in Appendix A. They now can set the minimum primary airflow to be 1.5 times the ventilation zone airflow. The system ventilation efficiency from the Simplified Procedure is generally higher than that calculated using Appendix A, which means the outdoor air intake through the AHU is less. Moreover, using percentages to determine minimums is problematic because VAV boxes are almost always oversized due to conservative load assumptions for occupants, lights, plug loads, etc. It is not unusual for boxes to be sized three or more times larger than they need to be, as was found in ASHRAE RP-1515 “Thermal and air quality acceptability in buildings that reduce energy by reducing minimum airflow from overhead diffusers.” (Arens et al. 2015) RP-1515 showed that even if the minimums were set to 20% instead of 30%, excess minimum air would have been supplied due to the oversized cooling maximum box sizing, wasting fan energy, reheat energy, and cooling energy.

In summary, Addenda *au* and *cm* save energy by 1) reducing outdoor air intake at the central system; and 2) reducing the actual airflow minimums in VAV boxes using the cfm-based approach rather than percentage-based minimums previously used in 90.1. When the minimum airflow in VAV boxes is reduced, less air volume needs to be reheated, saving both cooling and heating energy.

Modeling Strategy. There are 7 prototype buildings with multiple-zone VAV systems (i.e., Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, and Hospital). Section 2.2.6 in the PNNL report *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (Goel et al. 2014) describes the modeling strategy used in the baseline prototypes to calculate system ventilation efficiency using Appendix A of Standard 62.1-2013. Where the efficiency is lower than 0.6, VAV box minimums of the critical zones are adjusted from 20% to be higher values to reach a target efficiency of 0.6. Then, the design outdoor air intake is determined using this efficiency and can be dynamically reset during the operation using the dynamic efficiency reflecting the zone loads at each time step. For VAV systems serving low occupancy density zones, the VAV box minimums remain at 20%.

In the advanced prototypes, the VAV box minimum, system ventilation efficiency, and design and operation outdoor air intake are based on different calculations as required by Addenda *au* and *cm* and the referenced Addendum *f* to Standard 62.1-2016. The VAV box minimum ($V_{pz\text{-}min}$) is changed to

$$V_{pz\text{-}min} = V_{oz} \times 1.5$$

Where,

$V_{pz\text{-}min}$ is minimum primary airflow, and

V_{oz} is ventilation zone airflow.

The Simplified Procedure allows the system ventilation efficiency and the corresponding outdoor air intake flow to be determined in accordance with the following equations

$$E_v = 0.88 * D + 0.22 \text{ for } D<0.60$$

$$E_v = 0.75 \text{ for } D \geq 0.60$$

$$V_{ot} = V_{ou} / E_v$$

Where,

E_v is the system ventilation efficiency, and

D is the occupancy diversity ratio,

V_{ot} is the design outdoor air intake flow

V_{ou} is the uncorrected outdoor air intake.

To simplify the calculation, we assumed D always to be greater than 0.6 for all VAV systems in the prototypes. The change in E_v from 0.6 to 0.75 results in a significant reduction in the design outdoor air intake flow. Although both editions require Multiple-Zone VAV System Ventilation Optimization Control, also known as dynamic ventilation reset, in Section 6.5.3.3 of Standard 90.1, the design outdoor air intake flow serves a maximum outdoor air, which leads to energy reduction. The dynamic ventilation reset can be modeled using native EnergyPlus controls, which are able to follow the Normative Appendix A Multiple-zone System Ventilation Efficiency in Standard 62.1-2016 during the operational hours.

PNNL consulted with the SSPC 90.1 Mechanical Subcommittee experts and clarified that Appendix A is intended to be used during building operation for 90.1-2019. The reduced design outdoor air intake flow V_{ot} calculated with the Simplified Procedure should be used as the maximum outside airflow for the dynamic ventilation reset, except for economizer mode, and the maximum is implemented in the prototypes through an EMS program.

B.2.8 Addendum *be*: CRAC Unit Efficiencies

Addendum Description. Addendum *be* clarifies that the computer room air conditioners listed in Table 6.8.1-11 are floor mounted computer room units. Efficiency requirements were modified to align with current industry levels. The addendum also adds a new Table 6.8.1-19 that covers small ceiling-mounted computer room units.

Modeling Strategy. Computer rooms and IT closets were added to the Large Office prototype as part of an enhancement in 2014 (Goel et al. 2014). Computer room air conditioning (CRAC) units were modeled as water source heat pumps (WSHP) to simulate a water-cooled air conditioner during its debut into the prototypes, and the modeled efficiency was based on Standard 90.1-2010 efficiency requirements. Seasonal coefficient of performance (SCOP) was converted to coefficient of performance (COP) inputs along with performance curves that correspond to the WSHP configurations used in EnergyPlus.

The CRAC unit efficiency requirements were introduced in 90.1-2010 and were updated in 2013 and 2016; however, these interim changes were not included in the prior analysis because there was pending federal rulemaking. The analysis of Addendum *be* includes the change to the 90.1-2019 efficiencies. The baseline and improved COP for the CRAC units in the basement computer rooms and IT closets is based on typical equipment sizes used in data centers, even though the EnergyPlus model thermal zoning grouped areas that would be served by multiple CRAC units into a large thermal zone and modeled them as one unit.

This addendum saves energy by reducing the compressor energy needed to transfer heat from the data center area and reject it outside. Because there is less compressor heat to reject, there is also a reduction in the fan use in the dry cooler that provides heat rejection for the water cooled CRAC units.

B.2.9 Addendum *bq*: Heat Rejection Efficiency

Addendum Description. Addendum *bq* raises the minimum efficiencies for axial and centrifugal fan evaporative condensers due to a change in the rating fluid to R-448A from R-507A, with R-448A having a lower Global Warming Potential (GWP). The addendum also adds axial fan, air cooled fluid coolers (better known as dry coolers) to Table 6.8.1.7. The addendum saves energy for buildings with heat rejection equipment.

Modeling Strategy. The minimum efficiency requirement for dry coolers introduced by this addendum impacts the Large Office prototype. The dry cooler in the Large Office prototype is modeled using the FluidCooler:TwoSpeed object. Since the dry cooler efficiency is not a direct EnergyPlus input, modeled efficiency must be calculated as:

$$\text{Dry Cooler efficiency} = \text{pump (gpm)} / \text{fan (bhp)},$$

Where,

$$\text{fan(bhp)} = \text{fan (hp at high speed)} * 0.9.$$

The pump flow rate is dependent on the loads it serves, and the dry cooler serves the computer rooms and IT closets, in which the loads remain relatively constant across different climate zones. Per suggestions from SSPC 90.1 Mechanical Subcommittee experts, the baseline efficiency is assumed to be 4.0 gpm/hp and that for the advanced model is 4.5 gpm/hp based on Addendum *be*.

B.3 Lighting Addenda

B.3.1 Addenda *bb* and *cg*: LPD Values

Addendum Description. Addendum *bb* modifies the lighting power density (LPD) allowances using the space-by-space method. This addendum results in changes in Table 9.6.1. Addendum *cg* modifies the lighting power allowances using the building area method. The values from Addendum *bb* (Table 9.6.1, space-by-space) were used by the SSPC 90.1 Lighting Subcommittee to update Table 9.5.1, building area method as part of Addendum *cg*. The changes in LPD are the result of improving lighting technology, changes in lighting baseline (model is 100% LED), changes to Illuminating Engineering Society (IES) recommended light levels, changes to space geometry assumptions, and additional room surface reflectance values. The addenda save energy in multiple ways. There is direct lighting power reduction. In addition, the reduced lighting power reduces the internal gains which reduces cooling loads and saves cooling energy. In some climate zones, the reduction in lighting power results in an increased need for heating during colder outside conditions, so there may be an increase in heating energy use. These three impacts are combined for a net savings of building energy.

Modeling Strategy. Addenda *bb* and *cg* collectively affect all prototypes. The following describes how the appropriate LPD allowance is chosen for the prototype buildings:

1. The Large Office, Medium Office, and Small Office prototypes use the office building LPD allowance from the building area method (Table 9.5.1). Similarly, the basement zone in the Large Hotel, Hospital, and the office zone in the Non-refrigerated Warehouse use the LPD allowance from the building area method.
2. Most other zones in the prototypes are mapped to a single space-by-space category and the LPD allowance from that category is used directly.
3. A few zones in the prototypes (for example, the Back Space zone in the Stand-alone Retail prototype) are considered a mix of two or more space types; in such cases, the NC3 database (Richman et al. 2008) is used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single LPD allowance for those spaces.
4. A room cavity ratio adjustment has been applied to a few spaces such as corridors, and exercise rooms.

Using these rules and the values in Addenda *bb* and *cg*, the LPD allowances for all prototypes and zones were determined. The design LPD allowance is modeled in EnergyPlus as a direct input to the zone general lighting object.

B.3.2 Addendum *cw*: Continuous Dimming Control

Addendum Description. Addendum *cw* changes daylight responsive requirements from either continuous dimming or stepped dimming to continuous dimming for all spaces. This measure saves energy because a stepped control cannot switch to the next lower power level until enough daylight is available to maintain the desired light level. This results in a period between steps where more than the required light level is maintained, resulting in a higher average power level that would be achieved with continuous dimming that adjusts the power smoothly to maintain just the needed lighting level. There is also a modest impact on HVAC energy use similar to the LPD reduction addenda.

Modeling Strategy. Several prototype models already have stepped daylighting control for either top lighting or side lighting, including Small, Medium, and Large Offices, Stand-alone Retail, Primary and Secondary Schools, Outpatient Healthcare, Hospital, Small and Large Hotels, Warehouse, and Quick

Service and Full Service Restaurants. This addendum affects all of them. The control type in the Energyplus prototype was changed from three steps (i.e., power fraction of 0.66, 0.33, and 0) to ContinousOff (proportionally reduces the lighting power as the daylight increases until a minimum power fraction of 0.2). The lights will be completely off when the daylight reaches the target illuminance level.

B.4 Appendix B References

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Significant changes 2013-2016 ASHRAE 90.1 Commercial Provisions

[Sources: ASHRAE 90.1-2016 and PNNL-SA-127543]

- Standard reformatted for ease of use
- New Climate maps (to align with ASHRAE 169) [5.1.4.1]
    - 16 Ohio counties will change from Zone 5A to Zone 4A [Annex 1]
- Adds a new path to demonstrate compliance – Performance Rating Method [4.2.1.1 (c) and Appendix G]

Building Envelope

- Air Leakage Verification requirements added [5.4.3.1.3 and 5.9.2.2]
    - Whole building pressurization test for air leakage
    - Continuous air barrier installation inspection and verification during construction
- Increased testing requirements for air leakage of overhead coiling doors [A7.1]
- Increased stringency requirements for fenestration and opaque doors [Table 5.5-4, Table 5.5-5, and 5.5.3.6]
- Clarified topics such as building orientation [5.5.4.5], default assumptions for the effective R-value of air spaces [A9.4.2], and calculation procedures for insulating metal building walls [A3.2.2, Table A3.2.3, A9.4.6]

Mechanical

- Increased equipment efficiencies for chillers, heat pumps, computer room AC, Dedicated Outdoor Air Systems (DOAS), Rooftop AC, Cooling Towers, and Variable Refrigerant Flow
- Clarified that control must be "configured to" meet the requirements, not just be "capable of" meeting the requirements [throughout]
- New HVAC set point and fan control requirements for hotel and motels with greater than 50 guest rooms [6.4.3.3.5]
- Adds HVAC control requirements for cooled vestibules [6.4.3.9]
- Large, electric-driven chilled-water plants are required to be monitored for electric energy use and efficiency [6.4.3.11]
- Air-cooled DX cooling units with economizers are required to have a Fault Detection and Diagnostics (FDD) monitoring system to determine that the air economizer is working properly [6.4.3.12]
- Adds control requirements for return and relief fans [6.5.3.2.4]
- Adds control requirements for parallel-flow fan-powered VAV air terminals [6.5.3.4]
- Dedicated outdoor air systems (DOAS) now include both efficiency and rating requirements for compliance [6.5.3.7]
- Adds pump flow control requirements for chilled and hot water hydronic piping distribution systems [6.5.4.2]
- Adds new requirements for the selection of chilled-water cooling coils [6.5.4.7]
- Prescribes motor fan speed controls for heat-rejection devices [6.5.5.2]
- Adds new requirements for transfer air delivered to a space having mechanical exhaust [6.5.7]

Service Water Heating

- Adds a new requirement for insulation of the first 8 ft of branch piping connections to recirculated, heat traced, or impedance heated service hot-water piping systems [7.4.3]

Power

- Limits the combined voltage drop of feeder conductors and branch circuits to 5% [8.4.1]
- Increased three-phase transformer efficiencies [Table 8.4.4]

Lighting

- Interior and exterior lighting power allowance have been modified (reduced) to reflect new lighting levels in the IES lighting handbook and to recognize LED technology [9.2.2.3 and 9.4.2]
- Lighting control requirements have been modified to add additional controls in some space types and options to others to allow easier application of advanced controls [9.4.1]
    - Reduce exterior lighting power by 50% (previously was 30%) during periods of inactivity or after business hours [9.4.1.4]
    - Certain outdoor parking areas required to reduce power by 50% during periods of inactivity [9.4.1.4]
- Adds a requirement that 75% of permanently installed dwelling unit lighting fixtures use high efficacy lamps [9.4.4]

Other Equipment

- Updates electric motor terminology, adds exceptions, and adds efficiency tables consistent with federal regulations [10.4.1]
- Elevator efficiency specifications are required to be provided on design documents, including both usage category and energy efficiency class. While a minimum threshold is not listed, the first step is taken toward including minimum elevator efficiency requirements in a future standard [10.4.3.4]

Energy Cost Budget Method (ECB)

No significant changes

Performance Rating Method (Appendix G)

- Appendix G now can be used as a path for compliance with the standard. Previously, Appendix G was used only to rate beyond-code performance of buildings
- The proposed design requires computation of a new metric, Performance Cost Index (PCI), and demonstration that it is less than that shown in Table 4.2.1.1, based on building type and climate zone
- The baseline design is now fixed at a certain level of performance, the stringency or baseline of which is expected not to change with subsequent versions of the standard. In this way, a building of any era can be rated using the same method
- Other modifications to Appendix G include changes to elevator, motor, and refrigeration baselines; changes to the baseline for existing building projects; and changes to specific opaque assemblies for the baseline envelope model. Modeling rule changes were made to heat pump auxiliary heat, economizer shutoff, lighting controls, humidification systems, cooling towers, and the simulation of preheat coils

MEMORANDUM

Pacific Northwest NATIONAL LABORATORY

Date:	**6/12/2019**		
To:	**Debbie Ohler**	Information Release #	**PNNL-SA-144221**
From:	**Matthew Tyler**		
Subject:	**Preliminary Cost-Effectiveness of ASHRAE Standard 90.1-2016 for the State of Ohio**		

Moving to the ASHRAE Standard 90.1-2016 edition from Standard 90.1-2010 is expected to be cost-effective for the State of Ohio. This assessment of cost-effectiveness is based on expected changes in construction cost related to energy savings analyzed for similar climate zones. The analysis is based on a larger study (not yet published) that evaluates six building prototypes[1] and five of the 16 climate zones present in the United States.

Climate zones are defined in ASHRAE Standard 169, with the hottest being climate zone 0 and the coldest being climate zone 8. Letters A, B, and C are applied in some cases to denote the level of moisture, with A indicating moist or humid, B indicating dry, and C indicating marine.

Of the five climate zones analyzed, Climate Zones 4A and 5A are in Ohio. Climate Zone 4A is in southern Ohio, while Climate Zone 5A is in central and northern Ohio.

The analysis included the following six building prototypes: small office, large office, standalone retail, primary school, small hotel, and mid-rise apartment.

Life Cycle Cost (LCC) savings is the primary measure DOE uses to assess the economic impact of building energy codes. Net LCC savings is the calculation of the present value of energy savings minus the present value of non-energy incremental costs over a 30-year period. The costs include initial equipment and construction costs, maintenance and replacement costs, less the residual value of components at the end of the 30-year period. When net LCC is positive, the updated code edition is considered cost-effective.

Two LCC scenarios[2] are analyzed with the inputs shown in Table 1 and the differences are outlined here:

- Scenario 1: represents publicly-owned buildings, considers initial costs, energy costs, maintenance costs, and replacement costs without borrowing or taxes. These LCC results per square foot are shown in Table 2 by building type and climate zone.

[1] https://www.energycodes.gov/development/commercial/prototype_models
[2] https://www.energycodes.gov/commercial-energy-and-cost-analysis-methodology

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- Scenario 2: represents privately-owned buildings, adds borrowing costs (financing of the incremental first costs) and tax impacts (such as mortgage interest and depreciation deductions using corporate tax rates). These LCC results per square foot are shown in Table 3 by building type and climate zone.

The energy prices used in the analysis are:

- Electricity price: $0.0993/kWh
- Natural gas price: $0.5637/therm

These prices are the state average commercial energy costs for January 2018 through December 2018. This is a weighted average by monthly retail sales of electricity and natural gas for commercial buildings in Ohio. The prices and sales data are from the United States Energy Information Administration (EIA) *Electricity Power Monthly* and *Natural Gas Monthly.*[3,4]

Table 4 below shows the economic impact of upgrading to Standard 90.1-2016 by building type and climate zone in terms of the annual energy cost savings in dollars per square foot. Table 5 shows the additional construction cost per square foot required by the additional energy code requirements.

The added construction cost is negative for some building types, which represents a reduction in first costs and a savings that is included in the net LCC savings. This is due to the following:

- Fewer light fixtures are required when the allowed lighting power is reduced. Also changes from fluorescent to LED technology results in reduced lighting costs in many cases and longer lamp lives, requiring fewer lamp replacements.
- Smaller heating, ventilating, and air-conditioning (HVAC) equipment sizes can result from the lowering of heating and cooling loads due to other efficiency measures, such as better envelope. For example, Standard 90.1-2016 has more stringent fenestration U-factors for Climate Zones 4A and 5A. This results in smaller equipment and distribution systems, resulting in a negative first cost.

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[3] https://www.eia.gov/electricity/monthly/
[4] https://www.eia.gov/naturalgas/monthly/

Table 1. Economic Analysis Parameters

Economic Parameter	Scenario 1	Scenario 2
Study Period – Years	30	30
Nominal Discount Rate	*3.10%*	6.00%
Real Discount Rate	3.00%	4.05%
Inflation	*-0.20%*	1.87%
Electricity Price, per kWh	$0.0993	$0.0993
Natural Gas Price, per therm	$0.5637	$0.5637
Electricity and Natural Gas Price Escalation	Uniform present value factors Electric 21.94, Gas 23.69	Uniform present value factors Electric 16.16, Gas 17.45
Loan Interest Rate	NA	6.00%
Federal Corporate Tax Rate	NA	21.00%
State Corporate Tax Rate	NA	12.00%

Table 2. Net LCC Savings, Scenario 1 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment
4A	$2.54	$1.64	$14.60	$5.97	$7.36	$2.57
5A	$3.21	$1.74	$14.98	$6.43	$7.66	$3.36

Table 3. Net LCC Savings, Scenario 2 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment
4A	$1.93	$1.15	$11.57	$4.29	$5.39	$1.89
5A	$2.39	$1.25	$11.82	$4.68	$5.64	$2.52

Table 4. Annual Energy Cost Savings ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment
4A	$0.19	$0.11	$0.32	$0.39	$0.25	$0.08
5A	$0.19	$0.09	$0.31	$0.40	$0.27	$0.11

Table 5. Incremental Construction Cost ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment
4A	$2.61	$0.85	$0.43	$1.04	($1.54)	$0.03
5A	$1.83	$0.48	$0.35	$0.85	($1.42)	($0.11)

Note: The reduction in construction cost in small hotels (both climate zones) and apartments (Climate Zone 5A) is mostly due to the extended life of LED lamps vs. fluorescent lamps in the baseline.

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Energy Savings Analysis:
ANSI/ASHRAE/IES Standard 90.1-2016

October 2017

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Energy.gov/eere/buildings

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List of Acronyms

AEO	Annual Energy Outlook
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CBECS	Commercial Building Energy Consumption Survey
CFL	compact fluorescent lamp
DDC	direct digital control
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
ECI	energy cost intensity
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EMS	energy management system
ERV	energy recovery ventilator
EUI	energy use intensity
HVAC	Heating, Ventilating, and Air Conditioning
HVACR	Heating, Ventilating, Air Conditioning and Refrigerating
IEER	integrated energy efficiency ratio
IES	Illuminating Engineering Society
LPD	lighting power density
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient
SSPC	Standing Standards Project Committee
SWH	service water heating
VAV	variable air volume
VFD	variable frequency drive
VRF	variable-refrigerant-flow
VSD	variable speed drive
Wh	Watt-hour

Executive Summary

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for building energy conservation standards, administered by the DOE Building Energy Codes Program. (42 U.S.C. 6831 et seq.) Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA Standard 90.1-1989 (Standard 90.1-1989 or 1989 edition), or any successor to that code, is revised, the Secretary of Energy (Secretary) must make a determination, not later than 12 months after such revision, whether the revised code would improve energy efficiency in commercial buildings, and must publish notice of such determination in the Federal Register. (42 U.S.C. 6833(b)(2)(A))

Standard 90.1 is developed under ANSI-approved consensus procedures, and is under continuous maintenance by a Standing Standard Project Committee (commonly referenced as SSPC 90.1). ASHRAE has an established program for regular publication of addenda, or revisions, including procedures for timely, documented, consensus action on requested changes to the Standard.[1] Standard 90.1-2016 was published in October 2016, triggering the statutorily-required DOE review process.

To meet the statutory requirement, DOE conducted an analysis to quantify the expected energy savings associated with Standard 90.1-2016. This report documents the methodology used to conduct the analysis below.

Based on the analysis, DOE has determined that the 2016 edition of the ANSI/ASHRAE/IES Standard 90.1 would improve overall energy efficiency in buildings subject to the code compared to the 2013 edition of Standard 90.1.

Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analysis and determinations, and is based on a combination of *qualitative* and *quantitative* assessments:

- **Qualitative**: The first phase of analysis was a comparative review of the textual requirements of the Standard, examining specific changes (known as 'addenda') made between Standard 90.1-2016 and the previous 2013 edition. ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard, and then bundles them together to form the next published edition. Addenda with direct impact on energy use were identified, and their anticipated impact on energy use was determined.
- **Quantitative**: The second phase of analysis examined the impact of addenda having a direct impact on energy use. The quantitative phase uses whole-building energy simulation and relies upon the established DOE methodology for energy analysis, which is based on sixteen representative building types across all U.S. climate zones, as defined by Standard 90.1. Energy use intensities (EUIs) by fuel type and by end-use were developed for each building type, and weighted by the relative square footage of construction to estimate the difference between the aggregated national energy use under Standard 90.1-2013, which serves as the baseline, and Standard 90.1-2016.

Results

In creating Standard 90.1-2016, ASHRAE published 121 addenda in total, of which:

- 46 are expected to *decrease* energy use (i.e., increased energy savings);
- 5 are expected to *increase* energy use (i.e., decreased energy savings), and;
- 70 are expected to have *no direct impact* on energy savings (such as administrative or clarifications or changes to alternative compliance paths).

[1] More information on ANSI/ASHRAE/IES Standard 90.1-2016 is available at: https://www.ashrae.org/resourcespublications/bookstore/standard-90-1.

New commercial buildings meeting the requirements of Standard 90.1-2016 that were analyzed in the Quantitative Analysis exhibit national savings of approximately (compared to Standard 90.1-2013):

- 8.3 percent energy *cost* savings;
- 7.9 percent *source* energy savings, and;
- 6.8 percent *site* energy savings.

The quantitative analysis relies upon prototype buildings reflecting a mix of typical U.S. building types and construction practices. In creating its prototypes, DOE leverages recent U.S. construction data which is mapped to the commercial building types defined by the Energy Information Administration (EIA) and adapted for use by Standard 90.1. In combination with resulting building type weighting factors, the prototypes represent approximately 80 percent of the total square footage of new commercial construction (Jarnagin and Bandyopadhyay 2010).

Energy cost indices (ECIs) and EUIs by building type are shown in Table ES.1 and Table ES.2 for Standard 90.1-2013 and Standard 90.1-2016, respectively, including site and source energy. Percentage savings aggregated at the national level are shown in Figure ES.1 and analogous tables aggregated by climate zone are included in Section 4.2.

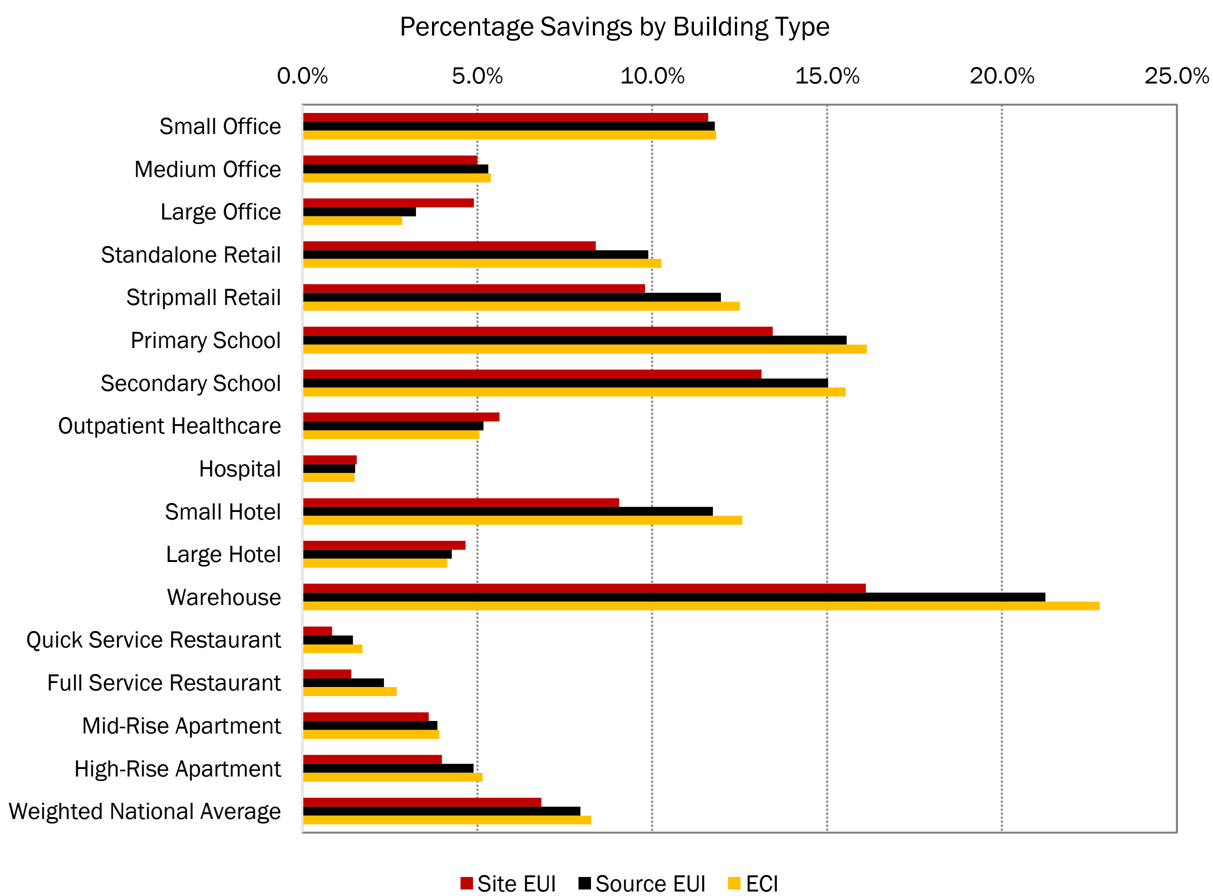

Figure ES.1. Percentage Savings by Building Type from 90.1-2013 to 90.1-2016

Table ES.1. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	29.4	85.8	$0.88
	Medium Office	6.05	33.4	93.1	$0.95
	Large Office	3.33	70.6	197.5	$2.01
Retail	Stand-Alone Retail	15.25	45.7	119.2	$1.19
	Strip Mall	5.67	57.6	152.6	$1.53
Education	Primary School	4.99	50.4	124.7	$1.23
	Secondary School	10.36	42.1	107.3	$1.07
Healthcare	Outpatient Health Care	4.37	118.8	303.6	$3.02
	Hospital	3.45	122.0	286.2	$2.78
Lodging	Small Hotel	1.72	60.5	134.6	$1.29
	Large Hotel	4.95	89.4	191.0	$1.80
Warehouse	Non-Refrigerated Warehouse	16.72	17.6	39.9	$0.38
Food Service	Quick Service Restaurant	0.59	569.5	971.8	$8.41
	Full Service Restaurant	0.66	371.3	694.9	$6.25
Apartment	Mid-Rise Apartment	7.32	43.6	123.2	$1.26
	High-Rise Apartment	8.97	47.2	113.9	$1.12
National		100.00	54.1	132.3	$1.30

Table ES.2. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	26.0	75.7	$0.78
	Medium Office	6.05	31.8	88.2	$0.90
	Large Office	3.33	67.2	191.1	$1.95
Retail	Stand-Alone Retail	15.25	41.8	107.4	$1.07
	Strip Mall	5.67	51.9	134.3	$1.34
Education	Primary School	4.99	43.6	105.3	$1.03
	Secondary School	10.36	36.6	91.2	$0.90
Healthcare	Outpatient Health Care	4.37	112.1	287.9	$2.87
	Hospital	3.45	120.1	281.9	$2.74
Lodging	Small Hotel	1.72	55.0	118.8	$1.12
	Large Hotel	4.95	85.2	182.8	$1.73
Warehouse	Non-Refrigerated Warehouse	16.72	14.8	31.5	$0.30
Food Service	Quick Service Restaurant	0.59	564.6	957.7	$8.27
	Full Service Restaurant	0.66	366.1	678.7	$6.08
Apartment	Mid-Rise Apartment	7.32	42.0	118.5	$1.21
	High-Rise Apartment	8.97	45.4	108.3	$1.06
National		100.00	50.4	121.8	$1.19

Table ES.3. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Building Type

Building Type	Prototype	Floor Area Weight (%)	Savings (%)		
			Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.6	11.8	11.8
	Medium Office	6.05	5.0	5.3	5.4
	Large Office	3.33	4.9	3.2	2.9
Retail	Stand-Alone Retail	15.25	8.4	9.9	10.3
	Strip Mall	5.67	9.8	12.0	12.5
Education	Primary School	4.99	13.4	15.6	16.1
	Secondary School	10.36	13.1	15.0	15.5
Healthcare	Outpatient Health Care	4.37	5.6	5.2	5.1
	Hospital	3.45	1.6	1.5	1.5
Lodging	Small Hotel	1.72	9.1	11.7	12.6
	Large Hotel	4.95	4.7	4.3	4.1
Warehouse	Non-Refrigerated Warehouse	16.72	16.1	21.2	22.8
Food Service	Quick Service Restaurant	0.59	0.8	1.4	1.7
	Full Service Restaurant	0.66	1.4	2.3	2.7
Apartment	Mid-Rise Apartment	7.32	3.6	3.9	3.9
	High-Rise Apartment	8.97	4.0	4.9	5.1
National		100.00%	6.8%	7.9%	8.3%

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1. Introduction

ANSI/ASHRAE/IES Standard 90.1 is recognized by the U.S. Congress as the national model energy code for commercial buildings under the Energy Conservation & Production Act (ECPA), as amended, (42 USC 683). With each new edition of Standard 90.1, Section 304(b) of ECPA directs the Secretary of Energy to make a *determination* as to whether the update would improve energy efficiency in commercial buildings.

Standard 90.1-2016 (ASHRAE 2016), the most recent edition, was published in October 2016, triggering the statutorily-required DOE review and determination process. A notice of the determination must be published in the Federal Register not later than 12 months after such revision. (42 U.S.C. 6833 (b)(2)(A)). Within two years of publication of the determination, each State is required to certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency with respect to the revised or successor code and to include in its certification a demonstration that the provisions of its commercial building code, regarding energy efficiency, meet or exceed the revised Standard. (42 U.S.C. 6833(b)(2)(B)(i))

On September 26, 2014, DOE issued an affirmative determination of energy savings for Standard 90.1-2013 (ASHRAE 2013a), which concluded that it would achieve greater overall energy efficiency in commercial buildings required to meet the standards than the previous edition, Standard 90.1-2010 (79 FR 57900 2014). Through this determination, Standard 90.1-2013 became the national model energy code for commercial buildings. Consequently, and consistent with previous determinations, it also then represents the baseline to which future changes are compared, including the current review of Standard 90.1-2016. In performing its determination, DOE recognizes that not all states adopt the national model energy code directly, and many states adopt and update their codes at different rates. Instead of adopting Standard 90.1 directly, many states adopt the International Energy Conservation Code which includes the option to comply with Standard 90.1 by reference (ICC 2015). The DOE Building Energy Codes Program tracks the status of state code adoption (DOE 2018).

To fulfill its statutory directive, DOE analyzed Standard 90.1-2016 to understand its overall impact on energy efficiency in commercial buildings required to meet the standard. Section 2 of this report summarizes the addenda included in Standard 90.1-2016; Section 3 documents the qualitative and quantitative analysis methodology; Section 4 presents the analysis results. In addition, Appendix A: discusses addenda not included in the quantitative analysis. Appendix A: details the modeling strategies for individual addenda included in the quantitative analysis.

1.1 Compliance with Standard 90.1

Standard 90.1-2016 includes several paths for compliance in order to provide flexibility to users of the Standard. The prescriptive path, which is widely considered the most traditional, establishes criteria for energy-related characteristics of individual building components such as minimum insulation levels, maximum lighting power, and controls for lighting and HVAC&R systems. Some of those requirements are considered "mandatory", meaning that they must be met even when one of the other optional paths are utilized (e.g., performance path). These other optional paths are further described below.

In addition to the prescriptive path, Standard 90.1 includes two optional whole building performance paths. The first, known as the *Energy Cost Budget* (ECB) method, provides flexibility in allowing a designer to "trade-off" compliance. This effectively allows a designer to not meet a given prescriptive requirement if the impact on energy cost is offset by exceeding other prescriptive requirements, as demonstrated through established energy modeling protocols. A building is deemed in compliance when the annual energy cost of the proposed design is no greater than the annual energy cost of the reference building design (baseline). In addition, Standard 90.1-2016 includes a second performance approach, Appendix G, the *Performance Rating Method*. In previous editions of Standard 90.1 (i.e., prior to the current 2016 edition), Appendix G has been used to rate the performance of buildings that exceed the requirements of Standard 90.1 for “beyond code” programs, including the LEED Rating System, ASHRAE Standard 189.1, the International Green Construction Code (IgCC), and other above-code programs. Beginning with the 2016 edition of Standard 90.1, Appendix G also adds the capability to demonstrate minimum energy code compliance.

2. Summary of Addenda Included in Standard 90.1-2016

ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard, and then bundles them together to form the next published edition. In creating the 2016 edition, ASHRAE published 121 addenda in total (listed in Appendix H of Standard 90.1-2016). Review drafts and additional information for each addendum can be found on the ASHRAE website (ASHRAE 2016b).

Table 1 shows the number of addenda included in Standard 90.1-2016 grouped into the primary sections of the standard they impact.

Table 1. Number of Addenda affecting Various Sections in Standard 90.1-2016

Section	Number of Addenda
5. Building Envelope	19
6. Heating, Ventilating, and Air Conditioning	43
7. Service Water Heating	4
8. Power	2
9. Lighting	18
10. Other Equipment	3
Addenda Affecting Performance Paths (including Appendices C and G)	29
Normative References	1
Various	2
Total	121

More broadly, DOE characterized the individual addenda into four categories which helped guide the analysis. Those that:

1. are clarifications, administrative, or update references to other documents;
2. modify prescriptive and mandatory design and construction requirements for the envelope, HVAC, service water heating (SWH), power, lighting, and other equipment sections of the standard;
3. modify the performance path options for compliance (the energy cost budget, building envelope trade-off option, and performance rating method sections of Standard 90.1), or;
4. modify normative references.

3. Methodology

3.1 Overview

The *qualitative* phase of the analysis made initial assessments as to whether an individual change decreased energy use, increased energy use, or did not affect energy use in a direct manner. The *quantitative* phase then used whole-building energy modeling and simulation to quantify the impact of the collection of addenda on overall energy use. The following steps provide a general overview of the process:

Qualitative Analysis:

1. Determine whether each addendum was applicable to the *prescriptive* and *mandatory* requirements of Standard 90.1-2016.

2. Determine whether each addendum applicable to the prescriptive path directly impacts energy use.

3. Of the addenda that directly impact energy use, determine whether they increase or decrease energy use.

Quantitative Analysis:

4. Of the addenda that directly impact energy use, determine those that should be captured in the quantitative analysis.

5. Quantify the national impact on energy use of the addenda in step 4.

Additional detail on each phase of the analysis is provided in Sections 3.2 and 3.3.

3.2 Qualitative Analysis

Expanding upon the steps presented in the previous section, the first and second steps of the qualitative analysis are used to filter out addenda that were considered to not directly impact energy use (within the context of this analysis). Addenda were excluded if they:

1. Were not applicable to the *prescriptive* and *mandatory* requirements of the Standard, meaning they only applied to the performance paths in Standard 90.1: Section 11 (Energy Cost Budget Method), Appendix C (Methodology for Building Envelope Trade-off Option), and Appendix G (The Performance Rating Method). The performance paths are intended to provide equivalent performance to the prescriptive path. As the stringency of the prescriptive path is increased, the performance path rules and targets are changed to mirror that increase. Using the prescriptive and mandatory requirements therefore effectively represents changes to the entire standard. Additionally, the purpose of the performance paths is to give designers and builders flexibility which they do by allowing an almost limitless number of trade-off combinations which will comply with the Standard. Analytically, it is not practical or possible to model all these combinations.

2. Affected the prescriptive path but had no impact on energy use or an undetermined impact within the scope of the analysis. Addenda with no impact include administrative changes or clarifications, updates of references to other documents, and other text changes that may improve the usability of Standard 90.1. Addenda with undetermined impact include those related to metering, to equipment that could be subject to future federal rulemaking, and to those whose impact on energy is highly dependent on occupant behavior.

The addenda that were considered to not have a direct impact on energy use, as described above, are compiled in Appendix A:. The remaining addenda were passed to the next step in the qualitative analysis, which was to make a determination of the anticipated impact on energy use, i.e., whether the addendum will decrease or increase energy use. Section 4.1 presents the results of the qualitative analysis.

3.3 Quantitative Analysis

The present quantitative analysis builds on previous work by DOE to assess the energy performance of new editions of Standard 90.1. As described in the previous section, whole-building energy models were used to quantify the impact of addenda on energy use. Individual building models were created to represent each unique combination of the mandatory and prescriptive requirements for Standard 90.1-2013 for each of 16 prototype building types in each of 16 climate zones. Each of these compliant models was then duplicated, with the second version amended only to incorporate the new requirements of 90.1-2016. Additional details of the implementation into the prototype building models for each of the 21 addenda are provided in Appendix B.

The models were simulated using *EnergyPlus Version 8.0* (DOE 2013). Those addenda that were not captured through the quantitative analysis were filtered out and are labeled as such in Table 4 in Section 4.1. Addenda were not included in the quantitative analysis when they:

1. Impact features not found in typical building designs: As explained below in Section 3.3.1, the prototype models include the most common design features found in each building type in the U.S. Therefore, there are many less common features that are not represented in the prototypes, such as variable refrigerant systems, swimming pools, underground parking garages, and so on. Addenda affecting these features of buildings were not be captured via the prototypes in order to preserve representation of the typical building stock.

2. Impact only existing buildings: This analysis is primarily equipped to assess the impact of Standard 90.1 on new commercial building construction (relative to a previous model code edition). Standard 90.1 includes provisions applicable to existing buildings and can be applied in commercial additions, alterations and renovations. While it is recognized that Standard 90.1 is commonly applied in these situations, provisions applying to existing buildings are generally omitted from the quantitative portion of the DOE analysis. This is because the conditions for the baseline building are highly specific to the individual building being modified, and can vary significantly depending upon the age of the building baseline systems, and past modifications. Further, analytical infrastructure does not currently exist that would yield reasonable levels of precision and certainty relative to the new construction analysis. Therefore, while Standard 90.1 provisions impacting existing buildings certainly have an impact at the building level, they are not currently included in the quantitative analysis.

3. Adopt standard practice: The systems and their configuration in the prototype models is based on standard practice that has been widely adopted in the U.S. When an addendum incorporated such standard practice into the code, it did not trigger a change to the prototypes and thus, had no affect within the quantitative analysis.

4. Were related to verification or commissioning: Addenda related to verification, commissioning, and fault-detection generate savings only when there is imperfect operation. Because the models and simulation assume ideal operation, including these addenda would have no impact.

5. Incorporated federal minimum equipment standards: These addenda will improve efficiency even in the absence of Standard 90.1-2016, and therefore, they were left out of the quantitative analysis. Additional discussion is provided in Section 3.3.4.

3.3.1 Building Types and Model Prototypes

The sixteen prototype buildings used in the quantitative analysis largely correspond to a classification scheme established in the 2003 DOE/Energy Information Administration (EIA) Commercial Building Energy

Consumption Survey (CBECS) (EIA 2003). CBECS separates the commercial sector into 29 categories and 51 subcategories using the two variables "principal building activity" (PBA) and "detailed principal building activity" (PBAplus, for more specific activities). DOE relied heavily on these classifications in determining the buildings to be represented by the set of prototype building models. By mapping CBECS observations to each prototype building, DOE also used the CBECS building characteristics data to develop prototypes that could best represent the building stock.

The exception to this is multi-family housing buildings which are not included in CBECS but are covered by Standard 90.1, if more than three stories high. Consequently, DOE developed mid-rise and high-rise multi-family prototype buildings to add to the 14 prototype buildings identified through the review of CBECS. The characteristics of the mid-rise and high-rise multi-family buildings were developed using data from a separate study by Pacific Northwest National Laboratory (PNNL) (Gowri et al. 2007).

Table 2 lists the broad building category, the prototype building, floor area of the prototype building, and its construction weight relative to the other building types. DOE developed three sizes and form factors characteristic of small, medium, and large office buildings to reflect the wide variation in office building design. Similarly, retail, education, healthcare, lodging, food service, and apartments have two representative prototypes each.

The sixteen prototype buildings are representative of the characteristics of new construction in the U.S. It is not feasible to simulate all building types and possible permutations of building design. Further, data are simply not available to correctly weight each possible permutation in each U.S. climate zone as a fraction of the national building construction mix. Hence, the quantitative analysis focuses on the use of prototype buildings that reflect a representative mix of typical construction practices. Together with the construction weighting factors (described in Section 3.3.3), the 16 prototypes represent approximately 80% of the total square footage of new commercial construction, including multi-family buildings more than three stories tall, consistent with the scope of Standard 90.1 (Jarnagin and Bandyopadhyay 2010).

Table 2. Commercial Prototype Building Models

Building Type	Prototype Building	Floor Area (ft^2)	Floor Area (%)
Office	Small Office	5,502	5.61
	Medium Office	53,628	6.05
	Large Office	498,588	3.33
Retail	Stand-Alone Retail	24,692	15.25
	Strip Mall	22,500	5.67
Education	Primary School	73,959	4.99
	Secondary School	210,887	10.36
Healthcare	Outpatient Health Care	40,946	4.37
	Hospital	241,501	3.45
Lodging	Small Hotel	43,202	1.72
	Large Hotel	122,120	4.95
Warehouse	Non-Refrigerated Warehouse	52,045	16.72
Food Service	Quick Service Restaurant	2,501	0.59
	Full Service Restaurant	5,502	0.66
Apartment	Mid-rise Apartment	33,741	7.32
	High-rise Apartment	84,360	8.97
Total		1,515,674	100.00

3.3.2 Climate Zones

Building models were analyzed in standardized climate zones described in ASHRAE Standard 169-2013 (ASHRAE 2013b). Standard 169-2013 includes nine thermal zones and three moisture regimes. The United States climate zones and moisture regimes are shown in Figure 1.

For this analysis, a specific climate location (city) was selected as a representative of each of the 16 climate/moisture zones found in the U.S. These are also consistent with representative cities approved by the Standing Standards Project Committee (SSPC) 90.1 for setting the criteria for 90.1-2016.

The 16 cities used in the current analysis are:

- 1A: Honolulu, Hawaii (very hot, humid)
- 2A: Tampa, Florida (hot, humid)
- 2B: Tucson, Arizona (hot, dry)
- 3A: Atlanta, Georgia (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Diego, California (warm, marine)
- 4A: New York, New York (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Seattle, Washington (mixed, marine)
- 5A: Buffalo, NY (cool, humid)
- 5B: Denver, Colorado (cool, dry)
- 5C: Port Angeles, Washington (cool, marine)
- 6A: Rochester, Minnesota (cold, humid)
- 6B: Great Falls, Montana (cold, dry)
- 7: International Falls, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

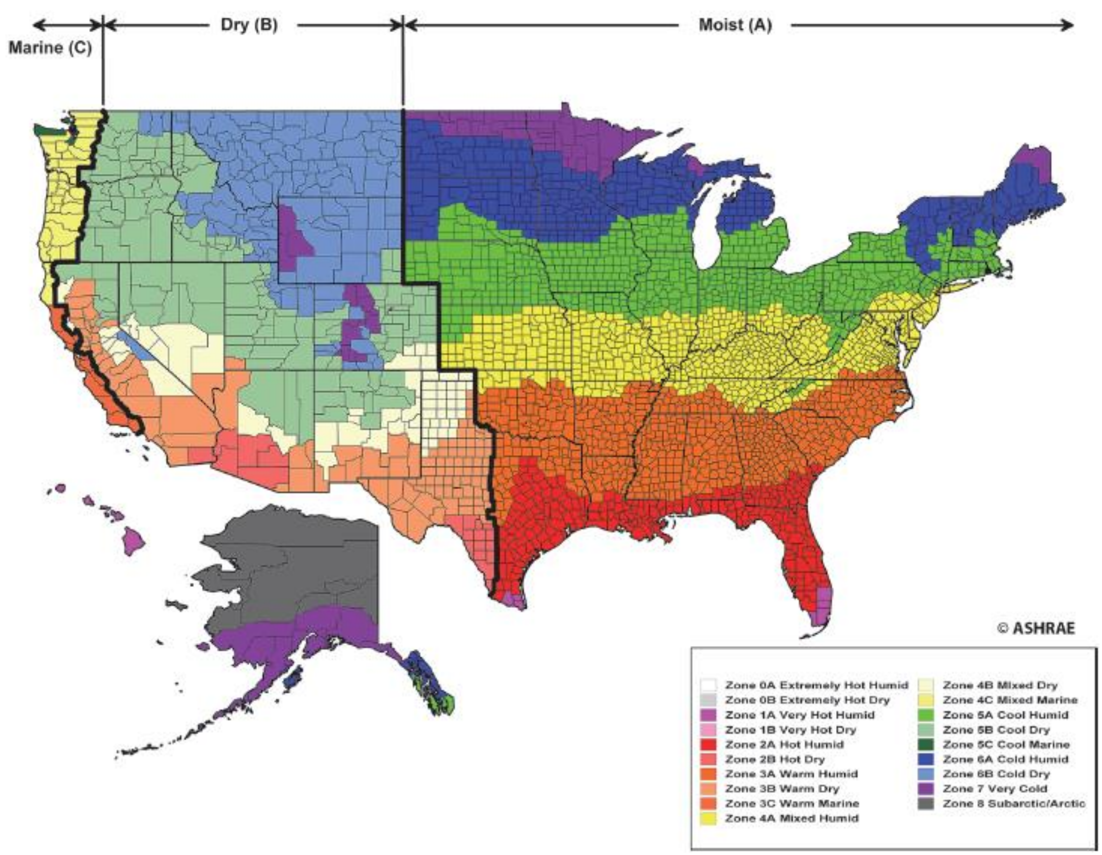

Figure 1. United States Climate Zone Map

The climate zones included in Standard 90.1-2016 are defined by ASHRAE Standard 169-2013 (ASHRAE 2013b), which is incorporated into Standard 90.1 by reference. Standard 169 was recently updated (to the 2013 edition), which resulted in changes to climate zone assignments for some locations in Standard 90.1, as well as the incorporation of a new Climate Zone 0. While the revision of Standard 169 is not the focus of the current analysis, this change indirectly affects how climate zones are defined and applied through Standard 90.1. For example, the recent update shifted a relatively small number of locations to warmer climate zones where they were typically subject to less stringent requirements, therefore increasing energy use in those instances. These impacts, as well as the overall effects resulting from the incorporation of Standard 169-2013, are captured in the quantitative analysis.

3.3.3 Development of Weighting Factors

Weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level were developed from construction data purchased from McGraw Hill. This data represents all new buildings, as well as additions to existing facilities, over a period of five years (2003-2007), and based on a set of 254,158 individual records of commercial building construction across the U.S. covering a total of 8.2 billion square feet. Details of their development are further discussed in a PNNL report (Jarnagin and Bandyopadhyay 2010).[2] Table 3 lists the resulting weighting factors by climate and by prototype building used in the analysis. These data are used to develop the relative fractions of new construction floor space represented by prototype building and within the 16 climate zones.

Using the EUI statistics from each building simulation and the corresponding relative fractions of new construction floor space, DOE developed floor-space-weighted national EUI statistics by energy type for each building type and standard edition. DOE then summed these energy type-specific EUI estimates to obtain the national site energy EUI by building type and standard edition. DOE also applied national data for average energy prices and average source energy conversion rates to the energy type-specific EUI data to obtain estimates of national source energy EUI and national energy cost intensity (ECI), again by building type and by standard edition.

3.3.4 Treatment of Federal Minimum Equipment Standards

Standard 90.1 contains requirements for specific types of equipment that are regulated by federal efficiency standards for manufacturing and import. As mentioned in Section 3.2, addenda that adopted federal efficiency standards were excluded from the analysis to ensure that savings from energy codes and efficiency standards were not double counted, and to avoid speculating on future rulemaking processes. In the quantitative analysis, this was accomplished by assuming current minimum federal equipment efficiencies (i.e. as published in Standard 90.1-2016) in both the 2013 and 2016 prototype building models, which is consistent with historical DOE determination analyses.

[2] The original weighting factors were based on the climate to county mapping in Standard169-2006. This analysis uses updated mapping from 169-2013 and the construction weights were updated accordingly. The impact of changing construction weights is described in Athalye et al. (2016).

Table 3. Relative Construction Volume Weights for 16 Prototype Buildings by Climate Zone (percent)

Building Type	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Weights by Bldg Type
Large Office	0.13	0.39	0.06	0.49	0.28	0.12	1.05	0.00	0.15	0.44	0.12	0.00	0.08	0.00	0.01	0.00	3.33
Medium Office	0.21	0.85	0.29	0.83	0.72	0.14	1.16	0.04	0.19	1.00	0.35	0.01	0.21	0.03	0.02	0.01	6.05
Small Office	0.17	1.13	0.29	1.02	0.47	0.08	0.84	0.06	0.12	0.89	0.32	0.01	0.18	0.03	0.02	0.00	5.61
Stand-Alone Retail	0.41	2.33	0.51	2.57	1.25	0.19	2.44	0.13	0.41	3.36	0.79	0.02	0.69	0.08	0.06	0.01	15.25
Strip Mall	0.20	1.08	0.25	1.11	0.63	0.10	0.89	0.02	0.11	0.96	0.20	0.00	0.09	0.01	0.00	0.00	5.67
Primary School	0.16	0.99	0.16	0.96	0.45	0.05	0.87	0.03	0.09	0.82	0.23	0.00	0.12	0.03	0.02	0.00	4.99
Secondary School	0.32	1.59	0.23	1.99	0.82	0.11	1.97	0.06	0.23	2.15	0.45	0.01	0.30	0.08	0.05	0.01	10.36
Hospital	0.06	0.51	0.10	0.49	0.27	0.04	0.66	0.03	0.10	0.80	0.21	0.00	0.12	0.02	0.03	0.00	3.45
Outpatient Health Care	0.08	0.62	0.13	0.63	0.28	0.06	0.81	0.02	0.17	1.06	0.22	0.01	0.23	0.03	0.03	0.00	4.37
Full Service Restaurant	0.02	0.11	0.02	0.12	0.05	0.01	0.12	0.01	0.01	0.13	0.03	0.00	0.02	0.00	0.00	0.00	0.66
Quick Service Restaurant	0.02	0.10	0.02	0.10	0.06	0.01	0.09	0.01	0.01	0.12	0.03	0.00	0.02	0.00	0.00	0.00	0.59
Large Hotel	0.13	0.69	0.12	0.70	0.79	0.11	0.90	0.04	0.12	0.90	0.20	0.00	0.16	0.05	0.03	0.00	4.95
Small Hotel	0.03	0.30	0.03	0.27	0.11	0.02	0.32	0.02	0.04	0.35	0.09	0.00	0.08	0.03	0.02	0.00	1.72
Non-Refrigerated Warehouse	0.51	3.07	0.58	2.70	2.30	0.15	2.84	0.08	0.43	3.01	0.70	0.00	0.29	0.03	0.03	0.00	16.72
High-rise Apartment	1.69	1.48	0.08	0.62	0.74	0.17	2.38	0.00	0.36	1.25	0.12	0.00	0.06	0.02	0.01	0.00	8.97
Mid-rise Apartment	0.34	1.19	0.09	0.82	0.86	0.26	1.58	0.02	0.36	1.15	0.32	0.01	0.23	0.06	0.03	0.00	7.32
Weights by Zone	4.46	16.43	2.98	15.42	10.08	1.61	18.92	0.57	2.92	18.39	4.37	0.07	2.89	0.49	0.37	0.05	100.00

3.4 Comments on Methodology

The goal of this analysis was to determine if the 2016 edition of 90.1 is more energy-efficient relative to the 2013 edition. The approach selected to make this determination has certain limitations. These limitations are outlined below.

State Code Adoption: As discussed in the Introduction (Section I), states adopt and update their energy codes in a variety of different manners. Some states adopt updated model codes as published while others draft state-level amendments to modify the model code. States also adopt codes at varying rates, with some states updating relatively quickly after a new edition is available, while others may remain on older editions for a longer duration. While these variables are not included in the DOE determination analysis, they ultimately affect the impacts of the model codes as applied across adopting states and localities

Prototype Representation: Not all the addenda impacting energy use can be captured by the quantitative analysis due to the fixed nature of the prototypes, as explained in Section 3.3.1. Thus, the impact resulting from the quantitative analysis can be considered conservative. At the same time, the impact could be considered generous because the addenda that were included impacted all buildings of a given type, i.e., the weighting factors carried the impact to all buildings of a given type in a climate zone even though some of those buildings may not fit the descriptions of the prototype buildings. For example, the analysis assumes all large office buildings have water-cooled chillers—a property of the Large Office prototype. In reality, some have air-cooled, some have packaged equipment, some have variable refrigerant volume systems, etc. If the water-cooled chiller efficiency improved more than the other systems, the analysis overestimates savings, whereas, if the efficiency improved less than the other systems, the analysis will have underestimated savings.

Combination of Qualitative & Quantitative Analysis: In any high-level analysis there is a need to balance precision, accuracy and practicality. The approach selected here addresses that by performing both a qualitative and quantitative analysis. The quantitative analysis taken together with the qualitative analysis provides a more robust and defensible determination. If the qualitative analysis determines that a large majority of addenda are expected to decrease energy use, and the quantitative analysis also shows a reduction in energy use from addenda impacting representative building designs, then taken together, the determination can be said to be more robust and reliable.

4. Results

4.1 Qualitative Analysis Results

The qualitative analysis concluded that 51 of the 121 addenda had a direct impact on energy use as defined in Section 3.2 — 46 decrease energy use in commercial buildings, while 5 lead to increased energy use. The 70 remaining changes were determined to have no direct impact on energy use. A graphical summary of the qualitative analysis results is shown in Figure 2. The 51 addenda with a direct impact are shown in Table 4, while the remainder are shown in Appendix A:. Six columns of information are listed for each addendum in Table 4:

1. **Addendum**: the letter addenda designation assigned by ASHRAE.
2. **Code Section(s)**: a list of the section numbers in Standard 90.1-2016 that are affected by the addendum.
3. **Description of Change**: a brief description of the change made by the addendum.
4. **Impact on Energy Use**: the anticipated impact of the addendum on energy use.
5. **Included in Quantitative Analysis**: whether the addendum can be included in the forthcoming Quantitative Analysis (see Section 4.2).
6. **Discussion**: how the impact on energy use was determined (and why the addendum was excluded from the quantitative analysis, if applicable).

The DOE determination analysis accounts for *all* changes regardless of whether the individual change is expected to increase or decrease energy use. While the vast majority of changes are found to decrease energy use, changes increasing energy use are occasionally incorporated into the Standard based on updated data sources or to reflect the evolution of standard engineering practices From the perspective of the DOE determination analysis, and to best understand the interative nature of individual code provisions, it is important to consider all changes both increasing and decreasing energy use.

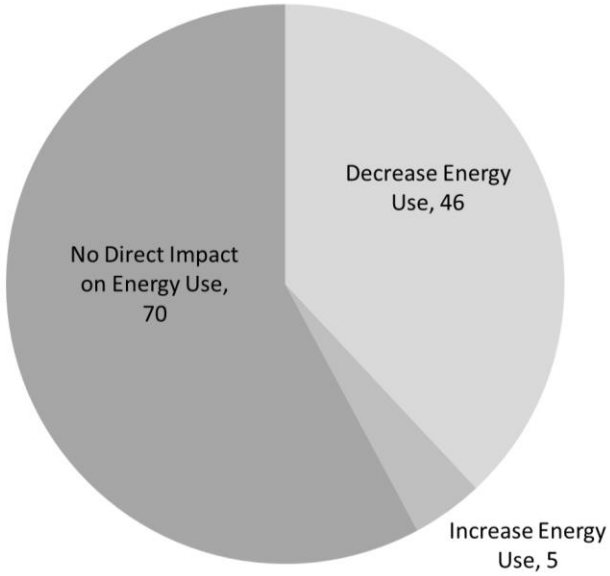

Figure 2. Categorization of Addenda

Table 4. Results of Qualitative Analysis of Standard 90.1-2016

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
a	3.2, 5.1.2.1	Modifies the definition of conditioned space and modifies the heated space criteria table.	Decreases Energy Use	No	Lowers the threshold for spaces to be considered heated resulting in a requirement for additional insulation. Excluded from quantitative analysis because the prototype space classifications are held constant from one edition of the standard to the next.
d	6.3.2, 6.4.3.3	Requires deeper thermostat setback for networked guestrooms or those unoccupied for more than 16 hours/day. Also requires ventilation to be turned off when guestrooms are unoccupied.	Decreases Energy Use	Yes	Increases stringency of hotel/motel guest room control.
e	9.1.2	Increases requirements for alterations to existing building lighting systems.	Decreases Energy Use	No	Excluded from quantitative analysis because the analysis considers new construction only and this applies only to existing buildings.
f	9.4.1.1	Changes an exception to the automatic daylight control requirements for daylight areas under skylights from visible transmittance to effective aperture.	Decreases Energy Use	No	Changes an exception that increases stringency. Excluded from quantitative analysis because typical designs as represented by the prototypes do not qualify for the exception.
i	6.5.1	Eliminates separate cooling capacity thresholds for requiring an economizer in computer rooms. Computer rooms will be required to follow the same thresholds and climate zone requirements as comfort cooling applications.	Decreases Energy Use	Yes	Smaller computer rooms will now need economizers.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
j	6.5.3.3	Requires variable air volume (VAV) system ventilation optimization even when energy recovery ventilator (ERV) is installed.	Decreases Energy Use	Yes	Removes the ventilation optimization exception for ERV, making the requirement more stringent.
l	4.2.4, 4.2.5, 5.2.1, 5.2.9 (new section)	Adds verification requirements for envelope components, including insulation, fenestration, doors, and air leakage.	Decreases Energy Use	No	Excluded from quantitative analysis because the analysis does not take credit for verification or commissioning.
n	Tables 6.8.1-9, 6.8.1-10	Modifies integrated energy efficiency ratio (IEER) values for air-cooled variable refrigerant flow (VRF) air conditioners and heat pumps above 65,000 Btu/h. The new IEERs are between 15% and 20% more stringent.	Decreases Energy Use	No	Excluded from quantitative analysis because typical designs, as represented by the established prototypes, do not include VRF systems.
q	Table 6.5.3.1-2	Allows only the following systems to use the fan power allowance for fully ducted return and/or exhaust systems: (1) systems required to be fully ducted by code or accredited standards; (2) systems required to maintain air pressure differentials between adjacent rooms.	Decreases Energy Use	No	Reduces fan energy through improved efficiency in other components in designs that utilize ducted return or exhaust by choice. Excluded from quantitative analysis because typical designs as represented by prototypes do not utilize this extra return or exhaust duct credit.
s	6.5.2.1	Relieves parallel fan powered box and dedicated outdoor air system (DOAS) with direct digital control (DDC) from requirements c & d in exception 2 of Section 6.5.2.1.	Increases Energy Use	No	Increases energy use because it allows some designs to avoid a requirement for two stages of heating. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include perimeter heating or parallel fan-powered terminal units.
u	6.5.7	Applies transfer air requirements more broadly than to just kitchen exhaust systems, and clarifies the sources of transfer air.	Decreases Energy Use	Yes	Makes transfer air requirements more stringent.
v	5.5.4.5	Deletes exception 2 of the fenestration orientation requirement for obstructions to south-facing glazing.	Decreases Energy Use	No	Deletes the exception increasing stringency. Excluded from quantitative analysis because obstructions are not modeled in the prototypes.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
w	Multiple, Chapters 3, 4, 5, 6, 9, 12, Appendices A, B, D, E, G, Reference Standard Reproduction Annex (new)	Refers 90.1 to new climatic data based on Standard 169-2013 resulting in changes to climate zone assignments for some locations, the creation of a new climate zone 0, and the addition of criteria for climate zone 0. Adds method for rating the solar reflectance index of walls with glass spandrel area and adjusts criteria for minimum skylight area in climate zone 0.	Increases Energy Use	Yes	This change indirectly affects how climate zones are defined and applied through Standard 90.1. For example, the recent update shifted a relatively small number of locations to warmer climate zones where they were typically subject to less stringent requirements, therefore increasing energy use in those instances.
ac	A9.4	Allows the use of the R-value of an airspace in enclosed cavities with or without insulation (Appendix A). Expands the R-value table in Appendix A (based on Chapter 26 of the 2009 Handbook of Fundamentals).	Decreases Energy Use	No	Sets criteria limiting when the R-value of air spaces may be included in calculations. Excluded from quantitative analysis because it did not change opaque envelope U-factors if assemblies modeled in the prototypes.
ag	6.4.3.9	Limits mechanical cooling to 85°F for vestibules, except when the vestibule is tempered with transfer air or heated with recovered energy.	Decreases Energy Use	No	Limits cooling setpoint in vestibules. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include vestibules with cooling.
ah	9.4.1.1	Clarifies that all lighting, including egress lighting on emergency circuits, shall be turned off when the space is unoccupied with 0.02 W/sf in exception.	Decreases Energy Use	Yes	Increases application of controls for emergency lighting.
ai	5.5.4.1, Tables 5.5-0 through 5.5-8	Prescribes lower solar heat gain coefficient (SHGC) for vertical fenestration in climate zone 0 and lower U-factors for vertical fenestration in climate zones 4 through 8.	Decreases Energy Use	Yes	Requires more stringent window U-factor and SHGC.
aj	6.5.3.2.1, 6.5.3.2.4	Requires return and relief fans larger than 0.5 hp to have variable frequency drive (VFD) control, to maintain building pressure, and to avoid disabling of economizer operation.	Decreases Energy Use	No	Ensures proper pressurization that allows economizers to function more efficiently. Excluded from quantitative analysis because return and relief fans are not explicitly modeled in the prototypes.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
ak	6.5.4.1, 6.5.4.3	Addresses a number of issues with hydronic section (6.5.4.1) including removal of the pump power threshold, limiting Section 6.5.4.1 to heating and cooling hydronic systems only, lowering the flow limit exception, and other changes.	Decreases Energy Use	No	Increases application of variable flow hydronic systems and reduces the required minimum flow. Excluded from quantitative analysis because the requirement is standard practice that was already assumed in the prototypes.
al	5.4.3.2	Prescribes air leakage criteria for metal coiling doors in semi-heated spaces.	Decreases Energy Use	Yes	Adds coiling door air leakage requirements.
am	9.4.1.2	Increases the parking garage lighting reduction from 30% to 50% in response to no occupancy, specifies a 50% reduction in lighting power in response to the presence of daylighting, and removes a duplicate exception.	Decreases Energy Use	No	Excluded from quantitative analysis because the prototypes do not include parking garages.
as	9.4.1.4	Requires luminaires in parking areas with input power greater than 78W and mounting height less than 24 ft to reduce power by 50% in response to occupancy.	Decreases Energy Use	Yes	Adds parking lot occupancy controls, thereby reducing parking lot lighting use.
aw	6.5.6.1	Clarifies and limits the exceptions to exhaust air energy recovery requirements (6.5.6.1).	Decreases Energy Use	No	Excluded from quantitative analysis because the exceptions are not used by typical designs as represented by the prototypes.
ay	5.4.3.1.3	Allows non-adhered single-ply roof membranes to qualify as an air barrier material.	Increases Energy Use	No	Increases energy use because it potentially increases heat loss through fluttering. Excluded from quantitative analysis because single-ply non-adhered roofing membranes are not included in the prototypes.
bc	Tables 5.5.0 through 5.5.8	Lowers U-factor criteria for doors.	Decreases Energy Use	Yes	
bi	6.5.2.6	Limits ventilation air heating (DOAS systems).	Decreases Energy Use	No	Limits simultaneous heating and cooling. Excluded from quantitative analysis because the DOAS system in the Large Hotel prototype already meets this requirement.
bj	6.5.4.7	Establishes minimum chilled water coil selection delta T.	Decreases Energy Use	Yes	Reduces pumping energy.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
bk	6.5.3.4	Specifies control of fans in fan powered parallel VAV boxes	Decreases Energy Use	No	Includes several control strategies that reduce energy use in fan powered terminal units. Excluded from quantitative analysis because typical design as represented by the prototypes does not employ parallel fan-powered terminal units.
bn	6.3.2, 6.5.3.6	Requires heat recovery when design calls for greater than 135 percent of industry-accepted ventilation levels.	Decreases Energy Use	No	Requires heat recovery to mitigate to energy impacts of ventilation exceeding industry-accepted levels. Excluded from quantitative analysis because prototype OA is set at ASHRAE Standard 62.1 limits and is already below the maximum.
bs	Table 6.8.1-10	Increases water-cooled VRF efficiencies.	Decreases Energy Use	No	Excluded from quantitative analysis because typical designs as represented by the prototypes do not include VRF systems.
bt	Table 8.4.4	Updates transformer efficiency requirements.	Decreases Energy Use	No	Excluded from quantitative analysis because transformers are a federally-regulated product.
by	7.4.3	Requires insulation of the first 8 ft of branch piping from recirculating SWH systems.	Decreases Energy Use	Yes	Reduces heat loss from SWH branch piping.
ca	6.5.2.2.1	Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp. Eliminates the exception for climate zones 1 and 2.	Decreases Energy Use	Yes	
cb	6.4.4.1.2, Tables 6.8.2-1, 6.8.2-2, 6.8.2	Increases ductwork insulation requirements.	Decreases Energy Use	No	Increases required duct insulation. Excluded from quantitative analysis because duct heat loss is not accounted for in the prototypes.
ce	Tables 6.5.6.1-1 and 6.5.6.1-2	Raises minimum threshold for energy recovery.	Increases Energy Use	Yes	Raises minimum exhaust air energy recovery threshold resulting in fewer systems subject to the requirement.
cf	6.1.1.3.1	Requires replacement HVACR equipment to meet most Section 6 requirements.	Decreases Energy Use	No	Requires replacement equipment to be more energy-efficient. Excluded from quantitative analysis because analysis considers new construction only.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
cg	9.4.2	Reduces exterior lighting power allowances.	Decreases Energy Use	Yes	
ch	Tables 9.5.1 and 9.6.1	Reduces interior lighting power allowances.	Decreases Energy Use	Yes	
ci	5.5.4.5	Modifies fenestration orientation requirements.	Decreases Energy Use	Yes	Increases stringency of fenestration orientation requirements.
cq	6.5.5.2.1	Bases variable speed thresholds for heat rejection fans on motor power, including service factor.	Decreases Energy Use	Yes	Includes service factor in the heat rejection VFD threshold, effectively lowering the threshold.
cv	3.2, 10.4.1, Tables 10.8.1, 10.8.2, and 10.8.3	Increases motor efficiencies.	Decreases Energy Use	No	Excluded from quantitative analysis because motors are a federally regulated product not captured in determination.
cy	3.2, 6.4.1.1, Table 6.8.1-14	Adds definition for indoor pool dehumidifier and moisture removal efficiency. Adds new table with efficiency requirements and rating conditions.	Decreases Energy Use	No	Adds new requirements for pool dehumidifiers. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include indoor pools.
dd	6.5.4.2, Table 6.5.4.2	Reduces the threshold for variable flow pumping requirements for chilled water pumps and adds requirement for heating water pumps.	Decreases Energy Use	Yes	
dg	5.4.3.2	Establishes leakage requirements for glazed, power-operated sliding and folding doors. Provides default U-factors for unlabeled metal coiling and other metal non-swinging doors.	Increases Energy Use	No	Allows higher air leakage for glazed, power-sliding and folding doors, thus increasing energy use. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include these doors.
dk	TABLE 6.8.1-7	Increases the minimum efficiency for axial fan closed circuit cooling towers.	Decreases Energy Use	No	Excluded from quantitative analysis because closed circuit cooling towers are not included in the prototypes.
do	9.4.1	Adds efficacy requirements for lighting installed in dwelling units.	Decreases Energy Use	Yes	Requires high efficiency dwelling unit lighting.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
dp	9.4.1.1	Adds exception to restriction on automatic energizing of lighting for open office spaces.	Decreases Energy Use	No	Allowing the use of available advanced control systems that were previously not possible to install without the exception. Excluded from quantitative analysis because the exception is not used by typical designs as represented by the prototypes.
dq	9.6.2	Reduces retail display lighting adder.	Decreases Energy Use	Yes	
dr	3.2, 9.6.2	Reduces decorative lighting adder.	Decreases Energy Use	No	Excluded from quantitative analysis because the prototypes do not include decorative lighting.
du	6.5.1	Requires water-side economizers for chilled water systems including non-fan systems, such as radiant cooling or passive chilled beam systems.	Decreases Energy Use	No	Expands the application of economizers which reduces the reliance on mechanical cooling for more systems. Excluded from quantitative analysis because typical designs do not include radiant cooling or passive chilled beams.
el	6.3.2, 6.4.3, 6.4.3.12	Adds fault detection requirements for DX equipment with economizers.	Decreases Energy Use	No	Allows fault detection to notify operators that systems are malfunctioning. Excluded from quantitative analysis because the analysis does not take credit for verification or commissioning.

4.2 Quantiative Analysis Results

The quantitative analysis only includes those addenda that have a direct impact on energy use as described in Section 3.2 and Section 3.3. A graphical summary of the addenda included in the quantitative analysis is shown in Figure 3. The category labeled "Unquantified Energy Impact" includes those addenda that were determined to have a direct impact on energy use but are not be included in the quantitative analysis. Appendix B describes the implementation of addenda into the prototype models.

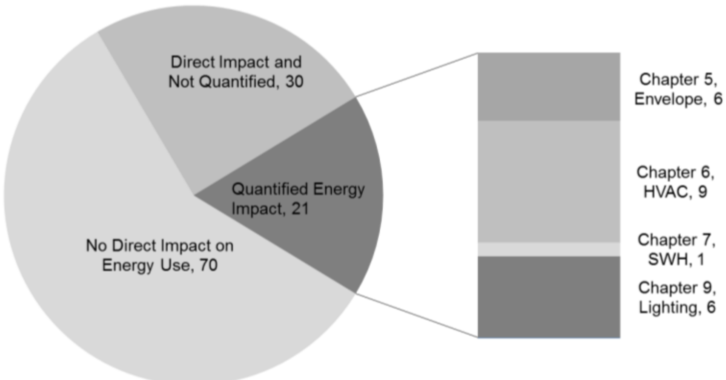

Figure 3. Categorization of Quantified Addenda

Table 5 through Table 8 show the quantitative analysis results by building type and climate zone for Standard 90.1-2013 and 90.1-2016, respectively. The results were aggregated on a national basis for each Standard, based on the weighting factors discussed in Section 3.3.3. In these tables, site energy refers to the energy consumed at the building site, source energy (or primary energy) refers to the energy required to generate and deliver energy to the site. To calculate source energy, conversion factors were applied to the electricity and natural gas consumption. Development of these conversion factors is explained below.

The electric energy source conversion factor of 10,072 was calculated from EIA's Annual Energy Outlook (AEO) 2017 Table A2[3] as follows:

- Delivered commercial electricity, 2016: 4.64 quads
- Commercial electricity related losses, 2016: 9.06 quads
- Total commercial electric energy use, 2016: 13.70 quads
- Commercial electric source ratio, U.S. 2016: 2.95
- Source electric energy factor (3413 Btu/kwh site) 10,072 Btu/kWh[4]

Natural gas EUIs in the prototype buildings were converted to source energy using a factor of 1.088 Btu of source energy per Btu of site natural gas use, based on the 2016 national energy use estimate shown in Table A2 of the AEO 2017 as follows:

- Delivered total natural gas, 2016: 26.27 quads
- Natural gas used in well, field and pipeline: 2.31 quads
- Total gross natural gas use, 2016: 28.58 quads
- Total natural gas source ratio, U.S. 2016: 1.088
- Source natural gas energy factor (100,000 Btu/therm site): 108,800 Btu/therm

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[3] Available at https://www.eia.gov/outlooks/aeo/
[4] The final conversion value of 10,072 is calculated using the full seven digit values available in Table A2 of AEO2017. Other values shown in the text are rounded.

To calculate the energy cost, DOE relied on national average commercial building energy prices based on EIA statistics for 2016 in Table 2, "U.S. Energy Prices," of the March 2017 Short Term Energy Outlook for commercial sector natural gas and electricity[5] of:

- $0.1037/kWh of electricity
- $7.26 per 1000 cubic feet ($0.701/therm) of natural gas

DOE recognizes that actual energy costs will vary somewhat by building type within a region, and even more across regions. However, the use of national average figures sufficiently illustrates energy cost savings and the effect on energy efficiency in commercial buildings, as is the purpose of the DOE determination.

Table 9 and Table 10 present the estimated percent energy and energy cost savings between the 2013 and 2016 editions of Standard 90.1 by building type and climate zone respectively.

Overall, the analysis indicates that Standard 90.1-2016 will result in increased energy efficiency in commercial buildings. On a weighted national average basis, Standard 90.1-2016 saves 7.9% of source energy, 6.8% site energy, and 8.3% of energy cost. Weighted national average savings results by building type and climate zone are shown in Figure 4 and Figure 5.

Table 5. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013 (national weighted average)

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)
Office	Small Office	5.61	29.4	85.8	$0.88
	Medium Office	6.05	33.4	93.1	$0.95
	Large Office	3.33	70.6	197.5	$2.01
Retail	Stand-Alone Retail	15.25	45.7	119.2	$1.19
	Strip Mall	5.67	57.6	152.6	$1.53
Education	Primary School	4.99	50.4	124.7	$1.23
	Secondary School	10.36	42.1	107.3	$1.07
Healthcare	Outpatient Health Care	4.37	118.8	303.6	$3.02
	Hospital	3.45	122.0	286.2	$2.78
Lodging	Small Hotel	1.72	60.5	134.6	$1.29
	Large Hotel	4.95	89.4	191.0	$1.80
Warehouse	Non-Refrigerated Warehouse	16.72	17.6	39.9	$0.38
Food Service	Quick Service Restaurant	0.59	569.5	971.8	$8.41
	Full Service Restaurant	0.66	371.3	694.9	$6.25
Apartment	Mid-Rise Apartment	7.32	43.6	123.2	$1.26
	High-Rise Apartment	8.97	47.2	113.9	$1.12
National		100.00	54.1	132.3	$1.30

[5] EIA Short Term Energy Outlook available at http://www.eia.gov/forecasts/steo/report/.

Table 6. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics		
			Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	26.0	75.7	$0.78
	Medium Office	6.05	31.8	88.2	$0.90
	Large Office	3.33	67.2	191.1	$1.95
Retail	Stand-Alone Retail	15.25	41.8	107.4	$1.07
	Strip Mall	5.67	51.9	134.3	$1.34
Education	Primary School	4.99	43.6	105.3	$1.03
	Secondary School	10.36	36.6	91.2	$0.90
Healthcare	Outpatient Health Care	4.37	112.1	287.9	$2.87
	Hospital	3.45	120.1	281.9	$2.74
Lodging	Small Hotel	1.72	55.0	118.8	$1.12
	Large Hotel	4.95	85.2	182.8	$1.73
Warehouse	Non-Refrigerated Warehouse	16.72	14.8	31.5	$0.30
Food Service	Quick Service Restaurant	0.59	564.6	957.7	$8.27
	Full Service Restaurant	0.66	366.1	678.7	$6.08
Apartment	Mid-Rise Apartment	7.32	42.0	118.5	$1.21
	High-Rise Apartment	8.97	45.4	108.3	$1.06
National		100.00	50.4	121.8	$1.19

Table 7. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2013

Climate Zone	Climate Zone Floor Area Weight %	Whole Building EUI Data for Building Population		
		Site EUI kBtu/ft2-yr	Source EUI kBtu/ft2-yr	ECI $/ft2-yr
1A	4.46	49.2	131.1	$1.32
2A	16.43	51.3	134.4	$1.34
2B	2.98	50.7	133.0	$1.33
3A	15.42	52.6	130.9	$1.29
3B	10.08	48.1	121.7	$1.21
3C	1.61	46.9	120.4	$1.20
4A	18.92	54.9	132.3	$1.30
4B	0.57	56.2	135.2	$1.32
4C	2.92	50.6	121.5	$1.19
5A	18.39	59.8	135.8	$1.31
5B	4.37	56.2	132.5	$1.29
5C	0.07	52.7	128.8	$1.27
6A	2.89	69.0	153.4	$1.47
6B	0.49	64.0	145.3	$1.40
7	0.37	76.8	165.2	$1.56
8	0.05	72.8	147.8	$1.37
National	100.00	54.1	132.3	$1.30

Table 8. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2016

		Whole Building EUI Data for Building Population		
Climate Zone	Climate Zone Floor Area Weight %	Site EUI kBtu/ft2-yr	Source EUI kBtu/ft2-yr	ECI $/ft2-yr
1A	4.46	46.0	121.8	$1.22
2A	16.43	47.4	123.1	$1.23
2B	2.98	47.0	122.2	$1.22
3A	15.42	48.5	119.2	$1.17
3B	10.08	44.9	112.6	$1.11
3C	1.61	44.0	112.1	$1.11
4A	18.92	51.4	122.6	$1.20
4B	0.57	53.0	125.7	$1.23
4C	2.92	47.6	112.6	$1.10
5A	18.39	55.9	124.9	$1.20
5B	4.37	52.9	122.6	$1.19
5C	0.07	49.1	118.7	$1.16
6A	2.89	64.6	141.5	$1.35
6B	0.49	59.3	133.1	$1.28
7	0.37	72.1	153.2	$1.44
8	0.05	66.5	133.0	$1.23
National	100.00	50.4	121.8	$1.19

Table 9. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Building Type

			Savings (%)		
Building Type	Prototype Building	Floor Area (%)	Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.6	11.8	11.8
	Medium Office	6.05	5.0	5.3	5.4
	Large Office	3.33	4.9	3.2	2.9
Retail	Stand-Alone Retail	15.25	8.4	9.9	10.3
	Strip Mall	5.67	9.8	12.0	12.5
Education	Primary School	4.99	13.4	15.6	16.1
	Secondary School	10.36	13.1	15.0	15.5
Healthcare	Outpatient Health Care	4.37	5.6	5.2	5.1
	Hospital	3.45	1.6	1.5	1.5
Lodging	Small Hotel	1.72	9.1	11.7	12.6
	Large Hotel	4.95	4.7	4.3	4.1
Warehouse	Non-Refrigerated Warehouse	16.72	16.1	21.2	22.8
Food Service	Quick Service Restaurant	0.59	0.8	1.4	1.7
	Full Service Restaurant	0.66	1.4	2.3	2.7
Apartment	Mid-Rise Apartment	7.32	3.6	3.9	3.9
	High-Rise Apartment	8.97	4.0	4.9	5.1
National		100.00	6.8	7.9	8.3

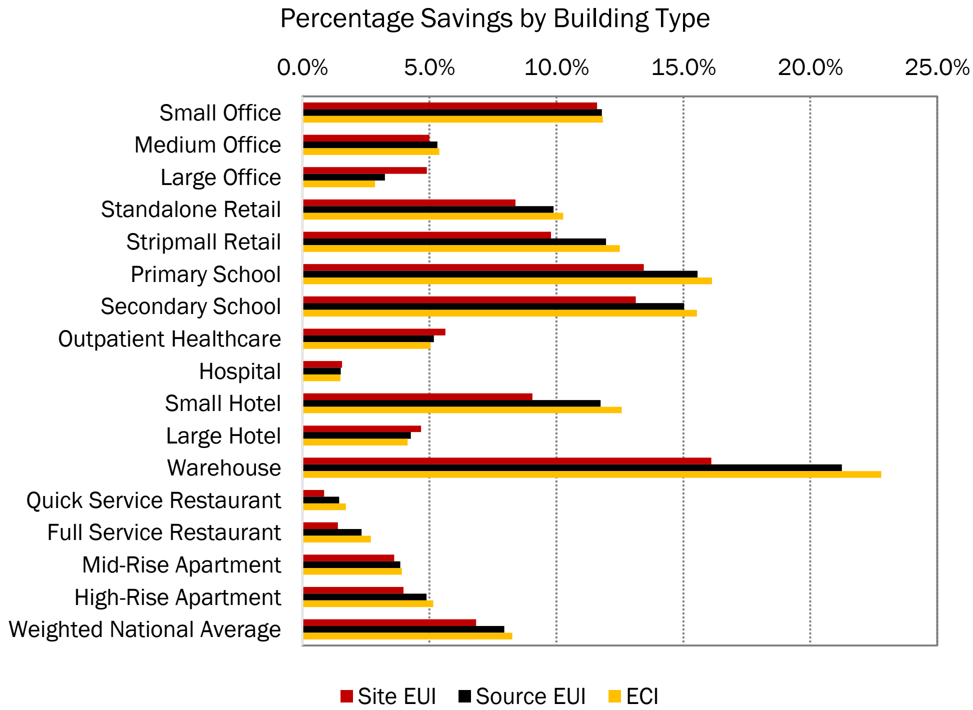

Figure 4. Percentage Savings by Building Type from 90.1-2013 to 90.1-2016

Table 10. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Climate Zone

Climate Zone	Climate Zone Floor Area Weight %	Savings (%)		
		Site EUI	Source EUI	ECI
1A	4.46	6.5	7.1	7.2
2A	16.43	7.6	8.4	8.6
2B	2.98	7.4	8.1	8.3
3A	15.42	7.7	8.9	9.3
3B	10.08	6.6	7.5	7.8
3C	1.61	6.2	6.9	7.1
4A	18.92	6.4	7.4	7.7
4B	0.57	5.8	7.0	7.3
4C	2.92	5.9	7.3	7.8
5A	18.39	6.5	8.1	8.5
5B	4.37	6.0	7.5	7.9
5C	0.07	6.8	7.8	8.0
6A	2.89	6.4	7.8	8.2
6B	0.49	7.4	8.4	8.7
7	0.37	6.2	7.3	7.6
8	0.05	8.6	10.0	10.5
National	100.00	6.8	7.9	8.3

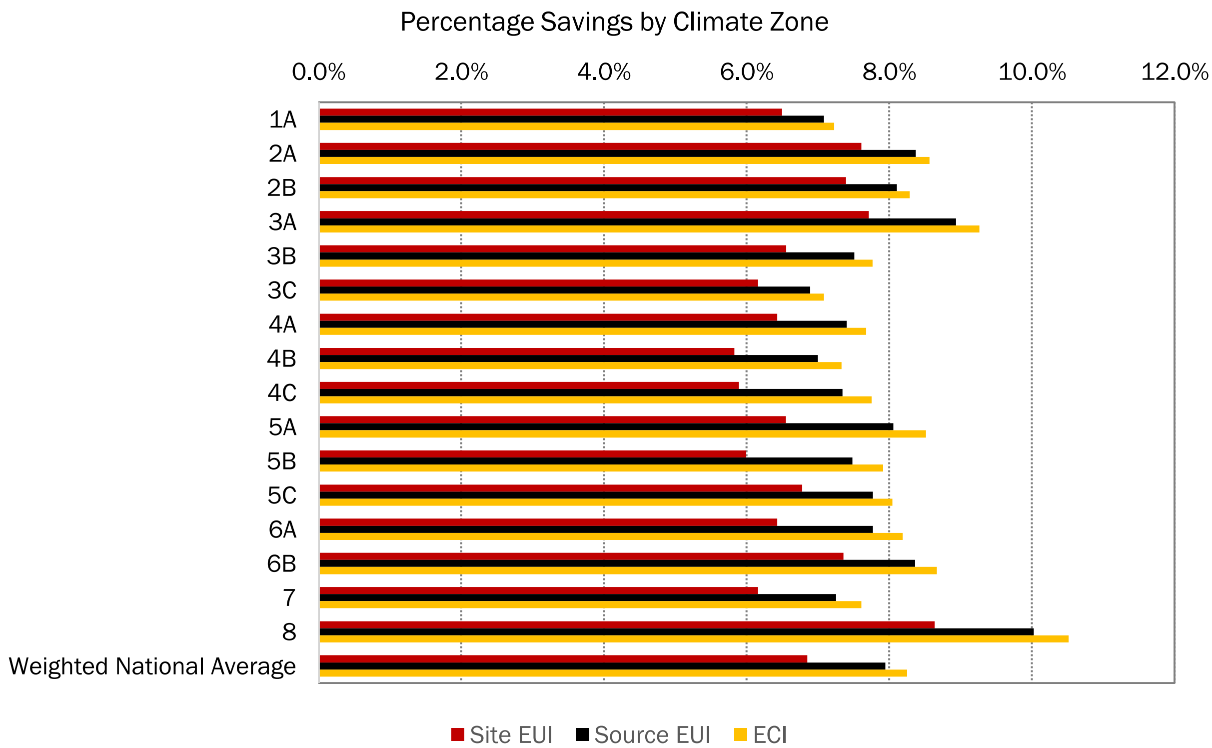

Figure 5. Percentage Savings by Climate Zone from 90.1-2013 to 90.1-2016

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Appendix A: Addenda Not Quantified in Energy Savings Analysis

Addendum	Sections Affected	Description of Change	Discussion
c	8.4	Specifies combined maximum voltage drop of 5% instead of separate voltage drops for branch (3%) and feeder (2%) circuits.	Cumulative voltage drop remains the same.
g	Table 6.5.3.1-2	Clarifies interpretation of the equation used for pressure drop adjustment calculation for energy recovery devices.	Clarification only.
h	C3.5.8	Modifies the language in Appendix C to separate fan power from the cooling and heating efficiency calculation.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
k	Table G3.1	Requires opaque assemblies in the baseline building to match the descriptions in Appendix A.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
m	10.4.1	Adds text on electric motors to identify the tables that must be followed based on size and type (Tables 10.8-4 and 10.8-5).	Clarification only.
o	6.4.4.2.1	Clarifies the wording regarding duct seal class by removing text to avoid misinterpretation.	Clarification only.
p	Table 6.8.1-7	Adds reference to Cooling Tower Institute Standard CTI STD-201 RS for testing certain equipment types in Table 6.8.1-7.	References update only.
r	G3.1.1, Table G3.1.1-3	Clarifies the hierarchy for selecting baseline HVAC systems, including what floors to count, and specifies what building type to use when no one use is predominant.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
z	G3.1.3.1	Modifies modeling of electric auxiliary heat in air-source heat pumps such that they are controlled by an outdoor air thermostat and the heat pump continues to operate while the auxiliary heat is energized.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
aa	Table G3.1	Clarifies which spaces in the proposed design can be modeled without mechanical cooling (Appendix G).	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
ab	Table A2.3	Adds a filled cavity metal building roof assembly (R-19+R-11) to Appendix A.	Adds alternative assembly only.
ad	G3.1.2.4, G3.1.3.19	Specifies baseline systems 5 through 8 to be modeled with a preheat coil.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ae	3.2, 10.4.1	Updates definition of nameplate horsepower, and relates power ratings of smaller electric motors to their output power.	Clarification.
af	Table 7.8	Specifies the rating conditions for measuring the efficiency of heat pump pool heaters.	Clarification only.
an	Table 9.6.1	Removes mandatory local control from restrooms and stairwells.	In some instances, it will increase energy use and others decrease, based on occupant behavior.
ao	Table G3.1	Requires humidification systems in the baseline building model to be non-adiabatic in buildings where humidification is required.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ap	6.5.3	Moves the minimum 5 hp threshold for fan power to individual requirements under 6.5.3 as applicable. Clarifies that fan motors smaller than 1 hp have separate requirements. Clarifies that fan power allowance does not apply to relief fans that operate only during economizer mode.	Clarification only.
aq	Tables 6.8.1-1, 6.8.1-2, 6.8.1-5	Modifies footnotes in Tables 6.8.1-1 and 6.8.1-2 and 6.8.1-5 to state that residential air conditioners, heat pumps, and furnaces are now regulated by DOE and not by The National Appliance Energy Conservation Act of 1975. Clarifies that certain efficiencies in the tables only apply to three-phase equipment.	Clarification only.
ar	3.2, Table 6.5.3.1-2, 6.5.6.1, 6.5.7.1.4, 6.5.7.2	Replaces “energy recovery effectiveness” with “energy recovery ratio,” which clarifies the intent of the Standard with regard to the performance requirements of air-to-air heat exchangers.	Clarification only.
at	9.4.1.1	Clarifies that the calibration of daylighting controls be performed such that the sensor field of view is not blocked by objects or persons conducting the calibration.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
au	G3.1.3.5, G3.1.3.10, G3.1.3.11	Specifies in greater detail the modeling of hot water pumps, chilled water pumps and heat rejection equipment in the baseline model.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
av	Multiple, Chapters 3 and 6	Adds the phrase “and be configured to” after the phrase “capable of” throughout the standard. The word “capable” does not guarantee that savings will be achieved, especially in the context of control requirements.	Clarification only.
az	Appendix G	Requires Appendix G fenestration and skylight glazing fraction to be set in G instead of referencing prescriptive requirements.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ba	Appendix G	Changes G1.2.2 end-use load note from informative to mandatory.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bb	G3.1.2.5	Modifies fan modeling for packaged HVAC.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bd	6.4.3.1.1	Requires metering on large (>1,500 ton) chiller plants.	Adds metering requirement only.
bh	8.4.3.2	Requires DDC metering and GUI display in buildings required to have DDC systems.	Adds metering requirement only.
bl	6.5.1.2.1	Clarifies that water economizers may use dry coolers.	Clarification only.
bm	Multiple, Appendix G	Allows the use of Appendix G as a compliance path. Formulates methodology for showing compliance with 90.1.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bo	5.5.4.4.1 and Table 5.5.4.4.1	Modifies the exceptions related to the SHGC credit for shading by permanent projections, eliminating credit for north facing overhangs.	Eliminated exception was developed to be energy neutral.
bp	TABLE G3.1.2.8	Modifies Appendix G economizer high limit shutoff.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
bq	G3.1.2.5 & G3.1.3.14	Sets baseline control requirements for Systems 6 & 8 (fan powered terminal units) in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
br	6.4.3.4.2, 6.5.3.4, 6.5.5.2.1, 6.5.6.1, C3.5.8, G3.1.2.11, Tables 6.4.3.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.1.3, 6.5.1.2.1, 6.5.6.1.1, 6.5.6.1.2, 6.6.1, 6.8.2.1, 6.8.2.2, G3.1.1.3, G3.1.1.7, G3.4.1	Adds requirements for new climate zone 0A and 0B.	Requirements for new climate zone 0 are set at climate zone 1 levels as was the case for those locations before the introduction of climate zone 0.
bv	G3.1.4.4, G3.1.4.9	Adds hydronic reset exceptions for purchased heating and cooling.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bw	G3.1.6	Appendix G lighting controls modeling rules.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bx	G3.1.2.9.1	Appendix G design airflow rate modeling rules.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bz	Table 6.8.1-11, 12	Computer room air conditioning (CRAC) unit efficiencies.	May be subject to future federal rulemaking that will determine the impact.
cc	3.2	Adds definition for sidelight effective aperture.	New definition only.
cd	3.2, Tables 6.8.1-14 and 6.8.1-15	Establishes a product class and efficiency requirements for DX-DOAS.	May be subject to future federal rulemaking that will determine the impact.

Addendum	Sections Affected	Description of Change	Discussion
cj	G3.1.1.2	Adds footnote about Appendix G System 11 to Table G3.1.1.2.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ck	G3.1.4.11, Table G3.1.4.11	Establishes Appendix G heat rejection leaving water temperature control modeling requirements.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
cl	Appendix F, Tables 6.8.1.1, G.8.1.2, 6.8.1.5, 7.8	Moves federally regulated air conditioner and water heating efficiency requirements to informative Appendix F.	No requirements are changed.
cm	Table A9.4.3.1	Clarifies and simplifies the default U-factors within Appendix A for wood panels and wood sub-floors, corrects the dimensional lumber sizes in the tables, and re-organizes the material list by putting similar materials together.	Clarification only.
cn	Table 4.2.1.1	Adds Climate Zone 0 to Table 4.2.1.1, Building Performance Factors for compliance with Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
co	12	Normative Reference updates.	References update only.
cp	A3.2, A9.2, A9.4.5, Table A3.2.3	Provides a U-factor calculation procedure for metal building wall assemblies with filled cavity insulation systems and adds U-factor values to Table A3.2.3 calculated using this procedure. Does not change the criteria of the standard.	Calculation procedure change only.
ct	3.2, 6.5.1, 6.5.4.5.1, 11.5.2, Tables 6.5.1.2.1, 6.5.1.3	Changes water economizer to fluid economizer to account for refrigerant-based economizers.	Clarification only.
da	4.2, Table G3.1.2	Establishes modeling rules for existing buildings in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
db	3.2, 6.5.3.1.2, 11.5.2 G1.1, G1.3, G2.5, G3.1.2.4, G3.1.2.3, G3.1.2.6, Table 11.5.1.6, Table G.3.1	Building official definition and other language clarifications.	Administrative provisions only.
dc	Table G3.1.4	Updates reference to Standard 55 in Appendix G.	References update only.
de	10.4.3.4	Requires specification of ISO use category and energy efficiency class for elevators.	No efficiency requirement is included.
dh	9.6.2	Clarifies that display lighting adder cannot be taken if display lighting exception is taken.	Clarification only.
di	Table G3.1, G3.9	Adds new table for motor efficiency for Appendix G baseline.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dl	6.4.1.2.1	Changes rating conditions for centrifugal chillers at non-standard conditions using K_{adj} formula.	The change in rating conditions does not impact the efficiency requirements.
dm	Table 6.8.1.3	Clarifies which hydronic heating and cooling pumps need variable flow controls.	Clarification only.
dn	6.5.6.1	Clarifies energy recovery requirement exceptions that apply to heating systems.	Clarification only.
ds	9.4.1.1	Specifies daylighting controls adjustment location.	This requirement makes calibration easier, but does not save energy.
dt	3.2, 9.1.2, 9.4.1.1, 9.5.1, 9.6.1, 9.6.4, C3.5.7; Tables 9.4.2.2, 9.5.1, 9.6.1, 11.5.1	Modifies the definition of lighting power density (LPD) and clarifies language related to LPD.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
dv	11.4.1.4, C3.1.4	Updates the reference to Standard 140.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dw	Appendix F, Tables G3.1, G3.9, G3.9.2, G3.9.3	Establishes baseline elevator efficiency requirements for Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dx	Tables G3.7 and G3.8	Modifies Appendix G to capture revisions from other addenda impacting prescriptive and mandatory requirements (addenda co, cr, dl to 90.1-2010).	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dz	A.3.2.1, A9.2, A9.4.5	Clarifies metal building wall insulation descriptions.	Clarification only.
ea	3.2, 5, 6, 9, 11, Appendix A	Clarifies the definition and application of wall and exterior wall in various locations in the standard.	Clarification only.
eb	3.2; Appendices C and G	Clarifies the definition and application of wall and exterior wall in Appendices C and G.	Clarification to alternative compliance path only.
ec	Table 4.2.1.1	Corrects an error in Building Performance Factor Table.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ed	G3.1.3.18	Adds three baseline system types to the rules governing dehumidification in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ef	Tables G3.1, G3.1.1.2	In Appendix G, clarifies that one baseline SWH system is modeled per building area type, adds two new building area types to SWH type table, and changes the SWH fuel source for two building area types.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
eg	G3.1.2.6.1	Removes a caveat in Appendix G that airside economizers can be modeled if the simulation software does not model waterside economizers.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
ej	3.2, 3.3, 6.4.5, 9.1.2, 9.1.3, 9.1.4	Add a definition for driver as it relates to LED fixtures and makes several changes to assure lighting requirements apply to LED fixtures.	Clarification only.
ek	Tables G3.1, G3.10.1, G3.10.2	Sets baseline efficiency requirements for refrigeration system modeling in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Appendix B: Modeling of Individual Addenda

This appendix details the modeling of the 21 addenda to Standard 90.1-2013 simulated for the quantitative analysis. Where individual addenda modify the same section of Standard 90.1, they are discussed together.

B.1 Addenda Implementation in Modeling

The procedures for implementing the addenda into the Standard 90.1-2013 and 90.1-2016 prototype models include identifying the changes to the prototypes required by each addendum, developing model inputs to simulate those changes, applying those changes to the prototype models, running the simulations, and extracting and post-processing the results. This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for EnergyPlus. The terms "baseline" and "advanced" are used in some cases to describe the modeling of the addenda. The baseline case is Standard 90.1-2013 and the advanced case is Standard 90.1-2016. In some instances, a new addendum to Standard 90.1-2013 identifies the need for a change to baseline 2013 models. There are generally two reasons why a baseline change was necessary: (1) in the course of modeling an addendum, an opportunity to increase the accuracy of the simulation was identified and (2) to add additional detail to the models so that the impact of a particular addendum could be captured. For example, prior to simulation of the 2016 standard, exterior doors were not explicitly simulated in most of the prototypes. In order to accurately simulate addendum *bc*, which reduced door factor requirements, explicit modeling of exterior doors was added to most prototypes.

B.1.1 Building Envelope

B.1.1.1 Addendum w: Climate Zone Reassignment

Addendum Description. Addendum *w* incorporates several changes introduced by the 2013 edition of ASHRAE Standard 169, *Climatic Data for Building Design Standards* (ASHRAE 2013a). ASHRAE 169-2013 reassigned climate zones to U.S. counties based on a more recent period of weather data and also added a new, extremely hot climate zone 0. Approximately 300 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones. Addendum *w* references ASHRAE 169-2013 for climatic data and adds a new annex that reproduces multiple sections from ASHRAE 169-2013. It also adds requirements for climate zone 0 throughout the Standard.

Modeling Strategy. Climate zone 0 is not found in the U.S. so the related requirements in addendum *w* are not applicable to this analysis (see discussion of climate zones in 3.3.2). The other change in addendum *w*—the reassignment of counties to different climate zones—does have an indirect impact because buildings constructed to ASHRAE 90.1-2016 in counties that were reassigned will now be modeled as having different requirements from those before this change, independent of specific 2016 addenda. The Standard 90.1 committee reviewed these impacts when considering whether to incorporate the updated Standard 169, and Athalye et al. (2016) quantified the energy impact of county-climate zone reassignment. At a national level it was very small, with an increase of 0.18% in the site energy consumption of buildings compared to those compliant with ASHRAE 90.1-2013. To capture the impact of the climate zone reassignment, construction weights used in the analysis were revised. New construction weights were determined for each building type in each climate zone based on the new county-climate zone mapping and are shown in Table 3. These construction weights were applied to both the baseline and advanced cases.

B.1.1.2 Addendum *ai*: Fenestration U-factors and SHGC

Addendum Description. Addendum *ai* updates the prescriptive fenestration U-factor and solar heat gain coefficient (SHGC) requirements in Tables 5.5-0 through 5.5-8 of Standard 90.1; specifically, the maximum allowable SHGC for vertical fenestration was reduced in climate zones 0, 4, and 5, the maximum allowable U-factor for vertical fenestration was reduced in climate zones 2 through 7, and the maximum allowable U-factor for skylights was reduced in climate zone 8. The addendum also changed an exception to allow area-weighting between multiple classes of construction for showing compliance, which was previously not allowed.

Modeling Strategy. All the prototypes have vertical fenestration and four have skylights (Stand-alone Retail, Primary School, Secondary School, and Warehouse). Both the 2013 and the 2016 editions of Standard 90.1 have four classes of construction for vertical fenestration: non-metal, metal fixed, metal operable, and metal entrance door. The U-factor requirements are different for different classes of construction but the SHGC requirements are the same for all classes. For each prototype building, a weighted U-factor was developed using the fenestration type weighting factors (Thornton et al. 2011). Then a layer-by-layer window construction was selected that matches the required weighted U-factor, SHGC, and visible light transmittance for the prototype as closely as possible. If a construction that closely matches the code requirements was not available, then it was created using the WINDOW software (LBNL 2016) and exported to EnergyPlus. A similar approach was followed for skylights, except that there is only one class of construction, and thus weighting was not required.

B.1.1.3 Addendum *al*: Metal Coiling Door Air Leakage

Addendum Description. Addendum *al* requires air leakage of metal coiling doors in semiheated spaces in climate zones 1-6 to not exceed 1 cfm/ft^2 at 75 Pa, where previously metal coiling doors had no requirement for air leakage in these climate zones.

Modeling Strategy. The semiheated space (Bulk Storage) in the Warehouse prototype has 15 overhead doors. Metal coiling overhead doors are typically used when the available space above the overhead door is limited. The Bulk Storage space in the Warehouse prototype is a high bay space, and therefore, the likelihood of metal coiling doors being employed in this space is low. A literature review did not find data on the proportion of metal coiling doors out of all overhead doors in typical warehouses. A representative from Door & Access Systems Manufacturers Association was contacted, who estimated the market share for metal coiling doors to be as much as 50% of all overhead doors. A conservative estimate of 25% was used to calculate the number of metal coiling doors in the Warehouse prototype Bulk Storage space.

Previously, none of the doors were assumed to be of the metal coiling variety, and so their infiltration in the closed position was equal to 0.40 cfm/ft^2 at 0.3" w.g., i.e., the current requirement in 90.1-2013 for overhead doors. After addendum *al*, 25% of the overhead doors were assumed to be metal coiling and the infiltration rates for these doors in the baseline and advanced case were determined. Table B.1 shows the air leakage rates for metal coiling doors taken from ASHRAE Research Project 1236 (McGowan 2009).

Table B.1. Air Leakage Rates for Metal Coiling Doors

Climate Zone	90.1-2013 Air Leakage Rate (cfm/ft^2)	90.1-2016 Air Leakage Rate (cfm/ft^2)
1-6	4.40	1.00
7-8	0.40	0.40

For each overhead door for 90.1-2013, the infiltration in closed position was calculated as follows:

$(0.4 \text{ cfm/ ft}^2 \times 0.75 + 4.4 \text{ cfm/ ft}^2 \times 0.25) \times 8 \text{ ft} \times 10 \text{ ft} = 112 \text{ cfm}$

For each door for 90.1-2016, the infiltration in closed position was calculated as follows:

$(0.4 \text{ cfm/ ft}^2 \times 0.75 + 1.0 \text{ cfm/ ft}^2 \times 0.25) \times 8 \text{ ft} \times 10 \text{ ft} = 44 \text{ cfm}$

Table B.2 shows the calculation of the infiltration input in the EnergyPlus models for various 90.1 editions. A single input was used for both the opaque envelope infiltration (base infiltration) and the door infiltration.

Table B.2. Infiltration Rates for Bulk Storage for Climate Zones 1-6 for 90.1-2013 and 90.1-2016

Infiltration Parameters	90.1-2013	90.1-2016
Base Infiltration (opaque envelope), cfm	1,913	1,913
Dock Door Closed Infiltration, per door, cfm	112	44
Dock Door Open Infiltration, per door, cfm	783	783
Number of Dock Doors	15	15
Number of Dock Doors Open	3.2	3.2
Total cfm	5,740	4,938

B.1.1.4 Addendum *bc*: Door U-factors

Addendum Description. Addendum *bc* reduces the U-factors of opaque doors in residential, non-residential, and semiheated buildings. It also adds exceptions for glazed, non-swinging, horizontally hinged sectional doors (garage doors).

Modeling Strategy. This addendum affects all prototypes. It involved a baseline change because only the Strip Mall and Warehouse prototypes have doors that have been explicitly modeled. For all other prototypes, exterior doors were added to capture the impact of this addendum. Assumptions developed previously to calculate exterior lighting power allowance for illuminating doors were used to calculate the number of doors in each prototype. These assumptions are based on the NC[3] database (Richman et al. 2008). Only opaque doors were added to capture the impact of addendum *bc*; glass doors were not considered. The number of opaque doors added to each prototype are summarized in Table B.3. Swinging doors were assumed to be 7 ft tall by 3 ft wide, and rollup doors were assumed to be 10 ft tall by 8 feet wide.

Table B.3. Number of Opaque Doors Added to Prototypes

Prototype	Number of Swinging Doors Added	Number of Rollup Doors Added
Full Service Restaurant	1	0
Large Hotel	5	1
Hospital	16	1
Large Office	12	0
Medium Office	6	0
Small Hotel	3	0
Outpatient Health Care	17	0
Primary School	25	0
Quick Service Restaurant	1	0
Stand-alone Retail	8	5
Secondary School	32	0

Prototype	Number of Swinging Doors Added	Number of Rollup Doors Added
Small Office	2	0
Strip Mall	0	0
Warehouse	1	12

Doors were new elements in the geometry of most prototypes and certain rules were followed to determine their location in the model:

1. Doors were not placed in exterior bathroom zones.

2. A few prototypes, such as the Medium Office, Large Office, Primary School, Secondary School, have ribbon windows spanning the entire perimeter. For these prototypes, adding doors required a break in the ribbon window. In such cases, the sill height of the window was reduced to ensure that the total glazed area remained the same, and so that there was no impact on the daylight area.

3. Zones with daylighting controls have photosensors; in such zones, care was taken to not place an opaque door near the daylighting sensor.

The U-factors in addendum *bc* were applied to the 2016 models, whereas those in the 2013 edition of 90.1 were applied to the 2013 models.

B.1.1.5 Addendum *ci*: Fenestration Orientation

Addendum Description. Addendum *ci* requires that the vertical fenestration comply with either (a) or (b) below:

(a.) $A_W \leq (A_T)/4$ and $A_E \leq (A_T)/4$

(b.) CZ 0-3:

$$A_W \times SHGC_W \leq (A_T \text{ x } SHGC_C)/4 \text{ and } A_E \times SHGC_E \leq (A_T \times SHGC_C)/4$$

CZ 4-8:

$$A_W \times SHGC_W \leq (A_T \times SHGC_C)/5 \text{ and } A_E \times SHGC_E \leq (A_T \times SHGC_C)/5$$

where

Aw = west-oriented *vertical fenestration area* (oriented within 45 degrees of true west to the south and within 22.5 degrees of true west to the north in the northern hemisphere; oriented within 45 degrees of true west to the north and within 22.5 degrees of true west to the south in the southern hemisphere)

Ae = east-oriented *vertical fenestration area* (oriented within 45 degrees of true east to the south and within 22.5 degrees of true east to the north in the northern hemisphere; oriented within 45 degrees of true east to the north and within 22.5 degrees of true east to the south in the southern hemisphere)

A_T = total *vertical fenestration area*

$SHGC_C$ = *SHGC* criteria in Tables 5.5-0 through 5.5-8 for each climate zone

$SHGC_E$ = *SHGC* for east-oriented *fenestration* that complies with Section 5.5.4.4.1

$SHGC_W$ = *SHGC* for west-oriented *fenestration* that complies with Section 5.5.4.4.1

In 90.1-2013, option (a), fenestration area trade-off, above is identical, but option (b), SHGC trade-off, included a denominator of 4 on the right-hand side of the equation for all climate zones. Addendum *ci* separated out climate zones 4 through 8 and set the denominator to 5, meaning east- and west-facing fenestration will require a lower SHGC compared to 90.1-2013 when using option (b) in climate zones 4 through 8.

Modeling Strategy. The implementation of requirements within addendum *ci* was very similar to that of addendum 90.1-2010*bw* and is described by Halverson et al. (2014). As was the case with addendum *bw*, prototypes were examined to see if they first met option (a) in the fenestration orientation requirement, either with their current orientation or if rotated 90 degrees. Small Hotel, Hospital, Quick Service Restaurant, and Full Service Restaurant were the only prototypes that did not comply using option (a).

The Small Hotel prototype was rotated 90 degrees from its default orientation to meet the fenestration orientation requirements of 90.1-2013, and in this rotated form it meets the requirements of addendum *ci* as well. Thus, there is no impact on Small Hotel from addendum *ci*. Similarly, there is no impact on the Hospital prototype because after rotating 90 degrees, its east-facing fenestration meets exception 5 of the fenestration orientation requirement (Section 5.5.4.5), and the west-facing orientation meets the option (a). Similarly, this is how it was modeled to comply with the requirements in 90.1-2013.

For the Quick Service and Full Service Restaurant prototypes, the SHGCs of the east- and west-facing fenestration were calculated and then used to select the window as described in Section B.1.1.2. Table B.4 shows the new SHGC values calculated for the east- and west-facing fenestration by climate zone.

Table B.4. Calculation of SHGC for East- and West-facing Fenestration

Prototype	SHGC Type	CZ 4	CZ 5	CZ 6	CZ 7
Quick Service Restaurant	90.1-2016 Prescriptive SHGC	0.36	0.38	0.4	0.45
	Calculated East and West SHGC	0.29	0.30	0.32	0.36
Full Service Restaurant	90.1-2016 Prescriptive SHGC	0.36	0.38	0.4	0.45
	Calculated East and West SHGC	0.24	0.26	0.27	0.30

B.1.2 Mechanical Addenda

B.1.2.1 Addendum *d*: Hotel Guest Room Controls

Addendum Description. Addendum *d* requires deeper thermostat setback for networked guest rooms or those unoccupied for more than 16 hours. It also requires ventilation to be turned off when guestrooms are unoccupied. The changes appear in a new Section 6.4.3.3.5 and only apply to hotels and motels with greater than 50 guest rooms. A definition is added for networked guest room control systems. The addendum requires heating and cooling setpoints to be lowered and raised respectively by 4°F when rented rooms are unoccupied. For unrented unoccupied periods, heating and cooling setpoints are to be lowered to 60°F and raised to 80°F respectively. Ventilation and exhaust airflow must also be turned off when rooms are unoccupied. Unrented periods can be determined either by the networked guest room control system or by a longer unoccupied period up to 16 hours. Key card control systems may be used to indicate occupancy.

Modeling Strategy. This addendum only impacts the two hotel prototypes. The Small Hotel already had separate blocks of vacant guest rooms, while vacancy was managed through an average schedule in the Large Hotel. The baseline of the Large Hotel was modified to have separate blocks of rented and unrented rooms like the Small Hotel, with the quantities of each based on the prior partial occupancy schedule. The Small Hotel has 65% occupancy on average, while the Large Hotel has 58% occupancy. The ventilation for rented rooms is turned off 6 hours per day, and the ventilation for unrented rooms is turned off 23 hours per day, with a one hour daily ventilation purge. Lighting schedules remained the same as lighting controls were affected by a previous addendum in the last cycle. The baselines had minor temperature setback in occupied rooms, as this was previously required in the general thermostat requirements. The temperature setpoints and ventilation operation for the various modes are as shown in Table B.5.

Table B.5. Addendum d Guest Room Setpoints and Ventilation Control

	90.1-2013			90.1-2016		
Guest Room Condition	Heating	Cooling	Ventilation	Heating	Cooling	Ventilation
Occupied	70°F	70°F	Continuous	70°F	70°F	Continuous
Rented Unoccupied	66°F	74°F	Continuous	66°F	74°F	Off 6 hr/day
Unrented Unoccupied	66°F	74°F	Continuous	60°F	80°F	Off 23 hr/day

B.1.2.2 Addendum *i*: Separate Computer Room Economizer Thresholds Eliminated

Addendum Description. Addendum *i* eliminates separate cooling capacity thresholds when determining if economizers are required in computer rooms. The addendum deletes the old Table 6.5.1-2 and the reference to it under Section 6.5.1. The climate zones where economizers are exempt are different, and with the elimination of the separate computer room tables, economizers are required in climate zones 2a, 3a, and 4a, where there was no economizer requirement for computer rooms previously.

Modeling Strategy. This addendum only impacts the Large Office prototypes, specifically the basement data center. There are small data closets in other parts of the Large Office prototype; however, the cooling capacity for these areas is below the economizer requirement threshold in all climate zones. For the basement data center in 90.1-2016, the economizer variable is switched from “no economizer” to “differential enthalpy economizer” for all climate zones, except 1A and 1B, because the data center cooling capacity always exceeds the economizer threshold of 54,000 Btu/h. Thus economizers are required in more climate zones for the data center resulting in energy savings.

B.1.2.3 Addendum *j*: ERV with Ventilation Optimization

Addendum Description. Addendum *j* eliminates the exception to Section 6.5.3.3 that allowed systems with exhaust energy recovery to be exempt from the multi-zone variable air volume (VAV) ventilation optimization control.

Modeling Strategy. Dynamic ventilation optimization or dynamic ventilation reset was simulated using the mechanical controller object in EnergyPlus. This object has an option to turn on the ventilation rate procedure calculations for optimizing system outdoor air flow in multi-zone VAV systems. Previously, dynamic ventilation reset was only turned on when there was no energy recovery ventilator (ERV) in the system. This was done using an automated process, where Perl[6] scripts read the output of a sizing run and dynamically assign ERVs to systems where necessary, and the final model is simulated again. To implement addendum *j*, an exception was created in the script for 90.1-2016 cases so that dynamic ventilation reset was turned on even when the system required an ERV.

B.1.2.4 Addendum *u*: Expands Use of Transfer Air

Addendum Description. Addendum *u* expands the requirement for use of transfer air as make-up air by applying it more broadly than to just kitchen exhaust systems. Now, most exhaust systems, including restroom exhaust, are required to use transfer air when available. The language is in a new Section 6.5.7.1 (the kitchen exhaust section moved to 6.5.7.2) and requires that conditioned supply air be limited to the air flow required for heating, cooling, or ventilation loads, as long as the air is transferable to adjacent zones based on the Class of Air Recirculation Limitations in ASHRAE Standard 62.1 (ASHRAE 2013b). The new requirements do not apply to (1) biosafety level classified laboratories 3 or higher, (2) vivarium spaces, (3) spaces required to be maintained at positive pressure relative to an adjacent space, and (4) air from other smoke compartments, other floors, or that require more than 15 feet of ductwork. The provision saves energy by reducing the overall volume of conditioned air in a facility, saving fan power and energy for heating or cooling.

Modeling Strategy. Different methods were applied depending on how restrooms were implementation in the prototype models.

- For the Primary and Secondary Schools and Outpatient Health Care prototypes, restrooms were separately modeled with full makeup ventilation air for the exhaust, so the transfer air could be modeled directly, reducing makeup air for the restroom zones and also reducing exhaust available for heat recovery in the source zones. The restroom exhaust fan object was changed so that other makeup air was not required in the restroom zone for balancing.
- For the Hospital, Small Hotel, Large Hotel, Strip Mall, Mid-rise, and High-rise apartments and Warehouse the ventilation rate previously calculated for the baseline had transfer air already accounted for relative to restroom exhaust in the spaces, so there was no change.
- For the Full Service and Quick Service restaurants, all transfer air was used by kitchen exhaust, so there was no additional impact from restroom transfer air being required.
- For the Medium and Large Office prototypes there were not separate zones or exhaust fans set up in the baseline for the restrooms; consequently the minimum damper position according to the multi-space calculation could not be properly determined if transfer air to the restrooms was implemented, so it was not modeled.
- For the Small Office and Stand-alone Retail, there were not separate zones or exhaust fans set up in the baseline for the restrooms, and if restrooms were located on the perimeter of the building transfer air is not likely to meet thermal loads; consequently, the use of transfer was not modeled.

B.1.2.5 Addendum *bj*: Minimum Hydronic Cooling Coil Design Temperature Difference

Addendum Description. Addendum *bj* requires that hydronic cooling coils be designed for a minimum of 15°F waterside temperature difference at design conditions. The requirement is in a new Section 6.5.4.7. There are several exceptions, such as design airflow rates below 5,000 cfm, high pressure drop coils (>0.70 in.wc.),

[6] https://www.perl.org/

constant volume air systems, chiller limitations, convective coils, high design chilled water supply temperatures (≥50ºF) and low entering air temperatures (≤65ºF). The purpose of this addendum is to reduce system chilled water flow and pump energy use; there is also potential chiller efficiency increase due to greater temperature differences.

Modeling Strategy. This addendum impacts the following prototypes with hydronic cooling systems: Large Office, Large Hotel, Secondary School, and Hospital. The design waterside temperature difference was increased from the baseline 10°F to 15°F for the coil design in the EnergyPlus model for the advanced cases.

B.1.2.6 Addendum *ca* & *cq*: Reduced Threshold for VAV Heat Rejection Fans

Addendum Description. Addendum *ca* reduces the threshold for variable flow water-cooled heat rejection device fans from 7.5 to 5 hp and eliminates the exception for climate zones 1 and 2. Addendum *cq* includes the service factor power in the determination of a 5 hp threshold. The requirements are revisions to Section 6.5.5.2.

Modeling Strategy. Addendum *ca* together with *cq* potentially impacts the following prototypes with water-cooled heat rejection: High-rise Apartment, Large Office, and Hospital. The High-rise Apartment water-loop heat pump heat rejection system fan is close to 5 hp, so it will be affected. However, the Hospital and Large Office prototypes have cooling tower fans that are much greater than 7.5 hp; therefore, they are not impacted. These large cooling towers were established as variable speed by standard practice in the 2004 prototypes, so there was no change made for removing the exception in climate zones 1 and 2. For the High-rise Apartment, the evaporative fluid cooler type in the EnergyPlus model was changed from “SingleSpeed” in the 90.1-2013 baseline to “TwoSpeed” for 90.1-2016.

B.1.2.7 Addendum *ce*: Raises Minimum Energy Recovery Threshold

Addendum Description. Addendum *ce* raises the minimum threshold for energy recovery ventilation (ERV) from zero cfm to a reasonable amount based on minimum equipment sizes that are readily available. The addendum revises Tables 6.5.6.1-1 and 6.5.6.1-2. Generally, the base (≥80% outside air) threshold in the highest heat recovery climate zones is set at 40 cfm of outside air with operating hours ≥8000 hr/yr and 80 cfm with operating hours <8000 hr/yr. This base value is then adjusted in proportion to percent outside air or other table values to eliminate the zero values. Overall this will have the impact of reducing the requirement for ERV is certain climates where small size units were not readily available.

Modeling Strategy. The inclusion of an ERV in a system in the prototype model depends on the climate zone, system air flow and the design outdoor air fraction. An initial design simulation is performed, and based on the system supply and outdoor air flow rates, a script automatically inserts the ERV into the system where required. The requirement in addendum *ce* impacts systems with small supply and outdoor air flow rates, such as those found in the Mid- and High-rise Apartment prototypes. There was no change in ERV selection between the 2013 and 2016 models because there none of the models had systems meeting the lower thresholds in 90.1-2013, and thus, the higher threshold in addendum *ce* did not cause a change to the models. After including all addenda to 90.1-2016, the 2016 models do show a few instances where ERVs were added where they were not required in the 2013 models. This is because of a reduction in loads caused by other addenda, which increases the outdoor air fraction and triggers the ERV requirements.

B.1.2.8 Addendum *dd*: Modified Threshold for VSD Pumps

Addendum Description. Addendum *dd* changes the threshold for requiring variable speed drive (VSD) pump control from >5 hp to a threshold that varies by climate zone as shown in Table B.6. Where formerly only chilled water pumps were covered, large heating water pumps are now included. The requirements are revisions to Section 6.5.4.2.

Table B.6. Addendum dd Modified Thresholds for VSD Pumps

Motor Nameplate Horsepower	Chilled Water Pumps in These Climate Zones	Heating Water Pumps in These Climate Zones
≥2 hp	0A, 0B, 1A, 1B, 2B	NR
≥3 hp	2A, 3B	NR
≥5 hp	3A, 3C, 4A, 4B	7, 8
≥7.5 hp	4C, 5A, 5B, 5C, 6A, 6B	3C, 5A, 5C, 6A, 6B
≥10 hp		4A, 4C, 5B
≥15 hp	7, 8	4B
≥25 hp		2A, 2B, 3A, 3B
≥100 hp		1B
≥200 hp		0A, 0B, 1A

Modeling Strategy. This addendum potentially impacts the following prototypes with hydronic heating or cooling systems: Large Hotel, Large Office, Secondary School, Primary School, Outpatient Health Care, and Hospital. The baseline was modified to include a pump motor sizing factor of 1.25 times the required brake horsepower. Heating pumps did not require VSD in the baseline, so pumps are assumed to vary flow by "riding the pump curve." For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table B.6. For cooling pumps, the baseline was a VSD when the pump nameplate hp was greater than 5 hp, otherwise riding the pump curve. For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table B.6.

B.1.3 Lighting

B.1.3.1 Addendum *ah*: Egress Lighting Control

Addendum Description. Addendum *ah* modifies Sections 9.4.1.1(h) and (j) and requires lighting connected to emergency circuits to be turned off in spaces that comply with the automatic full off or scheduled off requirements when there are no occupants. The addendum provides an exception to the automatic full off and scheduled off requirements for egress lighting by allowing 0.02 W/ft^2 or less lighting power to remain on during the unoccupied period. The addendum targets the common practice of allowing emergency lighting circuits to run continuously throughout the unoccupied period. By allowing a specific exemption for egress lighting, the addendum clarifies that all other lighting must be turned off.

Modeling Strategy. The addendum is not applicable to prototypes with 24-hour operation (High-rise Apartment, Mid-rise Apartment, Small Hotel, and Large Hotel), or where safety and security could be a concern (Hospital, and Outpatient Health Care). Thus, the prototypes where the addendum was applied are: Large Office, Medium Office, Small Office, Quick Service Restaurant, Full Service Restaurant, Stand-alone Retail, Strip Mall, Primary School, Secondary School, and Warehouse.

All the applicable prototypes are required to have building sweep controls (scheduled off). To implement the addendum, the lighting power would have to be turned down to 0.02 W/ft^2 during the night when there are no occupants and if the lighting power is greater than 0.02 W/ft^2. The Energy Management System (EMS) within EnergyPlus was used to implement the strategy. The zone lighting power, occupancy, and area are sensed and, if the occupancy is zero and the lighting power density is greater than 0.02 W/ft^2, then it was reduced to 0.02 W/ft^2. One set of sensors, actuators, and the EMS code are required per zone. The EMS code was included in the EnergyPlus input file only for the 90.1-2016 cases.

During implementation, several cases were discovered that required special treatment. For the Strip Mall prototype, there is additional lighting power allowance for display lighting, which is modeled using a separate lighting power object. Two EMS actuators are required in this case to deal with the two lighting power objects in each zone. The display lighting is reduced to zero and the general lighting is set to 0.02 W/ft^2. For the corridor space, which is found in schools and other prototypes, the occupancy is always zero, and therefore building level occupancy data is used as a surrogate in the EMS program. For the data center in the basement of the Large Office prototype, the addendum is not implemented because the space operates continuously.

B.1.3.2 Addendum *as*: Parking Area Luminaire Control

Addendum Description. Addendum "*as"* modifies Section 9.4.1.4 and adds two requirements:

- Previously, exterior lighting not specified as facade or landscape lighting, including advertising signage, was required to be automatically reduced to 30% of its peak power between midnight or within 1 hour of business closing, whichever is later, and until 6 am or business opening, whichever is earlier. Addendum "*as"* states that the reduction in peak power must equal at least 50%.
- Activity sensing controls are now required for pole-mounted lighting in parking lots with mounting heights lower than 24 feet and with lighting power greater than 78 W. The controls must reduce lighting power of the pole-mounted luminaire by at least 50% after no activity is sensed for 15 minutes in the area illuminated by the luminaire. A group of luminaires can be controlled together as long as the total power is less than 1,500 W. This requirement, unlike exterior lighting control requirements in 90.1-2013, will produce savings during hours when parking lot lighting is expected to be on.

Modeling Strategy. Prototypes with 24/7 operation, including the High-rise and Mid-rise Apartments, Small and Large Hotels, and the Hospital and Outpatient Health Care prototypes, are considered exempt from the requirements of addendum "*as*." For the remaining prototypes, the following steps were followed to implement addendum as:

1. Previously, exterior lighting power was modeled using two exterior lighting objects in EnergyPlus: one for façade lighting and another for entrance and parking lot lighting because of the different lighting control requirements for those exterior lighting categories. For addendum "*as*," the lighting power for entrance and parking lots was separated into two objects, one for entrances and another for parking lots. Thus there are now three exterior lighting objects for the 90.1-2016 cases.

2. For entrance door exterior lighting, the automatic reduction was changed from 30% to 50% per the requirements of addendum "*as*." This change was implemented simply by changing the lighting schedule value from 0.7 to 0.5 for the applicable hours for the entrance door exterior lighting object.

3. For the parking lot lighting, *Parking Generation* 4th ed. (McCourt and Hooper 2010) was used to determine the fraction of lights that would be off for each hour for each prototype. Using this data, a lighting schedule was formulated that reduced the peak lighting power for the parking lot exterior lighting object.

B.1.3.3 Addendum *cg*: Exterior Lighting Power

Addendum Description. Addendum *cg* reduces the exterior lighting power allowances for all categories and:

1. Clarifies that the scope includes all lighting served through the building's electrical service.

2. Exempts public art display lighting.

3. Revises the exterior lighting power allowance table as follows:
    a. Adds allowances for exterior dining areas.

b. Combines the categories of "Main Entries" and "Other Doors" into a single category of "Pedestrian and Vehicular Entrances and Exits."

c. Clarifies that the allowance for building facades is applicable for the entire area of the wall being lit.

d. Clarifies that the allowance for building entrances is also applicable to "Uncovered Entrances."

e. Clarifies that the allowance for loading docks is also applicable to "Uncovered loading docks."

The addendum modifies Sections 9.1.1, 9.1.2, 9.4.2, and Table 9.4.2-2. The exterior lighting allowance in 90.1-2013 and those in addendum *cg* are summarized in Table B.7. Where more than one lighting zone is shown in Table B.7, the allowances of the listed lighting zones have been averaged.

Table B.7. Exterior Lighting Power Allowances for 90.1-2013 and 90.1-2016

Lighting Zone	Parking Lots (W/ft^2)		Building Façade (W/ft^2)		Doors (W/ft)			
					90.1-2013		90.1-2016	
	90.1-2013	90.1-2016	90.1-2013	90.1-2016	Main Doors	Other Doors	Main Doors	Other Doors
0	0	0	0	0	0	0	0	0
1	0.04	0.03	0	0	20	20	14	14
2	0.06	0.04	0.1	0.1	20	20	14	14
3	0.1	0.06	0.15	0.15	30	20	21	21
4	0.13	0.08	0.2	0.2	30	20	21	21
2,3	0.08	0.05	0.125	0.125	25	20	17.5	17.5
3,4	0.115	0.07	0.175	0.175	30	20	21	21
2,3,4	0.0967	0.06	0.15	0.15	26.67	20	18.67	18.67

Modeling Strategy. The requirements in addendum *cg* are applicable to all prototypes.

Table B.8 shows exterior lighting zones selected for each prototype. Where more than one lighting zone is selected, an average of the requirements for the multiple zones is used.

Table B.8. Exterior Lighting Zones for Prototypes

Prototype	Exterior Lighting Zone
Quick Service Restaurant	2,3,4
Full Service Restaurant	2,3,4
Strip Mall	2,3
Large Office	4
Outpatient Health Care	2,3
Warehouse	2,3
Stand-alone Retail	2,3
Small Office	2,3
Medium Office	2,3
Primary School	2
Secondary School	2,3
Hospital	3,4
Small Hotel	3
Large Hotel	3,4
Mid-rise Apartment	2,3
High-rise Apartment	3,4

The development of assumptions for exterior lighting in prototypes has been described in Thornton et al. (2011). Using the exterior lighting power allowances in addendum *cg*, the total exterior lighting power was calculated for parking lots, building facades, and building entrances for all prototypes. Table B.9 summarizes the total exterior lighting power for each prototype for 90.1-2013 and for 90.1-2016. The implementation of addendum *cg* was straightforward. The calculated exterior lighting power is assigned to the three exterior lighting objects in EnergyPlus models as described previously in Section B.1.3.2.

Table B.9. Exterior Lighting Power in Prototypes for 90.1-2013 and 90.1-2016

	Parking Lot		Building Entrances		Building Façade	
Prototype	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)
Small Office	713	446	149	115	51	51
Medium Office	6,947	4,342	456	376	519	519
Large Office	42,265	26,027	1,037	968	12,979	12,979
Stand-alone Retail	2,800	1,751	1,528	1,304	316	316
Strip Mall	3,390	2,120	3,285	2,498	418	418
Primary School	881	584	2,351	1,646	151	151
Secondary School	4,745	2,974	3,807	2,995	442	442
Outpatient Health Care	6,634	4,148	1,664	1,402	174	174
Hospital	8,905	5,432	1,669	1,499	2,932	2,932
Small Hotel	3,368	2,022	247	225	573	573
Large Hotel	10,182	6,192	487	444	4,997	4,997
Warehouse	1,604	1,005	4,594	3,955	114	114
Quick Service Restaurant	979	608	55	42	123	123
Full Service Restaurant	2,154	1,337	143	123	154	154
Mid-rise Apartment	2,286	1,429	0	0	222	222
High-rise Apartment	8,227	5,011	0	0	2,493	2,493

B.1.3.4 Addendum *ch*: Interior Lighting Power

Addendum Description. Addendum *ch* modifies the lighting power density (LPD) allowance for both building area and space-by-space methods. Tables 9.5.1 and 9.6.1 are modified by this addendum.

Modeling Strategy. The addendum affects all prototypes. The following describes how the appropriate LPD allowance is chosen for the prototype buildings:

1. The Large Office, Medium Office, and Small Office prototypes use the office building LPD allowance from the building area method (Table 9.5.1). Similarly, the basement zone in the Large Hotel, Hospital, and the office zone in the Warehouse use the LPD allowance from the building area method.
2. Most other zones in the prototypes are mapped to a single space-by-space category and the LPD allowance from that category is used directly.
3. A few zones in the prototypes (for example, the Back Space zone in the Stand-alone Retail prototype) are considered a mix of two or more space types; in such cases, the NC^3 database (Richman et al. 2008) is used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single LPD allowance for those spaces.
4. A room cavity ratio adjustment has been applied to a few spaces such as corridors, and exercise rooms.

Using these rules and the values in addendum *ch*, the LPD allowances for all prototypes and zones were determined. The implementation in EnergyPlus is straightforward and involved using the design LPD allowance as the input to the zone general lighting object.

B.1.3.5 Addendum *do*: Dwelling Unit Lighting Efficacy

Addendum Description. Addendum "*do*" adds a new section, Section 9.4.4, that requires at least 75% of permanently installed lighting fixtures in dwelling units to have a lamp with an efficacy of at least 55 lumens/W, or have a luminaire efficacy of at least 45 lumens/W. Lighting controlled with dimmers or automatic control devices is exempted from the requirement. The addendum also eliminates the exception that exempted dwelling units from lighting power and control requirements.

Modeling Strategy. Prior to addendum "*do*," lighting in dwelling units, i.e., the Mid-rise Apartment and High-rise Apartment prototypes, was based on a Building America Research Index Report[7] from 2005. Since then, a number of other studies have been published with more recent data on typical lighting usage in multi-family buildings. A study by Gifford et al. (2012) was used to update the baseline lighting usage in the two apartment prototypes. The baseline LPD and the mix of lamp types was calculated from the report using the following data:

1. From Table 4.2 of the referenced report, the average daily consumption for a typical multi-family dwelling unit in the U.S. was found to be 1,803 Wh and the total number of lamps equaled 24.8.
2. From Table 4.4, 21% of lamps in multifamily dwelling units are compact fluorescent (CFL), 62% are incandescent and the rest fall into the "other" category.
3. From Table 4.3, the average power of a CFL lamp is 15.13 W, an incandescent lamp is 58.31 W, and other lamps is 79.82 W.

Thus, the total lighting power is equal to 1,270 W (sum of number of lamps of each type times the average power for each lamp) and the average number of hours all the lamps are on is 1.42 hours per day (1,803 Wh divided by 1,269.6 W).

For addendum "*do*," 75% of the lamps must have an efficacy of 55 lumens/W. 21% of lamps in the baseline already meet this requirement. The rest were met by reducing the proportion of incandescent lamps and changing that proportion to CFLs, keeping the proportion of "other" lamps in the total the same. For 90.1-2016, the proportion of lamps was as follows: incandescent lamps 8%, CFLs 75%, and other lamps 17%. The lighting power was calculated to 568 W per dwelling unit. The hours lamps were energized remained the same between baseline and advanced cases. Implementation in EnergyPlus models is straightforward and is accomplished by inputting the lighting power and applying the schedule to each zone. Hourly values for the existing lighting schedule for apartment zones was scaled to ensure that the total operating hours per day were equal to 1.42.

B.1.3.6 Addendum *dq*: Display Lighting Adder

Addendum Description. Addendum *dq* reduces the allowance for retail display lighting found in Section 9.6.2. Table B.10 shows the retail display allowance for each of four sales area categories both before and after addendum dq.

Table B.10. Retail Display Lighting Adder

Retail Display Area	Area Function	90.1-2013 Display Adder	90.1-2016 Display Adder
1	Other areas not listed below	0.6 W/ft^2	0.45 W/ft^2
2	Sale of vehicles, sporting goods, and small electronics	0.6 W/ft^2	0.45 W/ft^2

[7] https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/44816.pdf.

3	Sale of furniture, clothing, cosmetics, and artwork	1.4 W/ft^2	1.05 W/ft^2
4	sale of jewelry, crystal, and china	2.5 W/ft^2	1.88 W/ft^2

Modeling Strategy. The Strip Mall prototype is the only prototype with display lighting. Each zone in the Strip Mall prototype is a separate retail store, and Table B.11 shows the classification for each store for the purpose of determining display lighting power.

In addition to the display lighting allowance for different types of merchandise, a base 1,000 W adder is provided for display lighting in Standard 90.1-2013 and remains in addendum *dq*. To implement addendum *dq*, the base display lighting adder of 1,000 W was combined with the reduced display lighting allowance to determine the total LPD for display lighting in each zone. Table B.12 shows the calculations for display LPD for 90.1-2013 and 90.1-2016. Implementation of display lighting was completed through the lighting object in EnergyPlus.

Table B.11. Strip Mall Store Classification for Display Lighting

Strip Mall Zone Name	Area (ft^2)	Retail Area Type for Display Lighting
LGstore 1	3,749	3
SMstore 1	1,874	
SMstore 2	1,874	2
SMstore 3	1,874	
SMstore 4	1,874	
LGstore 2	3,749	No Display Lighting
SMstore 5	1,874	
SMstore 6	1,874	
SMstore 7	1,874	
SMstore 8	1,874	

Table B.12. Display LPD for 90.1-2013 and 90.1-2016

Strip Mall Zone	Area (ft^2)	Area assumed for Display Lighting	90.1-2013 Display Allowance (W/ft^2)	90.1-2013 Display Adder (W)	90.1-2013 Display LPD (W/ft^2)	90.1-2016 Display Allowance (W/ ft^2)	90.1-2016 Display Adder (W)	90.1-2016 Display LPD (W/ft^2)
LGstore 1	3,749	25%	1.4	1000	0.617	1.05	1000	0.529
SMstore 1	1,874	25%	1.4	1000	0.884	1.05	1000	0.796
SMstore 2	1,874	25%	0.6	1000	0.684	0.45	1000	0.646
SMstore 3	1,874	25%	0.6	1000	0.684	0.45	1000	0.646
SMstore 4	1,874	25%	0.6	1000	0.684	0.45	1000	0.646

B.1.4 Service Hot Water Addenda

B.1.4.1 Addendum *by*: Require first 8 feet of SHW piping runout to be insulated

Addendum Description. Addendum "*by*" requires insulation of the first 8' of branch piping from recirculating SWH systems. The requirement was added to Section 7.4.3 as item c. The purpose of this addendum is to reduce heat loss from run-out piping between the recirculation piping and the fixture. As a result, less water will need to be dumped at the fixture before hot water arrives when there is a moderate time lag between hot water uses.

Modeling Strategy. This addendum impacts the following prototypes with recirculating service hot water systems: Large and Medium Office, Large and Small Hotel, Primary and Secondary School, Outpatient Health Care, Hospital, High-rise Apartment, and Full Service Restaurant. The baseline was changed to add the heat loss from runout piping not previously included. The total pipe loss heating use was modified in the EnergyPlus model as shown in Table B.13.

Table B.13. Addendum "by" Service Hot Water Runout Insulation

	Total (Main Loop + Branches with the new method)			
Prototype/Zone	New Total Pipe Heat Loss for 90.1-2004, 2007 (W)	New Total Pipe Heat Loss for 90.1-2010, 2013 (W)	New Total Pipe Heat Loss for 90.1-2016 (W)	Estimated Saving of Addendum *by*, comparing to 90.1-2013 (%)
High-rise Apartment	9,465	9,260	8,167	11.8
Hospital	20,291	20,036	17,147	14.4
Large Hotel	18,667	18,467	15,908	13.9
Large Office	8,376	8,146	7,280	10.6
Medium Office	2,109	2,003	1,886	5.8
Outpatient Health Care	7,639	7,514	6,496	13.6
Primary School	1,065	1,006	970	3.6
Secondary School	1,332	1,268	1,205	5.0
Full Service Restaurant	1,053	993	947	4.6
Small Hotel	8,432	8,296	7,231	12.8

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Acronyms and Abbreviations

AVERT	U.S. EPA AVoided Emissions and geneRation Tool
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
CH_4	Methane
CO_2	Carbon Dioxide
DOE	U.S. Department of Energy
E.O.	Executive Order
eGRID	EPA Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
HVAC	Heating, Ventilating, and Air-Conditioning
LCC	Life-Cycle Cost
MMT	Million Metric Tons
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
SOx	Sulfur Oxides
UPV	Uniform Present Value

1.0 Highlights

Moving to the ASHRAE Standard 90.1-2019 (ASHRAE 2019) edition from Standard 90.1-2016 (ASHRAE 2016) is cost-effective for Ohio. Standard 90.1-2019 will provide an annual energy cost savings of $0.054 per square foot on average across the state. It will reduce statewide CO_2 emissions by 9.2 MMT (30 years cumulative), equivalent to the CO_2 emissions of 2,009,000 cars driven for one year.

Updating the state energy code based on Standard 90.1-2019 will also stimulate the creation of high-quality jobs across the state. Standard 90.1-2019 is expected to result in buildings that are energy efficient, more affordable to own and operate, and based on current industry standards for health, comfort, and resilience.

The tables below show the expected impact of upgrading to Standard 90.1-2019 from a consumer perspective and statewide perspective. These results are weighted averages for all building types in all climate zones in the state, based on weightings shown in Table 4. The methodology used for this analysis is consistent with the methodology used in the national cost-effectiveness analysis.[1] Additional results and details on the methodology are presented in the following sections.

Consumer Impact	
Annual (first year) energy cost savings, $/ft²	$0.054
Added construction cost, $/ft²	-$1.225
Publicly-owned scenario LCC Savings, $/ft²	4.02
Privately-owned scenario LCC Savings, $/ft²	3.57

Statewide Impact - Emissions	First Year	30 Years Cumulative
Energy cost savings, 2020$	1,501,000	649,900,000
CO_2 emission reduction, Metric tons	13,250	9,239,000
CH_4 emissions reductions, Metric tons	1.35	938
N_2O emissions reductions, Metric tons	0.191	133
NOx emissions reductions, Metric tons	6.99	4,875
SOx emissions reductions, Metric tons	8.99	6,271

Statewide Impact - Jobs Created	First Year	30 Years Cumulative
Jobs Created Reduction in Utility Bills	134	4,230
Jobs Created Construction Related Activities	336	10,613

[1] National cost-effectiveness report: https://www.energycodes.gov/development/commercial/cost_effectiveness

The report provides analysis of two LCC scenarios:

- **Scenario 1**, representing *publicly-owned* buildings, considers initial costs, energy costs, maintenance costs, and replacement costs—without borrowing or taxes.
- **Scenario 2**, representing *privately-owned* buildings, adds borrowing costs and tax impacts.

Figure 1 compares annual energy cost savings, first cost for the upgrade, and net annualized LCC savings. The net annualized LCC savings per square foot is the annual energy savings minus an allowance to pay for the added cost under scenario 1. Figure 2 shows overall state weighted net LCC results for both scenarios. When net LCC is positive, the updated code edition is considered cost-effective.

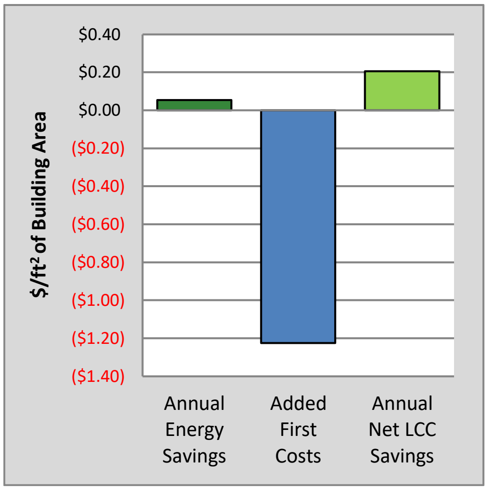

Figure 1. Statewide Weighted Costs and Savings

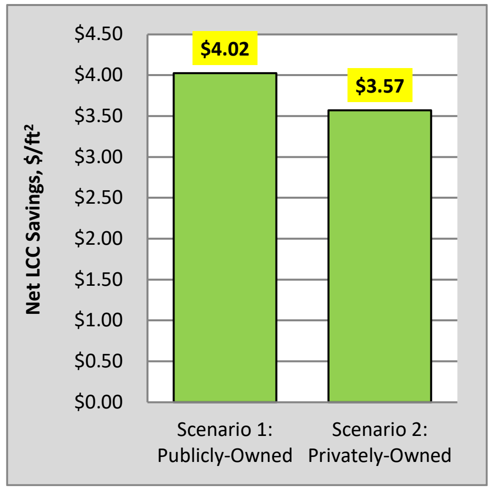

Figure 2. Overall Net Life-Cycle Cost Savings

2.0 Cost-Effectiveness Results for ASHRAE Standard 90.1-2019 in Ohio

This section summarizes the cost-effectiveness analysis results applicable to the building owner. Life Cycle Cost (LCC) savings is the primary measure established by the U.S. Department of Energy to assess the cost effectiveness and economic impact of building energy codes. Net LCC savings is the calculation of the present value of energy savings minus the present value of non-energy incremental costs over a 30-year period. The non-energy incremental costs include initial equipment and construction costs, and maintenance and replacement costs, less the residual value of components at the end of the 30-year period. When net LCC is positive, the updated code edition is considered cost-effective. Savings are computed for two scenarios:

- **Scenario 1:** represents *publicly-owned buildings*, includes costs for initial equipment and construction, energy, maintenance and replacement and does not include loans or taxes.
- **Scenario 2:** represents *privately-owned buildings*, includes the same costs as Scenario 1, with the initial investment financed through a loan amortized over 30 years and federal and state corporate income tax deductions for interest and depreciation.

Both scenarios include the residual value of equipment with remaining useful life at the end of the 30-year assessment period. Totals for building types, climate zones, and the state overall are averages based on Table 4 construction weights. Factors such as inflation and discount rates are different between the two scenarios, as described in the Cost-Effectiveness Methodology section.

LCC is affected by many variables, including the applicability of individual measures in the code, measure costs, measure lifetime, replacement costs, state cost adjustment, energy prices, and so on. In some cases, the LCC can be negative for a given building type or climate zone based on the interaction of these variables. However, the code is considered cost-effective if the weighted statewide LCC is positive.

Table 1 shows the present value of the net LCC savings over 30 years for buildings in scenario 1 averages $4.02 per square foot for Standard 90.1-2019.

Table 1. Net LCC Savings for Ohio, Scenario 1 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$3.78	$3.79	$3.99	$4.54	$12.83	$1.90	$3.76
5A	$3.73	$3.79	$4.06	$4.50	$12.79	$1.88	$4.22
State Average	$3.75	$3.79	$4.04	$4.51	$12.80	$1.89	**$4.02**

Table 2 shows the present value of the net LCC savings over 30 years averages $3.57 per square foot for scenario 2.

Table 2. Net LCC Savings for Ohio, Scenario 2 ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$3.26	$3.21	$3.51	$3.91	$12.37	$1.73	$3.33
5A	$3.21	$3.21	$3.57	$3.88	$12.33	$1.72	$3.74
State Average	$3.23	$3.21	$3.55	$3.89	$12.34	$1.73	**$3.57**

2.1 Energy Cost Savings

Table 3 shows the economic impact of upgrading to Standard 90.1-2019 by building type and climate zone in terms of the annual energy cost savings in dollars per square foot. The annual energy cost savings across the state averages $0.054 per square foot.

Table 3. Annual Energy Cost Savings for Ohio ($/ft^2)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	$0.039	$0.048	$0.077	$0.056	$0.069	$0.017	$0.049
5A	$0.038	$0.048	$0.078	$0.056	$0.067	$0.016	$0.057
State Average	$0.038	$0.048	$0.078	$0.056	$0.068	$0.017	**$0.054**

2.2 Construction Weighting of Results

Energy and economic impacts were determined and reported separately for each building type and climate zone. Cost-effectiveness results are also reported as averages for all prototypes and climate zones in the state. To determine these averages, results were combined across the different building types and climate zones using weighting factors shown in Table 4. These weighting factors are based on the floor area of new construction and major renovations for the six analyzed building prototypes in state-specific climate zones. The weighting factors were developed from construction start data from 2003 to 2018 (Dodge Data & Analytics) based on an approach documented in Lei, et al.

Table 4. Construction Weights by Building Type

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	4.3%	3.8%	13.2%	6.9%	1.6%	12.4%	42.1%
5A	7.7%	1.9%	24.7%	11.9%	2.9%	8.6%	57.9%
State Average	12.0%	5.8%	37.9%	18.8%	4.5%	21.0%	100.0%

2.3 Incremental Construction Cost

Cost estimates were developed for the differences between Standard 90.1-2016 and Standard 90.1-2019 as implemented in the six prototype models. Costs for the initial construction include material, labor, commissioning, construction equipment, overhead and profit. Costs were also estimated for replacing equipment or components at the end of the useful life. The costs were developed at the national level for the national cost-effectiveness analysis and then adjusted for local conditions using a state construction cost index (Hart et al. 2019, Means 2020a,b).

Table 5 shows incremental initial cost for individual building types in state-specific climate zones and weighted average costs by climate zone and building type for moving to Standard 90.1-2019 from Standard 90.1-2016.

The added construction cost can be negative for some building types, which represents a reduction in first costs and a savings that is included in the net LCC savings. This is typically due to the interaction between measures and situations such as the following:

- Fewer light fixtures are required when the allowed lighting power is reduced. Also, changes from fluorescent to LED technology result in reduced lighting costs in many cases and longer lamp lives, requiring fewer lamp replacements.
- Smaller heating, ventilating, and air-conditioning (HVAC) equipment sizes can result from the lowering of heating and cooling loads due to other efficiency measures, such as better building envelopes. For example, Standard 90.1-2019 has more stringent fenestration U-factors for some climate zones. This results in smaller equipment and distribution systems, resulting in a negative first cost.

Table 5. Incremental Construction Cost for Ohio ($\$/ft^2$)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	($1.722)	($1.967)	($1.266)	($1.990)	$0.646	($0.362)	($1.158)
5A	($1.701)	($1.975)	($1.297)	($1.973)	$0.651	($0.366)	($1.274)
State Average	($1.708)	($1.970)	($1.286)	($1.979)	$0.649	($0.364)	**($1.225)**

2.4 Simple Payback

Simple payback is the total incremental first cost divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. Simple payback is not used as a measure of cost-effectiveness as it does not account for the time value of money, the value of energy cost savings that occur after payback is achieved, or any replacement costs that occur after the initial investment. However, it is included in the analysis for states who wish to use this information. Table 6 shows simple payback results in years.

Table 6. Simple Payback for Ohio (Years)

Climate Zone	Small Office	Large Office	Stand-Alone Retail	Primary School	Small Hotel	Mid-Rise Apartment	All Building Types
4A	Immediate	Immediate	Immediate	Immediate	9.4	Immediate	Immediate
5A	Immediate	Immediate	Immediate	Immediate	9.7	Immediate	Immediate
State Average	Immediate	Immediate	Immediate	Immediate	9.6	Immediate	**Immediate**

3.0 Societal Benefits

3.1 Benefits of Energy Codes

It is estimated that by 2060, the world will add 2.5 trillion square feet of buildings, an area equal to the current building stock. As a building's operation and environmental impact is largely determined by upfront decisions, energy codes present a unique opportunity to assure savings through efficient building design, technologies, and construction practices. Once a building is constructed, it is significantly more expensive to achieve higher efficiency levels through later modifications and retrofits. Energy codes ensure that a building's energy use is included as a fundamental part of the design and construction process. Making this early investment in energy efficiency will pay dividends to residents of Ohio for years into the future.

3.2 Greenhouse Gas Emissions

The urban built environment is responsible for 75% of annual global greenhouse gas (GHG) emissions while buildings alone account for 39%.[2] While carbon dioxide emissions represent the largest share of greenhouse gas emissions, building electricity use and on-site fossil fuel consumption also contribute to other emissions, two of which, methane (CH_4) and nitrous oxide (N_2O), are significant greenhouse gases in their own right.

For natural gas combusted on site, emission metrics are developed using nationwide emission factors from U.S. Environmental Protection Agency publications for CO_2, NOx, SO_2, CH_4 and N_2O (EPA 2014).

For electricity, marginal carbon emission factors are provided by the U.S. Environmental Protection Agency (EPA) AVoided Emissions and geneRation Tool (AVERT) version 3.0 (EPA 2020). The AVERT tool forms the basis of the national marginal emission factors for electricity also published by EPA on its Greenhouse Gas Equivalencies Calculator website and are based on a portfolio of energy efficiency measures examined by EPA. AVERT is used here to provide marginal CO_2 emission factors at the State level.[3] AVERT also provides marginal emission factor estimates for gaseous pollutants associated with electricity production, including NOx and SO_2 emissions. While not considered significant greenhouse gases, these are EPA tracked pollutants. The current analysis uses AVERT to provide estimates of corresponding emission changes for NOx and SO_2 in physical units but does not monetize these.

AVERT does not develop associated marginal emissions factors for CH_4 or N_2O. To provide estimates for the associated emission reductions for CH_4 and N_2O, this report uses emission factors separately provided through the U.S. Environmental Protection Agency (EPA) Emissions

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[2] Architecture 2030, https://architecture2030.org/2030_challenges/2030-challenge

[3] AVERT models avoided emissions in 14 geographic regions of the 48 contiguous United States and includes transmission and distribution losses. Where multiple AVERT regions overlap a state's boundaries, the emission factors are calculated based on apportionment of state electricity savings by generation across generation regions. The most recent AVERT 3.0 model uses EPA emissions data for generators from 2019. Note that AVERT estimates are based on marginal changes to demand and reflect current grid generation mix. Emission factors for electricity shown in Table 7 do not take into account long term policy or technological changes in the regional generation mix that can impact the marginal emission benefits from new building codes.

& Generation Resource Integrated Database (eGRID) dataset. eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States and the emission characteristics for electric power generation for each of the above emissions can also be found aggregated down to the state level in eGRID (EPA 2021a). The summary emission factor data provided by eGRID does not provide marginal emission factors, but instead summarizes emission factors in terms of total generation emission factors and non-baseload generation emission factors. Non-baseload emission factors established in eGRID are developed based on the annual load factors for the individual generators tracked by the EPA (EPA 2021b). Because changes in building codes are unlikely to significantly impact baseload electrical generators, the current analysis uses the 2019 non-baseload emission factors established in eGRID by state to estimate CH_4 or N_2O emission reductions due to changes in electric consumption.

Table 7 summarizes the marginal emission factors available from AVERT, eGRID and the EPA Greenhouse Gas Equivalencies Calculator.

Table 7. Greenhouse Gas Emission Factors by Fuel Type

GHG	Electricity lb/MWh	Natural Gas (lb/mmcf)
CO_2	1,567	120,000
SO_2	1.194	0.6
NO_X	0.774	96
N_2O	0.025	0.23
CH_4	0.175	2.3

Table 8 shows the annual first year and projected 30-year energy cost savings. This table also shows first year and projected 30-year greenhouse gas (CO_2, CH_4, and N_2O) emission reductions, in addition to NOx and SO_2 reductions.

Table 8. Societal Benefits of Standard 90.1-2019

Statewide Impact	First Year	30 Years Cumulative
Energy cost savings, 2020$	1,501,000	649,900,000
CO_2 emission reduction, Metric tons	13,250	9,239,000
CH_4 emissions reductions, Metric tons	1.35	938
N_2O emissions reductions, Metric tons	0.191	133
NOx emissions reductions, Metric tons	6.99	4,875
SOx emissions reductions, Metric tons	8.99	6,271

3.3 Jobs Creation through Energy Efficiency

Energy-efficient building codes impact job creation through two primary value streams:

1. Dollars returned to the economy through reduction in utility bills and resulting increase in disposable income, and;
2. An increase in construction-related activities associated with the incremental cost of construction that is required to produce a more energy efficient building.

When a building is built to a more stringent energy code, there is the long-term benefit of the ratepayer paying lower utility bills.

- This is partially offset by the increased cost of that efficiency, establishing a relationship between increased building energy efficiency and additional investments in construction activity.

- Since building codes are cost-effective, (i.e., the savings outweigh the investment), a real and permanent increase in wealth occurs that can be spent on other goods and services in the economy, just like any other income, generating economic benefits and creating additional employment opportunities.

Table 9 shows the number of jobs created because of efficiency gains in Standard 90.1-2019.

Table 9. Jobs Created from Standard 90.1-2019

Statewide Impact	First Year	30 Years Cumulative
Jobs Created Reduction in Utility Bills	134	4,230
Jobs Created Construction Related Activities	336	10,613

4.0 Overview of the Cost-Effectiveness Methodology

This analysis was conducted by Pacific Northwest National Laboratory (PNNL) in support of the DOE Building Energy Codes Program. DOE is directed by federal law to provide technical assistance supporting the development and implementation of residential and commercial building energy codes. The national model energy codes – the International Energy Conservation Code (IECC) and ANSI/ASHRAE/IES Standard 90.1 – help adopting states and localities establish minimum requirements for energy-efficient building design and construction, as well as mitigate environmental impacts and ensure residential and commercial buildings are constructed to modern industry standards.

The current analysis evaluates the cost-effectiveness of Standard 90.1-2019 relative to Standard 90.1-2016. The analysis covers six commercial building types. The analysis is based on the current prescriptive requirements of Standard 90.1. The simulated performance rating method is not in the scope of this analysis, as it is generally based on the core prescriptive requirements of Standard 90.1, and due to the unlimited range of building configurations that are allowed. Buildings complying via this path are generally considered to provide equal or better energy performance compared to the prescriptive requirements, as the intent of these paths is to provide additional design flexibility and cost optimization, as dictated by the builder, designer, and owner.

The current analysis is based on the methodology by DOE for assessing building energy codes (Hart and Liu 2015). The LCC analysis perspective described in the methodology appropriately balances upfront costs with longer term consumer costs and savings and is therefore the primary economic metric by which DOE evaluates the cost-effectiveness of building energy codes.

4.1 Cost-Effectiveness

DOE has established standard economic LCC cost-effectiveness analysis methods in comparing Standard 90.1-2019 and Standard 90.1-2016, which are described in *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes* (Hart and Liu 2015). Under this methodology, two metrics are used:

- **Net LCC Savings:** This is the calculation of the present value of energy savings minus the present value of non-energy incremental costs over a 30-year period. The costs include initial equipment and construction costs, maintenance and replacement costs, less the residual value of components at the end of the 30-year period. When net LCC is positive, the updated code edition is considered cost-effective.
- **Simple Payback:** While not a true cost-effectiveness metric, simple payback is also calculated. Simple payback is the number of years required for accumulated annual energy cost savings to exceed the incremental first costs of a new code.

Two cost scenarios are analyzed:

- **Scenario 1** represents publicly-owned buildings, considers initial costs, energy costs, maintenance costs, and replacement costs without borrowing or taxes.
- **Scenario 2** represents privately-owned buildings and includes the same costs as Scenario 1 plus financing of the incremental first costs through increased borrowing with tax impacts including mortgage interest and depreciation deductions. Corporate tax rates are applied.

The cost-effectiveness analysis compares the cost for new buildings meeting Standard 90.1-2019 versus new buildings meeting Standard 90.1-2016. The analysis includes energy savings estimates from building energy simulations and LCC and simple payback calculations using standard economic analysis parameters. The analysis builds on work documented in *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019* (DOE 2021), and the national cost-effectiveness analysis documented in *National Cost-effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019* (Tyler et al. 2021).

4.2 Building Prototypes and Energy Modeling

The cost-effectiveness analysis uses six building types represented by six prototype building energy models. These six models represent the energy impact of five of the eight commercial principal building activities that account for 74% of the new construction by floor area covered by the full suite of 16 prototypes. These models provide coverage of the significant changes in ASHRAE Standard 90.1 from 2016 to 2019 and are used to show the impacts of the changes on annual energy usage. The prototypes represent common construction practice and include the primary conventional HVAC systems most commonly used in commercial buildings.[4]

Each prototype building is analyzed for each of the climate zones found within the state. Using the U.S. DOE EnergyPlus software, the six building prototypes summarized in Table 10 are simulated with characteristics meeting the requirements of Standard 90.1-2016 and then modified to meet the requirements of the next edition of the code (Standard 90.1-2019). The energy use and energy cost are then compared between the two sets of models.

Table 10. Building Prototypes

Building Prototype	Floor Area (ft²)	Number of Floors
Small Office	5,500	1
Large Office	498,640	13
Stand-Alone Retail	24,690	1
Primary School	73,970	1
Small Hotel	43,210	4
Mid-Rise Apartment	33,740	4

4.3 Climate Zones

Climate zones are defined in ASHRAE Standard 169, as specified in ASHRAE Standard 90.1, and include eight primary climate zones in the United States, the hottest being climate zone 1 and the coldest being climate zone 8. Letters A, B, and C are applied in some cases to denote the level of moisture, with A indicating humid, B indicating dry, and C indicating marine. Figure 3 shows the national climate zones. For this state analysis, savings are analyzed for each climate zone in the state using weather data from a selected city within the climate zone and state, or where necessary, a city in an adjoining state with more robust weather data.

[4] More information on the prototype buildings and savings analysis can be found at www.energycodes.gov/development/commercial/90.1_models

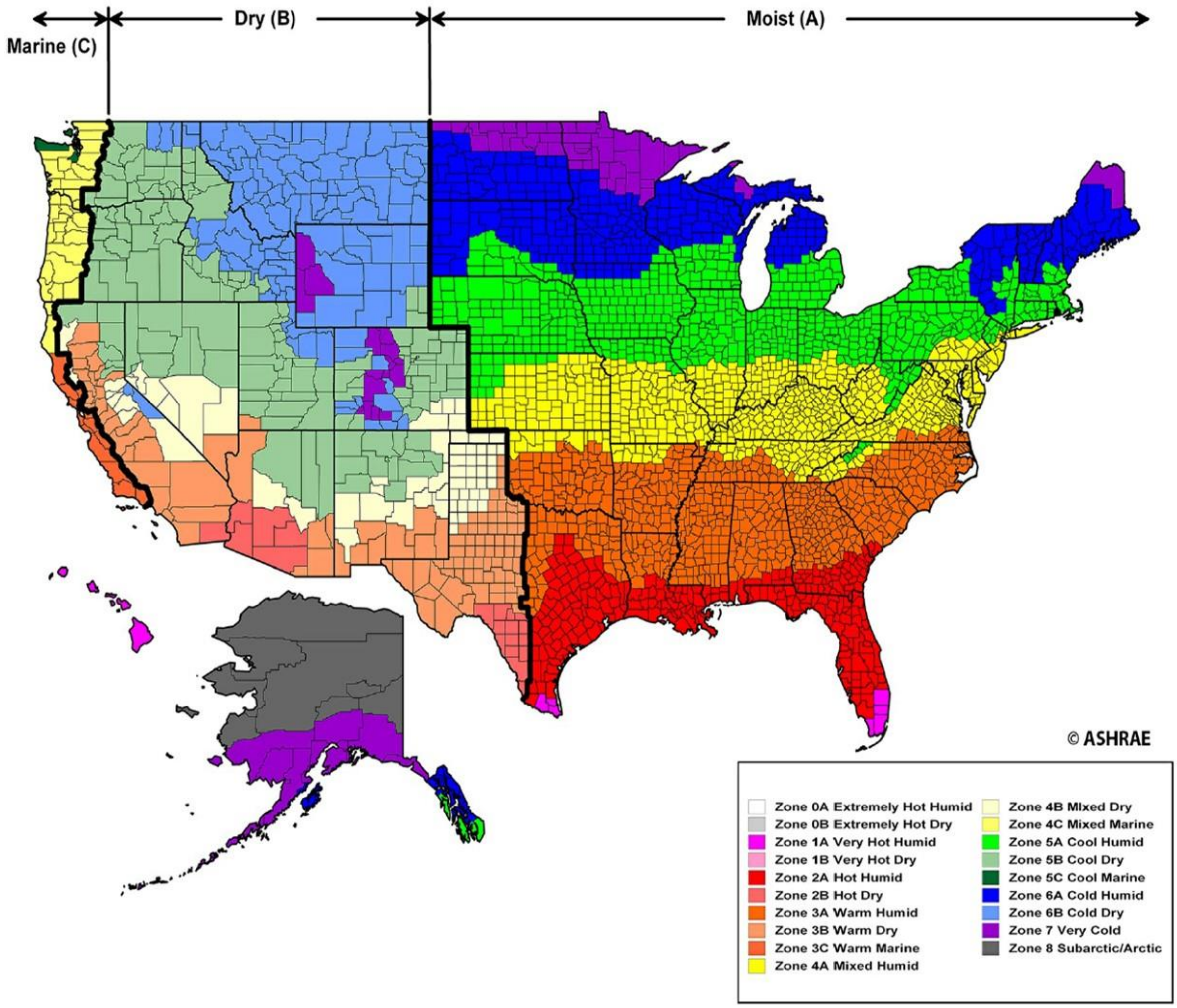

Figure 3. National Climate Zones

4.4 Cost-Effectiveness Method and Parameters

The DOE cost-effectiveness methodology accounts for the benefits of energy efficient building construction over a multi-year analysis period, balancing initial costs against longer term energy savings. DOE evaluates energy codes and code proposals based on LCC analysis over a multi-year study period, accounting for energy savings, incremental investment for energy efficiency measures, and other economic impacts. The value of future savings and costs are discounted to a present value, with improvements deemed cost-effective when the net LCC savings (present value of savings minus cost) is positive.

The U.S. DOE Building Energy Codes Program has established LCC analysis criteria similar to the method used for many federal building projects, as well as other public and private building projects (Fuller and Petersen 1995). The LCC analysis method consists of identifying costs (and revenues if any) and in what year they occur; then determining their value in today's dollars (known as the present value). This method uses economic relationships about the time value of money. Money in-hand today is normally worth more than money received in the future, which is why we pay interest on a loan and earn interest on savings. Future costs are discounted to the present based on a discount rate. The discount rate may reflect the interest rate at which money can be borrowed for projects with the same level of risk or the interest rate that can be earned on other conventional investments with similar risk.

The LCC includes incremental initial costs, repairs, maintenance, and replacements. Scenario 2 also includes loan costs and tax impacts including mortgage interest and depreciation deductions. The residual value of equipment (or other component such as roof membrane) that has remaining useful life at the end of the 30-year study period is also included for both scenarios. The residual value is calculated by multiplying the initial cost of the component by the years of useful life remaining for the component at year 30 divided by the total useful life, a simplified approach included in the Federal Energy Management Program (FEMP) LCC method (Fuller and Petersen 1995). A component will have zero residual value at year 30 only if it has a 30-year life, or if it has a shorter than 30-year life that divides exactly into 30 years (for example, a 15-year life).

The financial and economic parameters used for the LCC calculations are shown in Table 11.

Table 11. LCC Economic Parameters

Economic Parameter	Scenario 1	Scenario 2
Study Period – Years[1]	30	30
Nominal Discount Rate[2]	3.10%	5.25%
Real Discount Rate[2]	3.00%	3.34%
Effective Inflation Rate[3]	0.10%	1.85%
Electricity Prices[4] (per kWh)	$0.0941	$0.0941
Natural Gas Prices[4] (per therm)	$0.5352	$0.5352
Energy Price Escalation Factors[5]	*Uniform present value factors*	*Uniform present value factors*
Electricity Price UPV[5]	19.17	17.37
Natural Gas Price UPV[5]	23.45	21.25
Loan Interest Rate[6]	NA	5.25%
Federal Corporate Tax Rate[7]	NA	21.00%
State Corporate Tax Rate[8]	NA	0.00%
Combined Income Tax Impact[9]	NA	21.00%
State and Average Local Sales Tax[10]	7.17%	7.17%
State Construction Cost Index[11]	0.925	0.925

[1] A 30-year study period captures most building components useful lives and is a commonly used study period for building project economic analysis. This period is consistent with previous and related national 90.1 cost-effectiveness analysis. It is also consistent with the cost-effectiveness analysis that was done for the residential energy code as described in multiple state reports and a summary report (Mendon et al. 2015). The federal building LCC method uses 25 years and the ASHRAE Standard 90.1 development process uses up to 40 years for building envelope code improvement analysis. Because of the time value of money, results are typically similar for any study periods of 20 years or more.
[2] The Scenario 1 real and nominal discount rates are from the National Institute of Standards and Technology (NIST) 2019 annual update in the *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the NIST 2019 annual supplement without citation) (Lavappa and Kneifel 2019). The Scenario 2 nominal discount rate is taken as the marginal cost of capital, which is set equal to the loan interest rate (see footnote 6). The real discount rate for Scenario 2 is calculated from the nominal discount rate and inflation.
[3] The Scenario 1 effective inflation rate is from the NIST 2019 annual update for the federal LCC method (Lavappa and Kneifel 2019). The Scenario 2 inflation rate is the 30-year average Producer Price Index for non-residential construction, June 1990 to June 2020 (Bureau of Labor Statistics 2021).
[4] Scenario 1 and 2 electricity and natural gas prices are state average annual prices for 2020 from the United States Energy Information Administration (EIA) *Electric Power Monthly* (EIA 2021a) and *Natural Gas Monthly* (EIA 2021b).
[5] Scenario 1 energy price escalation rates are from the NIST 2019 annual update for the FEMP LCC method (Lavappa and Kneifel 2019). The NIST uniform present value (UPV) factors are multiplied by the first-year annual energy cost to determine the present value of 30 years of energy costs and are based on a series of different annual escalation rates for 30 years. Scenario 2 UPV factors are based on NIST UPVs with an adjustment made for the scenario difference in discount rates.
[6] The loan interest rate is estimated from multiple online sources listed in the references (Commercial Loan Direct 2021; Realty Rates 2021).
[7] The highest federal marginal corporate income tax rate is applied.
[8] The highest marginal state corporate income tax rate is applied from the Federation of Tax Administrators (FTA 2021).
[9] The combined tax impact is based on state tax being a deduction for federal tax and is applied to depreciation and loan interest.
[10] The combined state and average local sales tax is included in material costs in the cost estimate (Tax Foundation 2020).
[11] The state construction cost index is based on weighted city indices from the state (Means 2020b).

5.0 Detailed Energy Use and Cost

On the following pages, specific detailed results for Ohio are included:

- Table 12 shows the average energy rates used.
- Table 13 shows the per square foot energy costs for Standard 90.1-2016 and Standard 90.1-2019 and the cost savings from Standard 90.1-2019.
- Table 14 shows the per square foot energy use for Standard 90.1-2016 and Standard 90.1-2019 and the energy use savings from Standard 90.1-2019.
- Tables 15.A and 15.B show the energy end use by energy type for each climate zone in the state.

Table 12. Energy Rates for Ohio, Average $ per unit

Electricity	$0.0941	kWh
Gas	$0.5352	Therm

Source: Energy Information Administration, annual average prices for 2020 (EIA 2021a,b)

Table 13. Energy Cost Saving Results in Ohio, $ per Square Foot

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity	$0.703	$0.663	$0.039	5.5%	$0.715	$0.676	$0.039	5.5%
Gas	$0.007	$0.008	$0.000	0.0%	$0.009	$0.010	-$0.001	-11.1%
Totals	$0.710	$0.671	$0.039	5.5%	$0.724	$0.686	$0.038	5.2%
Large Office								
Electricity	$1.409	$1.361	$0.048	3.4%	$1.414	$1.368	$0.047	3.3%
Gas	$0.016	$0.015	$0.001	6.3%	$0.019	$0.018	$0.001	5.3%
Totals	$1.425	$1.377	$0.048	3.4%	$1.434	$1.386	$0.048	3.3%
Stand-Alone Retail								
Electricity	$0.859	$0.776	$0.083	9.7%	$0.862	$0.778	$0.084	9.7%
Gas	$0.110	$0.116	-$0.006	-5.5%	$0.130	$0.136	-$0.006	-4.6%
Totals	$0.969	$0.892	$0.077	7.9%	$0.991	$0.914	$0.078	7.9%
Primary School								
Electricity	$0.840	$0.786	$0.055	6.5%	$0.839	$0.784	$0.054	6.4%
Gas	$0.065	$0.063	$0.002	3.1%	$0.073	$0.071	$0.002	2.7%
Totals	$0.905	$0.849	$0.056	6.2%	$0.912	$0.856	$0.056	6.1%
Small Hotel								
Electricity	$0.850	$0.782	$0.069	8.1%	$0.859	$0.792	$0.067	7.8%
Gas	$0.131	$0.131	$0.000	0.0%	$0.134	$0.134	$0.000	0.0%
Totals	$0.982	$0.913	$0.069	7.0%	$0.992	$0.926	$0.067	6.8%
Mid-Rise Apartment								
Electricity	$0.939	$0.920	$0.019	2.0%	$0.943	$0.925	$0.018	1.9%
Gas	$0.018	$0.020	-$0.002	-11.1%	$0.024	$0.027	-$0.003	-12.5%
Totals	$0.956	$0.940	$0.017	1.8%	$0.968	$0.952	$0.016	1.7%

Table 14. Energy Use Saving Results in Ohio, Energy Use per Square Foot

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity, kWh/ft^2	7.469	7.050	0.419	5.6%	7.601	7.188	0.413	5.4%
Gas, therm/ft^2	0.013	0.014	-0.001	-7.7%	0.017	0.018	-0.001	-5.9%
Totals, kBtu/ft^2	26.841	25.486	1.355	5.0%	27.634	26.327	1.307	4.7%
Large Office								
Electricity, kWh/ft^2	14.973	14.467	0.506	3.4%	15.030	14.533	0.497	3.3%
Gas, therm/ft^2	0.030	0.028	0.001	3.3%	0.036	0.034	0.002	5.6%
Totals, kBtu/ft^2	54.060	52.226	1.833	3.4%	54.887	53.036	1.851	3.4%
Stand-Alone Retail								
Electricity, kWh/ft^2	9.127	8.246	0.881	9.7%	9.157	8.266	0.891	9.7%
Gas, therm/ft^2	0.206	0.217	-0.011	-5.3%	0.242	0.254	-0.012	-5.0%
Totals, kBtu/ft^2	51.796	49.873	1.922	3.7%	55.490	53.634	1.856	3.3%
Primary School								
Electricity, kWh/ft^2	8.932	8.348	0.584	6.5%	8.914	8.335	0.579	6.5%
Gas, therm/ft^2	0.121	0.118	0.003	2.5%	0.136	0.133	0.003	2.2%
Totals, kBtu/ft^2	42.545	40.263	2.283	5.4%	44.053	41.773	2.280	5.2%
Small Hotel								
Electricity, kWh/ft^2	9.038	8.306	0.731	8.1%	9.124	8.416	0.707	7.7%
Gas, therm/ft^2	0.245	0.245	0.000	0.0%	0.250	0.250	0.001	0.4%
Totals, kBtu/ft^2	55.344	52.820	2.524	4.6%	56.162	53.692	2.470	4.4%
Mid-Rise Apartment								
Electricity, kWh/ft^2	9.977	9.776	0.200	2.0%	10.023	9.827	0.196	2.0%
Gas, therm/ft^2	0.033	0.037	-0.004	-12.1%	0.046	0.051	-0.005	-10.9%
Totals, kBtu/ft^2	37.325	37.079	0.246	0.7%	38.771	38.640	0.131	0.3%

Table 15.A. Annual Energy Usage for Buildings in Ohio in Climate Zone 4A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$	Electric kWh/ $ft^2 \cdot yr$	Gas therms/ $ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.641	0.013	0.715	0.018	0.000	0.170	0.000	0.058	0.698	0.016	0.000	0.033
Cooling	0.682	0.000	1.648	0.000	1.400	0.000	1.327	0.000	1.575	0.000	0.750	0.000
Fans, Pumps, Heat Recovery	0.900	0.000	1.383	0.000	1.719	0.000	1.500	0.000	1.060	0.000	0.612	0.000
Lighting, Interior & Exterior	1.898	0.000	1.959	0.000	3.822	0.000	1.406	0.000	2.118	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.136	3.351	0.000
Total	7.469	0.013	14.973	0.030	9.127	0.206	8.932	0.121	9.038	0.245	9.977	0.033
ASHRAE 90.1-2019												
Heating, Humidification	0.649	0.014	0.714	0.017	0.000	0.181	0.000	0.056	0.789	0.016	0.000	0.037
Cooling	0.642	0.000	1.531	0.000	1.305	0.000	1.252	0.000	1.467	0.000	0.720	0.000
Fans, Pumps, Heat Recovery	0.826	0.000	1.324	0.000	1.648	0.000	1.383	0.000	1.003	0.000	0.595	0.000
Lighting, Interior & Exterior	1.585	0.000	1.630	0.000	3.107	0.000	1.158	0.000	1.461	0.000	0.900	0.000
Plugs, Refrigeration, Other	2.438	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.136	3.352	0.000
Total	7.050	0.014	14.467	0.028	8.246	0.217	8.348	0.118	8.306	0.245	9.776	0.037
Total Savings	0.419	-0.001	0.506	0.001	0.881	-0.011	0.584	0.003	0.731	0.000	0.200	-0.004

Table 15.B. Annual Energy Usage for Buildings in Ohio in Climate Zone 5A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr	Electric kWh/ ft^2·yr	Gas therms/ ft^2·yr
ASHRAE 90.1-2016												
Heating, Humidification	0.812	0.017	0.766	0.024	0.000	0.206	0.000	0.074	0.848	0.019	0.000	0.046
Cooling	0.671	0.000	1.650	0.000	1.374	0.000	1.290	0.000	1.517	0.000	0.741	0.000
Fans, Pumps, Heat Recovery	0.877	0.000	1.386	0.000	1.776	0.000	1.522	0.000	1.056	0.000	0.620	0.000
Lighting, Interior & Exterior	1.893	0.000	1.959	0.000	3.821	0.000	1.403	0.000	2.117	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.138	3.399	0.000
Total	7.601		15.030	0.036	9.157	0.242	8.914	0.136	9.124	0.250	10.023	0.046
ASHRAE 90.1-2019												
Heating, Humidification	0.819		0.766	0.023	0.000	0.217	0.000	0.071	0.955	0.019	0.000	0.051
Cooling	0.634	0.000	1.529	0.000	1.279	0.000	1.226	0.000	1.415	0.000	0.713	0.000
Fans, Pumps, Heat Recovery	0.805	0.000	1.339	0.000	1.694	0.000	1.395	0.000	1.000	0.000	0.605	0.000
Lighting, Interior & Exterior	1.582	0.000	1.631	0.000	3.106	0.000	1.158	0.000	1.460	0.000	0.900	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.037	0.097	0.016	0.000	0.138	3.400	0.000
Total	7.188		14.533	0.034	8.266	0.254	8.335	0.133	8.416	0.250	9.827	0.051
Total Savings	0.413	-0.001	0.497	0.002	0.891	-0.012	0.579	0.003	0.707	0.001	0.196	-0.005

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Energy and Energy Cost Savings Analysis of the 2015 IECC for Commercial Buildings

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U.S. DEPARTMENT OF ENERGY

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Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and greenhouse gas emissions for the life of buildings. As required by federal statute (42 USC 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2013 would achieve greater energy efficiency in buildings compared to the 2010 edition of the standard. In support of DOE's determination, Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2013 (Halverson et al. 2014). While Standard 90.1 is the national model energy standard for commercial buildings (42 USC 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings.

This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2015 IECC would save energy and energy costs as compared to the 2012 IECC. PNNL also compared the energy performance of the 2015 IECC with the corresponding Standard 90.1-2013. The purpose of this analysis is to help states and local jurisdictions make informed decisions regarding model code adoption.

The analysis builds on previous work done by PNNL that assessed the energy performance of the 2012 IECC compared to the 2006 and 2009 editions of the IECC (Zhang et al. 2013). For this analysis, PNNL first reviewed all code changes from the 2012 to 2015 IECC and identified those having a quantifiable impact on energy. These changes were then implemented in a suite of 16 prototype building models covering all 15 climate zones in the United States. This results in a total of 480 building models, 240 models each for the 2012 and 2015 editions of the IECC. Prototype models for the 2015 IECC were developed by implementing code changes to the 2012 IECC models. The 16 prototype building models represent more than 80% of the national stock of commercial buildings in the United States.

Whole-building energy simulations were conducted using DOE's *EnergyPlus Version 8.0* (DOE 2013) building simulation software. The resulting energy use from the complete suite of 480 simulation runs was converted to site energy use intensity (EUI, or energy use per unit floor area), and energy cost index (ECI) for each simulation. For each prototype, the resulting EUIs and ECIs in each climate zone were weighted to calculate the aggregate national level EUI and ECI. Weighting factors were developed using commercial construction data and are based on construction floor area of the different building types in each climate zone (Jarnagin and Bandyopadhyay 2010). Finally, the EUIs were aggregated across building types to the national level using the same weighting data.

Overall, the 2015 edition of the IECC results in site energy savings of 11.5% at the aggregate national level compared to the 2012 IECC edition; on a national average basis for all prototypes combined, the 2015 IECC and Standard 90.1-2013 are within 1% for both energy use and energy costs (see Appendix B in this report). Savings from the 2012 to 2015 IECC vary significantly by prototype. This is expected

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

because code requirements are different by building type and by climate. A few high impact changes resulting in significant energy savings are listed below:

- Envelope: Changes to opaque envelope (see Section 3.2.1 in this report) and continuous air barrier (see Section3.2.2).
- HVAC: Equipment efficiency improvements (see Section 3.3.1), ERV (see Section 3.3.3), kitchen exhaust systems (see Section 3.3.4), staged cooling (see Section 3.3.9), fan airflow control (see Section 3.3.10), VAV reheat control (see Section 3.3.14), VAV system for critical area in healthcare facility (see Section 3.3.15), and outdoor air ventilation optimization (see Section 3.3.17).
- Lighting: Daylight responsive control (see Section 3.5.3), exterior lighting control (see Section 3.5.5), interior lighting power (see Section 3.5.6), and exterior lighting power (see Section 3.5.7).

Table ES.1 summarizes the analysis results. The 16 building prototypes are listed along with their construction weighting factors. Side-by-side comparisons of the site EUI and ECI for the 2012 and 2015 IECC are shown in the table along with their percent savings. Positive percentage savings indicate a reduction in energy or energy costs from the 2012 IECC. As shown in Table ES.1, the analysis shows an estimated site energy savings of 11.1% and energy cost savings of 11.5% on a national aggregated basis. The analysis also indicates that all building prototypes, except the Warehouse prototype, use less energy under the 2015 IECC. The Warehouse prototype uses more energy because the requirements in the 2015 IECC resulted in reduced daylit area under control compared to the 2012 IECC. These changes are specific to the Warehouse prototype and are more pronounced because lighting energy is a large portion of the total energy consumption in the Warehouse prototype.

Table ES.1. Site Energy and Energy Cost Savings between the 2012 and 2015 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI (kBtu/ft^2-yr)		Site EUI Savings (%)	ECI ($/ft²-yr)		ECI Savings (%)
			2012 IECC	2015 IECC		2012 IECC	2015 IECC	
Office	Small Office	5.6	31.1	29.6	4.8	0.93	0.88	4.8
	Medium Office	6.0	35.5	34.6	2.5	0.99	0.97	1.9
	Large Office	3.3	76.2	71.7	6.0	2.15	2.04	5.2
Retail	Standalone Retail	15.3	54.1	47.3	12.6	1.44	1.21	16.0
	Strip Mall	5.7	58.3	54.0	7.4	1.54	1.39	9.7
Education	Primary School	5.0	62.3	55.5	10.9	1.52	1.34	11.4
	Secondary School	10.4	51.8	42.8	17.4	1.35	1.12	16.8
Healthcare	Outpatient Healthcare	4.4	137.2	117.6	14.3	3.53	3.07	13.0
	Hospital	3.4	172.2	128.0	25.7	3.72	2.98	20.0
Lodging	Small Hotel	1.7	66.4	60.4	9.2	1.49	1.3	12.6
	Large Hotel	5.0	109.5	87.9	19.8	2.37	1.81	23.9
Warehouse	Warehouse	16.7	15.0	15.5	-3.1	0.34	0.36	-5.2
Food Service	Quick-Service Restaurant	0.6	602.5	582	3.4	9.66	8.83	8.6
	Full-Service Restaurant	0.7	405.6	373.8	7.8	7.22	6.44	10.8
Apartment	Mid-Rise Apartment	7.3	45.0	44.2	1.7	1.23	1.22	1.0
	High-Rise Apartment	9.0	49.1	47.6	3.0	1.14	1.11	3.1
National Weighted Average		**100**	**61.4**	**54.5**	**11.1**	**1.49**	**1.31**	**11.5**

Figures ES.1 and ES.2 illustrate the weighted EUI and ECI for each prototype and the national weighted average results for the 2012 and 2015 editions of the IECC, respectively.

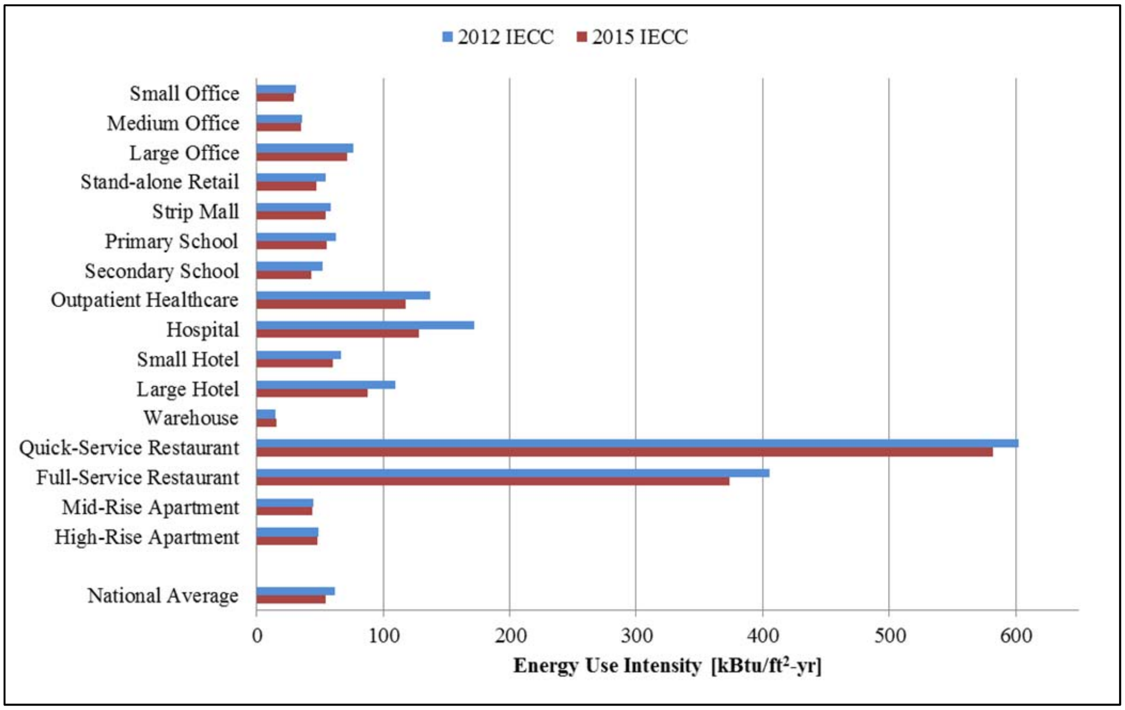

Figure ES.1. National Average Energy Use Intensity for all IECC Prototypes

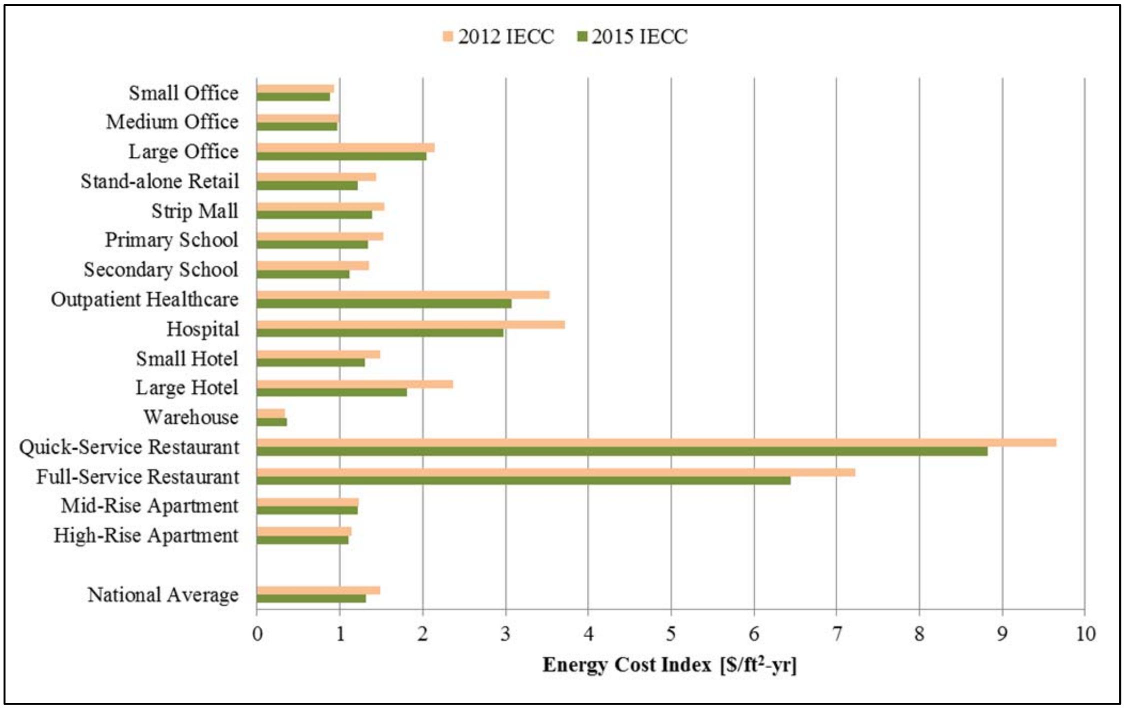

Figure ES. 2. National Average Energy Cost Index for all IECC Prototypes

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Jian Zhang, Ph.D.
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Acronyms and Abbreviations

AEDG	Advanced Energy Design Guide
AIA	American Institute of Architects
ANSI	American National Standards Institute
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BECP	Building Energy Codes Program
bhp	brake horsepower
Btu/h	British thermal unit(s) per hour
CBECS	Commercial Building Energy Consumption Survey
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DX	direct expansion
EC	electronically commutated
ECI	energy cost index
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EMS	energy management system
EPAct	Energy Policy Act
ERV	energy recovery ventilator
EUI	energy use intensity
ft^2	square feet
hp	horsepower
HVAC	heating, ventilation, and air-conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IMC	International Mechanical Code
$kBtu/ft^2$-yr	thousand British thermal unit(s) per square foot per year
kBtu/h	thousand British thermal unit(s) per hour
kWh	kilowatt hour(s)
LPD	lighting power density
MAT	mixed air temperature
NAECA	National Appliance Energy Conservation Act
PLR	part load ratio

PNNL	Pacific Northwest National Laboratory
SAT	supply air temperature
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SWH	service water heating
TMY	typical meteorological year
VAV	variable air volume
VT	visible transmittance
WSHP	water source heat pump
WWR	window-to-wall ratio
w.c.	water column

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1.0 Introduction

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and greenhouse gas emissions for the life of buildings.

As required by federal statute (42 USC 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2013 would achieve greater energy efficiency in buildings subject to the code compared to the 2010 edition of the standard.[2] Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2013 in support of the determination (Halverson et al. 2014). While Standard 90.1 is the national model energy standard for commercial buildings (42 USC 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings. Of the 47 states with statewide commercial building energy codes currently, 37 use a version of the IECC (BECP 2015). The Commercial Energy Efficiency chapter in the 2015 IECC (International Code Council, ICC 2015a) allows users to either follow the provisions in the IECC or use Standard 90.1-2013 as an alternative compliance path. This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2015 IECC would save energy and energy costs compared to the 2012 IECC (ICC 2012). Because PNNL used the same methodology for both this 2015 IECC analysis and the previous Standard 90.1-2013 analysis, comparisons between the estimated energy performance of the 2015 IECC and that of its referenced Standard 90.1-2013 are presented in Appendix B of this report. The goal of this analysis is to help states and local jurisdictions make informed decisions regarding model code adoption.

This report documents the approach and results for PNNL's analysis for energy and energy cost savings of the 2015 IECC for commercial buildings. PNNL first reviewed all code changes from the 2012 to 2015 IECC and identified those having a quantifiable impact. PNNL then used two suites of building prototypes, each suite complying with one edition of the IECC. Each suite consists of 240 building prototypes; a combination of 16 building prototypes in all 15 U.S. climate zones. The 2012 IECC prototypes were taken from PNNL's previous analysis of the energy performance of the 2012 IECC compared to its previous editions which was documented in *Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings* (Zhang et al. 2013), referred to here as *Analysis of the 2012 IECC*.

The current report is organized as follows: Section 2.0 summarizes the general methodology about the building prototypes, their development, and simulation for their energy use and cost. The same methodology was applied in the previous *Analysis of the 2012 IECC* and the Standard 90.1-2013 determination (Halverson et al. 2014). Section 3.0 describes how PNNL developed the 2015 IECC prototypes using the 2012 IECC prototypes as a basis. Finally, Section 4.0 summarizes the results of the comparison of the two editions of the IECC. Appendix A summarizes the identified code changes between the 2012 and 2015 IECC (with quantified energy impacts) and identifies which building prototypes are impacted by each change. Appendix B provides energy and energy cost comparisons between Standard 90.1-2013 and the 2015 IECC.

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air- Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)
[2] For more information on the DOE Determination of energy savings, see http://www.energycodes.gov/regulations/determinations

2.0 Methodology

To support the development and implementation of building energy codes, PNNL researchers have developed building prototypes that comply with various editions of energy codes including both Standard 90.1 and IECC. These building prototypes represent the majority of new commercial building stock and were developed using DOE's *EnergyPlus Version 8.0* building energy simulation software (DOE 2013). The results allow comparison of the national weighted average savings of one code to its earlier edition and the relative performance differences between the codes. This section summarizes the general methodology used for this 2015 IECC analysis, which is consistent with that used for the *Analysis of the 2012 IECC*.

2.1 Building Prototypes

For this analysis, PNNL used a suite of building prototypes representing the first seven principal building activities in the Commercial Buildings Energy Consumption Survey (CBECS; EIA 2003). These seven principal building activities represent 76% of the building energy usage of commercial buildings. In addition, two multifamily prototypes (Mid-Rise and High-Rise Apartments) which are not included in CBECS were added into the suite of prototypes. These two prototypes were included in the analysis because they are regulated by the commercial provisions of the IECC. Table 2.1 shows the seven principal activities as defined in CBECS and the added apartment activity. These eight building activities were further divided into 16 building prototypes as listed in Table 2.1 along with their floor area, representing 80% of new construction floor area in the United States. Detailed descriptions of these prototypes and enhancements are documented in Thornton et al. (2011) and Goel et al. (2014).

2.2 Climate Zones

The climate zone and moisture regime definitions used by the IECC include eight zones (climate zones 1 through 8) and three moisture regimes (A – moist, B – dry, and C – marine). Each combination of climate zone and moisture regime defines a climate subzone. For this analysis, a specific climate (city) is selected (representing 15 climate subzones covering the entire United States) as shown in Figure 2.1 (Briggs et al. 2003). The term climate zone is used interchangeably with climate subzone in this report.

Table 2.1. Building Prototypes

Building Activity	Building Prototype	Prototype Floor Area (ft^2)
Office	Small Office	5,500
	Medium Office	53,630
	Large Office	498,640
Retail	Standalone Retail	24,690
	Strip Mall	22,500
Education	Primary School	73,970
	Secondary School	210,910
Healthcare	Outpatient Healthcare	40,950
	Hospital	241,410
Lodging	Small Hotel	43,210
	Large Hotel	122,120
Warehouse	Warehouse	52,050
Food Service	Quick-Service Restaurant	2,500
	Full-Service Restaurant	5,500
Apartment	Mid-Rise Apartment	33,740
	High-Rise Apartment	84,360

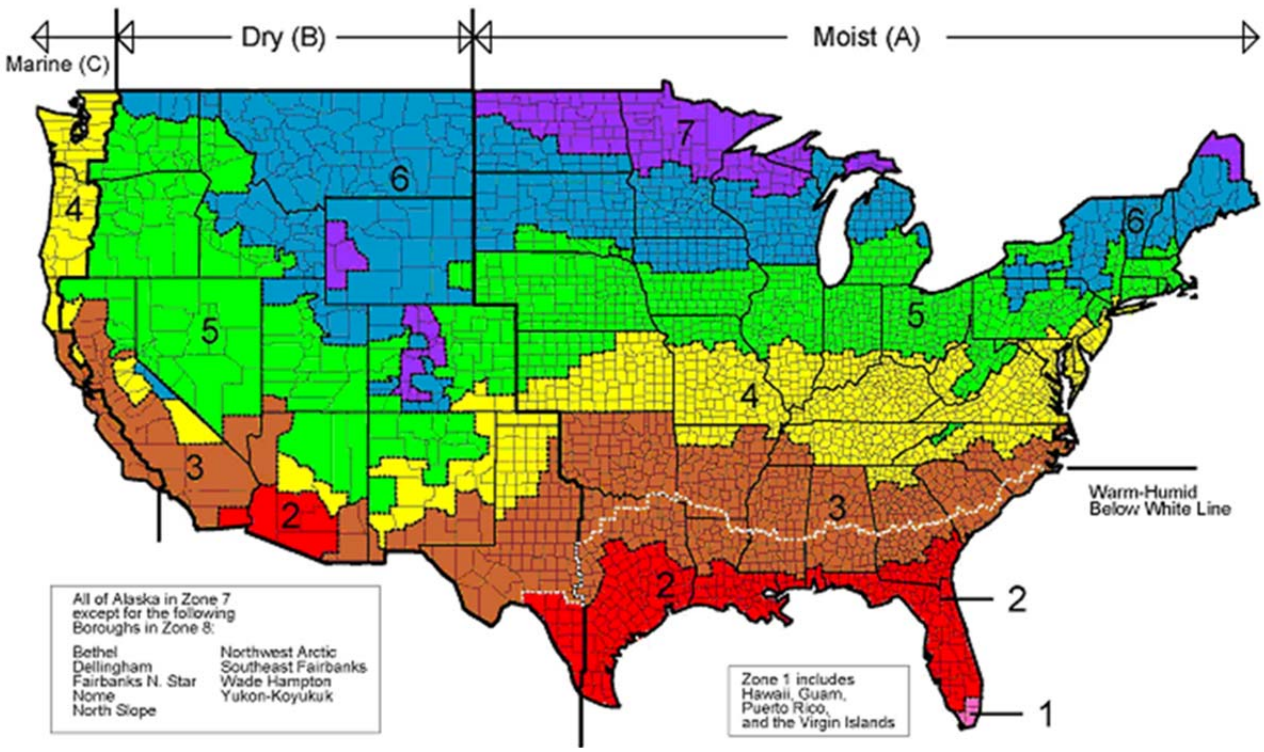

Figure 2.1. Climate Zone Map (Briggs et al. 2003)

The 15 climate locations representing the climate zones are:

- 1A: Miami, Florida (very hot, humid)
- 2A: Houston, Texas (hot, humid)
- 2B: Phoenix, Arizona (hot, dry)
- 3A: Memphis, Tennessee (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Francisco, California (warm, marine)
- 4A: Baltimore, Maryland (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Salem, Oregon (mixed, marine)
- 5A: Chicago, Illinois (cool, humid)
- 5B: Boise, Idaho (cool, dry)
- 6A: Burlington, Vermont (cold, humid)
- 6B: Helena, Montana (cold, dry)
- 7: Duluth, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

2.3 Comparison Metrics and Construction Weights

Annual electricity and natural gas energy use in each building prototype was simulated across 240 buildings, a combination of 16 prototypes in all 15 U.S. climate zones. This simulated energy use is utility electricity and natural gas delivered and used at the building site. The site energy use was converted to site energy use intensity (site EUI, or energy use per unit floor area).

To estimate the energy cost, PNNL used annual national average commercial building energy prices of $0.1029/kWh of electricity and $8.17 per 1000 cubic feet ($0.796/therm) of natural gas. These prices were available from the Energy Information Administration (EIA) and are listed in Table 2, "U.S. Energy Prices," of the February 2014 Short Term Energy Outlook for commercial sector natural gas and electricity[1]. The same set of prices was used for all prototypes and in all climate zones. The annual energy costs for each building were calculated for each fuel type (electricity and natural gas) by using the energy prices for all buildings. These costs were converted to energy cost index (ECI, or energy cost per unit floor area) for each building.

The EUI and ECI results of each building are weighted by construction volume for each building prototype and climate zone to calculate the national weighted average EUI and ECI. Weighting factors developed by building type and climate-related geographic areas in the United States were derived from 5 years of recent construction data (Jarnagin and Bandyopadhyay 2010). Table 2.2 lists the weighting factors assigned to each prototype in all 15 U.S. climate zones.

[1] EIA Short Term Energy Outlook available at http://www.eia.gov/forecasts/steo/report/.

Table 2.2. Construction Area Weights by Building Prototype and Climate Zone (Jarnagin and Bandyopadhyay 2010)

	1A (%)	2A (%)	2B (%)	3A (%)	3B (%)	3C (%)	4A (%)	4B (%)	4C (%)	5A (%)	5B (%)	6A (%)	6B (%)	7 (%)	8 (%)	Weights by Building Type (%)
Small Office	0.084	1.064	0.289	0.963	0.475	0.078	0.936	0.047	0.123	0.920	0.322	0.241	0.030	0.032	0.005	5.608
Medium Office	0.129	0.813	0.292	0.766	0.715	0.136	1.190	0.036	0.196	1.060	0.342	0.298	0.035	0.033	0.007	6.047
Large Office	0.102	0.326	0.061	0.445	0.285	0.117	1.132	0.000	0.154	0.442	0.121	0.133	0.000	0.011	0.000	3.327
Standalone Retail	0.224	2.220	0.507	2.386	1.250	0.191	2.545	0.119	0.428	3.429	0.792	0.948	0.091	0.109	0.014	15.254
Strip Mall	0.137	0.991	0.254	1.021	0.626	0.103	1.008	0.023	0.107	1.023	0.201	0.153	0.016	0.007	0.001	5.669
Primary School	0.064	0.933	0.164	0.944	0.446	0.048	0.895	0.030	0.094	0.920	0.224	0.168	0.037	0.023	0.003	4.994
Secondary School	0.160	1.523	0.230	1.893	0.819	0.109	2.013	0.063	0.243	2.282	0.438	0.415	0.086	0.075	0.012	10.361
Outpatient Healthcare	0.037	0.567	0.134	0.581	0.275	0.061	0.818	0.023	0.181	1.058	0.218	0.342	0.033	0.039	0.002	4.371
Hospital	0.040	0.479	0.096	0.468	0.273	0.039	0.615	0.022	0.106	0.812	0.218	0.221	0.024	0.034	0.001	3.448
Small Hotel	0.010	0.288	0.030	0.268	0.114	0.022	0.315	0.020	0.039	0.365	0.089	0.107	0.031	0.020	0.004	1.721
Large Hotel	0.109	0.621	0.125	0.635	0.793	0.106	0.958	0.037	0.123	0.919	0.200	0.227	0.058	0.038	0.004	4.951
Warehouse	0.349	2.590	0.580	2.966	2.298	0.154	2.446	0.068	0.435	3.580	0.688	0.466	0.049	0.043	0.002	16.716
Quick-Service Restaurant	0.008	0.092	0.020	0.102	0.063	0.007	0.089	0.005	0.014	0.128	0.026	0.025	0.003	0.004	0.000	0.587
Full-Service Restaurant	0.009	0.106	0.025	0.111	0.047	0.006	0.127	0.006	0.010	0.143	0.031	0.031	0.004	0.004	0.000	0.660
Mid-Rise Apartment	0.257	1.094	0.093	0.825	0.862	0.260	1.694	0.022	0.371	1.122	0.318	0.313	0.056	0.032	0.000	7.321
High-Rise Apartment	1.521	1.512	0.076	0.652	0.741	0.173	2.506	0.000	0.358	1.163	0.115	0.125	0.016	0.008	0.000	8.967
Weights by Climate Zone	**3.242**	**15.217**	**2.975**	**15.025**	**10.081**	**1.609**	**19.286**	**0.522**	**2.981**	**19.366**	**4.344**	**4.214**	**0.569**	**0.513**	**0.056**	**100**

2.4 Enhancements to the 2012 IECC Building Prototypes

The 2012 IECC prototypes from the *Analysis of the 2012 IECC* served as a starting point for developing the 2015 IECC prototypes. In this analysis, PNNL made enhancements to the 2012 IECC prototypes for several reasons. The major ones, grouped by reason, include:

1) Improvements to simulation accuracy

   a. added multilevel automatic daylighting control to the multipurpose room in Primary School;

   b. revised modeling strategy for demand control ventilation in Primary School and Secondary School;

   c. revised modeling inputs for pipe heat loss of service water heating (SWH) for all prototypes;

2) Simulation infrastructure updates

   a. updated simulation models of the prototypes from DOE *EnergyPlus Version 6.0* to *8.0*;

   b. updated the weather files from typical meteorological year (TMY) 2 to TMY3;

3) Enhancements to provide more detail to capture new requirements

   a. added additional infiltration loads to selected guestrooms in Small Hotel and Large Hotel to reflect balcony door opening;

   b. revised thermostat setpoints during the morning warmup hours for heating, ventilation, and air-conditioning (HVAC) systems in Small Office, Large Office, Primary School, Secondary School, Quick-Service Restaurant, Full-Service Restaurant, Mid-Rise Apartment, and High-Rise Apartment;

   c. revised part-load curves of boilers in Large Office, Primary School, Secondary School, Outpatient Healthcare, Hospital, and High-Rise Apartment;

   d. added plug-in lights to Mid-Rise and High-Rise Apartments; and

   e. added retail display lighting allowance for Strip Mall.

In addition, there are code changes in the 2015 IECC which reflect changes to DOE's Appliance and Commercial Equipment Standards for HVAC, SWH, and refrigeration equipment[1]. These standards were previously developed by DOE or enacted independently through federal legislation. Because the energy savings attributable to these would accrue no matter what edition of the IECC is complied with, they were not considered as code changes contributing to energy savings in this analysis. Therefore, PNNL updated the efficiency of the affected products in the 2012 IECC prototypes to match requirements in the 2015 IECC as follows:

- refrigerators, freezers, and walk-in coolers and freezers in Primary School, Secondary School, Hospital, Large Hotel, Quick-Service Restaurant, and Full-Service Restaurant; and
- gas-fired boiler with capacity under 300,000 British thermal unit(s) per hour (Btu/h) in Outpatient Healthcare.

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[1] Energy efficiency standards for appliances and equipment established by DOE are available at the http://energy.gov/eere/buildings/appliance-and-equipment-standards-program

Table 2.3 shows the site EUI for the 2012 IECC before and after the enhancements were made to the prototypes. Although these enhancements show different levels of impacts on the results on a prototype -by- prototype basis, the impacts on the national weighted average site EUI is small, from 62.1 to 61.4 thousand British thermal units per square foot per year (kBtu/ft^2-yr).

Table 2.3. Site EUI of the 2012 IECC Before and After Enhancements

Building Type	Building Prototype	Floor Area Weight %	Site EUI (kBtu/ft^2-yr) Pre-Enhancements	Site EUI (kBtu/ft^2-yr) Post-Enhancements
Office	Small Office	5.6	30.5	31.1
	Medium Office	6.0	36.2	35.5
	Large Office	3.3	77.7	76.2
Retail	Standalone Retail	15.3	53.8	54.1
	Strip Mall	5.7	55.8	58.3
Education	Primary School	5.0	63.3	62.3
	Secondary School	10.4	51.2	51.8
Healthcare	Outpatient Healthcare	4.4	147.9	137.2
	Hospital	3.4	173.4	172.2
Lodging	Small Hotel	1.7	66.2	66.4
	Large Hotel	5.0	109.3	109.5
Warehouse	Warehouse	16.7	15.6	15.0
Food Service	Quick-Service Restaurant	0.6	609.5	602.5
	Full-Service Restaurant	0.7	412.2	405.6
Apartment	Mid-Rise Apartment	7.3	44.6	45.0
	High-Rise Apartment	9.0	51.5	49.1
National Weighted Average		**100**	**62.1**	**61.4**

3.0 2015 IECC Building Prototype Development

The starting point for the 2015 prototypes was the enhanced versions of the 2012 prototypes as described in the preceding section. In this section, PNNL compares code changes in commercial energy efficiency provisions between the 2012 and 2015 IECC and documents how they were implemented in the 2015 IECC prototypes and modeled in *EnergyPlus*. Where an implementation approach is similar to one described in previous PNNL reports (e.g., Thornton et al. 2011, Zhang et al. 2013, Goel et al. 2014, and Halverson et al. 2014), reference is made to these reports rather than reproducing the text here.

3.1 Review of Code Changes

Chapter 4 Commercial Energy Efficiency of the IECC provides three alternative paths for a new building to show compliance: (1) the mandatory and prescriptive requirements in the IECC; (2) the mandatory and total building performance requirements in the IECC; or (3) the requirements in the referenced Standard 90.1. This analysis looks only at compliance path (1), comparing the energy performance of the 2012 requirements relative to the 2015 requirements.

PNNL classified code changes into three categories, including 1) clarify requirements without changing their efficiency; 2) result in energy efficiency impacts but cannot be quantified using the building prototypes; and 3) result in energy efficiency impacts that can be quantified. Only those in the third category (see Appendix A) were incorporated into the 2015 IECC building prototypes. The most common reason why a change in the second category was not implemented was that the class of equipment or the particular requirements impacted by the change were not represented in the building prototypes. Other reasons were if *EnergyPlus* was not able to simulate the change or the change applied only to existing buildings instead of new buildings.

3.2 Building Envelope

Section C402 of the 2012 and 2015 IECC specifies requirements for building thermal envelope performance. The code as it relates to the envelope was modified in three areas: opaque envelope performance, fenestration area, and continuous air barrier. Because the fenestration area requirements are related to code changes for daylight responsive controls, these changes are discussed in Section 3.5.3 of this report.

3.2.1 Opaque Envelope Performance

Table C402.1.2 in the 2012 IECC becomes Table C402.1.4 in the 2015 IECC. This table lists opaque thermal envelope assembly requirements using U-factor, C-factor and F-factor-based method. The code changes in the U-factor requirements for roof (insulation entirely above deck type) and exterior wall (mass wall type) are applicable to all building prototypes, except for Small Office, Quick-Service Restaurant, and Full-Service Restaurant. PNNL calculated the R-value of the insulation layer in the wall or roof construction assembly in a prototype by using the changed U-factor requirements. PNNL implemented this R-value in the simulation models of the 2015 IECC prototypes.

3.2.2 Continuous Air Barrier

Section C402.4 of the 2012 IECC addresses the air leakage requirements. A continuous air barrier (CAB) is needed throughout the building envelope except for buildings in climate zones 1 through 3. Three compliance options are provided: (1) materials, (2) assemblies, and (3) whole building air leakage test. In this study, PNNL assumed a prototype has an air leakage rate of 1.8 cfm/ft^2 of exterior wall under a pressure differential of 0.30 in. water column (w.c.) if it is exempted from the CAB requirement. We assumed a rate of 1.0 cfm/ft^2 when the CAB requirement applied. These values were derived in previous analysis (see Section 5.2.1.1 of Thornton et al 2011).

The 2015 IECC (Section C402.5) only allows climate zone 2B to be exempted from the CAB requirement. To implement the code change, PNNL extended CAB to the 2015 IECC prototypes in climate zones 1A, 2A, 3A, 3B, and 3C by using an air leakage rate of 1.0 cfm/ft^2.

3.3 Building Mechanical Systems

Section C403 of the 2012 and 2015 IECC specifies requirements for building mechanical systems. There are several code changes to the Section C403, such as changes to minimum equipment efficiency, controls of HVAC equipment, and extension of the scope to cover more equipment types. Because the building prototypes only cover limited types of equipment and systems with certain capacity ranges, this analysis only estimates the code changes that are applicable to the prototypes.

3.3.1 Heating, Ventilating, and Air-Conditioning Equipment Performance Requirements

Section C403.2.3 of the 2012 IECC specifies minimum efficiency requirements for various HVAC equipment types. The requirements for the following types of equipment were changed from the 2012 to 2015 IECC:

- air-cooled unitary air conditioners (single package, size category of <65 thousand British thermal units per hour, or kBtu/h),
- air-cooled unitary heat pumps (single package, both heating and cooling modes, size category of <65 kBtu/h),
- water-to-air water loop heat pumps (cooling mode, size categories of <17 kBtu/h, 17-65 kBtu/h, and 65-135 kBtu/h),
- water-to-air water loop heat pumps (heating mode, size category of <135 kBtu/h),
- packaged terminal air conditioners (all sizes),
- hot water boilers (gas-fired, size category of <300 kBtu/h),
- air-cooled chillers (all sizes),
- water-cooled chillers (all sizes), and
- axial fan for open-circuit cooling tower (all sizes).

The changed efficiency was modeled in the 2015 IECC prototypes using the same methodology as in the 2012 IECC prototypes. Required equipment efficiency is based on equipment capacity that was calculated for each prototype at each climate zone using a design day sizing simulation in *EnergyPlus*. PNNL used this capacity to identify the required efficiency in the IECC and then ran an annual simulation using this efficiency. When efficiency values vary by effective dates in the IECC, PNNL used the values with latest dates. For example, Table C403.2.3(1) in the 2015 IECC lists single package air-cooled air conditioners under 65,000 Btu/h to have a minimum efficiency of 13 seasonal energy efficiency ratio (SEER) before January 1, 2016, and 14 SEER as of January 1, 2016. Efficiency of 14 SEER was used in this analysis.

While there is an increase in efficiency requirements for gas-fired hot water boilers with capacity less than 300 kBtu/h from the 2012 to 2015 IECC, this reflects the minimum federally mandated equipment efficiency for this type of boilers. Therefore, the higher boiler efficiency listed in the 2015 IECC was applied to both the 2012 and 2015 IECC building prototypes. Only Outpatient Healthcare has boilers smaller than 300,000 Btu/h.

3.3.2 Hot Water Boiler Outdoor Temperature Setback Control

Section C403.2.5 of the 2015 IECC introduces a new requirement that hot water boilers shall have a control that can automatically lower the boiler water temperature setpoint based on the outdoor air temperature. Section C403.4.2.4 of the 2012 IECC requires that hydronic heating systems have either a temperature reset control or variable flow.

Six building prototypes, i.e., Large Office, Secondary School, Outpatient Healthcare, Hospital, Large Hotel, and High-Rise Apartment, use hot water boilers for heating. Because the 2012 IECC buildings all use variable flow hydronic heating systems, temperature reset control was not implemented.

For the 2015 IECC, PNNL applied outdoor temperature setback control to Large Office, Secondary School, Outpatient Healthcare, Hospital, and Large Hotel. The implemented control is that boiler temperature setpoint is

- equal to the design supply temperature if the outdoor temperature is below 20°F,
- reset by 25% of the design supply-to-return water temperature difference if the outdoor temperature is above 50°F, and
- reset to a value that is linearly interpolated between the two setpoint temperatures above if the outdoor temperature is between 20°F and 50°F.

High-Rise Apartment uses a closed-loop water source heat pump (WSHP) system to provide both heating and cooling to the space. The recirculated water in WSHP serves as heating and cooling source for the water-to-air heat pump in each zone. The water temperature is maintained between two setpoints: 68°F and 86°F by a central fluid cooler and a central boiler. No central heating or cooling is needed if the temperature is within this range. Even when the water temperature is at the lower setpoint of 68°F, the water could serve as both heating and cooling sources for different zones at the same time. Therefore, resetting the setpoint from 68°F to a lower value is not desired. As such, PNNL did not implement this control requirement to High-Rise Apartment for the 2015 IECC. An exception to this hot water boiler outdoor temperature setback control requirement may be added for WSHP systems in the future edition of the IECC.

3.3.3 Energy Recovery Ventilator

Section C403.2.6 of the 2012 IECC specifies the energy recovery ventilator (ERV) requirements by climate zone for different outdoor air fraction and design supply fan size thresholds. These requirements are for systems with outdoor air fractions above 30%. The changes from the 2012 to 2015 IECC, in Table C403.2.7(1) in Section C403.2.7, reduced the fraction threshold to 10% in climate zones 1A, 2A, 3A, 4A, 5A, 6A, 6B, 7, and 8. Additionally, the requirements for climate zones 3B, 3C, 4B, 4C, and 5B for systems with the outdoor air fraction above 70% were removed from the 2012 to 2015 IECC. Finally, Table C403.2.7(2) in the 2015 IECC adds a new set of requirements for ventilation systems operating more than 8,000 hours per year.

Based on the HVAC system sizing information from the *EnergyPlus* design day simulation, each air handling unit (AHU) of the building prototypes in each climate zone was checked to determine whether an ERV should be required by the 2015 IECC. Hospital and Large Hotel are assumed to operate more than 8,000 hours per year. This code change was implemented in Medium Office, Large Office, Standalone Retail, Strip Mall, Primary School, Secondary School, Outpatient Healthcare, Hospital, and Large Hotel.

AHUs in Mid-Rise Apartment, High-Rise Apartment, and Small Hotel in certain climate zones meet the trigger for the ERV requirements in the 2015 IECC. However, ERVs were not added to these prototypes because ERV products are usually not available for those small AHUs. An exception to this ERV requirement may be added in the future edition of the IECC for systems with very low outdoor air intake.

3.3.4 Kitchen Exhaust Systems

The 2012 IECC does not have requirements for kitchen exhaust hoods and kitchen ventilation systems. Baseline assumptions were made in previous analysis (Zhang et al. 2013) for kitchens in Primary School, Secondary School, Quick-Service Restaurant, Full-Service Restaurant, Large Hotel, and Hospital based on engineering judgment and a review of actual kitchen designs for these building types.

The 2015 IECC introduces new requirements for all kitchen exhaust systems, as listed in Section C403.2.8. The requirements that were implemented to the 2015 IECC prototypes are:

- All available transfer air from adjacent spaces shall be used before any other makeup air is introduced to the kitchen for any size hood.
- All hoods shall meet maximum net exhaust flow rate requirements listed in Table C403.2.8 if the total kitchen exhaust airflow rate in the kitchen/dining facility is greater than 5,000 cfm.
- Kitchen/dining facilities with total kitchen hood exhaust airflow rate larger than 5,000 cfm shall meet one of three options: (a) at least 50% of replacement air from transfer air; (b) cooking-load-based demand control ventilation; and (c) energy recovery devices on exhaust airflow.

Changes to building prototypes for the 2015 IECC include the use of transfer air, reduction of exhaust airflow rate, and the use of demand control ventilation. These changes vary by prototype and by climate zone.

3.3.5 Fan Power Limitation Adjustment Credits

The 2012 IECC specifies maximum allowable fan power limits for HVAC systems at their fan system design conditions. Depending on the devices used in the systems, which affect the system air pressure drop, the IECC allows adjustments (credits) to the allowable limits using Table C403.2.10.1(2).

The 2015 IECC adds new adjustment items (deductions) to the table, Table C403.2.12.1(2). With this code change, systems without a central cooling coil are required to deduct 0.6 in. w.c. from their fan power limits. Systems without a central heating coil are required to deduct 0.3 in. w.c. Finally, systems with a central electric resistance heating element are required to deduct 0.2 in. w.c.

All building prototypes have central cooling coils but none has central electric resistance coils. Therefore, the code changes only affect those without central heating coils. All single-zone HVAC systems in the building prototypes need central heating coils. Hospital, Large Hotel, Large Office, Medium Office, Outpatient Healthcare, Primary School, and Secondary School have multiple-zone variable air volume (VAV) systems. A central heating coil in a VAV system serves to heat the mixed return and outdoor ventilation air from a mixed air temperature (MAT) to a supply air temperature (SAT) setpoint of 55°F. If the MATs never drop below 55°F, the VAV system does not need a central heating coil.

To determine the systems that must take the deduction to their fan power limits, PNNL calculated the lowest MAT for each prototype in each climate zone by using their heating design outdoor air temperature, return air temperature, and design outdoor air fraction. For those systems with the calculated lowest MATs higher or equal to 55°F, PNNL reduced their fan power limits by 0.3 in. w.c. in the 2015 IECC prototypes.

3.3.6 Reach-in Refrigerator and Freezer

The 2012 IECC does not prescribe requirements for commercial refrigerators and freezers. The 2015 IECC expands the scope of the code to add requirements for such equipment in Section C403.2.14. These new requirements reflect changes to national manufacturing standards per 10 Code of Federal Regulations (CFR) part 431, which went into effect on January 1, 2012. Because the energy savings that are attributable to these national manufacturing standards would accrue no matter what edition of the IECC is used, PNNL applied the same efficiency requirements in the 2015 IECC to both the 2012 and 2015 IECC building prototypes.

PNNL assumed that solid-door commercial refrigerators and freezers are used in the kitchens of Quick-Service Restaurant, Full-Service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. Table 3.1 shows the sizes and numbers of commercial freezers and refrigerators in the building prototypes. The efficiency requirements, in kWh/day, were modelled as a plug load with a constant operation schedule in *EnergyPlus*. Table 3.2 shows the energy use limits used to calculate the input power of commercial refrigerators and freezers for both the 2012 and 2015 IECC.

Table 3.1. Commercial Solid-Door Refrigerators and Freezers in Prototypes

Building Prototype	Number of Freezers (typical volume V=24 ft^3)	Number of Refrigerators (typical volume V=48 ft^3)
Quick-Service Restaurant	1	2
Full-Service Restaurant	1	2
Hospital	2	3
Large Hotel	1	1
Primary School	2	2
Secondary School	2	2

Table 3.2. The 2015 IECC Requirements for Commercial Refrigerators and Freezers in Prototypes

Equipment	Energy Use Limits (kWh/day)
Reach-in refrigerators with solid doors	0.10V + 2.04
Reach-in freezers with solid doors	0.40V + 1.38

3.3.7 Manufactured Walk-in Cooler and Freezer

The 2012 IECC does not have any requirements for walk-in coolers and freezers. The 2015 IECC expands the scope of the code to add requirements for such equipment as defined in Section C403.2.15. The new requirements have been defined and legislated as the national manufacturing standard and described in 10 CFR 431.306. The requirements are for cover doors, insulation, evaporator fan motor, lighting, anti-sweat heater, condenser fan motor, and their controls.

The code change affects six building prototypes with commercial kitchens: Quick-Service Restaurant, Full-Service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. PNNL assumed that the walk-in coolers and freezers in these prototypes are manufactured as opposed to site-assembled or site-constructed. We also assumed them to be packaged equipment without remote compressors and condensers.

Navigant (2009) developed characteristics of baseline walk-in coolers and freezers, which show typical efficiency levels of the equipment before the new manufacturing standard. PNNL found that these characteristics either meet or exceed most requirements in the 2015 IECC, except for the evaporator fan motor and the lighting requirements. To capture these new requirements, the evaporator fan motors in the prototypes were assumed to be electronically commutated (EC) motors with an average motor efficiency of 70%, which was determined by surveying typical efficiencies listed in manufacturer catalogs. The efficiency was modelled as the fan power inputs in *EnergyPlus* models of the prototypes. The impact of the lighting control requirement was modeled as a 10% reduction in the hourly lighting schedule from the baseline models. This simulates the energy saving benefits from an occupancy-sensor-based lighting control. Because the energy savings that are attributable to the national manufacturing standards would accrue no matter what edition of the IECC is used, PNNL applied the same efficiency requirements to both the 2012 and 2015 IECC building prototypes.

3.3.8 Economizer

There are several changes to the economizer requirements from the 2012 (Section C403.3.1 and C403.4.1) to 2015 IECC (Section C403.3) including capacity threshold increase, water economizer requirements, and combined requirements for simple and complex systems (previously separate in the 2012 IECC). This section describes the implementation for capacity threshold increase; Sections 3.3.9 and 3.3.10 discuss other code changes related to economizers in the prototypes.

To capture the energy impacts of the increased thresholds, first, a sizing simulation was conducted for each prototype with air economizers disabled in *EnergyPlus* to determine the cooling capacity of each direct expansion (DX) coil in the prototype. Second, the prototype was modified to enable the air economizer if the capacity exceeded the thresholds in the IECC. If the capacity was below the thresholds, the economizer remained disabled. This two-step procedure was followed for both the 2012 and 2015 IECC prototypes, and the differences between them are the thresholds shown in Table 3.3.

Table 3.3. Economizer Requirements by Cooling Capacity Thresholds and Climate Zones

Cooling Capacity Threshold (Btu/hr)	2012 IECC (climate zone)	2015 IECC (climate zone)
No requirement	1A, 1B	1A, 1B
>=33,000	2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8	
>=54,000		2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8

3.3.9 Staged Cooling

Section C403.3.1 in the 2015 IECC introduces a new staged cooling requirement for DX units, which is not contained in the 2012 IECC. According to item 3 under Section C403.3.1, for DX units that control 75,000 Btu/h or greater of rated capacity directly based on occupied space temperature (usually serving a single zone), a minimum of two stages of mechanical cooling capacity are required. Another related new code requirement (see Section 3.3.10 of this report) in Table C403.4.1.1 of the 2015 IECC requires a two-stage fan control for DX units with cooling capacity over 65,000 Btu/h (after January 1, 2016). In practice, a DX unit would either have both staged cooling and staged fan controls together or neither of them. For this reason, PNNL used 65,000 Btu/h as the threshold for the staged cooling requirement instead of 75,000 Btu/h.

Eight building prototypes use packaged single-zone DX cooling units: Standalone Retail, Strip Mall, Quick-Service Restaurant, Full-Service Restaurant, Primary School, Secondary School, Small Hotel, and Warehouse. For the 2012 IECC, these prototypes all use single-stage cooling control. For the 2015 IECC, except for the single-zone units in Small Hotel and Warehouse, the cooling capacities of DX units found in the prototypes are larger than 65,000 Btu/h in most climate zones; therefore, they were modelled with two-stage cooling. For units required to have two-stage cooling, the low-stage capacity was assigned to be half of the full capacity.

Improved economizer integration is a source of energy savings from the new staged cooling requirement in the 2015 IECC. When two-stage cooling and air economizer controls are both required in a 2015 IECC building prototype, economizer operation was modeled to represent increased economizer effectiveness. The fraction of time spent by the system in each mode—full economizer, partial economizer, and full mechanical cooling—was used to calculate an average economizer effectiveness for a given time step. PNNL adjusted the economizer effectiveness by changing the maximum outside air schedule that controls the amount of outside air available at a simulation time step. PNNL implemented this modeling strategy using the *EnergyPlus* energy management system (EMS) feature. The implementation is described in more detail in Section 5.2.2.6 of the PNNL report (Halverson et al. 2014).

3.3.10 Fan Airflow Control

Fan airflow control is another new requirement introduced in the 2015 IECC. Section C403.4.1.1 and Table C403.4.1.1 require two stages of fan control for DX units (capacity larger than 65,000 Btu/h) that control cooling capacity directly based on space temperature (usually serving a single zone). The requirement states that low or minimum fan speed shall not be greater than 66% of full speed. Section C403.4.1.1 of the 2015 IECC also requires that units with air economizers shall have a minimum of two speeds of fan control during economizer operation.

Six building prototypes, i.e., Standalone Retail, Strip Mall, Quick-Service Restaurant, Full-Service Restaurant, Primary School, and Secondary School, qualify for this requirement because they have packaged single-zone DX cooling units with capacity larger than 65,000 Btu/h. The requirements in the 2015 IECC are identical to those in Standard 90.1-2013 and their implementation in the prototype models has been described in a previous analysis (Halverson et al. 2014). The same modeling strategy applies to the 2012 and 2015 IECC models.

3.3.11 Part-load Controls for Hydronic Systems

Section C403.4.3.4 in the 2012 IECC requires hydronic heating and cooling systems with capacity over 300,000 Btu/h to include either supply-water temperature reset or variable flow controls. The 2015 IECC (Section C403.4.2.4) changes the capacity threshold to 500,000 Btu/h. Additionally, the code is changed from requiring one of these two controls to requiring both of them, plus a variable (or stepped) pumping control.

Six building prototypes, i.e., Large Office, Secondary School, Outpatient Healthcare, Hospital, Large Hotel, and High-Rise Apartment, have variable flow hydronic heating systems with variable flow pumps. Based on engineering judgment, PNNL assumed this type of system to be typical design in these prototypes no matter what edition of the IECC is used.

Four building prototypes, Large Office, Hospital, Secondary School, and Large Hotel, have primary-secondary variable-flow chilled water systems with variable-flow secondary pumps. Based on engineering judgment, PNNL assumed this type of system to be a typical design. Therefore, these prototypes meet the part-load control requirements for hydronic heating and cooling systems in the 2012 IECC.

For the 2015 IECC, the hydronic heating systems in the six prototypes already have the variable flow, variable pumping, and supply-water temperature reset (described in Section 3.3.2). As such, they meet the requirements in 2015 IECC already. For the hydronic cooling systems in the four prototypes, PNNL implemented supply-water temperature setpoint reset using the following reset rule, the setpoint is:

- the design supply temperature if the outdoor temperature is below 80°F,
- reset by 25% of the design supply-to-return water temperature difference if the outdoor temperature is above 60°F, and
- linearly interpolated between the two setpoint temperatures above if the outdoor temperature is between 60°F and 80°F.

The capacities of all hydronic systems in the building prototypes exceed the increased threshold of 500,000 Btu/h in the 2015 IECC. Therefore, the impact of the threshold change was not captured in the simulations.

3.3.12 Boiler Turndown

Section C403.4.2.5 in the 2015 IECC adds a boiler turndown requirement, which does not exist in the 2012 IECC. The new section requires that boiler systems with design input of 1,000,000 Btu/h or more comply with different turndown ratios, as shown in Table 3.4, using multiple single input boilers, one or more modulating boilers, or a combination of single input and modulating boilers.

Table 3.4. Boiler Turndown in Table C403.4.2.5 of the 2015 IECC

Boiler System Design Input (Btu/h)	Minimum Turndown Ratio
≥ 1,000,000 and less than or equal to 5,000,000	3 to 1
> 5,000,000 and less than or equal to 10,000,000	4 to 1
> 10,000,000	5 to 1

The following building prototypes use boilers that may be affected by the turndown requirements: Large Office, Hospital, Primary School, Secondary School, Large Hotel, High-Rise Apartment, and Outpatient Healthcare. PNNL assumed single-stage capacity control to be typical design in the 2012 IECC building prototypes based on a review of the certified boilers in the American Heating and Refrigeration Institute (AHRI) directory[1]. For the 2015 IECC, PNNL assumed that the prototypes would use modulating boiler capacity control, one of the three compliance options required by the 2015 IECC, if the building's system capacity was greater than 1,000,000 Btu/h.

EnergyPlus models boiler's part-load performance with a part-load efficiency (through a part-load curve as function of part load ratio (PLR)), which describes the normalized heating efficiency (as a fraction of nominal thermal efficiency) of the boiler's burner. PNNL modelled all boilers in the 2012 IECC prototypes using the curve described in Equation 3-1. For the 2015 IECC, PNNL applied Equation 3-1 curve to boilers with input capacity ≤1,000,000 Btu/h and Equation 3-2 curve to those with input

[1] AHRI's Directory of Certified Product Performance database. Last accessed in May 2013 at http://www.ahridirectory.org/ahridirectory/pages/cblr/defaultSearch.aspx

capacity >1,000,000 Btu/h. These curves are based on research by Bertagnolio and Andre (2010). Although these curves were only developed for PLR in the range of minimum turn down load and full load, *EnergyPlus* could allow a boiler to work at a PLR below the range. PNNL implemented an *EnergyPlus* EMS algorithm in the simulation models to adjust curve outputs when the PLR was lower than the range.

$$Curve_{\text{single-stage control}} = 0.907 + 0.320 * PLR - 0.420 * PLR^2 + 0.193 * PLR^3 \quad (3\text{-}1)$$

$$Curve_{\text{modulating control}} = 0.975+0.305 * PLR-0.527 * PLR^2+0.249 * PLR^3 \quad (3\text{-}2)$$

3.3.13 Heat Rejection Equipment

The 2015 IECC includes two major changes for heat rejection as compared to the 2012 IECC: fan control for multi-cell heat rejection equipment (Section C403.4.3.2.2) and open-circuit cooling tower fan flow turndown (Section C403.4.3.2.1). The second change also requires that the maximum number of fans to operate in multi-cell heat rejection equipment to minimize energy. It is more energy efficient to operate all fans in tandem at the same (lower) fan speed than to have an on/off or sequenced fan operation (operating a select number of cells at full speed to meet load). Using more cells also increases heat transfer area and more heat can be rejected with less airflow and fan speed.

Large Office and Hospital use open-circuit cooling towers. Each prototype has two variable-speed cooling towers. Each tower has one dedicated condenser water pump and two cells. Because the two cooling towers are equally sized, the two condenser water pumps have the same design flow rate. In the 2012 IECC building prototypes, the number of operating cooling towers and condenser water pumps corresponds to the number of operating chillers. When one chiller operates, one cooling tower operates and the corresponding condenser water pump operates. When both chillers are running, both cooling towers and both condenser water pumps are running.

The 2015 IECC requires that the maximum number of fans operate to minimize fan energy. This means that when one chiller is running, all four cell fans in the two cooling towers will be operating unless the fan in one cooling tower already runs at its minimum speed. Running two towers implies that the condenser water flow will be reduced by 50% for each cell in comparison with running one tower.

The strategy for modeling the cooling tower control requirements in the 2015 IECC includes the following:

- Change the cell control strategy for variable-speed cooling towers in *EnergyPlus* from “minimum cells” to “maximum cells.”
- For each time step, find the number of operating chillers.
- If one chiller is running and the current airflow ratio is greater than the minimum, run the two towers in parallel. Use the *EnergyPlus* EMS to halve the airflow ratio, which is then used to calculate the fan power according to the cubic power law. The EMS control is necessary because the *EnergyPlus* native control algorithms cannot run both towers in parallel while delivering the condenser water flow for just one chiller if there are two chillers in the plant.
- If two chillers are running or the current airflow is at the minimum when one chiller is running, the EMS algorithm will not override the tower fan curve input and output.

3.3.14 VAV Reheat Control

Section 403.4.5 in the 2012 IECC specifies requirements for zone airflow under multiple zone VAV systems. Thirty percent (30%) of the maximum supply air to each zone is required as the minimum zone supply airflow to reduce VAV reheat at the zone terminals. The 2015 IECC (Section C403.4.4) adds a new exception (item 4) to the 30% minimum; it states that a rate higher than 30% is allowed if it can be demonstrated to reduce overall system annual energy use by offsetting reheat/recool energy losses through a reduction in outdoor air intake for the system. Standard 90.1-2013 has a similar exception and PNNL has established a modeling strategy to determine the minimum zone supply airflow to meet this requirement. The calculation procedure includes four steps: (1) calculate zone ventilation efficiency; (2) calculate system ventilation efficiency; (3) increase the minimum damper fraction (i.e., ratio of minimum to maximum zone supply airflow) from 30% to a new value based on a target value of system ventilation efficiency; and (4) calculate the system design outdoor air intake.

In the 2012 IECC prototypes, only Steps 1, 2, and 4 were applied. For the 2015 IECC, all four steps were followed, which resulted in different minimum damper fractions and system design outdoor airflow rates from those in the 2012 IECC prototypes. The implementation of the four-step methodology is described in detail in Section 5.2.2.21 of Thornton et al. (2011) and Section 2.2.6 of Goel et al. (2014). All prototypes with multiple-zone VAV systems are affected by the code change related to VAV reheat control (i.e., Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, and Hospital).

3.3.15 VAV System for Critical Area in Healthcare Facility

Section C403.4.5 in the 2012 IECC includes Exception (1) to the VAV system requirement for supply air systems serving multiple zones. This exception is for “zones where special pressurization relationships or cross-contamination requirements are such that VAV systems are impractical”. This exception allows designers to use constant volume reheat systems in critical areas of hospitals and similar spaces needing pressure differentials with adjacent areas.

The exception for the VAV requirement is removed in the 2015 IECC (Section C403.4.4). Instead, the 2015 IECC adds an allowance to the airflow rate that can be reheated to achieve reasonable energy savings in these types of spaces, while not compromising health and safety. A new compliance option is to reduce the zone primary air supply to “the airflow rate required to comply with applicable codes or accreditation standards, such as pressure relationships or minimum air change rates”. The code changes mean that if the peak design airflow to any of these spaces is greater than the required minimum air change rate or the minimum rate required maintaining pressure differentials, the system must use VAV, reducing airflow as much as possible before reheat is allowed. Also, if the minimum air change rate is only required during occupied periods (as in operating rooms), the airflow must be reduced during those unoccupied periods before reheat is allowed.

The Hospital and Outpatient Healthcare prototypes include critical spaces that are affected by the changes from the 2012 to 2015 IECC. In the 2012 IECC Hospital and Outpatient Healthcare prototypes, critical spaces, such as operating rooms, patient rooms, intensive care units, and laboratories, were modelled to receive constant airflow with terminal reheat. To capture the impacts of the new requirement, PNNL compared the design airflow to the critical spaces with minimum airflow requirements according to the most commonly used accreditation standard, *AIA Guidelines for Design and Construction of*

Hospital and Health Care Facilities (American Institute of Architects, AIA 2001). PNNL determined that the operating rooms (during unoccupied periods) and patient rooms should be changed to use VAV systems for the 2015 IECC.

3.3.16 Fractional HP Fan Motors

The 2015 IECC adds a new Section C403.4.4.4 that requires motors from 1/12 horsepower (hp) to under 1 hp to be EC motors or have a minimum efficiency of 70%. The intention is to replace standard permanent-split capacitor (PSC) motors having efficiencies in the range of 15% to 65% with more-efficient EC motors. The intended applications are toilet exhaust fans, small kitchen exhaust fans, series fan-powered VAV boxes, and fan-coil units. The following motors are exempt under the new requirement: motors in an airstream where only heating is provided, motors in packaged equipment, poly-phase small motors, and capacitor-start capacitor-run and capacitor-start induction-run motors that are covered by Table C405.8(3) and Table C405.8(4) in the 2015 IECC.

In the building prototypes, the new requirements apply to fan-coil units, exhaust fans, kitchen exhaust fans, and elevator fans. Table 3.5 provides details on the building prototypes and fans to which the new requirements apply.

Table 3.5. Prototype Buildings Affected by Section C403.4.4.4 in the 2015 IECC

Prototype Building	Fan-Coil Unit	Exhaust Fan	Kitchen Exhaust Fan	Elevator Fan
High-Rise Apartment				Yes
Mid-Rise Apartment				Yes
Hospital			Yes	Yes
Large Hotel	Yes	Yes	Yes	Yes
Small Hotel				Yes
Large Office				Yes
Medium Office				Yes
Outpatient Healthcare		Yes		Yes
Quick-Service Restaurant		Yes	Yes	
Full-Service Restaurant		Yes	Yes	
Primary School		Yes	Yes	
Secondary School		Yes		Yes

To determine the motors whose efficiency must be changed, a set of criteria was established based on motor size. From a review of catalogs, motors in the smallest fans were selected from standard fractional horsepower motor sizes even if the required brake horsepower (bhp) is much lower. Therefore, maximum bhp is set at 90% of 3/4 hp or 560 W (above 90% of 3/4 hp, a 1 hp or larger motor would be used) and minimum bhp is set at 25% of 1/12 hp, or 14 W. Motors between the minimum and maximum bhp are considered to be applicable to the new IECC requirements.

To implement the new requirements, motor efficiency was changed in the prototypes. A motor efficiency of 29% was used in the 2012 IECC prototypes based on an intermediate value between highest potential efficiency and lowest efficiency found through literature review. For the 2015 IECC, the motor efficiency was set to 70%, which is close to the average typical EC motor efficiency.

3.3.17 Outdoor Air Ventilation Optimization Control

The 2015 IECC adds a multiple-zone VAV system ventilation optimization control requirement in Section C403.4.4.6. Under this requirement, multiple-zone VAV systems shall have automatic controls to reduce outdoor air intake flow from the design rates in response to dynamic system ventilation efficiency as defined by the 2015 International Mechanical Code (IMC) (ICC 2015b). According to Exception (2), a system having an ERV, as described in Section 3.3.3, is exempted from this requirement. Without such a requirement, the VAV systems in the 2012 IECC prototypes maintain constant outdoor air intake flowrate at the design level. This is a waste of energy to condition excess outdoor air intake.

To capture the savings of the 2015 IECC requirement, the Controller:MechanicalVentilation object in *EnergyPlus* was used with the System Outdoor Air field set to ventilation rate procedure. This is the option for meeting ventilation requirements in the 2015 IMC. Under these modeling settings, *EnergyPlus* implements the multiple-zone calculation per the 2015 IMC at each simulation time step and calculates system efficiency and system outdoor air intake, which is a reduced airflow from the design level. When a system has an ERV, the ventilation optimization control was not implemented; therefore, the system outdoor air intake remains at its design level. The energy savings impacts of the new 2015 IECC requirements were captured in Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, and Hospital.

3.4 Service Water Heating

PNNL reviewed all code changes under Section C404 Service Water Heating and determined that only the new demand-based control requirements for recirculation SWH systems have energy impacts that can be quantified using the building prototypes.

3.4.1 Demand-based Controls for Recirculated Service Water Heating Systems

Section C404.6.1 in the 2015 IECC adds new control requirements for buildings with recirculated SWH systems. The controls shall automatically turn off the circulation pumps when the water temperature in the circulation loop is either at or above the desired setpoint or when there is no hot water demand. These controls are not required in the 2012 IECC.

A recirculated SWH system provides more instant hot water at the water taps but energy losses are greater through pipe thermal losses and pump energy losses than a non-recirculated system. Ten prototypes use recirculated SWH systems. PNNL assumed that the SWH pumps in the 2012 IECC prototypes are always on at constant speed and the SWH temperatures are always maintained at their design setpoint. For each prototype, PNNL estimated the SWH pipe heat loss (kBtu/h) based on the average temperature difference between the water and indoor spaces, total pipe surface area, and pipe insulation. This loss was converted to SWH energy consumption inputs in the *EnergyPlus* models. Pump power in each prototype was also estimated based on pipe design, flow rate, and SWH system operations. This power was converted to pump pressure head in the *EnergyPlus* models. Details of the inputs are available in Section 2.1.4 of Goel et al. (2014). To estimate the energy savings impacts of the 2015 IECC requirements, reductions to the pipe heat loss inputs and recirculation pump power inputs were applied to the 2015 IECC building prototypes based on the baseline inputs in the 2012 IECC prototypes, as shown in Table 3.6. PNNL estimated the savings based on assumed SWH demand profiles in these prototypes.

Although Hospital, Small Hotel, and Large Hotel use recirculated SWH systems, PNNL did not quantify the impacts of the new requirements on them because we assumed the occupants in these building always have SWH demand.

Table 3.6. Percent Energy Savings of the 2015 IECC Controls Attributable to Reductions in Pipe Thermal Losses and Pump Energy Savings (as based on the 2012 IECC Building Prototypes)

Building Prototype	Energy Savings Attributable to Reductions in Pipe Thermal Loss	Savings Attributable to Pump Energy Savings
Medium Office	57%	89%
Large Office	57%	89%
Primary School	48%	90%
Secondary School	48%	90%
Outpatient Healthcare	57%	89%
High-Rise Apartment	44%	90%

3.5 Electrical Power and Lighting Systems

Section C405 of the 2012 and 2015 IECC specifies requirements for electrical power and lighting systems. Through review of the code changes, PNNL identified changes in several areas that have energy impacts and can be quantified using the building prototypes. Some of these changes are related to code changes in other areas, e.g., daylight responsive control is related to skylight and window areas and thermal performance of the fenestration components. These are also related to the changes in Section C406 (additional efficiency package options) of the two editions.

3.5.1 Additional Efficiency Package Options

Section C406 of the 2012 IECC requires choosing one from three additional efficiency package options:

1. Efficiency HVAC performance (Section C406.2),
2. Efficient lighting system (Section C406.3), and
3. On-site supply of renewable energy (Section C406.4).

The 2015 IECC modifies these options and adds three more options in Section C406. The six options are:

1. More efficient HVAC performance (Section C406.2),
2. Reduced lighting power density (LPD) system (Section C406.3),
3. Enhanced lighting controls (Section C406.4),
4. On-site supply of renewable energy (Section C406.5),
5. Provision of a dedicated outdoor air system for certain HVAC equipment (Section C406.6), and
6. High-efficiency service water heating (Section C406.7).

In the *Analysis for the 2012 IECC*, PNNL chose the high-efficiency lighting for the 2012 IECC prototypes because this option is more likely to be chosen for most building designs than the on-site supply of renewable energy option (Section C406.4). The efficient HVAC performance option (Section C406.2) was not chosen because this option would not allow a comparison of the 2012 IECC with its referenced Standard 90.1 with the HVAC equipment at the same minimum efficiencies addressed in the National Appliance Energy Conservation Act (NAECA), Energy Policy Act (EPAct), and the Energy Independence and Security Act (EISA). For the same reason and for keeping consistent choices for this analysis, PNNL chose the corresponding reduced LPD system option (Section C406.3 in the 2015 IECC) for the 2015 IECC prototypes. The impacts of the code changes in the selected option are related to daylight responsive control, skylights and window areas, and thermal performance of the fenestration components in the prototypes, and are discussed in Sections 3.5.3 and 3.5.6.1 in this report.

3.5.2 Occupant Sensor Controls

Section C405.2.2.2 in the 2012 IECC requires occupancy sensors in classrooms, conference/meeting rooms, employee lunch and break rooms, private offices, restrooms, storage rooms, janitorial closets, and other areas less than 300 ft^2 enclosed by floor-to-ceiling partitions. The control devices need to turn the lights off within 30 minutes of the occupants leaving the space and can be either manually turned on or automatically controlled to turn the lighting on to no more than 50% power. Full automatic-on controls are allowed in some specified areas.

The 2015 IECC (Section C405.2.1) extends the occupancy sensor control requirements to copy/print rooms, lounges, locker rooms, and warehouses.

An outline of the procedure for determining savings from occupancy sensors is as follows.

- Appropriate building areas that fall into the occupancy sensor requirements were identified.
- In prototypes like the Small, Medium, and Large Offices and Standalone Retail, where detailed zoning is unavailable, appropriate building areas were determined using the National Commercial Construction Characteristics database.[1] This database provides a compilation of the building prototypes and the proportion of common building areas.
- Percent lighting energy reduction from the use of occupancy sensors was determined for all qualifying areas based on literature review.
- This percentage reduction was applied to the occupied hour values of the lighting schedule used by the specific zone.
- Where a separate zone does not exist in the model for a particular space, the reduction factor was calculated as a product of (1) space area as a fraction of whole-building area from the National Commercial Construction Characteristics database, and (2) target lighting energy savings percentage. This reduction was similarly applied to the occupied hours of the whole-building lighting schedule.

[1] National Commercial Construction Characteristics Database (NC^3), an internal PNNL database of nationwide commercial construction energy-related characteristics.

3.5.3 Daylight Responsive Controls and Fenestration Area

The daylight control requirements in the IECC are related to several other requirements, such as window size, fenestration performance, and lighting power density. The requirements and their implementation in the prototypes are separately discussed in this section for sidelight (daylight through windows) and toplight (daylight through skylights).

3.5.3.1 Sidelighting Area and Control Requirements in the 2012 IECC

The 2012 IECC defines daylight zone adjacent to vertical fenestration in Chapter 2 and specifies control options for sidelight daylight zone in Section C405.2.2.3. However, automatic daylighting controls are not required. However, because the efficient lighting system option was chosen (see Section 3.5.1 and 3.5.6.1), an LPD of 0.9 W/ft^2 from Table C406.3 was selected to meet the reduced LPD requirements for the Small Office and Medium Office prototypes. This triggered Footnote (b) of the table to apply. Therefore, two prototypes, which have sidelight daylight zones over 30% of their total conditioned floor area, are required to have automatic daylighting controls. Automatic stepped daylight controls were implemented in the two prototypes for all climate zones for the 2012 IECC.

A window provides a path for daylight entering the space. The 2012 IECC (Section 402.3.1) limits maximum window-to-wall ratio (WWR) of 30%. In climate zones 1 through 6, a maximum WWR of 40% is allowed if 50% of the conditioned floor area is within a daylight zone (including sidelight and toplight areas) and automatic daylighting controls are installed. Through a literature review, PNNL defined typical WWR for each prototype, which is assumed in its design characteristic. Such characteristics remain the same unless certain code provision requires them to be changed. Most prototypes have WWRs of less than 30% as their characteristics. However, four prototypes (Primary School, Secondary School, Medium Office, and Large Office) have typical WWRs between 30% and 40%. PNNL verified that the 40% limit does not apply to these prototypes because they do not have sufficient daylight area. Therefore, their WWRs were reduced from their typical values to 30% for the 2012 IECC prototypes.

In summary, Small Office and Medium Office prototypes were implemented with automatic controls for general lighting in their sidelight daylight zones. In addition, the WWRs of Primary School, Secondary School, Medium Office, and Large Office were set to 30% for the 2012 IECC.

3.5.3.2 Sidelighting Area and Control Requirements in the 2015 IECC

The 2015 IECC (Section C405.2.3) requires automatic daylight responsive controls for sidelight daylight area as opposed to manual controls (an allowed option in the 2012). It specifies 150 Watts of general lighting within sidelight daylight zone as the minimum threshold to apply the control requirement. As such, many sidelight zones in the 2015 prototypes were implemented with automatic daylight controls, such as Small Office, Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, Hospital, Small Hotel, Large Hotel, Warehouse, Quick-Service Restaurant, and Full-Service Restaurant.

In addition, the 2015 IECC specifies control settings for different space types. Where located in offices, classrooms, laboratories and library reading rooms, daylight responsive controls shall dim lights continuously from full light output to 15% of full light output or lower. Daylight responsive controls shall be capable of a complete shutoff of all controlled lights. For these space types, continuous dimming controls were used and for others, stepped controls were used.

Similar to the 2012 IECC, the 2015 IECC (Section C402.4.1.1) limits the maximum WWR to 30% but allows buildings in climate zones 1 through 6 to use WWR up to 40% if a certain amount of floor area falls under daylight zones. Code changes were made to the criteria for which the 40% limit applies. For buildings with two stories or less, the area in daylight zones must be at least 50% of the net floor area. For buildings with more than two stories, at least 25% of the net floor area must be in a daylight zone. Net floor area excludes corridors, stairwells, bathrooms and mechanical rooms from the conditioned floor area. As mentioned earlier, 30% WWR limit was implemented to Large Office, Medium Office, Primary School, and Secondary School for the 2012 IECC. PNNL checked these prototypes against the changed criteria and compared the ratio of the daylight area (including both sidelight and toplight areas) to the net floor area with the new criteria. It was found that the WWR of Medium Office can be changed to its characteristic size, i.e., WWR of 33%. This was implemented to this prototype in climate zones 1 through 6. In addition, the visible transmittance (VT) of these changed windows was changed to 1.1 times solar heat gain coefficient (SHGC) to meet Section C402.4.1.1 (4) requirement. The WWR remains at 30% in Medium Office (same as the 2012 IECC counterparts) in climate zones 7 and 8.

3.5.3.3 Toplighting Area and Control Requirements in the 2012 IECC

Skylight Area

Section C402.3.2 of the 2012 IECC requires a minimum skylight area in certain spaces larger than 10,000 ft^2 to provide toplight daylight area under skylights to be at least 50% of the space area. The skylight area shall not be less than 3% of this daylight area. Buildings in climate zones 6 through 8 are exempted.

Spaces in some of the building prototypes have skylights in their typical design, i.e., skylights are a characteristic of the prototype. Such characteristics remain the same unless certain code provisions require them to be changed. The spaces in these prototypes with skylights are listed in Table 3.7 along with other design characteristics related to daylight area under skylights. As seen in the table, the zones in Primary School and Secondary School meet the minimum skylight area requirements in Section C402.3.2 of the 2012 IECC.

Footnote (c) of Table C406.3 in the efficient light system option, used in the 2012 IECC prototype, as discussed in Section 3.5.6.1, requires 70% of floor area in warehouse and 30% in retail to be in the daylight zone. Because of this requirement, PNNL increased the number of skylights in the 2012 IECC Warehouse and Standalone Retail prototypes.

Daylight Responsive Control in Toplight Daylight Area

Section C402.3.2.1 in the 2012 IECC requires all lighting in the toplight daylight zone to be controlled by multilevel lighting controls except for climate zones 6 through 8. For Warehouse and Standalone Retail prototypes, Footnotes (b) and (c) of Table C406.3 require automatic daylighting control without climate zone exceptions. Therefore, these multilevel lighting controls were implemented to zones listed in Table 3.7 for Primary School and Secondary School in climate zones 1 through 5. Warehouse and Standalone Retail in all climate zones were modelled with automatic daylighting control.

Thermal Performance of Skylights

Sections C402.3.3.3 in the 2012 IECC allows skylights to have an increased SHGC from the requirements in Table C402.3 in climate zones 1 through 6 where the toplight daylight area under the skylights has automated daylighting controls. Similarly, according to Section C402.3.3.4, these skylights can use increased U-factor in all climate zones. These increased SHGC and U-factor requirements were implemented to the prototypes as they apply.

Table 3.7. Typical Skylight and Toplight Area in the Building Prototypes

Prototype	Zone Name	Zone Area (ft^2)	Skylight Area (ft^2)	Toplight Daylight Area (ft^2)	Toplight Daylight Area / Zone Area (%)	Skylight Area / Toplight Daylight Area (%)
Primary School	Multipurpose Room	3843	144	3843	100%	4%
Secondary School	Gymnasium	21269	864	21269	100%	4%
	Auxiliary Gymnasium	13433	576	13433	100%	4%
Warehouse	Bulk Storage [a, b]	34497	160	4876	14%	0%
	Fine Storage [a, b]	15000	0	0	0%	0%
Standalone Retail	Core Retail [a, b]	17227	72	2584	15%	0%

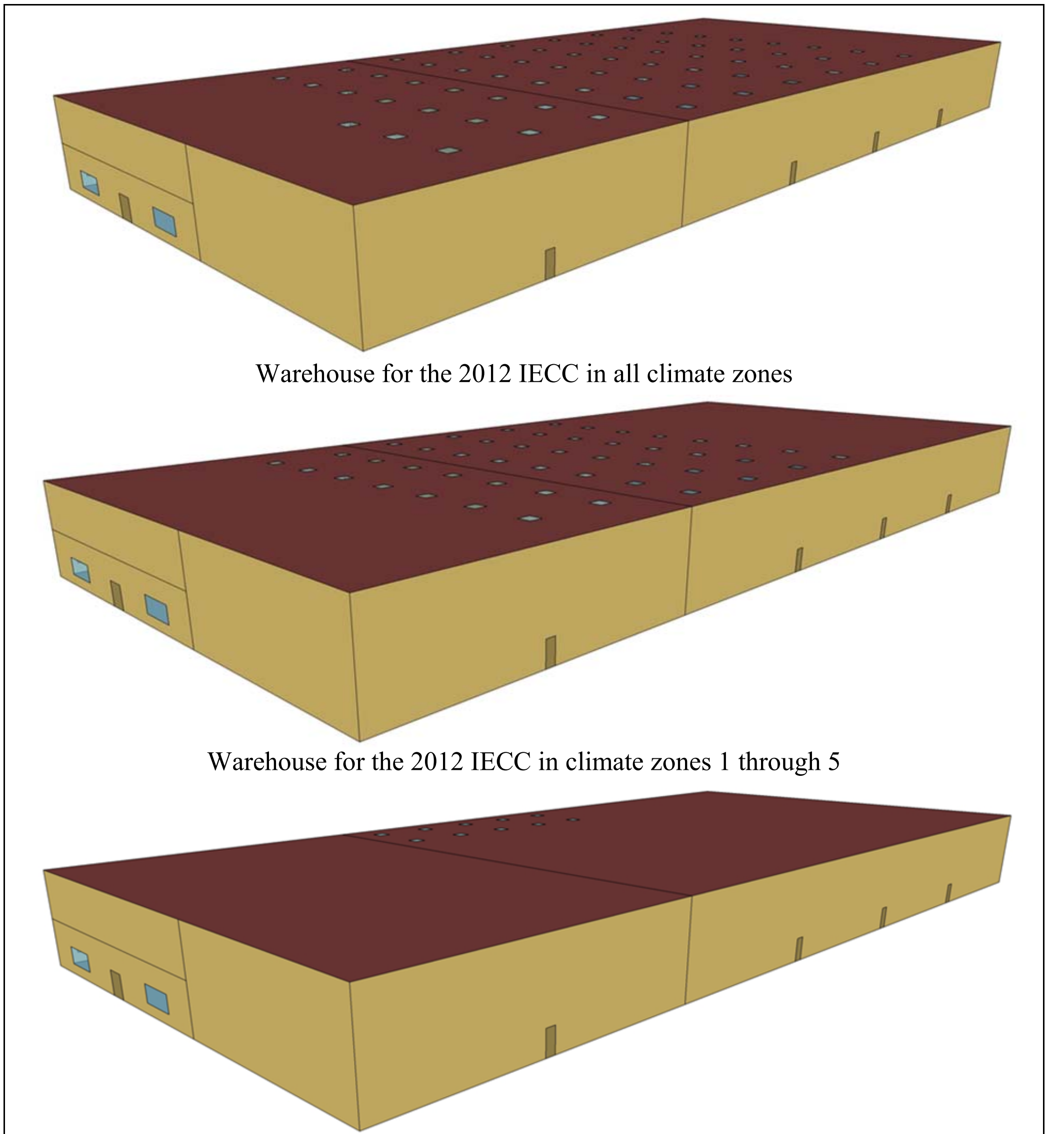
a. Daylight areas were increased to 70% (Warehouse) and 30% (Standalone Retail) of the zone area for all climate zones to meet the requirements of Footnotes (b) and (c) of Table C406.3 in the 2012 IECC.
b. Daylight areas were set to 50% to meet the requirements of Section C402.4.2 in the 2015 IECC for climate zones 1-5. They remain as values shown in this table for climate zone 6-8.

3.5.3.4 Toplight in the 2015 IECC

Skylight Area

To save energy from use of daylight responsive control, the requirements of minimum skylight area were modified in the 2015 IECC (Section C402.4.2). The size threshold of a zone, for which the requirements applies, was changed from 10,000 ft^2 to 2,500 ft^2. As shown in Table 3.7, this new threshold does not affect the Primary School and Secondary School because their skylight areas already exceed the requirements.

The reduced lighting power density system, Section C406.3 used in the 2015 IECC prototype, as discussed in Section 3.5.1 of this report, was changed from specifying requirements for LPD, minimum daylight area, and daylighting controls to LPD only. As such, the minimum skylight area requirements in Section C402.4.2 of the 2015 IECC were implemented to Warehouse and Standalone Retail with respect to their skylight areas. PNNL set the toplight daylight area in the bulk and fine storage zones in Warehouse and core retail zone in Standalone Retail in climate zones 1 through 5 to 50% of the zone area. The skylight areas remain the same as values shown in the Table 3.7 for those building prototypes located in climate zones 6 through 8. PNNL implemented the daylight area by changing the number of skylights on the roof. As illustrated in Figure 3.1 these changes resulted in a decrease in the number of skylights in Warehouse from the 2012 and the 2015 IECC buildings. The major impacts of these changes on energy performance of the warehouse include envelope thermal performance, daylight responsive control, and HVAC system sizes.



Warehouse for the 2012 IECC in all climate zones

Warehouse for the 2012 IECC in climate zones 1 through 5

Warehouse for the 2015 IECC in climate zones 6 through 8

Figure 3.1. Schematic of Skylights in the Warehouse Prototype

Daylight Responsive Control in Toplight Daylight Area

Section C402.4.2.1 in the 2015 IECC requires all lighting in the toplight daylight zone to be controlled for all climate zones, as opposed to having exceptions in climate zones 6 through 8. Section C405.2.3 also defines a new threshold of 150 watts of general lighting within the zone to qualify daylight responsive control defined in the 2015 IECC.

Section C405.2.3.1 in the 2015 IECC specifies continuously dimming control from full light output for offices, classrooms, laboratories, and library reading rooms. PNNL used a stepped control setting in *EnergyPlus* to model this requirement for all toplight daylight areas in zones listed in Table 3.7 in all climate zones.

Thermal Performance of Skylights

Similar to the 2012 IECC, the 2015 IECC permits increased SHGC and U-factor from values in Table C402.4 for skylights where located above daylight area with daylight controls. Requirements do not change from the 2012 to 2015. However, toplight daylight controls were not implemented in Primary School and Secondary School located in climate zones 6 through 8 for the 2012 IECC but were implemented for the 2015 IECC. These differences resulted in different U-factor inputs in the simulation models of these two schools between the two editions of the IECC.

3.5.4 Guestroom Lighting Controls

Section C405.2.4 in the 2015 IECC modified the existing requirement in the 2012 IECC (Section C405.2.4) for hotel and motel sleeping units and guest suites. The requirement changed from manual control to automatically switching off all installed luminaires and switched receptacles within 20 minutes after all occupants leave the room.

The new requirement affects Small Hotel and Large Hotel. The implementation assumes 10% reduction in lighting energy in bathroom lighting and that the bathroom lighting contributes 31% of the guestroom lights. Besides lighting control, the new requirement also applies to the switched receptacles in guestrooms. A new schedule for guestroom lighting was calculated using the hourly reduction fraction for guestroom lighting in the advanced case in the *Technical Support Document: 50% Energy Savings Design Technology Packages for Highway Lodging Buildings* (Jiang et al. 2009). The daily weighted reduction in the lighting power using this schedule is 38%. The hourly reduction fraction for guestroom receptacles in advanced models from Jiang et al. (2009) was used to calculate the 2015 IECC savings. This results in a daily weighted reduction of 17% in equipment energy consumption.

3.5.5 Exterior Lighting Automatic Controls

Section C405.2.4 in the 2012 IECC requires that lighting not designated for dusk-to-dawn operation shall be controlled by either a combination of a photosensor and a time switch, or an astronomical time switch. Lighting designated for dusk-to-dawn operation shall be controlled by an astronomical time switch or photosensor. These requirements mean the exterior lights are off during daytime but do not enforce light power to be reduced at night. The 2015 IECC (Section C405.2.5) requires exterior facade and landscape lighting to be automatically turned off as a function of dawn/dusk and a set business opening and closing time. Exterior lighting not specified as facade or landscape lighting is to be automatically reduced by 30% of its peak power from between no later than midnight to 6 a.m., or from 1 hour after business closing to 1 hour before business opening, or during any period when activity has not been detected for a time longer than 15 minutes.

The code changes have energy savings impacts on all prototypes except for those that are open 24 hours a day, such as Hospital, Outpatient Healthcare, Small Hotel, Large Hotel, Mid-Rise Apartment, and

High-Rise Apartment. Exterior lighting operating schedules were changed to reflect the minimum required power reduction at night. The exterior lighting schedule was separated into a facade schedule with lights off at night and the rest of the exterior lighting schedule with lights reduced by 30% at night.

3.5.6 Interior Lighting Power

The IECC requirements related to the interior lighting power were modified in three areas: general LPD, additional lighting power allowance for retail display lighting, and sleeping unit LPD.

3.5.6.1 Interior Lighting Power Density

The 2012 and 2015 IECC specify total interior lighting power allowance through Section C405. However, the building prototypes need to meet more stringent requirements in Section C406.3 because the efficient lighting system option (Section C406.3 in the 2012 IECC and Section C406.4 in the 2015 IECC) was selected. The reasons for the selection are discussed in Section 3.5.1 of this report.

Section C406.3 in the 2012 IECC specifies LPD allowance using the building area method. The LPDs listed in Table C406.3 were used to model the lighting systems in the prototypes. There are two spaces types, i.e., office and retail, that are each provided with two LPDs in the table. The table allows the higher LPD to be used if daylight zones comprise more than 30% of the total conditioned floor area in the building. It also requires that the daylight zone be controlled by automatic controls. Standalone Retail, Small Office, and Medium Office prototypes have daylight zones comprising 30% or more of the total conditioned floor area in the building. Therefore, the higher LPDs (0.9 W/ft^2 for office and 1.4 W/ft^2 for retail) were used in these prototypes. The implementation for the daylighting control requirements is described in Section 3.5.3 of this report.

The 2015 IECC has both space-by-space and building area methods to calculate the allowance in Section C406.3. PNNL switched the approach from building area method used in the 2012 IECC prototypes to the space-by-space method to develop the 2015 IECC prototypes for two reasons:

1. the space-by-space method allows use of zone-specific lighting powers, which help better capture the energy impacts of zone-specific lighting control requirements; and
2. the space-by-space method was used for the analysis for Standard 90.1-2013 (Halverson et al. 2014). Using the same method in the analysis for 2015 IECC means that PNNL kept consistent choices between these two analyses.

According to Section C406.3, the LPDs in the 2015 IECC prototypes were calculated by multiplying values from Table C405.4.2(2) by 90%. Table 3.8 shows a side-by-side comparison of the area-weighted prototype building LPD between the 2012 and 2015 IECC building prototypes. In the simulation models for the prototypes, space-specific LPDs were used as inputs and Table 3.8 shows their area-weighted average LPD for each prototype. LPD for dwelling units in Mid-Rise Apartment and High-Rise Apartment, sleeping units in Small Hotel and Large Hotel, and additional display lighting in Strip Mall were not included when calculating the average LPD. As shown in Table 3.8 , there are reductions in average LPD in all prototypes except for Warehouse and the two apartment prototypes. The changes in LPD (including all buildings) are partly because PNNL applied different methods. For the 2012 IECC prototypes, the building area method was used, which is the only method in the 2012 IECC. For the 2015 IECC prototypes, the space-by-space method was used. Table 3.9 shows an example of zone-specific

LPDs in Warehouse. This is a small difference (0.03 w/ft^2) in area-weighted average LPD between the two prototypes but the difference by zone is larger; for example, fine storage has an LPD of 0.59 W/ft^2 for the 2012 IECC and 0.86 W/ft^2 for the 2015 IECC. This can impact the whole- building energy performance when different zone-specific lighting controls are applied to these spaces.

Table 3.8. Area-weighted LPD of General Lighting in the 2012 and 2015 IECC Prototypes

Building Prototype	2012 IECC, LPD (W/ft^2)	2015 IECC, LPD (W/ft^2)
Small Office	0.9	0.74
Medium Office	0.9	0.74
Large Office	0.9	0.74
Standalone Retail	1.4	1.30
Strip Mall	1.3	1.22
Primary School	0.99	0.96
Secondary School	0.99	0.85
Outpatient Healthcare	0.87	0.92
Hospital	1.1	0.88
Small Hotel	0.88	0.71
Large Hotel	0.88	0.84
Warehouse	0.6	0.63
Quick-Service Restaurant	0.9	0.84
Full-Service Restaurant	0.89	0.88
Mid-Rise Apartment	0.6	0.68
High-Rise Apartment	0.6	0.64

Table 3.9. Comparison of LPDs in Warehouse Prototype Built to the 2012 and 2015 IECC

Zone Name	Area (ft^2)	2012 IECC, LPD (W/ft^2)	2015 IECC, LPD (W/ft^2)
Office	2549	0.74	0.74
Fine Storage	14993	0.59	0.86
Bulk Storage	34484	0.59	0.52
Area-Weighted Average		**0.60**	**0.63**

3.5.6.2 Additional Lighting Power Allowance for Retail Display Lighting

The 2012 IECC is not very clear whether the additional lighting power allowance for retail display lighting applies if the efficient lighting system option (Section C406.3 in the 2012 IECC) is selected. In the 2012 IECC prototypes, PNNL did not model the allowed display lighting in Strip Mall, in which some sales areas of certain merchandise qualify for the allowance.

Section C405.4.2.2.1 in the 2015 IECC indicates areas in Strip Mall that are allowed to have additional lighting power for display lighting. This provision applies when the reduced lighting power density option, Section C406.3, is selected. In addition, the base allowance (Equation 4-10 in the 2015 IECC) is changed from 1000 Watts in the 2012 IECC to 500 Watts.

To capture this code change, PNNL enhanced the Strip Mall prototype built to the 2012 IECC to add the allowance. The code change was captured by applying different display lighting power in the prototypes.

3.5.6.3 Sleeping Unit Lighting Power Density

Sleeping unit lighting in hotels is exempted from the interior LPD requirements in the 2012 IECC according to Exception 1.2 to Section C405.5.1. For the 2012 IECC, PNNL assumed an LPD of 1.1 W/ft^2 for guestrooms in Small and Large Hotel based on the early edition of Standard 90.1.

The 2015 IECC modified the provision (Exception 1.2 to Section C405.4.1) that this exemption applies, but 75% of permanently installed light fixtures must be fitted with high-efficacy lamps.

PNNL applied a reduction factor of 0.25 to 75% of the baseline. This factor is based on an assumption that the 60-Watt incandescent lamps in the 2012 IECC prototypes are switched to 15-Watt compact fluorescent lamps to meet the 2015 IECC requirement. Therefore, the LPD in the 2015 IECC hotel guestrooms is 75% x 1.1 W/ft^2 x 0.25 + 25% x 1.1 W/ft^2 = 0.48 W/ft^2.

3.5.7 Exterior Lighting Power

The building façade lighting power allowance in Table C405.6.2(2) of the 2012 IECC is modified in the 2015 IECC (Table C405.5.2(2)) to reduce allowance in lighting zones 2 through 4. The code change applies to all building prototypes. The reduced allowance was implemented using the modelled façade lighting power inputs in *EnergyPlus*.

3.5.8 Elevator Lighting and Ventilation

The 2012 IECC does not have requirements for elevators. Section C405.9.1 in the 2015 IECC does have such requirements. These include: 1) the cab lighting to have efficacy of not less than 35 lumens per Watt; 2) ventilation fans in elevators without air-conditioning systems shall not consume more than 0.33 watts/cfm at the maximum fan speed; and, 3) the cab lighting and ventilation should be off when the elevator is not used for over 15 minutes.

Medium Office, Large Office, Secondary School, Outpatient Healthcare, Hospital, Small Hotel, Large Hotel, Mid-Rise Apartment, and High-Rise Apartment have elevators. To analyze the energy savings of the code changes, the 2012 IECC baseline assumptions for elevator lights, fans, and their operation schedules are set and then modified lighting power, fan power, and operation schedules reflecting the code changes are used as the 2015 IECC model inputs. The same modeling strategy was used to quantify similar changes from Standard 90.1-2007 to Standard 90.1-2010. Details of the modeling assumptions can be found in Thornton et al. (2011).

4.0 Site Energy and Energy Cost Savings Results

This section summarizes the estimated site energy and energy cost savings for the 2015 IECC compared to the 2012 IECC. The results of the analysis are summarized in Table 4.1. This table groups the building prototypes by their principal activity and shows the construction weighting factors by building prototype. The table provides a side-by-side comparison of the site energy use intensity (EUI) and energy cost index (ECI) for the 2012 and 2015 editions of the IECC. Site energy is utility electricity and natural gas delivered and used at the building site. The EUI and ECI shown in Table 4.1 for each prototype are national weighted averages across climate zones in the United States. The percent savings (reduction) in EUI and ECI are presented as well. Negative percentages reflect increases in EUI or ECI. The last row of Table 4.1 shows the national weighted average results from all 16 prototypes and 15 climate zones using the construction weighting factors (see Table 2.2 in this report). As shown in Table 4.1, on a weighted national basis, the 2015 IECC results in 11.1% energy savings and 11.5% energy cost savings over the 2012 IECC. As a result of federally mandated efficiency improvements of appliances and equipment that have taken effect since (but independent of) the publication of the 2012 IECC, the actual EUI and ECI savings would be higher for most new buildings subject to the 2015 IECC than the results indicate. The savings attributed to DOE's Appliance and Commercial Equipment Standards are not included in the results in Table 4.1 as discussed in Section 2.4.

Table 4.1. Site Energy and Energy Cost Savings between the 2012 and 2015 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI ($kBtu/ft^2$-yr)		Site EUI Savings (%)	ECI ($\$/ft^2$-yr)		ECI Savings (%)
			2012 IECC	2015 IECC		2012 IECC	2015 IECC	
Office	Small Office	5.6	31.1	29.6	4.8	0.93	0.88	4.8
	Medium Office	6.0	35.5	34.6	2.5	0.99	0.97	1.9
	Large Office	3.3	76.2	71.7	6.0	2.15	2.04	5.2
Retail	Standalone Retail	15.3	54.1	47.3	12.6	1.44	1.21	16.0
	Strip Mall	5.7	58.3	54.0	7.4	1.54	1.39	9.7
Education	Primary School	5.0	62.3	55.5	10.9	1.52	1.34	11.4
	Secondary School	10.4	51.8	42.8	17.4	1.35	1.12	16.8
Healthcare	Outpatient Healthcare	4.4	137.2	117.6	14.3	3.53	3.07	13.0
	Hospital	3.4	172.2	128.0	25.7	3.72	2.98	20.0
Lodging	Small Hotel	1.7	66.4	60.4	9.2	1.49	1.3	12.6
	Large Hotel	5.0	109.5	87.9	19.8	2.37	1.81	23.9
Warehouse	Warehouse	16.7	15.0	15.5	-3.1	0.34	0.36	-5.2
Food Service	Quick-Service Restaurant	0.6	602.5	582	3.4	9.66	8.83	8.6
	Full-Service Restaurant	0.7	405.6	373.8	7.8	7.22	6.44	10.8
Apartment	Mid-Rise Apartment	7.3	45.0	44.2	1.7	1.23	1.22	1.0
	High-Rise Apartment	9.0	49.1	47.6	3.0	1.14	1.11	3.1
National Weighted Average		**100**	**61.4**	**54.5**	**11.1**	**1.49**	**1.31**	**11.5**

As can be seen from Table 4.1, the savings vary significantly by prototype. This is expected because code requirements are different by building type and by climate. PNNL did not separately quantify the national impacts of individual code changes because that would require substantial additional resources. Although this approach does not allow us to rank the code changes based on their energy savings impacts, we can still identify a few high impact changes resulting in significant energy savings as listed below:

a. Envelope: Changes to opaque envelope (see Section 3.2.1 in this report) and continuous air barrier (see Section3.2.2).

b. HVAC: Equipment efficiency improvements (Section 3.3.1), ERV (see Section 3.3.3), kitchen exhaust systems (Section 3.3.4), staged cooling (see Section 3.3.9), fan airflow control (see Section 3.3.10), VAV reheat control (see Section 3.3.14), VAV system for critical area in healthcare facility (see Section 3.3.15), and outdoor air ventilation optimization (see Section 3.3.17).

c. Lighting: Daylight responsive control (see Section 3.5.3), exterior lighting control (see Section 3.5.5), interior lighting power (see Section 3.5.6), and exterior lighting power (see Section 3.5.7).

The analysis also indicates that all building prototypes, except the Warehouse prototype, use less energy under the 2015 IECC. The Warehouse prototype uses more energy because the requirements in the 2015 IECC resulted in reduced daylit area under control compared to the 2012 IECC (see Section 3.5.3.4 in this report). These changes are specific to the Warehouse prototype and are more pronounced because lighting energy is a large portion of the total energy consumption in the Warehouse prototype.

Figures 4.1 and 4.2 illustrate the weighted EUI and ECI for each prototype and the national weighted EUI and ECI for the 2012 and 2015 editions of the IECC, respectively.

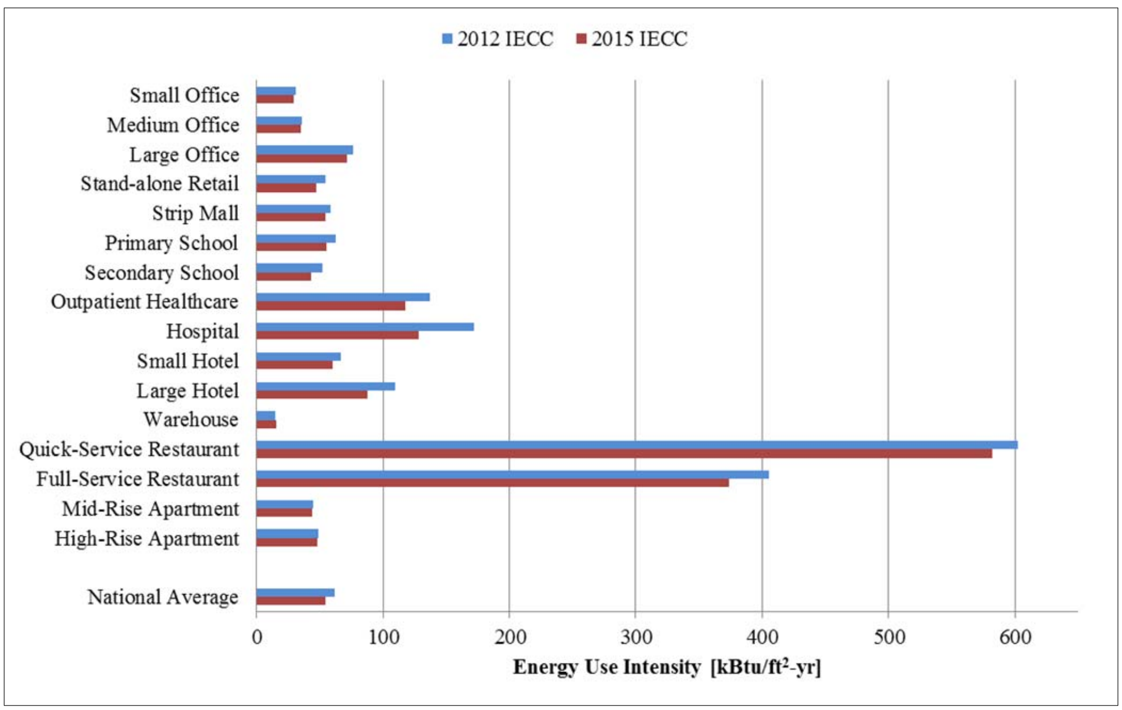


Figure 4.1. National Average Energy Use Intensity for all IECC Prototypes

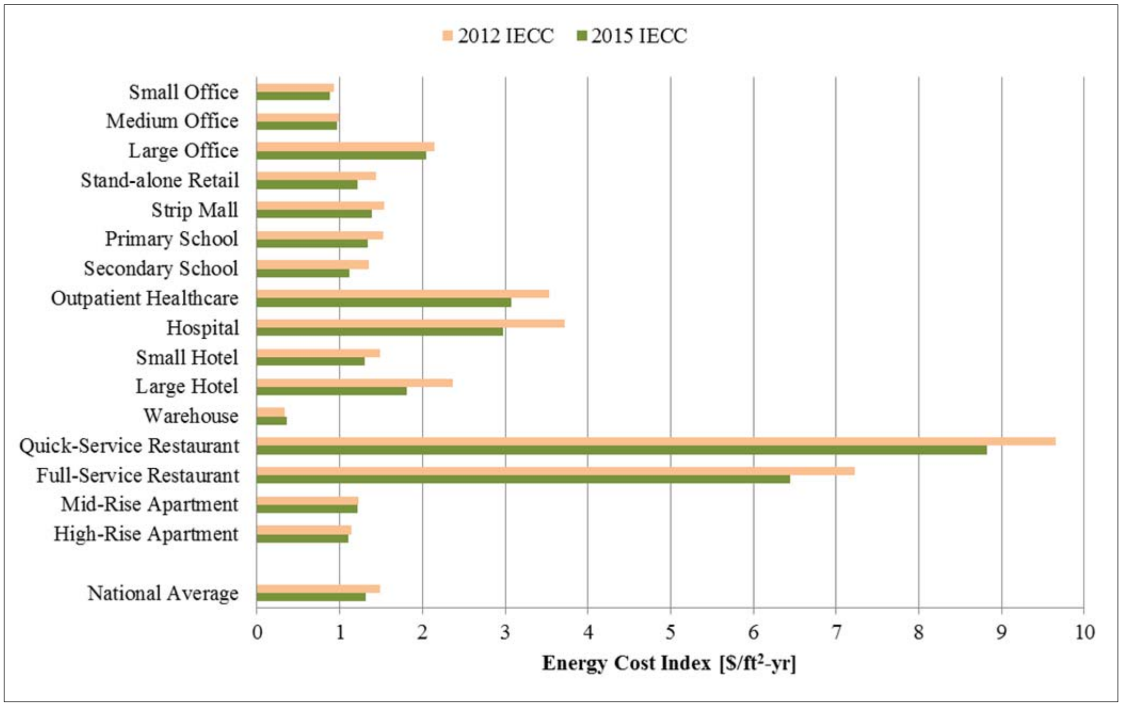


Figure 4.2. National Average Energy Cost Index for all IECC Prototypes

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Appendix A

Code Changes from the 2012 to 2015 IECC Included in Analysis and their Impact on Building Prototypes

Appendix A

Code Changes from the 2012 to 2015 IECC Included in Analysis and their Impact on Building Prototypes

Table A.1. Changes between the 2012 and 2015 IECC with Quantified Energy Impacts

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C402.1.4 Assembly U-factor, C-factor or F-factor-based method	Modifies the building envelope requirements for opaque assemblies using U-factor, C-factor or F-factor-based method in Table C402.1.4.		x	x	x	x	x	x	x	x	x	x	x			x	x
C402.4.1.1 Increased vertical fenestration area with daylight responsive controls	Modifies minimum daylighting area thresholds above which the maximum window-to-wall ratio of 40% is permitted.		x														
C402.4.2.1 Lighting controls in daylight zones under skylights	Removes the exception to responsive daylighting controls in daylighting zones under skylights in climate zones 6 through 8.				x		x	x					x				
C402.5.1 Air barriers	Extends continuous air barrier requirements to include climate zones 1, 2A, and 3.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.2.3 HVAC equipment performance requirements	Improves HVAC equipment efficiency.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C403.2.5 Hot water boiler outdoor temperature setback control	Requires boiler temperature setback control based on the outdoor temperature.			x				x	x	x		x					
C403.2.7 Energy recovery ventilation systems	Reduces the system size and outdoor air thresholds at which ERV is required. Relaxed in some climate zones. Adds new thresholds for systems that operate more than 8000 hours per year.		x	x	x		x	x	x	x		x					
C403.2.8 Kitchen exhaust systems	Modifies the requirements for kitchen hood exhaust and make-up air systems.						x	x		x		x		x	x		
C403.2.12.1 Allowable fan floor horsepower	Adjusts fan power limitation credits.		x	x			x	x	x	x		x					
C403.2.14 Refrigeration equipment performance	Adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment.						x	x		x		x		x	x		
C403.2.16 Walk-in coolers and walk-in freezers	Adds requirements for walk-in coolers and freezers and refrigerated display cases.						x	x		x		x		x	x		

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.3 Economizers (Prescriptive) Exception 2	Increases cooling capacity threshold for air economizer to be required in DX cooling systems from 33,000 Btu/h to 54,000 Btu/h.	x	x		x	x	x	x	x				x	x	x		
C403.3.1 Integrated economizer control	Enhances the requirements for integrated economizer control and defines DX unit capacity staging requirements.				x	x	x	x						x	x		
C403.4.1.1 Fan airflow control	Extends the requirements for fan speed control for unitary direct expansion systems based on cooling capacity and enhances the requirements for integrated economizer control.				x	x	x	x						x	x		
C403.4.2.4 Part-load controls	Increases capacity threshold for hydronic system part-load controls and extends the control types.			x				x		x		x					
403.4.2.5 Boiler turndown	Establishes minimum turndown for boilers and boiler plants with design input power of at least 1,000,000 Btu/h.			x			x	x	x	x		x					x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.4.3 Heat rejection equipment	Modifies heat rejection equipment (cooling tower) requirements to require that variable speed drive controlled fans operate all fans at the same speed instead of sequencing them, and require that open-circuit towers with multiple cells operate all cells in parallel down to 50% of design flow.			x						x							
C403.4.4 Requirements for complex mechanical systems serving multiple zones	Allows optimization of minimum damper positions based on multiple-zone calculation.		x	x			x	x	x	x		x					
C403.4.4 Requirements for complex mechanical systems serving multiple zones	Removes exception for VAV turndown for zones with special pressurization requirements.								x	x							
C403.4.4.4 Fractional hp fan motors	Requires fractional horsepower motors ≥1/12 hp to be EC motors or have a minimum 70% efficiency in accordance with DOE 10 CFR 431. Also requires adjustable speed or other method to balance airflow.		x	x			x	x	x	x	x	x		x	x	x	x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.4.4.6 Multiple-zone VAV system ventilation optimization control	Requires multi-zone VAV systems to have controls that optimize ventilation.		x	x			x	x	x	x		x					
C404.6.1 Circulation systems	Adds temperature maintenance and demand control for circulation pump.		x	x			x	x	x								x
C405.2.1 Occupant sensor controls	Adds lounge, locker room, and warehouse spaces to the list for occupancy sensor controls.	x	x	x	x		x	x	x	x	x	x	x		x		
C405.2.3 Daylight-responsive controls	Modifies control functions and threshold for both sidelight and toplight daylight controls.	x	x	x	x		x	x	x	x	x	x	x	x	x		
C405.2.4 Specific application controls	Requires automatic light controls for hotel and motel sleeping units										x	x					
C405.2.5 Exterior lighting controls	1. Requires exterior lighting controls rather than just control capability. 2. Adds bi-level controls for general all-night applications such as parking lots to reduce lighting when not needed. 3. Adds control of facade and landscaping lighting not needed after midnight.	x	x	x	x	x	x	x					x	x	x		

A.5

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C405.4.1 Total connected interior lighting power	Modifies sleeping unit exception to lighting power limits. They need to meet R404.1.										x	x					
C405.5.1 Exterior building lighting power	Changes façade lighting power in Table C405.5.2(2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C405.9.1 Elevator cabs	Adds requirements for elevator fan and lights.		x	x				x	x	x	x	x				x	x
C406.3 Reduced lighting power density	1. Replaces LPD table in the 2012 IECC with 10% increase in efficiency over the base LPD requirements for whole building or space-by-space. 2. Adds space-by-space method option to provides flexibility. 3. removes the daylighting control requirements in 2012 IECC table footnotes. 4. Removes additional skylight requirements (footnote c) in the 2012 for warehouse.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Appendix B

Energy and Energy Cost Savings for the 2015 IECC and Corresponding Standard 90.1-2013

Appendix B

Energy and Energy Cost Savings for the 2015 IECC and Corresponding Standard 90.1-2013

Section 304(b) of the ECPA (Energy Conservation and Production Act), as amended, requires the Secretary of Energy to make a determination each time a revised edition of Standard 90.1 is published with respect to whether the revised standard would improve energy efficiency in commercial buildings. When DOE issues an affirmative determination on Standard 90.1, states are statutorily required to certify within two years that they have reviewed and updated the commercial provisions of their building energy code, with respect to energy efficiency, to meet or exceed the revised standard (42 USC 6833).

In support of DOE's determination, PNNL conducted an energy savings analysis for Standard 90.1-2013 compared to Standard 90.1-2010 (Halverson et al. 2014). Based on that analysis, DOE issued a determination that Standard 90.1-2013 would achieve greater energy efficiency in buildings compared to the 2010 edition of the standard.

As many states have historically adopted the IECC for both residential and commercial buildings, PNNL has also compared energy performance of Standard 90.1-2013 with the 2015 IECC to help states and local jurisdictions make informed decisions regarding model code adoption. Of the 47 States with statewide commercial building energy codes currently, 37 use a version of the IECC (BECP 2015).

Table B.1 shows side-by-side comparisons of the site EUI and ECI for Standard 90.1-2013 and the 2015 IECC for each of 16 prototype buildings along with the percent difference between the two. The national weighted average of all prototypes combined is also shown. Figures B.1 and B.2 show the same results graphically. Negative percentage differences indicate higher energy or energy costs for buildings designed to the 2015 IECC compared to those designed to Standard 90.1-2013. For most prototypes, both EUIs and ECIs were slightly lower using Standard 90.1-2013. One notable exception is the Warehouse prototype where the 2015 IECC resulted in lower energy use and energy costs. This difference is because Standard 90.1-2013 has a category for semi-heated spaces allowing relaxed levels of insulation, while the 2015 IECC does not.

The comparisons show the combined energy impacts of differences between the 2015 IECC and Standard 90.1-2013. Although the current analysis does not compare or rank the individual differences based on their energy savings, a few high impact differences by category can be identified as follows:

a. Envelope
    - Prescriptive WWR limit: the 2015 IECC allows a WWR up to 30% unless a significant portion of the building is equipped with daylight responsive controls, in which case up to 40% is allowed. Standard 90.1-2013 requires WWR less than 40%.
    - Semi-heated space envelope requirements: the 2015 IECC does not have separate envelope requirements for semi-heated spaces. Semi-heated spaces are required to follow conditioned space requirements. Standard 90.1-2013 has less stringent insulation requirements for semi-heated spaces.

- Vertical fenestration U-factor independent of frame material: the U-factor requirements for vertical fenestrations in the 2015 IECC are independent of the frame material. Standard 90.1-2013 has higher U-factors for metal-framed fenestrations than for nonmetal-framed fenestrations.
- SHGC for north-oriented vertical fenestrations: the 2015 IECC sets higher maximum SHGCs for north-oriented fenestrations than those facing other orientations. Standard 90.1-2013 allows a much smaller relaxation of SHGC (SHGC-0.05) for north-oriented fenestrations. The impact of this difference is not captured in the current analysis because the prototype building facades are all facing true east, south, west, or north and the energy impact is negligible for true north-oriented facades. However, both the 2015 IECC and Standard 90.1-2013 define north-oriented fenestration as that which is facing within 45 degrees of true north in the northern hemisphere. For fenestration offset from true north by up to 45 degrees, the relaxation of SHGC may be significant.
- Vestibule exceptions: the 2015 IECC exempts building entrance doors that open up to a space less than 3,000 sf; Standard 90.1-2013 does not. The 2015 IECC also includes an exception from vestibule requirements if an air curtain is installed instead; Standard 90.1-2013 does not have such an exception.
- Fenestration orientation: the 2015 IECC does not limit the distribution of fenestration area. Standard 90.1-2013 limits the fenestration area on the east and west façades.

b. Building mechanical systems

- Shutoff damper controls: the 2015 IECC exempts buildings with less than 3 stories from the motorized damper requirements for ventilation air intakes; Standard 90.1-2013 does not have such an exception.

c. Lighting

- Dwelling unit (apartment) lighting power: the 2015 IECC requires 75% of all permanently installed luminaires in dwelling units to be high efficacy. Standard 90.1-2013 exempts dwelling units from lighting power requirements.
- Controls for secondary daylight zone: the 2015 IECC does not require secondary daylight zones to have daylight responsive controls; Standard 90.1-2013 does.

d. Additional efficiency package options

- The 2015 IECC requires one of the six high efficiency package options to be included; Standard 90.1-2013 does not have such options.

On a national average basis for all prototypes combined, the 2015 IECC and Standard 90.1-2013 are within 1% for both energy use and energy costs. The 2015 IECC has a national weighted EUI of 54.5 kBtu/ft^2-yr while the corresponding number for Standard 90.1-2013 is 54.1 kBtu/ft^2-yr. Likewise, the ECIs are very close between the 2015 IECC (1.31 \$/ft^2-yr) and Standard 90.1-2013 (1.30 \$/ft^2-yr).

Table B.1. Site Energy and Energy Cost Savings between Standard 90.1-2013 and the 2015 IECC

Building Prototype	Site EUI			ECI		
	Standard 90.1-2013 (kBtu/ft²/yr)	2015 IECC (kBtu/ft²/yr)	2015 IECC compared to 90.1-2013 (%)	Standard 90.1-2013 ($/ft²/yr)	2015 IECC ($/ft²/yr)	2015 IECC compared to 90.1-2013 (%)
Small Office	29.4	29.6	-0.7	0.88	0.88	0.0
Medium Office	34.1	34.6	-1.5	0.95	0.97	-2.1
Large Office	70.8	71.7	-1.3	2.01	2.04	-1.5
Standalone Retail	45.9	47.3	-3.1	1.20	1.21	-0.8
Strip Mall	55.1	54.0	2.0	1.42	1.39	2.1
Primary School	54.2	55.5	-2.4	1.28	1.34	-4.7
Secondary School	41.7	42.8	-2.6	1.08	1.12	-3.7
Outpatient Healthcare	115.8	117.6	-1.6	3.00	3.07	-2.3
Hospital	123.7	128.0	-3.5	2.85	2.98	-4.6
Small Hotel	60.0	60.4	-0.7	1.29	1.30	-0.8
Large Hotel	89.0	87.9	1.2	1.81	1.81	0.0
Warehouse	17.1	15.5	9.4	0.38	0.36	5.3
Quick-Service Restaurant	576.4	582.0	-1.0	8.78	8.83	-0.6
Full-Service Restaurant	372.5	373.8	-0.3	6.41	6.44	-0.5
Mid-Rise Apartment	43.9	44.2	-0.7	1.21	1.22	-0.8
High-Rise Apartment	46.9	47.6	-1.5	1.08	1.11	-2.8
National Weighted Average	**54.1**	**54.5**	**-0.7**	**1.30**	**1.31**	**-0.8**

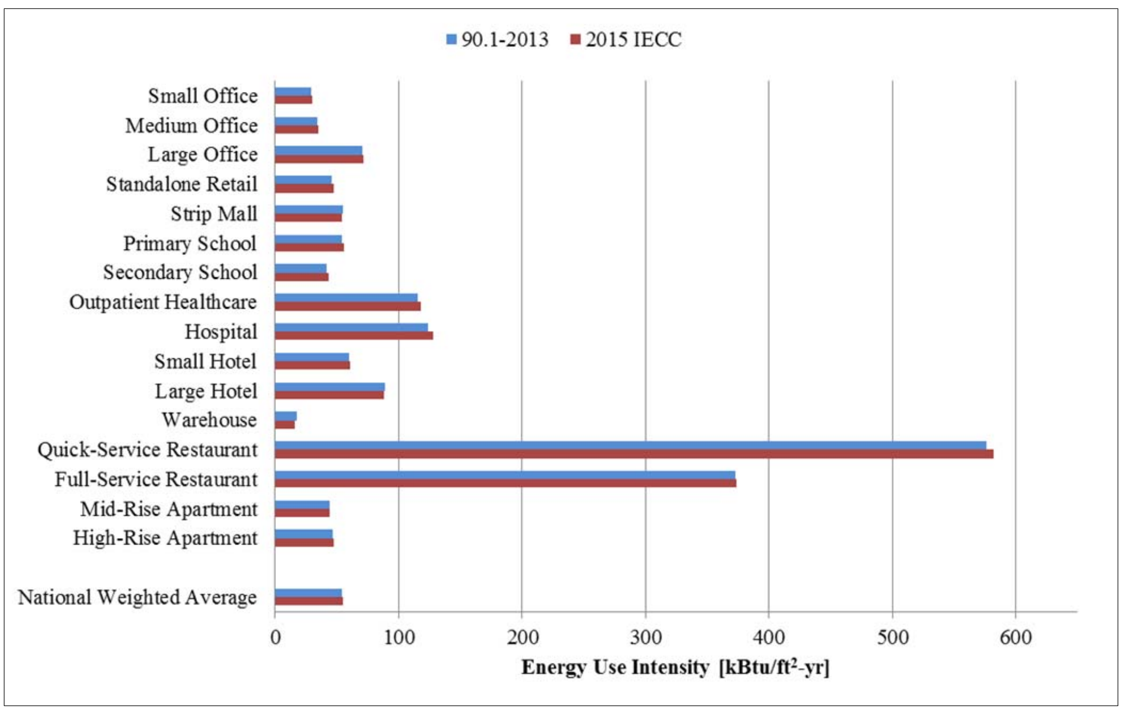

Figure B.1. National Average Energy Use Intensity for Standard 90.1 and IECC Prototypes

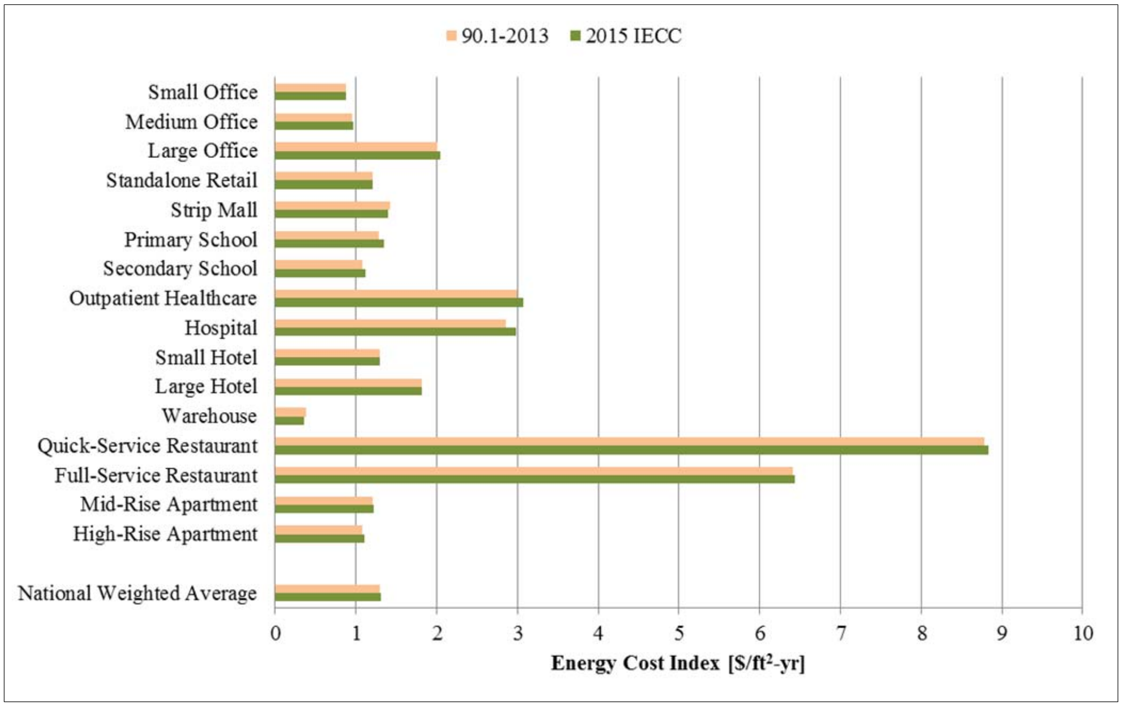

Figure B.2. National Average Energy Cost Index for Standard 90.1 and IECC Prototypes

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National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019

July 2021

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Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program provides technical assistance supporting the development and implementation of building energy codes and standards (42 USC 6833), which set minimum requirements for energy-efficient design and construction of new and renovated buildings, and impact energy use and environmental impacts over the life of buildings. Continuous improvement of building energy efficiency is achieved by periodically updating model energy codes through consensus-based code development processes, such as those administered by ASHRAE[1] and the International Code Council (ICC). DOE provides technical analysis of potential code revisions and amendments, supporting technologically feasible and economically justified energy efficiency measures. It is important to ensure that model code changes are cost-effective because this encourages their adoption and implementation at the state and local levels. Pacific Northwest National Laboratory (PNNL) prepared this analysis to support DOE in evaluating the economic impacts associated with updated codes in commercial buildings.

The purpose of this analysis is to examine the cost-effectiveness of the 2019 edition of ANSI/ASHRAE/IES[2] Standard 90.1 (Standard 90.1-2019)[3], which is developed by the ASHRAE Standard Standing Project Committee (SSPC) 90.1, and is the model energy standard for all commercial buildings and multifamily residential buildings over three floors.[4] PNNL analyzed the cost-effectiveness of changes in Standard 90.1-2019, compared to the previous 90.1-2016 edition, as applied in commercial buildings across the United States. In reviewing proposed changes to Standard 90.1, the SSPC considers the cost-effectiveness of individual changes (addenda). Due to the continuous nature of the development process, however, ASHRAE does not evaluate the entire package of addenda from one edition of the standard to the next, which is of particular interest to adopting state and local governments. Providing states with an analysis of cost-effectiveness facilitates a more comprehensive understanding of the impacts associated with updated model energy codes, informs the state decision-making process and its authorities, and ultimately encourages greater adoption of updated energy codes. This information also informs the development of future editions of Standard 90.1.

To establish the cost-effectiveness of Standard 90.1-2019, three main tasks were addressed:

- Identification of building elements impacted by the updated standard
- Allocation of associated costs (e.g., installation, maintenance, and replacement costs)
- Cost-effectiveness analysis of changes.

Various costs were needed to determine cost-effectiveness including installation, maintenance, and replacement costs, in addition to energy cost differences, which are the costs of the energy impacts associated with individual changes and efficiency measures. The energy costs for each edition of Standard 90.1 were determined previously under the development of Standard 90.1-2019, as described below.

This cost-effectiveness analysis builds on the PNNL analysis (as outlined in Section 5.2) of the energy use and energy cost saving impacts of Standard 90.1-2019. The overall energy savings analysis

[1] ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers
[2] ANSI – American National Standards Institute; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America
[3] ASHRAE. 2019. *ANSI/ASHRAE/IES 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE, Atlanta, GA.
[4] 42 USC 6833. ECPA, Public Law 94-385, as amended. Available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

used a suite of 16 prototype EnergyPlus[1] building models[2] simulated across all 16 U.S. climate zones. The detailed methodology and overall energy saving results are documented in the technical report titled *Preliminary Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019*.[3]

The cost-effectiveness analysis presented in this report uses the following approach. Researchers selected a subset of prototype models and climate locations, covering most of the changes to Standard 90.1-2016 that affect energy usage and construction costs. The individual changes included in the analysis are detailed in Section 3.0. The following prototype buildings (six total) and climate locations (five total) were selected for the analysis using the rationale described in Section 2.1:

Prototype Buildings	**Climate Locations**
Small Office	2A Tampa, Florida (hot, humid)
Large Office	3A Atlanta, Georgia (warm, humid)
Standalone Retail	3B El Paso, Texas (hot, dry)
Primary School	4A New York, New York (mixed, humid)
Small Hotel	5A Buffalo, New York (cool, humid)
Mid-rise Apartment	

These selected prototypes represent the energy impact of five of the eight commercial principal building activities (see Table 2.1) and account for 72% of new construction by floor area covered by the full suite of 16 prototypes. The five climate locations are from the set of representative cities approved by the SSPC 90.1 for establishing criteria for 90.1-2019. Each of the six selected prototype buildings was analyzed in the five selected climate locations for a total of 30 individual cost-effectiveness assessments.

DOE relies upon an established methodology for assessing the energy impacts and cost-effectiveness of building energy codes.[4] Consistent with the methodology, three economic metrics are used:

- Life-cycle cost analysis (LCCA)
- SSPC 90.1 Scalar Method
- Simple payback period

Although multiple metrics are employed in the analysis, LCCA is the primary metric by which DOE determines the cost-effectiveness of building energy codes. In addition, DOE often provides analysis based on additional metrics for informational purposes and to support the variety of perspectives employed by adopting states and other interested entities.

Table ES.1 summarizes the cost-effectiveness of Standard 90.1-2019. Findings demonstrate that the 2019 edition is cost-effective overall relative to the 2016 edition under the LCCA and SSPC 90.1 Scalar Method for all representative prototypes and climate locations. The results are aggregated across building types and climate zones using weighting factors based on new-building permit data as described in Section 2.4.

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[1] Available at https://energyplus.net
[2] Download from http://www.energycodes.gov/development/commercial/90.1_models
[3] DOE. 2020. “Preliminary Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019.” U.S. Department of Energy, Washington D.C. https://www.energycodes.gov/development/determinations.
[4] Hart, R, and B. Liu. 2015. “Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.” DOE Building Energy Codes Program. http://www.energycodes.gov/development/commercial/methodology.

Table ES.1. Summary of Cost-Effectiveness Analysis

Prototype Model	Climate Zone and Location					
Life-Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$4.20	$4.16	$4.23	$4.00	$3.98	$4.11
Large Office	$4.40	$4.39	$3.92	$4.29	$4.22	$4.29
Standalone Retail	$4.83	$4.56	$4.70	$4.34	$4.28	$4.50
Primary School	$5.43	$5.06	$5.45	$5.04	$5.10	$5.19
Small Hotel	$14.14	$14.04	$14.07	$13.86	$13.81	$13.97
Mid-rise Apartment	$2.65	$2.66	$2.19	$1.83	$1.80	$2.18
Weighted Total	$4.50	$4.44	$4.03	$3.79	$3.91	$4.12
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Large Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Standalone Retail	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	7.5	7.8	7.7	8.7	9.0	8.1
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Scalar Ratio, Limit = 22.08[(a)]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	(58)	(63)	(61)	(67)	(68)	(64)
Large Office	(40)	(39)	(44)	(50)	(46)	(45)
Standalone Retail	(17)	(27)	(34)	(31)	(33)	(28)
Primary School	(41)	(38)	(36)	(45)	(45)	(42)
Small Hotel	(97)	(103)	(101)	(115)	(121)	(108)
Mid-rise Apartment	(41)	(47)	(215)	(776)	(1,137)	(507)
Weighted Total	(39)	(43)	(110)	(328)	(403)	(203)

(a) Scalar ratio limit for an analysis period of 40 years.
Note: A negative scalar ratio indicates that the cost is negative. This occurs, for example, when there are net decreases in costs either from reductions in HVAC capacity, or reductions in installed lighting due to lower lighting power densities (LPDs), or reduction in replacement costs such as that which occurs with a switch to LED lighting.

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Matt Tyler, PE
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Acronyms and Abbreviations

AFUE	Annual Fuel Utilization Efficiency
AHRI	Air Conditioning, Heating and Refrigeration Institute
AHU	air handling unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASRAC	Appliance Standards and Rulemaking Federal Advisory Committee
BECP	Building Energy Codes Program
Btu	British thermal units
Btu/h	British thermal units per hour
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CFI	central fan integrated
CFM	cubic feet per minute
CHW	chilled water
COP	coefficient of performance
CRAC	computer room air conditioners
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
DX	direct expansion
EIA	Energy Information Administration
EMS	Energy Management System
ERR	enthalpy recovery ratio
ERV	energy recovery ventilator
ESC	Envelope Subcommittee (90.1 SSPC)
Et	thermal efficiency
FEMP	Federal Energy Management Program
GWP	Global Warming Potential
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
LCCA	life-cycle cost analysis
lm	lumens
LPD	lighting power density
LSC	Lighting Subcommittee (SSPC 90.1)
MEP	mechanical, electrical and plumbing

NC^3	National Commercial Construction Characteristics
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
PTAC	packaged terminal air conditioner
SAT	supply air temperature
SCOP	seasonal coefficient of performance
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
VAV	variable air volume
VSD	variable speed drive
VT	visible transmission
w.c.	water column
WSHP	water source heat pump
WWR	window-to-wall ratio

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1.0 Introduction

This study was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy (DOE) Building Energy Codes Program (BECP). BECP was founded in 1993 in response to the *Energy Policy Act of 1992*, which mandated that DOE participate in the development process for national model building energy codes and that DOE help states adopt and implement progressive energy codes. DOE has supported the development and implementation of building energy codes since the 1970s, with BECP being the only DOE program assigned specific mandates with regard to energy codes.

Building energy codes set baseline minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and associated emissions for the life of the buildings. Energy codes are part of the greater collection of regulations that govern the design, construction, and operation of buildings for the health and life safety of occupants. Effective building energy codes represent one of the largest opportunities to ensure consistent, cost-effective, and long-lasting energy efficiency impacts.

This report centers on *ANSI/ASHRAE/IES 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings*, the national model energy standard for commercial buildings.[1] The 2016 and 2019 editions of Standard 90.1 are the primary focus of this report (ASHRAE 2016, 2019). These standards are referred to as 90.1-2016 and 90.1-2019 respectively, or as Standard 90.1 when referring to multiple editions of the standard.

DOE provides technical assistance and supports the incremental upgrading of the model energy codes, and states' adoption and implementation of upgraded codes. DOE takes an active role by participating in the industry code maintenance and revision processes, as administered by ASHRAE and the International Code Council (ICC), seeking adoption of technologically feasible and economically justified energy efficiency measures, per the Department's statutory direction.

PNNL supports DOE in its code-improvement efforts, and is closely involved in the upgrading of the model codes. Specifically, PNNL provides significant technical assistance to the ASHRAE Standing Standard Project Committee for 90.1 (SSPC 90.1), which is responsible for developing the Standard. This assistance ranges from conducting technical analysis on revised codes and proposed changes, to serving on related technical committees, to developing change proposals (addenda) for consideration by the deliberating code review bodies. PNNL also conducts analyses on the energy-savings impacts of published codes in support of DOE energy savings determinations, which assess whether each updated edition of the model codes will improve energy efficiency in residential and commercial buildings.[2]

The Standard 90.1 process relied upon by ASHRAE considers cost-effectiveness of individual proposed changes, known as addenda, to the Standard. However, the process does not include an analysis of the total combined changes from one edition to the next, which is of particular interest to adopting states and localities, as well as to inform the SSPC in developing the next edition of Standard 90.1. Therefore, DOE requests that PNNL analyze the cost-effectiveness of 90.1-2019 as a whole compared to

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers (until 2012, then just ASHRAE); IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

[2] For more information on the DOE determination of energy savings, see https://www.energycodes.gov/development/determinations.

the previous edition, based on the established life-cycle cost analysis (LCCA) methodology. Through this action, DOE seeks to provide states with cost-effectiveness information to aid in adopting updated editions of commercial energy codes based on Standard 90.1 and for use in the development of future editions of the Standard. The cost-effectiveness analysis of Standard 90.1-2019, compared to the previous 2016 edition, is the subject of this current analysis and report.

1.1 Supporting State Energy Code Adoption

DOE is directed to provide technical assistance to assist states in reviewing and updating their energy codes, as well as to support state code implementation (e.g., compliance, enforcement, and workforce training activities). The cost-effectiveness analysis covered in this report is an instrumental part of DOE's technical assistance effort to encourage states to adopt the newest edition of Standard 90.1 (or its equivalent). States are at various stages of incorporating the latest edition of Standard 90.1 or its equivalent into their building codes. Figure 1.1 shows the current—as of June 2020—applicable energy standard or code that most closely matches the state's regulation (DOE 2020a).

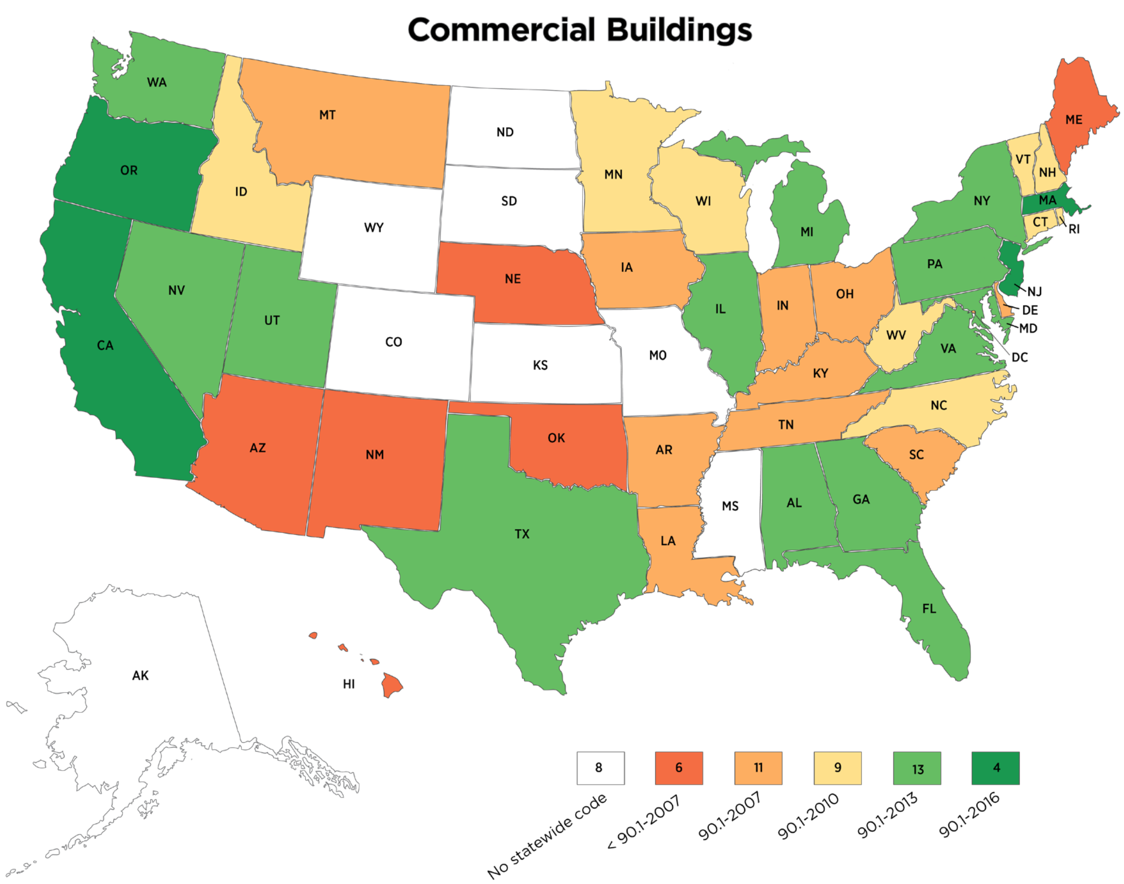

Figure 1.1. Commercial Building Energy Code Adoption Status (June 2020)

1.2 Contents of the Report

This report documents the approach and results for PNNL's analysis of the cost-effectiveness of 90.1-2019 compared to 90.1-2016. Much of the work builds on the previously completed cost-effectiveness comparison between 90.1-2007 and 90.1-2010 along with updates made for 90.1-2013 and 90.1-2016 (Thornton et al. 2013; Hart et al. 2015, 2020). The cost-effectiveness analysis began with the energy savings analysis for development of 90.1-2019, which included energy performance simulation for 16 prototype models in 16 climate locations and is discussed further in Section 5.2. The energy savings analysis was expanded to include five addenda related to federally regulated equipment efficiency improvements that were excluded from the determination analysis.

Development of the prototypes and simulation structure was originally completed during the energy savings analysis of 90.1-2010 compared to 90.1-2004 (ASHRAE 2004) and 90.1-2007. The technical analysis process, model descriptions, and results were presented in PNNL's technical report titled *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010,* referred to in this report as *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011). The prototype models used in the analysis, their development, and the climate locations are described in detail in the quantitative determination and are available for download[1] (DOE 2018, 2020).

Six prototypes and five climate locations were chosen from those used for the energy savings analysis simulation models to represent the building construction, energy, and maintenance cost impacts of the changes from 90.1-2016 to 90.1-2019. Section 2.0 provides an overview of the selected prototypes and climate locations utilized for this analysis. Section 3.0 describes the included addenda.

Costs were developed for each of the addenda items included in the cost-effectiveness analysis. The cost estimate methodology and cost items are described in Section 4.0, with a summary of the incremental costs provided. An expanded summary of the incremental costs is also included in Appendix A of this report. The complete cost estimates are available in a spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2019* (PNNL 2020). The cost-effectiveness analysis methodology and results are presented in Section 5.0.

The report has two appendixes. Appendix A includes a summary of incremental cost estimate data. Appendix B includes the energy analysis results for 90.1-2019 compared to 90.1-2016.

[1] Download from http://www.energycodes.gov/development/commercial/90.1_models.

2.0 Building Prototypes and Climate Locations

As part of its technical support to SSPC 90.1, PNNL quantified the energy savings of 90.1-2019 compared to 90.1-2016. The analysis used 16 prototype building models that were simulated in 16 climate locations present in the United States. These prototype models, their development, and the climate locations are described in detail in the quantitative determination and are available for download (DOE 2020b). PNNL selected six of the prototype buildings and developed cost estimates for these in five climate locations. The resulting cost-effectiveness analysis represents most of the energy and cost impacts of the changes in Standard 90.1. The results are presented in Section 5.0 and Appendix B.

2.1 Selection of Prototype Buildings

The 6 of 16 prototype models selected for the cost-effectiveness analysis are shown in bold font in Table 2.1. These six prototypes were chosen because they do the following:

- Provide a good representation of the overall code cost-effectiveness, without requiring simulation of all 16 prototype models
- Represent most of the energy and cost impacts of the changes in Standard 90.1
- Include all of the lighting systems and most of the heating, ventilating, and air conditioning (HVAC) systems represented in the prototypes, as shown in Table 2.2
- Capture 19 of the 22 addenda with quantifiable energy savings. The remaining three addenda affect building types not included in the six prototypes or were not applicable to the prototypes as modeled
- Represent the energy impact of five of the eight commercial principal building activities that account for 72% of the new construction by floor area covered by the full suite of 16 prototypes.

Table 2.1. Prototype Buildings

Principal Building Activity	Building Prototype	Included in Current Analysis
Office	**Small Office**	**Yes**
	Medium Office	No
	Large Office	**Yes**
Mercantile	**Standalone Retail**	**Yes**
	Strip Mall	No
Education	**Primary School**	**Yes**
	Secondary School	No
Healthcare	*Outpatient Healthcare*	No
	Hospital	No
Lodging	**Small Hotel**	**Yes**
	Large Hotel	No
Warehouse	*Warehouse (non-refrigerated)*	No
Food Service	*Quick-service Restaurant*	No
	Full-service Restaurant	No
Apartment	**Mid-rise Apartment**	**Yes**
	High-rise Apartment	No

2.2 Selection of Climate Locations

As energy usage varies with climate, there are multiple climate zones[1] used by ASHRAE for residential and commercial standards. These climate zones cover the entire United States, as shown in Figure 2.1 (ASHRAE 2013b).

For analysis of the Standard 90.1 energy impact in the United States, 16 specific climate locations (cities) selected by SSPC 90.1 represent characteristics of each climate zone. Representative cities for zones 0A, 0B, and 1B are also listed, even though these zones only represent areas outside the United States.

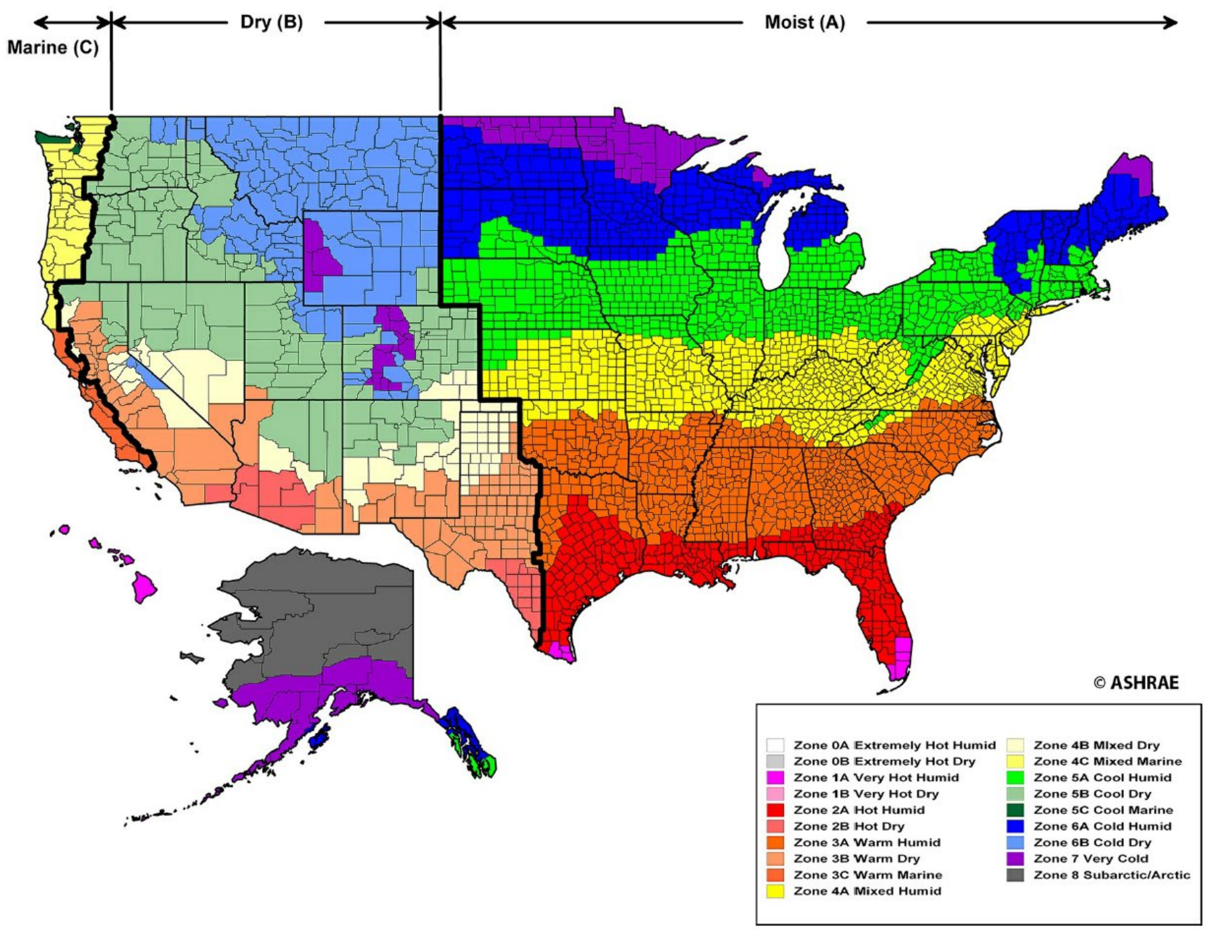

Figure 2.1. United States Climate Zone Map

The cities representing climate zones are listed in Table 2.2 with the five selected for the cost-effectiveness analysis shown in bold font. The selected zones cover most of the high population regions of the United States and include 79% of new construction by floor area (Thornton et al. 2011). The full climate location list was approved by the SSPC 90.1 for setting the criteria for 90.1-2016 and are different

[1] Thermal climate zones are numbered from 0 to 8, from hottest to coldest categorized by cooling and heating degree days. Letters designate moisture characteristics: (A) moist, (B) dry, and (C) marine.

from those used in previous analyses. These new climate locations are also consistent with those used in the determination of energy savings of Standard 90.1-2019 (DOE 2020b).

Table 2.2. Climate Locations by Climate Subzones

Climate Zone	Climate Zone Type	Representative City	Included in Current Analysis
0A	Extremely Hot, Humid	Tan Son Hoa (Ho Chi Minh City/Saigon), Vietnam	No
0B	Extremely Hot, Dry	Dubai International Airport, United Arab Emirates	No
1A	Very Hot, Humid	Honolulu, Hawaii	No
1B	Very Hot, Dry	New Delhi, India	No
2A	**Hot, Humid**	**Tampa Florida**	**Yes**
2B	Hot, Dry	Tucson, Arizona	No
3A	**Warm, Humid**	**Atlanta, Georgia**	**Yes**
3B	**Warm, Dry**	**El Paso, Texas**	**Yes**
3C	Warm, Marine	San Diego, California	No
4A	**Mixed, Humid**	**New York, New York**	**Yes**
4B	Mixed, Dry	Albuquerque, New Mexico	No
4C	Mixed, Marine	Seattle, Washington	No
5A	**Cool, Humid**	**Buffalo, New York**	**Yes**
5B	Cool, Dry	Denver, Colorado	No
5C	Cool, Marine	Port Angeles, Washington	No
6A	Cool, Humid	Rochester, Minnesota	No
6B	Cold, Dry	Great Falls, Montana	No
7	Very Cold	International Falls, Minnesota	No
8	Subarctic	Fairbanks, Alaska	No

2.3 Description of Selected Prototypes

Table 2.3 provides a brief overview of the six prototypes selected for this cost-effectiveness analysis. *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* provides further information (Thornton et al. 2011). The EnergyPlus input files and detailed modeling information for all the prototypes are available for download.[1] Information from the prototype profiles (also referred to as "scorecards") are also available at the same website. The scorecards include information on the overview tab for each prototype. References such as "See under Outdoor Air" or "See under Schedules" are to other tabs on the full profile spreadsheets.

Table 2.3. Overview of Six Selected Prototypes

			HVAC Systems		
Building Prototype	Floor area (ft²)	Number of Floors	Heating	Cooling	Main System
Small Office	5,502	1	Heat pump	Unitary direct expansion (DX)	Packaged constant air volume (CAV)
Large Office	498,588	12[(a)]	Boiler	Chiller, cooling tower	Variable air volume (VAV) with hydronic reheat
Standalone Retail	24,692	1	Gas furnace	Unitary DX	Packaged CAV[(a)]
Primary School	73,959	1	Boiler/Gas furnace	Unitary DX	Packaged VAV with hydronic reheat
Small Hotel	43,202	4	Electricity	DX	Packaged terminal air conditioner (PTAC)
Mid-rise Apartment	33,741	4	Gas furnace	DX	Split DX system

(a) Systems with a cooling capacity > 65,000 Btuh include two speed fans.

[1] Download from http://www.energycodes.gov/development/commercial/prototype_models

2.4 Construction Weighting

Weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level were developed from construction data purchased from McGraw Hill. These data represent all new buildings, as well as additions to existing facilities, over a period of 16 years (2003–2018), and are based on a set of 1,085,104 individual records of commercial building construction across the United States covering a total of 23.2 billion square feet. Details of their development are further discussed in a PNNL report (Lei et al. 2020).

New construction weights were determined for each building type in each climate zone based on the county-climate zone mapping from 90.1-2019. These construction weights were applied to both the baseline and advanced cases. The new full weighting table for all prototypes and U.S. climate zones is included in Lei et al. (2020). For this analysis, the weightings for the selected prototypes and climate zones were normalized to the weightings shown in Table 2.4.

Table 2.4. Construction Weights by Building Type and Climate Zone

Climate Zone	Small Office	Large Office	Stand-alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
2A	2.5%	1.8%	5.9%	3.2%	1.0%	7.4%	21.9%
3A	2.3%	1.8%	5.9%	3.1%	0.9%	5.9%	19.8%
3B	0.9%	0.8%	2.8%	1.2%	0.4%	3.9%	10.0%
4A	1.9%	3.7%	6.3%	2.9%	1.0%	10.0%	25.9%
5A	2.2%	1.6%	7.8%	2.6%	0.9%	7.3%	22.4%
U.S. Average	9.9%	9.8%	28.8%	13.0%	4.1%	34.5%	100.0%

Using the energy saving results from each building simulation, the incremental costs, and the corresponding relative fractions of new construction floor space, PNNL developed floor-space-weighted national energy savings results by energy type for each building type and climate zone. Life-cycle cost was completed for each building type. The individual building type and climate zone results were weighted to find a national cost-effectiveness result in Section 5.0.

3.0 Cost Estimate Items from 90.1-2016 Addenda

Of the 88 addenda included in 90.1-2019, 22 were considered to have quantifiable energy savings represented in the prototypes. Of those, 17 were modeled in DOE's 90.1-2019 determination and are described in more detail in the report documenting the determination quantitative analysis (DOE 2020b). The five that were not modeled for the determination analysis mirror federal appliance standards regulations. However, these five addenda and their associated savings are included in the cost-effectiveness analysis because they do have the potential to impact cost. The remaining 66 addenda do not have quantifiable savings, had no savings, do not directly affect building energy usage, or could not be quantified during the determination quantitative analysis.

3.1 Addenda Included in Cost-Effectiveness Analysis

As described in Section 2.1, the cost-effectiveness analysis uses a subset of six representative prototypes to quantify savings and costs. Of the 22 addenda with quantified savings, 19 were modeled in the six prototypes being used for the cost estimate. These are listed in Table 3.1. Figure 3.1 shows the breakdown of addenda captured in the cost estimate by chapter of the standard.

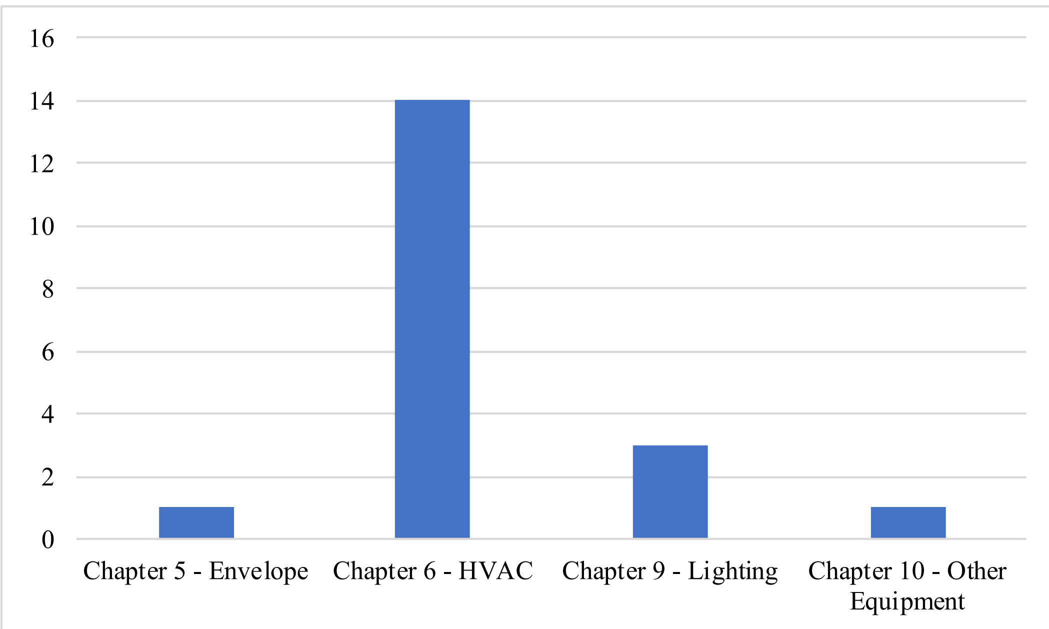

Figure 3.1. Quantity of Addenda Included in Analysis by Standard 90.1 Chapter

Table 3.1 provides a listing and a brief description of all the addenda modeled in this analysis and the prototypes to which they apply. The changes due to these addenda are described in Chapter 4.0 of this report. Material and labor costs were separated out for HVAC systems because there are adjustments in HVAC system capacities due to the other changes in the models, particularly reduced heat gains from lighting power reductions.

Throughout this report, each addendum is named according to a convention that begins with 90.1-16, followed by the letter identifier of the addendum (e.g., 90.1-16bo). In text it may be referred to by just the letter designation: *bo*.

Table 3.1. Addenda Included in Cost-Effectiveness Analysis

90.1 Addenda and Other Cost Items	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
Standard 90.1 Chapter 5 - Envelope							
90.1-16aw	Revises prescriptive fenestration U and SHGC requirements and makes them material neutral	X	X	X	X	X	X
Standard 90.1 Chapter 6 – Heating, Ventilating, and Air Conditioning							
90.1-16a	Changes term "ventilation air" to "outdoor air" in multiple locations. Revises tables and footnotes. Clarifies requirements for economizer return dampers.			X		X	
90.1-16g	Provides definition of "occupied-standby mode" and adds new ventilation air requirements for zones serving rooms in occupied-standby mode	X	X		X	X	X
90.1-16h	Clarifies that exhaust air energy recovery systems should be sized to meet both heating and cooling design conditions unless one mode is not exempted by existing exceptions						X
90.1-16k	Revises definition of networked guest room control system and aligns HVAC and lighting time-out periods					X	
90.1-16ap	Revises supply air temperature reset controls		X		X		
90.1-16au,cm,co	Eliminates the requirement that zones with DDC have flow rates ≤ 20% of zone design peak flow rate. Allows Simplified Ventilation Procedure from Standard 62.1.		X		X		
90.1-16ay	Provides separate requirements for nontransient dwelling unit exhaust air energy recovery						X
90.1-16be	Revises computer room air conditioner (CRAC) requirements to clarify these are for floor mounted units and adds a new table for ceiling mounted units		X				
90.1-16bo	Adds definition of Standby Power Mode Consumption. Increases furnace efficiency requirements.	X		X	X	X	X
90.1-16bq	Adds dry cooler efficiency requirements and increases efficiency requirements for evaporative condensors		X				
90.1-16br	Combines commercial refrigerator and freezer table with refrigerated casework table. Better efficiency requirements.				X		
90.1-16cn	Cleans up outdated language regarding walk-in cooler and walk-in freezer requirements, and makes the requirements consistent with current and future federal regulations				X		
Standard 90.1 Chapter 9 - Lighting							
90.1-16bb	Changes interior lighting power density (LPD) requirements for many space types	X	X	X	X	X	X
90.1-16cg	Revises LPDs using the Building Area Method	X	X	X	X	X	X
90.1-16cw	Changes the daylight responsive requirements from continuous dimming or stepped control to continuous dimming required for all spaces	X	X	X	X	X	
Standard 90.1 Chapter 10 – Other Equipment							
90.1-16an	Implements 2020 federal clean water pump requirements		X		X		

3.2 Addenda Not Included in Cost-Effectiveness Analysis

The remaining addenda with quantifiable energy savings affect prototypes not included in those selected for the cost-effectiveness analysis or not applicable to the subset of prototypes modeled. These are listed in Table 3.2 along with the reason for non-inclusion.

Table 3.2. Addenda Not Included in Cost-Effectiveness Analysis

90.1 Addenda	Description	Reason
90.1-16v	Adds a new requirement for heat recovery for space conditioning for in-patient hospitals	Does not apply to any of the six modeled prototypes
90.1-16bd	Adds new chiller table for heat pump and heat recovery chillers	Does not apply to any of the six modeled prototypes
90.1-16bp	Adds a new table to specify DOE covered residential water boiler efficiency requirements. Adds standby mode and improves efficiency.	Does not apply to any of the six modeled prototypes

4.0 Incremental Cost Estimates

This chapter describes the approach used for developing the incremental construction cost estimates, a description of each, and a summary of the results. The incremental cost estimates were developed for the sole purpose of evaluating the cost-effectiveness of the changes between 90.1-2016 and 90.1-2019. They should not be applied to actual building projects or used for any other purpose as these are aggregated estimates designed to represent the average building stock. Estimates rely on specific prototype designs and assembly cost surveys developed for the purpose of cost estimates for prior cycles, current estimates based on *RS Means* handbooks, and surveys of product costs. All costs are intended to be in the 2020 time frame, and earlier estimates are adjusted with equipment-specific inflation factors. Costs are for national average construction, and these represent total cost to building owners, including contractor overhead and profit.

4.1 Incremental Cost Estimate Approach

The first step in developing the incremental cost estimates was to define the items to be estimated, such as specific pieces of equipment and their installation. Part of the cost item information was extracted from the prototype building energy model inputs and outputs, and from addenda descriptions in the determination quantitative analysis report (DOE 2020b). In some cases, the prototype models did not include sufficient design detail to provide the basis for cost estimates—requiring additional details to be developed to support the cost estimating effort. These are described in Section 4.2 of this report along with the costs. A summary of the incremental costs is included in Appendix A of this report. The cost estimates are available in the spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2019* (PNNL 2020).

The second step in the cost estimating process began by defining the types of costs to be collected including material, labor, construction equipment, commissioning, maintenance, and overhead and profit. These were estimated for both initial construction as well as for replacing equipment or components at the end of the useful life.

The third step was to compile the unit and assembly costs needed for the cost estimates. PNNL worked with a cost estimating consulting firm and with a mechanical, electrical, and plumbing (MEP) consulting engineering firm, and utilized its own expertise to develop detailed design-based cost information during the development of the cost-effectiveness comparison between 90.1-2010 and 90.1-2007 (Thornton et al. 2013). For this report, PNNL limited its efforts to updating the prior developed costs where appropriate and completing in-house estimates where needed. *RS Means* cost handbooks were used extensively and provided nearly all of the labor costs (*RS Means* 2020a,b,c). Comparison with *RS Means* cost handbooks from 2012 and 2014 provided specific technology inflation factors where the costs developed in 2012 or 2014 were used (*RS Means* 2012a,b,c, 2014a,b,c). While specific references are included in the cost estimate spreadsheet, in this report the RS Means cost handbooks are referred to as *RS Means 2020, RS Means 2018, RS Means 2014,* and *RS Means 2012*, and the specific handbook used can be inferred from the type of cost item being discussed. Cost estimates for new work and later replacements were developed to approximate what a general contractor typically submits to the developer or owner, and these include subcontractor and contractor costs and markups. Maintenance costs were intended to reflect what a maintenance firm would charge, rather than in-house maintenance labor. Once initial costs were developed, a technical review was conducted by PNNL internal sources.

4.1.1 Source of Cost Estimates

Many of the general HVAC costs were originally developed while analyzing the cost-effectiveness of 90.1-2010 compared to 90.1-2007. Table 4.1 includes a description of all sources of cost estimates by category of costs. HVAC cost items were developed primarily by two consulting firms during prior analysis (Thornton et al. 2013). The cost estimating firm provided the cost for HVAC systems including packaged DX and chilled and hot water systems as well as central plant equipment. The engineering consulting firm provided most of the ductwork and piping costs, and most of the control items. These earlier cost estimates from 2012 and 2014 have been adjusted to 2020 values by applying inflation factors developed using RS Means cost handbooks from 2012, 2014, 2018, and 2020 (*RS Means* 2012a,b,c; 2014a,b,c; 2018a,b,c; 2020a,b,c).

For lighting and some HVAC items, PNNL developed new cost estimates. Online sources were used together with input from the 90.1 SSPC Lighting Subcommittee (LSC). For envelope items, national costs collected for the prior analysis by a cost estimating contractor were updated, including some input developed by the 90.1 SSPC Envelope Subcommittee (ESC). In addition to these summary tables, specific sources, such as the name of product suppliers, are included in the cost estimate spreadsheet (PNNL 2020).

Bare costs are the costs of materials and labor that the installation contractor pays. They do not include any markups for profit and overhead.

Table 4.1. Sources of Cost Estimates by Cost Category

Cost Category	Source
HVAC Motors included in this category	Cost estimator and PNNL staff used quotes from suppliers and manufacturers, online sources, and their own experience.(a)
HVAC Ductwork, piping, selected controls items	MEP consulting engineers provided ductwork and plumbing costs based on one-line diagrams they created; the model outputs, including system airflows, capacity, and other factors; and detailed costs by duct and piping components using *RS Means 2012*. The MEP consulting engineers also provided costs for several control items.(a) Additional items were costed using *RS Means 2020*.
HVAC Selected items	PNNL provided using staff expertise and experience supplemented with online sources.(a)
Lighting Interior lighting power allowance and daylighting controls	PNNL provided using staff with oversight from a member of 90.1 LSC. Product catalogs were used for consistency with some other online sources where needed.
Envelope Fenestration	Costs dataset developed by specialist cost estimator with additional input from the 90.1 ESC.(a)
Commissioning	Cost estimator, RS Means, MEP consulting engineers, or PNNL staff expertise.
Labor	*RS Means 2020* and the MEP consulting engineers for commissioning rate.
Replacement life	Lighting equipment including lamps and ballasts from product catalogs. Mechanical from 90.1 Mechanical Subcommittee protocol for cost analysis.
Maintenance	Available from the originator of the other costs for the affected items, or PNNL staff expertise.

(a) Detailed costs developed in 2012 or 2014 were updated to 2020 using equipment-specific inflation factors developed from RS Means handbooks.

4.1.2 Cost Parameters

Several general parameters were applied to all the bare cost estimates. These parameters are part of the general construction costs and represent profit and overhead items typical in the construction industry. These items included new construction material and labor cost adjustments, a replacement labor hour adjustment, replacement material and labor cost adjustments, and a project cost adjustment. These parameters are based on work by the cost estimating firm in the prior analysis and are described in Table 4.2.

Costs were not adjusted for climate locations, as this is intended to be a national analysis. The climate location results were intended to represent an entire climate subzone even though climate data for a particular city are used for modeling purposes. Even within a climate zone, costs will vary significantly between a range of urban, suburban, and rural areas. The five selected climate locations cross multiple states. Due to this variation, for this national analysis, average national U.S. construction costs are used. For those interested in a more local analysis, costs could be adjusted for specific cities based on city cost index adjustments from *RS Means 2020* or other sources.

Table 4.2. Cost Estimate Adjustment Parameters

Cost Items	Value[(a)]	Description[(b)]
New construction labor cost adjustment	52.6%	Labor costs used are base wages with fringe benefits. Added to this is 19%: 16% for payroll, taxes, and insurance including worker's comp, FICA, unemployment compensation, and contractor's liability and 3% for small tools. The labor cost plus 19% is multiplied by 25%: 15% for home office overhead and 10% for profit. A contingency of 2.56% is added as an allowance to cover wage increases resulting from new labor agreements.
New construction material cost adjustment	15.0% to 26.5%	Material costs are adjusted for a waste allowance set at 10% in most cases for building envelope materials. For other materials such as HVAC equipment, 0% waste is the basis. The material costs plus any waste allowance are multiplied by the sum of 10% profit on materials. An average value for sales taxes of 5% is applied.
Replacement - additional labor allowance	65.0%	Added labor hours for replacement to cover demolition, protection, logistics, cleanup, and lost productivity relative to new construction. Added prior to calculating replacement labor cost adjustment.
Replacement labor cost adjustment	62.3%	The replacement labor cost adjustment is used instead of the new construction labor cost adjustment for replacement costs. The adjustment is the same except for subcontractor (home office) overhead, which is 23% instead of 15% to support small repair and replacement jobs.
Replacement material cost adjustment	26.5% to 38.0%	The replacement material cost adjustment is used instead of the new construction material cost adjustment for replacement costs. The adjustment is for purchase of smaller lots and replacement parts. 10% is added and then is adjusted for profit and sales taxes.
Project cost adjustment	28.8%	The combined labor, material, and any incremental commissioning or construction costs are added together and adjusted for subcontractor general conditions and for general contractor overhead and profit. Subcontractor general conditions add 12% and include project management, job-site expenses, equipment rental, and other items. A general contractor markup of 10% and a 5% contingency is added to the subcontractor subtotal as an alternative to calculating detailed general contractor costs (*RS Means* 2018c).

(a) Values shown and used are rounded to first decimal place.
(b) Values provided by the cost estimator except where noted.

4.1.3 Cost Estimate Spreadsheet Workbook

The cost estimate spreadsheet (PNNL 2020) that supports cost estimates in this report is organized in the following sections, some with multiple worksheets, each highlighted with a different colored tab described in the introduction to the spreadsheet:

1. Introduction
2. HVAC cost estimates
3. Lighting cost estimates
    a. Interior lighting power density (LPD)
    b. Interior lighting controls
4. Envelope cost estimates
5. Cost estimate summaries and cost-effectiveness analysis results.

4.2 Modeling of Individual Addenda

This section details the simulation modeling of the applicable addenda. The procedures for implementing the addenda into the Standard 90.1-2016 and 90.1-2019 prototype models include identifying the changes to the models required by each addendum, developing model inputs to simulate those changes, applying those changes to the models, running the simulations, and extracting and post-processing the results.

This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for EnergyPlus. The terms “baseline” and “advanced” or “target” are used in some cases to describe the modeling of the addenda. The baseline case is Standard 90.1-2016 and the advanced case is Standard 90.1-2019. In some instances, a new addendum identifies the need for a change to baseline 2016 models. There are generally two reasons why a baseline change was necessary: (1) in the course of modeling an addendum, an opportunity to improve the accuracy of the simulation was identified and (2) to add additional detail to the models so that the impact of a particular addendum could be captured.

4.2.1 Building Envelope

Building envelope addenda included improvements to reduce fenestration heat loss and heat gain.

4.2.1.1 Addendum *aw*: Fenestration U and SHGC

Addendum *aw* revises the prescriptive U-factor and solar heat gain coefficient (SHGC) requirements in Tables 5.5-0 through 5.5-8 for vertical fenestrations and skylights. It also modifies the vertical fenestration categories from “Nonmetal,” “Metal fixed,” “Metal operable,” and “Metal entrance door” to “Fixed,” “Operable,” and “Entrance Door.” The adjusted categorization is independent of frame material type, provides increased consistency with the International Energy Conservation Code (IECC), and helps facilitate alignment of 90.1 and IECC criteria. The revised SHGC values for operable and vertical fenestrations are slightly lower than those for fixed windows, which is to acknowledge the fact that operable ones have a larger frame-to-glass ratio and therefore lower SHGC values with the same glazing type. The addendum generally reduces U-factor for fixed metal framed windows; however; it also increases the U-factor for non-metal framed windows. Since the predominant framing is metal in commercial construction, the average U-factor is reduced, in turn reducing heat loss and gain for commercial buildings, which provides an overall reduction in both annual and peak heating and cooling loads. SHGC is slightly reduced overall, contributing further to a reduction in cooling load and energy use.

Energy Modeling Strategy

All the prototypes have vertical fenestration and two have skylights (Standalone Retail and Primary School). These are all modeled using U-factor and SHGC inputs to Window Material – Simple Glazing System objects in EnergyPlus. To capture the window requirements with different categorizations introduced by this addendum, weighting factors of different window categories as shown in Table 4.3 were used to calculate weighted U-factor and SHGC values for each prototype based on recent market data from Ducker.[1] The weighting factors are slightly updated from those used in the previous analyses (Thornton et al. 2011). Although the required minimum ratio of visible transmittance (VT) to SHGC (VT/SHGC) is not changed by the addendum, the new SHGC values resulted in different VT inputs in the prototypes.

Table 4.3. Weighting Factors of Different Windows Categorized in 90.1-2016 and 90.1-2019

	Vertical fenestration categories in 90.1-2016			Vertical fenestration categories in 90.1-2019	
Building Prototype	Nonmetal	Metal - Fixed	Metal - Operable	Fixed	Operable
Small Office	2.5%	95.7%	1.8%	96.9%	3.1%
Large Office	2.5%	95.7%	1.8%	96.9%	3.1%
Stand-alone Retail	2.6%	96.2%	1.2%	97.8%	2.2%
Primary School	7.5%	86.6%	5.8%	89.8%	10.2%
Small Hotel	5.8%	89.7%	4.5%	92.0%	8.0%
Mid-Rise Apartment	17.3%	68.7%	14.0%	75.4%	24.6%

Incremental Cost Impact

The incremental costs are the same as those used for the 90.1-2016 analysis, with costs brought forward to 2020 dollars. Industry stakeholders reviewed these costs with their members. Some of the general feedback was that these costs were still reasonable when used as incremental costs. For some of the newer technologies where one would expect costs to decrease with increasing volume and market penetration, those potential decreases were offset by increases in material and shipping costs. Thus, the workgroup decided to stay with the same incremental costs as the prior analysis. This addendum will generally result in a reduction in peak heating and cooling loads, reducing the overall size of heating and cooling systems. Therefore, the cost for this addendum includes incremental increases associated with reduced U-factors and SHGC along with incremental reductions in HVAC system sizing.

[1] Detailed market data from https://www.ducker.com/ were processed by SSPC 90.1 Envelope Subcommittee.

4.2.2 Heating, Ventilating, and Air-Conditioning

A substantial part of the HVAC system cost estimate was tied to changes in system and plant equipment capacity between 90.1-2016 and 90.1-2019. Costs for these capacity changes are described together in Section 4.2.2.1 of this report.

Other cost estimates were tied to specific addenda. In some cases there was a net decrease in HVAC costs due to reductions in system capacity, airflow, and water flow offsetting increased costs from other addenda.

Many of the HVAC items for which costs were determined remained the same in the current analysis as they were in a prior cost-effectiveness analysis. For example, the change in equipment capacity requires costs for various equipment sizes, which were obtained during a previous analysis. For this round of analysis, costs for HVAC items from previous analyses were brought forward to 2020 costs by applying inflation adjustment factors that were calculated by comparing corresponding items in prior versions of *RS Means* to *RS Means 2020*.

4.2.2.1 HVAC System and Plant Equipment Capacity Changes

Costs were estimated to address changes in HVAC system and plant equipment capacity between the 90.1-2016 and 90.1-2019 prototype models. HVAC equipment capacity changes result from reductions in heating and cooling loads due to changes in fenestration U-factor and SHGC requirements and lighting power, for example. In some cases there may be a heating load increase as a result of reduced internal gains. The change in capacity is taken from the building simulations as an interactive effect of the other code changes implemented.

The HVAC capacity changes are a substantial part of the HVAC cost differences. The costs are developed for a range of equipment sizes corresponding to the prototype models. In most cases, equipment costs from two manufacturers were obtained and the average was used. These costs were originally developed for the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For capacity changes going from 90.1-2016 to 90.1-2019, the same costs were used but were brought forward to 2020 by multiplying them by an adjustment factor. The inflation adjustment factors inflate the material costs and are calculated by comparing corresponding equipment costs in *RS Means 2012, RS Means 2014,* and *RS Means 2018* with those in *RS Means 2020*. Labor costs were updated by using current labor crew rates from *RS Means 2020*.

Many of the HVAC capacity-related equipment costs in the component cost worksheet are the same for 90.1-2016 and 90.1-2019 for the same capacity equipment. The costs differ in the prototype-specific cost worksheets when there is a change in equipment capacity, based on data extracted from the simulation models. Changes in capacity often result in changes in efficiency, and those too are reflected in the costs. Ductwork and piping cost results were calculated separately because a total cost for each combination of prototype and climate location and the values for 90.1-2016 and 90.1-2019 are different, relative to system airflow or water flow.

Piping and ductwork costs were developed for a previous analysis by MEP consulting engineers. This effort included developing schematic-level single-line representative layouts of the ductwork and piping for each prototype. Detailed costs were previously developed at the level of duct and pipe size and length, and all fittings based on the component-by-component costs from *RS Means 2012*. These costs are brought forward to 2020 by applying an inflation factor. Most of the incremental differences from 90.1-2016 to 90.1-2019 are based on changes in heating load, cooling load, and airflow; thus, the cost estimates from the previous analysis are relevant. For some systems like PTACs in the Small Hotel prototype, the differences in capacity do not impact size selection, so costs are not adjusted for actual capacity requirements.

An example of the process for developing piping and ductwork costs is shown below. Figure 4.1 provides an exterior view of the Small Office prototype model and an image of the air distribution layout provided by the MEP consulting engineers. Table 4.4 shows an example of the level of ductwork detail developed. Costs for each air distribution element were estimated (primarily from *RS Means 2012*) and then summed. For example, for the Buffalo climate location, the 90.1-2007 material cost is $5,561 and the 90.1-2010 cost is $5,573 before adjusting to 2020 costs. More detailed costs are shown in the associated spreadsheet (PNNL 2020). Based on cost data from all the estimates, a curve fit was developed relating costs to airflow. Then, the resulting airflow for each climate location, prototype, and code edition was used to generate specific air distribution material and labor costs. These costs were then brought forward to 2020 with separate inflation factors for material and labor.

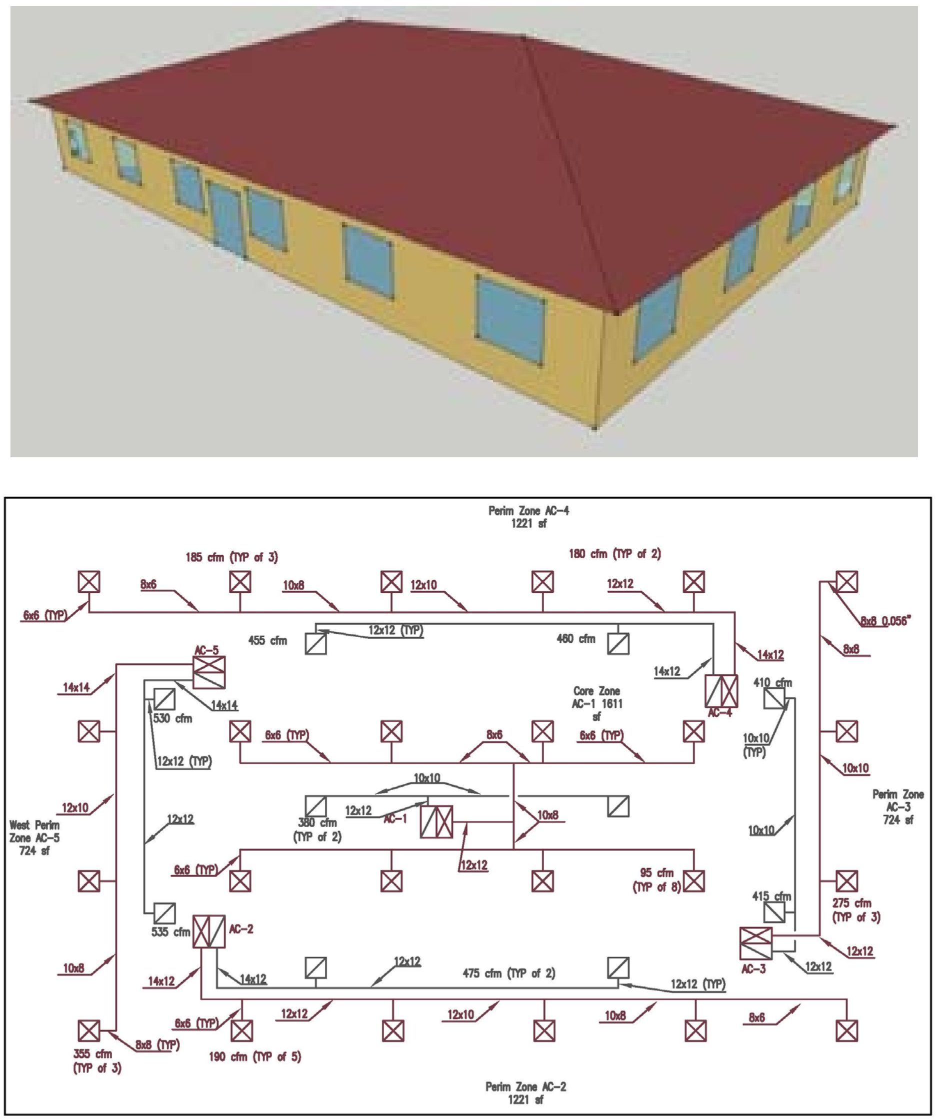

Figure 4.1. Small Office Air Distribution System

Table 4.4. Small Office Duct Details for One HVAC System

Description	Multiplier	Depth (in.)	Width (in.)	Area (ft^2)	Duct Length (ft)	Depth + Width	Duct Weight (lb)	Item Qty
Supply Side								
12x12 Duct	1	12	12	1.00	6	24	34.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	1	10	8	0.56		18		17.3
10x8 Duct	2	10	8	0.56	4	18	34.7	
SR5-14 Dovetail WYE	1	8	6	0.33		14		20.9
8x6 Duct	4	8	6	0.33	7	14	85.5	
SR5-13 Tee, 45 degrees (Qs)	4	6	6	0.25		12		15.2
SR5-13 Tee, 45 degrees (Qb)	1	6	6	0.25		12		
6x6 Duct	4	6	6	0.25	20	12	182.4	
CR3-14 Elbow (1.5" Vane Spc)	4	6	6	0.25		12		4.0
6x6 Duct	8	6	6	0.25	2	12	36.5	
Damper ϴ = 0°, 6x6	8							8.0
Diffuser, 6x6	8							8.0
Return Side								
12x12 Duct	8	12	12	1.00	2	24	92.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	2	10	10	0.69		20		38.7
10x10 Duct	2	10	10	0.69	15	20	145.2	
CR3-14 Elbow (1.5" Vane Spc)	2	10	10	0.69		20		2.0
10x10 Duct	2	10	10	0.69	2	20	19.4	
Damper ϴ = 0°, 10x10	2							2.0
Grille, NC 30 10"x10"	2							2.0
						Duct Weight	631.26	

4.2.2.2 Addendum *a*: Outdoor and Return Dampers

Addendum a makes a few clarifying changes such as modifying the term “ventilation air” to “outdoor air.” It also improves energy efficiency by requiring return dampers to meet Table 6.4.3.4.3, which means a lower leakage rate from return air to supply air than Standard 90.1-2016. This improves economizer operation by increasing the outside air entering the system during economizer mode, as leaky return air dampers result in mixing of some return air back into the mixed air, even when dampers are fully closed. In addition, an exception is added to Section 6.4.3.4.2. Without this exception, a system with continuous ventilation intake needs to have an outdoor air damper, which creates a pressure drop. With the exception, such a system without the outdoor air damper would have lower pressure drop and therefore less fan energy consumption.

Energy Modeling Strategy

When air-side economizers are modeled in single-zone unitary systems in the baseline prototypes, their maximum fraction of outdoor over design supply air is modeled to be 70% based on field measurements for unitary systems (Davis et al. 2002), which limits the maximum outdoor airflow during economizer operation. With the lower leakage damper required by the addendum, the improvement in economizer operation is modeled as an increase in the maximum outdoor air fraction from 70% to 75%, which is approximated based on the relationship between damper leakage rates and opening positions of sample products. The savings were only captured for single-zone systems with economizers. In some systems, the design outdoor airflow fraction is already higher than 70% due to zone exhaust or ventilation needs; therefore, the impacts of the addendum on these systems are not modeled. Similarly, for multiple-zone variable air volume (VAV) systems, the modeled maximum outdoor air fraction is already 100%; therefore, the impacts on these are not captured.

Incremental Cost Impact

Incremental material costs for low leakage return air dampers were obtained from a major damper manufacturer. Labor costs were obtained from *RS Means*.

4.2.2.3 Addendum *g*: Occupied Standby Controls

Standard 90.1-2016 Section 9.4.1.1 (see Table 9.6.1) already requires occupancy sensors for lighting control in certain spaces but some types of occupancy status are not required to control HVAC systems except for hotel/motel guest rooms (see Section 6.3.3.3.5). Standard 62.1-2016, referenced by Standard 90.1-2019, introduced a new definition for occupied-standby mode: when a zone is scheduled to be occupied and an occupant sensor indicates zero population within the zone. It now allows outside air ventilation to be shut off in occupied-standby mode for many occupancy categories including office and conference/meeting spaces (see Note H in Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone in Standard 62.1-2016). Addendum g requires zones, that already have occupancy sensors and qualify for the occupied-standby mode, to automatically enter an occupied standby mode, during which the zones should have a heating and cooling thermostat setback of 1°F and should completely shut off HVAC supply air within the deadband.

Addendum g provides energy savings for VAV systems by significantly reducing deadband airflow and thereby reducing fan, cooling, and reheat energy during the occupied-standby mode. Before this addendum, the full minimum amount of air was delivered to empty zones during the occupied-standby mode, resulting in excessive reheat to maintain temperature. Energy is saved by reducing reheat, primary air cooling, and fan use for unneeded airflow. Single-zone, dedicated outdoor air systems (DOAS) and other HVAC systems experience similar savings through shut off of airflow to temporarily unoccupied spaces unless there is a demand for thermal conditioning.

Energy Modeling Strategy

Prototype models were modified to include “occupied-standby” periods for some of the spaces as needed. Occupied-standby periods correspond to times during normal building occupancy when a space is unoccupied. This was achieved by modifying the space occupancy schedules. In general, around two of the normally occupied hours per day are now unoccupied as a result of the new occupied-standby schedule. The ventilation to the space completely shuts off during these periods along with a 1°F temperature setup/setback for the thermostat schedules. The fan operation for single-zone systems was changed from constant to cycling. There are similar changes to multi-zone systems. During occupied-standby periods, the fan operates only as needed to meet the heating and cooling loads. The minimum VAV box damper positions were modeled using hourly schedule fractions and the dampers were allowed to fully close when not heating or cooling.

Incremental Cost Impact

There is a labor cost but no incremental material cost to implement this addendum. The labor cost includes programming to interface the occupancy sensor to the HVAC system. Although once the programming becomes standard practice, the programing cost goes away. The labor is estimated at 15 minutes per conditioned zone and the labor cost is from *RS Means*.

4.2.2.4 Addenda *h* and *ay*: ERV Sizing Requirements + Residential Energy Recovery

Standard 90.1-2016 already has requirements for exhaust air energy recovery for ventilation systems based on the design supply fan airflow rate and the ratio of outdoor airflow rate to fan supply airflow rate at design conditions. Dwelling units are subject to the criteria in Table 6.5.6.1-2 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year. There has been confusion as to whether heating or cooling design should be used for sizing an energy recovery ventilator (ERV).

Addendum h clarifies that the ERV equipment should meet the greater enthalpy recovery ratio (ERR) of either heating or cooling, unless one mode is specifically excluded for the climate zone by exception. This addendum is primarily a clarification.

Addendum *ay* provides new requirements for the nontransient dwelling unit (apartment) exhaust air energy recovery that are distinct from other commercial buildings. Dwelling unit energy recovery uses different equipment than general commercial spaces, and has a different cost-effectiveness, so the addenda resulted in energy recovery being required in more climate zones than under the commercial requirements. Based on the SSPC 90.1 analysis, climate zone 3C is completely exempt, while the energy recovery device selection is based on heating only in climate zones 4 through 8 and cooling only in climate zones 0 through 2. Climate zones 3A and 3B must meet both heating and cooling requirements. Smaller apartments, less than 500 square feet, are exempt in climate zones 0 through 3 and 4C and 5C.

Exhaust air energy recovery provides energy savings by pre-heating or pre-cooling incoming outside air for ventilation using the heat energy in the exhaust air stream. Pre-treatment of the outside air reduces the energy use by the heating and cooling systems. While there is some increase in fan energy use, this is partially offset by reduced exhaust fan operation for ventilation. Overall, in the climate zones where it is required, exhaust air energy recovery will save more heating and cooling energy than the fan energy increase. The addendum specifies an enthalpy recovery ratio of at least 50% at cooling design condition and at least 60% at heating design condition. There are several exceptions to these requirements. The addendum increases the number of climate zones and situations where exhaust air energy recovery is required in apartments, dormitories, and residential institutions.

Energy Modeling Strategy

While Addendum *ay* specifies the ERR requirements for ERVs, the energy simulations require inputs in terms of heat recovery effectiveness. In order to convert the ERR values to effectiveness, PNNL collected representative data from equipment manufacturers for which both ERR and effectiveness are available. One complication in the translation of the ERR requirements of Addendum *ay* to effectiveness values for simulation is that the standard specifies the ERR values at the local design condition rather than at an Air Conditioning, Heating and Refrigeration Institute (AHRI) standard rating condition. For a given design ERR, the required heat exchanger effectiveness will vary from one climate to another. In order to handle this climate variation requirement, the actual ERR delivered by the same equipment was calculated in heating and cooling across climate zones, and the corresponding rated ERR values were determined for use as the reference point for calculating the heat exchanger effectiveness values.

The typical fan power of the units is also needed to characterize the performance of the ERVs. A review of manufacturers' literature was conducted to determine an appropriate value for this parameter. This yielded data for 18 different systems of varying capacity. For the typical apartment ventilation rate of 55 cubic feet per minute (cfm) per apartment, the corresponding fan power would be 65 watts per unit.

Incremental Cost Impact

Material and labor costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. For the cost analysis, the base case is a central fan integrated (CFI) ventilation supply air system, which is a common low-cost supply ventilation system. The enhanced case is an ERV installed in each apartment with fan efficacy of 1.2 cfm/W (minimum setting in IECC for residential ERVs). This system displaces two bathroom exhaust fans, using the ERV exhaust fans for this function. There is no defrost, economizing, or bypass. An additional offset to the cost is an average reduction in heating and cooling unit sizing that reduces the cost of apartment heating and cooling units.

4.2.2.5 Addendum *k*: Hotel/Motel HVAC Guest Room Controls

Standard 90.1-2016 already requires hotel/motel guest rooms to have automatic setback thermostat setpoint and shut off ventilation for rooms that are either rented and unoccupied or unrented and unoccupied. Addendum *k* clarifies the language by calling out the two modes with the same intent and the clarification does not have quantifiable energy impacts. The addendum saves more energy by reducing the time-out period for unoccupied indication from 30 minutes to 20 minutes. Consequently, there will be 10 minutes more per cycle with reduced ventilation and setback heating and cooling, reducing energy use.

Energy Modeling Strategy

The baseline Small Hotel prototype was already modeled to meet the control requirements through thermostat and ventilation schedules. The schedules in their advanced models were slightly adjusted to capture the added savings from the reduced time-out period.

Incremental Cost Impact

No cost impact as no additional materials or labor are needed.

4.2.2.6 Addendum *ap*: SAT Reset

HVAC systems with simultaneous heating and cooling (typically multiple-zone VAV systems) were previously required to provide supply air temperature (SAT) reset except in climate zones 0A through 3A. In these climate zones, several approaches can successfully dehumidify the outside air while still providing SAT reset and reducing reheat energy use. Addendum *ap* extends the requirement for SAT reset to the warm and humid climate zones where it was previously excepted. The dehumidification requirements of addendum *ap* can be met with either a separate outside air cooling coil or alternative approaches, including bypassing return air around the cooling coil, a dedicated outside air system, or series heat recovery.

Units smaller than 3,000 cfm are excepted from SAT reset in climate zones 0A, 1A and 3A, with units smaller than 10,000 cfm excepted in 2A. There are also requirements that the system is designed to allow simultaneous SAT reset and dehumidification with one of the strategies discussed above.

Supply air temperature reset saves significant heating energy in VAV reheat systems that require minimum airflow for ventilation. That savings is higher in northern climate zones than in climate zones 0A through 3A, which were previously excepted because outside air dehumidification (typically performed with a low dewpoint on the supply air) is required much of the year. Dehumidification can be achieved more efficiently by separately dehumidifying the outside air, as it reduces the total volume of air that must be cooled, significantly reducing cooling energy use in all the warm and humid climate zones and allowing SAT reset that reduces reheat energy use.

Energy Modeling Strategy

For 90.1-2019, addendum *ap* requires SAT reset to be used in climate zones 0A, 1A, 2A, and 3A even if there is dehumidification control. Therefore, all air VAV multizone air handling units (AHUs) in the prototypes in these warm and humid climates should have SAT reset.

An informative note in addendum *ap* suggests having a return air bypass or separate outside air cooling coil controlled by the zone humidistat to dehumidify the outside air stream will meet the requirement that dehumidification and SAT reset be able to function simultaneously without depressing the dewpoint temperature of the full supply airstream to provide dehumidification. After reviewing the change of zone humidity levels from no SAT reset to standard SAT reset, PNNL found that for the prototypes impacted by this addendum the humidity level was within an acceptable range after applying the regular SAT reset and that appropriate energy savings are achieved in the model.

Incremental Cost Impact

Addendum *ap* requires that when both SAT reset and dehumidification are used, that provisions are made to focus the dehumidification on the outside air stream, either with a separate outside air coil for dehumidification or controlled bypass of return air around the cooling coil. Costs were based on the bypass approach. Material and labor costs were obtained from *RS Means* and include the following:

- pair of modulating volume dampers with damper actuators
- bypass ductwork for return air to reduce dehumidification cooling use
- ductwork insulation
- associated controls.

4.2.2.7 Addenda *au*, *cm*, and *co*: DDC VAV Minimum Damper

Addendum *co* reflects the periodic update of Standard 90.1 normative references. It updates many references with new effective dates and adds some new references. One of them (i.e., the Addendum *f* to Standard 62.1-2016, Ventilation for Acceptable Indoor Air Quality), in particular, creates a “Simplified Procedure” to determine system ventilation efficiency. Addenda *au* and *cm* take advantage of the changes in Standard 62.1 to reduce the minimum airflow required in VAV boxes and outdoor air intake of the AHUs; hence, these reduce energy used to condition outdoor air intake and reheat of cooled primary air.

Addenda *au* and *cm* refer to this new minimum primary airflow rate to replace the provision in Standard 90.1 that allows VAV box minimum setpoints to be 20% of the design supply air rate. Outdoor air rates for zones with moderate occupancy density, such as offices, are generally much lower than 20% of the design supply air rate, but designers often need a higher percentage or an oversized VAV box when they follow the system ventilation efficiency specified in Standard 62.1 and its Normative Appendix A Multiple-zone System Ventilation Efficiency. With these addenda, Appendix A in Standard 62.1 becomes an alternative to the Simplified Procedure, by which designers no longer need to calculate what minimum rates are required using the multiple spaces equations in Appendix A. They now can set the minimum primary airflow to be 1.5 times the ventilation zone airflow. The system ventilation efficiency from the Simplified Procedure is generally higher than that calculated using Appendix A, which means the outdoor air intake through the AHU is less. Moreover, using percentages to determine minimums is problematic because VAV boxes are almost always oversized due to conservative load assumptions for occupants, lights, plug loads, etc. It is not unusual for boxes to be sized three or more times larger than they need to be, as was found in ASHRAE RP-1515 "Thermal and air quality acceptability in buildings that reduce energy by reducing minimum airflow from overhead diffusers." (Arens et al. 2015) RP-1515 showed that even if the minimums were set to 20% instead of 30%, excess minimum air would have been supplied due to the oversized cooling maximum box sizing, wasting fan energy, reheat energy, and cooling energy.

In summary, Addenda *au* and *cm* save energy by 1) reducing outdoor air intake at the central system; and 2) reducing the actual airflow minimums in VAV boxes using the cfm-based approach rather than percentage-based minimums previously used in 90.1. When the minimum airflow in VAV boxes is reduced, less air volume needs to be reheated, saving both cooling and heating energy.

Energy Modeling Strategy

Two of the prototypes used in this analysis include multiple-zone VAV systems (i.e., Large Office and Primary School). Section 2.2.6 in the PNNL report *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (Goel et al. 2014) describes the modeling strategy used in the 2016 prototypes to calculate system ventilation efficiency using Appendix A of Standard 62.1-2013. Where the efficiency is lower than 0.6, VAV box minimums of the critical zones are adjusted from 20% to be higher values to reach a target efficiency of 0.6. Then, the design outdoor air intake is determined using this efficiency and can be dynamically reset during the operation using the dynamic efficiency reflecting the zone loads at each time step. For VAV systems serving low occupancy density zones, the VAV box minimums remain at 20%.

In the 2019 prototypes, the VAV box minimum, system ventilation efficiency, and design and operation outdoor air intake are based on different calculations as required by Addenda *au* and *cm* and the referenced Addendum f to Standard 62.1-2016. The VAV box minimum ($V_{pz\text{-}min}$) is changed to

$$V_{pz\text{-}min} = V_{oz} \times 1.5$$

Where,

$V_{pz\text{-}min}$ is minimum primary airflow, and

V_{oz} is ventilation zone airflow.

The Simplified Procedure allows the system ventilation efficiency and the corresponding outdoor air intake flow to be determined in accordance with the following equations

$$E_v = 0.88 * D + 0.22 \text{ for } D<0.60$$

$$E_v = 0.75 \text{ for } D \geqslant 0.60$$

$$V_{ot} = V_{ou} / E_v$$

Where,

E_v is the system ventilation efficiency, and

D is the occupancy diversity ratio,

V_{ot} is the design outdoor air intake flow

V_{ou} is the uncorrected outdoor air intake.

To simplify the calculation, we assumed D always to be greater than 0.6 for all VAV systems in the prototypes. The change in E_v from 0.6 to 0.75 results in a significant reduction in the design outdoor air intake flow. Although both editions require Multiple-Zone VAV System Ventilation Optimization Control, also known as dynamic ventilation reset, in Section 6.5.3.3 of Standard 90.1, the design outdoor air intake flow serves a maximum outdoor air, which leads to energy reduction. The dynamic ventilation reset can be modeled using native EnergyPlus controls, which are able to follow the Normative Appendix A Multiple-zone System Ventilation Efficiency in Standard 62.1-2016 during the operational hours. PNNL consulted with the SSPC 90.1 Mechanical Subcommittee experts and clarified that Appendix A is intended to be used during building operation for 90.1-2019. The reduced design outdoor air intake flow V_{ot} calculated with the Simplified Procedure should be used as the maximum outside airflow for the dynamic ventilation reset, except for economizer mode, and the maximum is implemented in the prototypes through an EnergyPlus energy management system program.

Incremental Cost Impact

This addendum is not expected to increase the cost of construction. The requirement is simply for existing VAV terminal boxes to be set with a different dead band primary air minimum for dual maximum boxes. In some cases, the new simplified minimum may be below the typical VAV box sensor accuracy; however, the addendum allows the maximum deadband airflow to be met on an average basis—in accordance with Standard 62.1, Section 6.2.6.2 Short-Term Conditions—by cycling between a closed damper and a higher minimum that can be sensed by a standard sensor. This means that a higher cost or more accurate sensor is not required, as the average approach allows low minimum airflows to be met with time-limited higher airflows within the sensing range of a standard sensor. However, there is a cost reduction as any required energy recovery units can be downsized due to the lower outdoor airflow.

4.2.2.8 Addendum *be*: CRAC Unit Efficiencies

Addendum *be* clarifies that the computer room air conditioners (CRAC) listed in Table 6.8.1-11 are floor mounted computer room units. Efficiency requirements were modified to align with current industry levels. The addendum also adds a new Table 6.8.1-19 that covers small ceiling mounted computer room units.

Energy Modeling Strategy

Computer rooms and IT closets were added to the Large Office prototype as part of an enhancement in 2014 (Goel et al. 2014). CRAC units were modeled as water source heat pumps (WSHP) to simulate a water cooled air conditioner during its debut into the prototypes and the modeled efficiency was based on Standard 90.1-2010 efficiency requirements. Seasonal coefficient of performance (SCOP) was converted to coefficient of performance (COP). The efficiency inputs were also adjusted to match the WSHP configurations used in EnergyPlus.

The CRAC unit efficiency requirements were introduced in 90.1-2010 and were updated in 2013 and 2016; however, these interim changes were not included in the prior analysis because there was pending federal rulemaking. The analysis of Addendum *be* includes the change to the 90.1-2019 efficiencies. The baseline and improved COP for the CRAC units in the basement computer rooms and IT closets are based on typical equipment sizes used in data centers, even though the EnergyPlus model thermal zoning grouped areas that would be served by multiple CRAC units into a large thermal zone and modeled them as one unit.

This addendum saves energy by reducing the compressor energy needed to transfer heat from the data center area and reject it outside. Because there is less compressor heat to reject, there is also a reduction in the fan use in the dry cooler that provides heat rejection for the water cooled CRAC units.

Table 4.5 shows the efficiency of the units by code year and location in the building.

Table 4.5. Efficiency of CRAC Units by Code Year and Location in Building

Location	Cooling Capacity	90.1-2016			90.1-2019		
		CRAC SCOP	WSHP EER	Eplus COP	CRAC SCOP	WSHP EER	Eplus COP
Datacenter Basement	20 tons	2.50	10.29	3.562	2.73	11.24	3.878
Datacenter All Other Floors	3.5 tons	2.60	10.71	3.702	2.82	11.62	4.005

Incremental Cost Impact

Material costs for different efficiency levels were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.9 Addendum *bo*: Table 6.8.1.5 Furnace Efficiency

Addendum *bo* increases efficiency requirements for commercial gas-fired and oil-fired furnaces. The addendum also increases efficiency requirements for residential (consumer) gas and oil furnaces to match DOE levels and adds a new Table F-4 in “Informative Appendix F for Residential Warm Air Furnace” requirements for products sold in the United States.

The following changes are included in this addendum:

1. The efficiency of >225,000 Btu/h gas-fired furnaces was increased from 80% thermal efficiency to 81% and for oil fired from 81% to 82%. The effective date for these changes is 1/1/2023.
2. The efficiency of <225,000 Btu/h gas-fired furnaces was increased from 78% AFUE to 80% AFUE for non-weatherized units and to 81% for weatherized units.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=31

3. The efficiency of <225,000 Btu/h oil-fired furnaces was increased from 78% AFUE to 83% AFUE for non-weatherized units and is unchanged for weatherized units.
4. Efficiency requirements were added for <225,000 Btu/h electric furnaces.
5. Requirements were added for <225,000 Btu/h standby power mode consumption and off mode power consumption.
6. To be consistent with other changes, the <225,000 Btu/hr single phase furnace requirements for U.S. applications will be moved to a new table F-4 in appendix F.

This addendum saves energy by increasing the useful heat delivered by oil and gas furnaces per unit of fuel input, thus reducing the fuel used to meet the same heating load.

Energy Modeling Strategy

Since the commercial product changes are not effective until more than three years after the publication of Standard 90.1-2019, only the residential sized furnace efficiency improvements will be accounted for in the analysis. This is a simple change of efficiency for small gas furnaces smaller than 225 kBtu/hr. This addendum increases AFUE from 78% to 81%.

Incremental Cost Impact

Material costs at different efficiency levels were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.10 Addendum *bq*: Table 6.8.1.7 Heat Rejection Efficiency

Addendum *bq* raises the minimum efficiencies for axial and centrifugal fan evaporative condensers due to a change in the rating fluid to R-448A from R-507A, with R-448A having a lower Global Warming Potential (GWP). The addendum also adds axial fan, air cooled fluid coolers (better known as dry coolers) to Table 6.8.1.7. The addendum saves energy for buildings with heat rejection equipment.

Energy Modeling Strategy

The minimum efficiency requirement for dry coolers introduced by this addendum impacts the Large Office prototype. The dry cooler in the Large Office prototype is modeled using the FluidCooler:TwoSpeed object. Since the dry cooler efficiency is not a direct EnergyPlus input, modeled efficiency must be calculated as:

Dry Cooler efficiency = pump (gpm) / fan (bhp), where

fan(bhp) = fan (hp at high speed) * 0.9.

The pump flow rate is dependent on the loads it serves, and the dry cooler serves the computer rooms and IT closets, in which the loads remain relatively constant across different climate zones. Per

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=59

recommendations from SSPC 90.1 Mechanical Subcommittee experts, the baseline efficiency is assumed to be 4.0 gpm/hp and that for the advanced model is 4.5 gpm/hp based on Addendum *be*.

Incremental Cost Impact

Material costs for the baseline case were obtained from *RS Means*. Incremental material costs were obtained from a major manufacturer of dry coolers, which estimated the baseline material cost is 4% less than the new requirement. Labor costs were obtained from *RS Means*.

4.2.2.11 Addendum *br*: Commercial Refrigeration

Addendum *br* implements new federal refrigeration minimum efficiency requirements that went into effect on March 27, 2017. This addendum updates the requirements for commercial refrigerators and freezers and commercial refrigeration and combines them into a single table. The addendum saves energy by reducing the energy allowed for refrigerators by 39% and freezers by 45%.

Energy Modeling Strategy

This addendum covers both commercial reach-in refrigerators and freezers with solid doors. These are modeled in the primary school prototype building, which includes a commercial kitchen. The equipment power associated with the energy use limits before and after the addendum is calculated. These calculated values, as shown in Table 4.6, are then implemented in the models.

Table 4.6. Calculated Power for Commercial Refrigeration

Standard	Equipment	Power (watts)
90.1-2016	Freezer	915.0
90.1-2019	Freezer	555.0
90.1-2016	Refrigerator	570.0
90.1-2019	Refrigerator	313.3

Incremental Cost Impact

Material costs were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.12 Addendum *cn*: Walk-In Coolers and Walk-In Freezers

This addendum mirrors increases in federal walk-in cooler and freezer efficiency manufacturing requirements. The addendum saves energy by increasing the efficiency required for walk-in coolers by 132% and walk-in freezers by 55%.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=28

Energy Modeling Strategy

The primary school prototype is impacted as it includes a commercial kitchen. The walk-in cooler and walk-in freezer are not connected to remote compressors and condensers. Therefore, any heat rejected from the walk-in refrigeration was rejected to the surrounding zone and not rejected outdoors. PNNL modeled the refrigeration system efficiency using an improved compressor COP for the walk-in cooler and walk-in freezer objects as shown in Table 4.7.

Table 4.7. Addendum cn Compressor Coefficients of Performance

Walk-in Freezer		Walk-in Cooler	
90.1-2016 COP	90.1-2019 COP	90.1-2016 COP	90.1-2019 COP
1.5	2.32	3.0	6.98

Incremental Cost Impact

Material costs were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.3 Lighting

Standard 90.1-2019 incorporates three addenda that reduce lighting energy usage. Two reduce interior lighting power and the third impacts daylighting controls.

4.2.3.1 Addenda *bb* and *cg*: LPD Values Space-by-Space and LPD Building Area Method

Addenda *bb* and *cg* modify the LPD allowance for space-by-space and building area methods, respectively. The changes in LPD are the result of improving lighting technology, changes in lighting baseline (model is 100% LED), changes to Illuminating Engineering Society (IES) recommended light levels, changes to space geometry assumptions, and additional room surface reflectance values. The addenda save energy in multiple ways. There is direct lighting power reduction. In addition, the reduced lighting power reduces the internal gains which reduces cooling loads and saves cooling energy. In some climate zones, the reduction in lighting power results in an increased need for heating during colder outside conditions, so there may be an increase in heating energy use. These three impacts are combined for a net savings of building energy.

Energy Modeling Strategy

These addenda affect all prototypes. The following describes how the appropriate LPD allowance is chosen for the prototype buildings:

1. The Large Office and Small Office prototypes use the office building LPD allowance from the building area method.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=56

2. Most zones in the other prototypes are mapped to a single space-by-space category and the LPD allowance from that category is used directly.
3. A few zones in the other prototypes (for example, the Back Space zone in the Standalone Retail prototype) are considered a mix of two or more space types; in such cases, the NC^3 database (Richman et al. 2008) is used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single LPD allowance for those spaces.

Using these rules and the values in Addenda *bb* and *cg*, the LPD allowances for all prototypes and zones were determined. The design LPD allowance is modeled in EnergyPlus as a direct input to the zone general lighting object.

Incremental Cost Impact

Material and labor costs were estimated for each fixture type and lamp type. These costs were applied to the lighting design assumptions to calculate a cost per square foot for each space type or building area type.

In the few cases where the SSPC 90.1 Lighting Subcommittee incorporated a significant shift in lighting design philosophy from 2016 to 2019, which resulted in a change to lighting technology unrelated to a change in LPD, one of the designs was selected and adjustments were made in the quantity of fixtures installed while maintaining similar fixture types.

Fixture costs were determined using Grainger and Goodmart online catalogs (Grainger 2018; Goodmart 2018). *RS Means 2020* was used for labor costs and for a few lighting equipment items not available in the other sources (RS Means 2020b). Besides cost, light source life and complete connected luminaire wattage per fixture were recorded. Fixture cost per watt ($/W) was calculated by dividing the total cost by the fixture wattage.

The total cost per space type, $\$/ft^2$, was determined by combining the costs per fixture per square foot in proportion to the percentage of total illumination provided by each fixture described above. The cost per space type was multiplied by the area of each space type represented in each prototype to determine the total interior lighting power cost for each prototype. Virtually all spaces in 2016 and 2019 assume LED fixtures.

Replacement cost for LED fixtures was assumed to be 75% of the first cost of the LED fixture and replaced at the end of the operational life of the light fixture.

4.2.3.2 Addendum *cw*: Continuous Daylighting Control

Addendum *cw* changes daylight responsive requirements from either continuous dimming or stepped control to continuous dimming required for all spaces. It also adds a definition of continuous dimming. This measure saves energy because a stepped control cannot switch to the next lower power level until enough daylight is available to maintain the desired light level. This results in a period between steps where more than the required light level is maintained, resulting in a higher average power level that would be achieved with continuous dimming that adjusts the power smoothly to maintain just the needed lighting level. There is also a modest impact on HVAC energy use similar to the LPD reduction addenda.

Energy Modeling Strategy

This addendum affects all prototypes with daylighting control, which includes all the prototypes in this analysis. The EnergyPlus object Daylighting:Controls was changed from "Stepped" to "Continuous" to implement this change. Several of the prototype models that include stepped daylighting control for either top lighting or side lighting are impacted. These include Small and Large Offices, Stand-alone Retail, and School. The control type in the EnergyPlus model was changed from three steps (i.e., power fraction of 0.66, 0.33, and 0) to ContinuousOff (proportionally reduces the lighting power as the daylight increases until a minimum power fraction of 0.2). The lights will be completely off when sufficient daylight is available.

Incremental Cost Impact

The daylighting requirement already existed, so there is no cost increase for the daylight sensor and continuous dimming capability is standard for LED fixtures. Therefore, there is no increase in cost for this addendum.

4.2.4 Other Equipment

4.2.4.1 Addendum *an*: Pump Efficiency

Addendum *an* implements new federal standards for commercial and industrial clean water pumps which went into effect on January 27, 2020. This addendum adds a new table with the new efficiency requirements for these pumps. It defines "Clean-Water Pump" as a pump that is designed for use in pumping water with a maximum nonabsorbent free solid content of 0.016 lb/ft^3 and with a maximum dissolved solid content of 3.1 lb/ft^3, provided that the total gas content of the water does not exceed the saturation volume, and disregarding any additives necessary to prevent the water from freezing at a minimum of 14°F.

This addendum saves energy by reducing the pumping power required to move water in hydronic systems, either through pump or motor efficiency improvements. In addition, for chilled water systems, there is less heat transferred to the chilled water from the pumping process, so there is a small reduction in chiller energy use. For heating water systems, the increase in pump efficiency shifts some heating energy use from pump electricity to whatever the heating source is.

Energy Modeling Strategy

The federal appliance standards rulemaking reports show about 4.3% of average efficiency improvement, and after considering 25% of the market, about 1.1% of the final average efficiency improvement is estimated. For the Addendum *an* update, PNNL assumed that 1% of efficiency improvement can be applied to the HVAC pump variable (motor efficiency) in the current baseline prototypes based on this information.

The affected pumps in the large office prototype are the heating hot water pump, chilled water primary and secondary pumps, and cooling tower pump. The affected pump in the primary school prototype is the heating hot water pump.

Incremental Cost Impact

Material costs were obtained for different efficiency levels from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.3 Cost Estimate Results

The cost estimates result in incremental costs for new construction and replacement material, labor, any construction equipment, overhead and profit, as well as maintenance and commissioning. Appendix A includes incremental cost summaries for first cost, maintenance cost, replacement costs for years 1 to 29, and residual value of items with useful lives extending beyond the 30-year analysis period. Residual values are discussed in Section 5.1.1, and are used in the Life-Cycle Cost Analysis in Section 5.1.1.

The associated cost estimate spreadsheet (PNNL 2020) includes a worksheet with details of the summaries in Appendix A and a similar worksheet extending the analysis period to 40 years. The cost in a given year in these tables is a negative value if there was a replacement cost for 90.1-2016 that was greater than the replacement cost for 90.1-2019. The useful lives of corresponding items such as lamps and ballasts may not be the same for the 90.1-2016 and 90.1-2019 cases; therefore, replacement cost values can be positive or negative throughout the 30-year analysis period.

Table 4.8 includes total incremental first costs for each prototype and climate combination in units of total cost and cost per ft^2. Table 4.9 includes estimated total building costs per ft^2 from *RS Means 2020* for each prototype, and a rough indicator of the percentage increase due to the incremental costs (based on the RS Means costs being representative of buildings that meet 90.1-2016). As described in Section 4.1, these costs were not adjusted for climate location. In most cases moving from 90.1-2016 to 90.1-2019 resulted in an incremental reduction in first cost, shown as a negative value. This is due to reductions in HVAC equipment capacity, as well as for reductions in lighting costs in some cases.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=41

Table 4.8. Incremental Initial Construction Costs

Prototype	Value	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	First Cost	-$9,897	-$10,155	-$10,262	-$9,881	-$9,919
	$/ft^2	-$1.80	-$1.85	-$1.87	-$1.80	-$1.80
Large Office	First Cost	-$1,026,974	-$1,012,495	-$964,619	-$1,076,405	-$1,034,993
	$/ft^2	-$2.06	-$2.03	-$1.93	-$2.16	-$2.08
Standalone Retail	First Cost	-$33,265	-$33,727	-$34,252	-$34,054	-$34,679
	$/ft^2	-$1.35	-$1.37	-$1.39	-$1.38	-$1.40
Primary School	First Cost	-$160,141	-$144,443	-$157,341	-$153,557	-$155,314
	$/ft^2	-$2.17	-$1.95	-$2.13	-$2.08	-$2.10
Small Hotel	First Cost	$29,862	$29,271	$29,394	$29,143	$28,680
	$/ft^2	$0.69	$0.68	$0.68	$0.67	$0.66
Mid-rise Apartment	First Cost	-$11,992	-$12,389	-$13,661	-$9,966	-$9,674
	$/ft2	-$0.36	-$0.37	-$0.40	-$0.30	-$0.29

Table 4.9. Comparison of Total Building Cost and Incremental Cost (per ft^2 and percentage)

Prototype	Building First Cost ($/ft^2)	Incremental Cost for 90.1-2019				
		2A Tampa $/ft^2)	3A Atlanta ($/ft^2)	3B El Paso ($/ft^2)	4A New York ($/ft^2)	5A Buffalo ($/ft^2)
Small Office	$220	-$1.80 -0.82%	-$1.85 -0.84%	-$1.87 -0.85%	-$1.80 -0.82%	-$1.80 -0.82%
Large Office	$180	-$2.06 -1.14%	-$2.03 -1.13%	-$1.93 -1.07%	-$2.16 -1.20%	-$2.08 -1.15%
Standalone Retail	$116	-$1.35 -1.16%	-$1.37 -1.18%	-$1.39 -1.20%	-$1.38 -1.19%	-$1.40 -1.21%
Primary School	$225	-$2.17 -0.96%	-$1.95 -0.87%	-$2.13 -0.95%	-$2.08 -0.92%	-$2.10 -0.93%
Small Hotel	$197	$0.69 0.35%	$0.68 0.34%	$0.68 0.35%	$0.67 0.34%	$0.66 0.34%
Mid-rise Apartment	$218	-$0.36 -0.16%	-$0.37 -0.17%	-$0.40 -0.19%	-$0.30 -0.14%	-$0.29 -0.13%

5.0 Cost-Effectiveness Analysis

The purpose of this analysis is to determine the overall cost-effectiveness of Standard 90.1-2019 compared to the 90.1-2016 edition. Cost-effectiveness was analyzed using the incremental cost information presented in Section 4.0 and the energy cost information presented in this Section. Three economic metrics are presented:

- Net present value life-cycle cost savings
- The SSPC 90.1 scalar ratio
- Simple payback

Annual energy costs, a necessary part of the cost-effectiveness analysis, are presented in Section 5.2, with additional detail provided in Appendix B.

5.1 Cost-Effectiveness Analysis Methodology

The methodology for cost-effectiveness assessments has been established for analysis of prior editions of Standard 90.1 (Hart and Liu 2015). This report presents a cost-effectiveness assessment using an LCCA and the SSPC 90.1 Scalar Method for the combined changes in Standard 90.1-2016 to 2019 for each of the 30 combinations of prototype and climate evaluated[1]. The commonly used metric of simple payback period is also included for informational purposes.

5.1.1 Life-Cycle Cost Analysis

The LCCA perspective compared the present value of incremental costs, replacement costs, maintenance, and energy savings for each prototype building and climate location. The degree of borrowing and the impact of taxes vary considerably for different building projects, creating many possible cost scenarios. The LCCA analysis was based on a fixed scenario representative of public sector funding. Thus, these varying costs were not included in the LCCA. Private sector discounting and funding costs were included indirectly with the 90.1 Scalar Method as described in Section 5.1.3.

The LCCA approach is based on the LCCA method used by the Federal Energy Management Program (FEMP), a method required for federal projects and used by other organizations in both the public and private sectors (NIST 1995). The LCCA method consists of identifying costs (and revenues, if any) and the year in which they occur and determining their value in present dollars (known as the net present value). This method uses fundamental engineering economics relationships about the time value of money. For example, the value of money in hand today is normally worth more than money tomorrow, which is why we pay interest on a loan and earn interest on savings. Future costs were discounted to the present based on a discount rate. The discount rate may reflect what interest rate can be earned on other conventional investments with similar risk, or in some cases, the interest rate at which money can be borrowed for projects with the same level of risk.

[1] LCCA is the primary perspective by which DOE determines cost effectiveness for building energy codes

The following calculation method can be used to account for the present value of costs or revenues:

Present Value = Future Value / $(1+ i)^n$

"i" is the discount rate (or interest rate in some analyses)

"n" is the number of years in the future the cost occurs.

The present value of any cost that occurs at the beginning of year one of an analysis period is equal to that initial cost. For this analysis, initial construction costs occur at the beginning of year one, and all subsequent costs occur at the end of the future year identified.

In the LCCA, the present value of the incremental costs for new construction, replacement, maintenance, and energy of the 2019 edition of Standard 90.1 is analyzed and compared to similar results for the 2016 edition. If the present value cost of the 2019 edition is less than the present value cost of the 2016 edition, there is positive net present value savings and Standard 90.1-2019 is cost-effective.

The LCCA depends on the number of years into the future that costs and revenues are considered, known as the study period. The FEMP method uses 25 years; this analysis used 30 years. This is the same study period used for the cost-effectiveness analysis of the residential energy code, conducted by DOE and PNNL (DOE 2015) and is the same period used in the previous cost-effectiveness comparisons, for example between 90.1-2013 and 90.1-2016 (Hart et al. 2020). The 30-year study period is also widely used for LCCA in government and industry. The study period is also a balance between capturing the impact of future replacement costs, inflation, and energy escalation with understanding the increasing uncertainty of these costs as they are projected into the future.

Several factors go into choosing the length of the study period and the residual value of equipment beyond the period of analysis. Sometimes the useful life of equipment or materials extends beyond the study period. In this case, the longest useful life defined is 40 years for all envelope cost items, such as wall assemblies, as recommended by the 90.1 SSPC ESC. Forty years is longer than the typical 25- or 30-year study period for LCCA. A residual value of the unused life of a cost item is calculated at the last year of the study period for components with longer lives than the study period, or for items whose replacement life does not fit neatly into the study period, (e.g., a chiller with a 23-year useful life). The residual value is not a salvage value, but rather a measure of the available additional years of service not yet used. The FEMP LCCA method includes a simplified approach for determining the residual value. The residual value is the proportion of the initial cost equal to the remaining years of service divided by the initial cost. For example, the residual value of a wall assembly in year 30 is (40-30)/40 or 25% of the initial cost. The present value of the residual values applied in year 30 is included in the total present value.

The LCCA requires an estimate about the value of money today relative to the value of money in the future. Also required is an estimate of how values of the cost items will change over time, such as the cost of energy and HVAC equipment. These values are determined by the analyst depending on the purpose of the analysis. In the case of the FEMP LCCA method, the National Institute of Standards and Technology (NIST) periodically publishes an update of economic factors. The values published by NIST in March 2019 (Lavappa and Kneifel 2019) were used in this analysis.

The DOE nominal discount rate is based on long-term Treasury bond rates averaged over the 12 months prior to publication of the NIST report. The nominal rate is converted to a real rate to correspond with the constant-dollar analysis approach for this analysis. The method for calculating the real discount rate from the nominal discount rate uses the projected rate of general inflation published in the most recent *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the

NIST 2019 annual supplement without citation; Lavappa and Kneifel 2019). The mandated procedure would result in a discount rate for 2019 lower than the 3.0% floor prescribed in federal regulations (10 CFR 431.306). Thus, the 3.0% floor is used as the real discount rate for FEMP analyses in 2019. The implied long-term average rate of inflation was calculated as 0.1% (Lavappa and Kneifel 2019). Table 5.1 summarizes the analysis assumptions used.

Table 5.1. Life-Cycle Cost Analysis Parameters

Economic Parameter	Commercial State Cost-Effectiveness Scenario 1 without Loans or Taxes	
	Value	Source
Nominal Discount Rate[(a) (d)]	3.1%	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2019*, NIST annual update (Lavappa and Kneifel 2019).
Real Discount Rate[(b) (d)]	3.0%	
Inflation Rate[(c) (d)]	0.1%	
Electricity and Gas Price	\$0.1063/kWh, \$0.98/therm	SSPC-90.1 for 90.1-2019 scalar
Energy Price Escalation	Uniform present value factors Electricity 19.17 Natural gas 23.45	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2019*, NIST annual update (Lavappa and Kneifel 2019). The NIST uniform present value factors are multiplied by the first year annual energy cost to determine the present value of 30 years of energy costs and are based on a series of different annual real escalation rates for 30 years.

(a) Nominal discount rate is like a quoted interest rate and takes into account expectations about the impact of inflation on future values. Higher nominal rates imply higher expectations of inflation.
(b) Real discount rate excludes inflation so that future amounts can be defined in today's dollars in the calculations. This is not a quoted interest rate. If inflation is zero, real and nominal discount rates are the same. Inflation is captured in the process of using constant dollar costs and the modified discount rate.
(c) General inflation is the background level of price increases for all costs other than energy. This is indirectly applied to replacement and maintenance costs through the real discount rate.
(d) Note that only the real discount rate is needed for the Scenario 1 LCCA calculation. The implied nominal discount rate and inflation rate are shown for comparison to other methods.

5.1.2 Simple Payback

Simple payback, or simple payback period, is a more basic and common metric often used to assess the reasonableness of an energy efficiency investment. It is based on the number of years required for the sum of the annual return on an investment to equal the original investment. In this case, simple payback is the total incremental first cost (described in Section 4.0) divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. This method does not take into account any costs or savings after the year in which payback is reached, does not consider the time value of money, and does not take into account any replacement costs, even those that occur prior to the year simple payback is reached. The method also does not have a defined threshold for determining whether an alternative's payback is cost-effective. Decision makers generally set their own threshold for a maximum allowable payback. The simple payback perspective is reported for informational purposes only, not as a basis for concluding that 90.1-2019 is cost-effective.

5.1.3 SSPC 90.1 Scalar Method

The SSPC 90.1 does not consider cost-effectiveness when evaluating the entire set of changes for an update to the whole Standard 90.1. Instead, cost-effectiveness is considered when evaluating a specific addendum to Standard 90.1. The Scalar Method was developed by SSPC 90.1 to evaluate the cost-effectiveness of proposed changes (McBride 1995). The Scalar Method is an alternative life-cycle cost approach for individual energy efficiency changes with a defined useful life, taking into account first costs, annual energy cost savings, annual maintenance, inflation, energy escalation, and financing impacts. So, the scalar method addresses the major drawback of the simple payback method: identifying a target or threshold that indicates cost-effectiveness. The Scalar Method allows a discounted payback threshold (scalar ratio limit) to be calculated based on the measure life. For example, the scalar threshold for an electricity saving measure with a 40-year life is 22.1 years. As this method is designed to be used with a single measure with one value for useful life, it does not account for replacement costs. A measure is considered cost-effective if the simple payback (scalar ratio) is less than the scalar threshold or limit. For example, a measure that saves cooling or electricity and has a 40-year life is considered cost-effective if the simple payback is less than 22.1 years.

Table 5.2 shows the economic parameters used for the 90.1-2019 analysis for this study. These parameters were adopted by the SSPC 90.1 in an ANSI consensus process. The parameters are constant for all measure lives. Given a certain measure life—40 years is used in the table example (typical for building envelope measures, and the life used in this analysis with replacement costs included)—a scalar limit can be determined. Due to differences in energy price escalation, different scalar ratio limits are provided by measure life for heating or natural gas and cooling or electricity. When there is a mix of savings, the two scalar limits are weighted by savings to arrive at a project scalar limit.

Table 5.2. Scalar Ratio Method Economic Parameters and Scalar Ratio Limit

Input Economic Variables – Linked	Heating (Natural Gas)	Cooling (Electricity)
Constant Parameters:		
Down Payment - $	0.00	0.00
Energy Escalation Rate - %[(a)]	2.73[(a)]	2.07[(a)]
Nominal Discount Rate - %[(b)]	8.5	8.5
Loan Interest Rate - %	5.0	5.0
Heating – Natural Gas Price, $/therm	$0.98	
Cooling - Electricity Price $/kWh		$0.1063
Measure Life Example:		
Economic Life - Years	40	40
Scalar Ratio Limit (Weighted: 22.08)	**25.2**	**22.1**

(a) The energy escalation rate used in the scalar calculation for 90.1-2019 includes inflation, so it is a nominal rather than a real escalation rate. For the first 30 years, it is based on NIST reported parameters sourced from EIA nominal price projections and is assumed to be the general rate of inflation beyond 30 years.

PNNL extended the Scalar Method to allow for the evaluation of multiple measures with different useful lives. This extension is necessary to evaluate a complete code edition, since the 90.1 Scalar Method was developed to only evaluate single measures with individual lives. This extended method takes into account the replacement of different components in the total package of 90.1-2019 changes, allowing the net present value of the replacement costs to be calculated over 40 years. The SSPC 90.1 ESC uses a 40-year replacement life for envelope components, and most other cost component useful lives in the cost estimate are less than that. For example, an item with a 20-year life would be replaced once during the study period. The residual value of any items with useful lives that do not fit evenly within the 40-year period is calculated using the method described in Section 5.1.1. Using this approach, an adjusted payback is compared to the scalar limit rather than using a simple payback. The adjusted payback is calculated as the sum of the first costs and present value (PV) of the replacement costs less the PV of residual costs, divided by the difference of the energy cost savings and incremental maintenance cost, as shown in this formula:

$$Adjusted\ Payback = \frac{[Initial\ Incremental\ Construction\ Cost] + [PV\ of\ Replacement\ Costs] - [PV\ Residual\ Costs]}{[Annual\ Energy\ Cost\ Savings] - [Increased\ Annual\ Maintenance\ Costs]}$$

The result is compared to the weighted scalar ratio limit for the 40-year period, 22.08, as shown in Table 5.2. This limit or threshold is determined as follows:

- Due to differing escalation rates for different energy types, the scalar threshold is determined separately for heating (primarily gas) and cooling (primarily electricity).
- To develop one scalar threshold that can be used across building types, the gas and electric savings per floor area from each building type and climate zone are weighted by expected construction share.
- Then the distinct gas and electric scalar ratio thresholds are weighted by that savings share.
- Since the total national savings in this cycle are primarily electric, the weighted scalar threshold is quite close to the lower threshold for electricity.
- The packages of changes for each combination of prototype and climate location were considered cost-effective under the scalar ratio method if the corresponding scalar ratio was less than the scalar ratio limit.

When the adjusted payback is less than the scalar ratio limit, the measure or group of measures is determined to be cost-effective. Therefore, the 90.1 scalar ratio method accounts for the discounted value of future energy savings, by assigning a 40-year measure life a threshold of 22.08 years that it has to meet. If the future savings were not discounted, a 40-year simple payback would be allowed for a 40-year measure life. Reducing that threshold to 22.08 years accounts for the fact that energy savings received in the future are less valuable than savings received immediately today.

5.2 Energy Cost Savings

Annual energy costs are a necessary part of the cost-effectiveness analysis. Annual energy costs were lower for all of the selected 90.1-2019 models compared to the corresponding 90.1-2016 models. The energy costs for each edition of Standard 90.1 were based primarily on DOE's determination of energy savings of 90.1-2019. Detailed methodology and overall energy savings results from Standard 90.1-2019 are documented in the DOE technical report titled *Preliminary Energy Savings Analysis ANSI/ASHRAE/IES Standard 90.1-2019* (DOE 2020b).

The current savings analysis builds on the 90.1-2019 determination analysis by including savings from equipment efficiency upgrades that are specifically excluded[1] from the determination analysis. Table 5.3 shows the resulting annual energy cost savings (total and cost/ft^2). Appendix B includes the energy simulation results and additional details of these energy cost savings.

Energy rates used to calculate the energy costs from the modeled energy usage were $0.98/therm for fossil fuel[2] and $0.1063/kWh for electricity. These rates were used for the 90.1-2019 energy analysis and derived from the U.S. DOE Energy Information Administration (EIA) data. These were the values approved by the SSPC 90.1 for cost-effectiveness for the evaluation of individual addenda during the development of 90.1-2019.

Table 5.3. Annual Energy Cost Savings, 90.1-2019 Compared to 90.1-2016

		Climate Zone and Location				
Prototype		2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	Total	$278	$259	$271	$237	$235
	$/ft²	$0.05	$0.05	$0.05	$0.04	$0.04
Large Office	Total	$36,020	$36,525	$29,947	$29,898	$31,038
	$/ft²	$0.07	$0.07	$0.06	$0.06	$0.06
Standalone Retail	Total	$2,674	$2,309	$2,395	$2,035	$1,927
	$/ft²	$0.11	$0.09	$0.10	$0.08	$0.08
Primary School	Total	$6,320	$6,085	$6,945	$5,411	$5,439
	$/ft²	$0.09	$0.08	$0.09	$0.07	$0.07
Small Hotel	Total	$4,002	$3,754	$3,833	$3,364	$3,203
	$/ft²	$0.09	$0.09	$0.09	$0.08	$0.07
Mid-rise Apartment	Total	$1,747	$1,581	$732	$542	$522
	$/ft²	$0.05	$0.05	$0.02	$0.02	$0.02

5.3 Cost-Effectiveness Analysis Results

Table 5.4 shows the results of the analysis from all three methods: LCCA, simple payback, and scalar ratio. This analysis demonstrates that 90.1-2019 is cost-effective relative to 90.1-2016 for all the analyzed prototypes in each climate location for all three methods. Although multiple metrics are employed in the analysis, LCCA is the primary metric by which DOE determines the cost-effectiveness of building energy codes, as discussed in the DOE cost-effectiveness methodology (Hart and Liu 2015). In addition, DOE often provides analysis based on additional metrics for informational purposes and to support the variety of perspectives employed by adopting states and other interested entities. For the two life-cycle cost and simple payback metrics shown in Table 5.4, cost-effectiveness is determined as follows:

[1] The determination only includes savings originating uniquely in the ASHRAE 90.1 Standard and excludes savings from federally mandated appliance efficiency improvements. These savings are included here, as this analysis considers the cost-effectiveness of Standard 90.1 in its entirety.

[2] The fossil fuel rate is a blended heating rate and includes proportional (relative to national heating fuel use) costs for natural gas, propane, heating oil, and electric heat. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas equipment, but in practice, natural gas equipment may be operated using propane or boilers that are modeled because natural gas may use oil in some regions.

- The life-cycle cost net savings is greater than zero. The life-cycle cost net savings is the present value of energy savings for a building built under 90.1-2019 compared to 90.1-2016, less the incremental cost difference, less the present value of the replacement and residual cost difference. The national net savings, weighted across climate zones and building types, is $4.12 per square foot. A positive number indicates cost-effectiveness. Note that the life-cycle net savings is positive for all analyzed building types in all climate zones.
- The simple payback period (years) is the first cost divided by first year energy savings. It does not include discounted future energy savings or replacement costs. The national simple payback, weighted across climate zones and building types, is immediate. This indicates cost-effectiveness.
- The scalar ratio is less than the scalar limit for the analysis. The scalar ratio is calculated using the 90.1 methodology and is similar to a discounted payback. The national scalar ratio, weighted across climate zones and building types, is negative, indicating cost-effectiveness.
- The national weighted values use weighting factors discussed in Section 2.4.

Table 5.4. Cost-Effectiveness Analysis Results

Prototype Model	Climate Zone and Location					
Life-Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$4.20	$4.16	$4.23	$4.00	$3.98	$4.11
Large Office	$4.40	$4.39	$3.92	$4.29	$4.22	$4.29
Standalone Retail	$4.83	$4.56	$4.70	$4.34	$4.28	$4.50
Primary School	$5.43	$5.06	$5.45	$5.04	$5.10	$5.19
Small Hotel	$14.14	$14.04	$14.07	$13.86	$13.81	$13.97
Mid-rise Apartment	$2.65	$2.66	$2.19	$1.83	$1.80	$2.18
Weighted Total	$4.50	$4.44	$4.03	$3.79	$3.91	$4.12
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Large Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Standalone Retail	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	7.5	7.8	7.7	8.7	9.0	8.1
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Scalar Ratio, Limit = 22.08[a]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	(58)	(63)	(61)	(67)	(68)	(64)
Large Office	(40)	(39)	(44)	(50)	(46)	(45)
Standalone Retail	(17)	(27)	(34)	(31)	(33)	(28)
Primary School	(41)	(38)	(36)	(45)	(45)	(42)
Small Hotel	(97)	(103)	(101)	(115)	(121)	(108)
Mid-rise Apartment	(41)	(47)	(215)	(776)	(1,137)	(507)
Weighted Total	(39)	(43)	(110)	(328)	(403)	(203)

(a) Scalar ratio limit for an analysis period of 40 years.
Note: A negative scalar ratio indicates that the cost is negative. This occurs, for example, when there are net decreases in costs either from reductions in HVAC capacity or reductions in installed lighting due to lower LPDs, or reduction in replacement costs such as that which occurs with a switch to LED lighting.

6.0 References

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Appendix A

Incremental Cost Estimate Summary

This appendix includes summary cost data used in the cost-effectiveness analysis. Cost tables for each building prototype show cost data grouped by HVAC, Lighting, Envelope and Power, and Total. Cost data includes the incremental cost of implementing 90.1-2019 compared to 90.1-2016. Incremental costs include New Construction or initial cost, annual maintenance cost, replacement costs for years 1 through 29, and residual costs in year 30.

A.1 Small Office Cost Summary

Small Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$412	-$322	-$429	$22	-$16	-$10,042	-$10,042	-$10,042	-$10,042	-$10,042
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
15	-$722	-$607	-$734	-$407	-$242	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$1,907	-$1,792	-$1,919	-$1,296	-$1,428	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$1,031	$992	$1,035	$728	$871	$1,394	$1,394	$1,394	$1,394	$1,394

Small Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$557	$209	$209	$139	$139	-$9,897.3	-$10,155	-$10,262	-$9,881	-$9,919
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
15	$0	$0	$0	$0	$0	-$722	-$607	-$734	-$407	-$242
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$1,907	-$1,792	-$1,919	-$1,296	-$1,428
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$2,425	$2,386	$2,429	$2,122	$2,265

A.2 Large Office Cost Summary

Large Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$159,886	-$118,371	-$70,495	-$176,848	-$135,437	-$910,359	-$910,359	-$910,359	-$910,359	-$910,359
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$111,828	-$112,316	-$30,465	-$103,170	-$103,449	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$82,035	$91,420	$62,416	$20,172	$55,597	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	-$35,522	-$10,666	-$3,941	-$12,114	-$5,025	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$266,879	-$252,629	-$242,490	-$261,838	-$244,112	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	-$7,955	-$10,638	-$9,442	-$12,183	-$14,457	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$156,729	$142,881	$160,626	$153,772	$141,961	$713,604	$713,604	$713,604	$713,604	$713,604

Large Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$43,271	$16,234	$16,234	$10,802	$10,802	-$1,026,974	-$1,012,495	-$964,619	-$1,076,405	-$1,034,993
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$111,828	-$112,316	-$30,465	-$103,170	-$103,449
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$82,035	$91,420	$62,416	$20,172	$55,597
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	-$35,522	-$10,666	-$3,941	-$12,114	-$5,025
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$266,879	-$252,629	-$242,490	-$261,838	-$244,112
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	-$7,955	-$10,638	-$9,442	-$12,183	-$14,457
36	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$870,333	$856,485	$874,230	$867,376	$855,565

A.3 Standalone Retail Cost Summary

Standalone Retail	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$4,794	-$4,663	-$5,188	-$4,045	-$4,670	-$30,207	-$30,207	-$30,207	-$30,207	-$30,207
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$17	-$17	-$17	-$17	-$17
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
15	-$2,064	-$1,670	-$2,063	-$1,567	-$1,679	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$832	$832	$832	$832	$832	-$17	-$17	-$17	-$17	-$17
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$7,041	-$6,892	-$7,529	-$6,136	-$6,982	-$17	-$17	-$17	-$17	-$17
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$202,518	$0	-$205,038	$3,568	$4,095	$6,578	$6,578	$6,578	$6,578	$6,578

Standalone Retail	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,736	$1,143	$1,143	$198	$198	-$33,265	-$33,727	-$34,252	-$34,054	-$34,679
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$17	-$17	-$17	-$17	-$17
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
15	$0	$0	$0	$0	$0	-$2,064	-$1,670	-$2,063	-$1,567	-$1,679
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$814	$814	$814	$814	$814
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$7,058	-$6,909	-$7,547	-$6,153	-$7,000
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$209,096	$6,578	-$198,459	$10,146	$10,673

A.4 Primary School Cost Summary

Primary School	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$20,220	-$768	-$13,667	-$8,947	-$10,692	-$145,557	-$145,557	-$145,557	-$145,557	-$145,557
Maintenance	-$10	-$15	$29	-$13	-$15					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
15	-$11,959	-$5,885	-$2,237	-$3,685	-$5,319	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$90	$13,130	-$16	$323	$335	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$86,662	-$19,803	-$23,467	-$15,334	-$17,633	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	-$1,158	-$1,015	-$1,555	-$995	-$981	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$54,781	$12,111	$16,232	$9,847	$10,823	$20,594	$20,594	$20,594	$20,594	$20,594

Primary School	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$5,637	$1,883	$1,883	$947	$936	-$160,141	-$144,443	-$157,341	-$153,557	-$155,314
Maintenance	$0	$0	$0	$0	$0	-$10	-$15	$29	-$13	-$15
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
15	$0	$0	$0	$0	$0	-$11,959	-$5,885	-$2,237	-$3,685	-$5,319
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	-$2,200	$10,840	-$2,306	-$1,968	-$1,955
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$88,953	-$22,093	-$25,757	-$17,625	-$19,924
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	-$1,158	-$1,015	-$1,555	-$995	-$981
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$75,375	$32,705	$36,826	$30,442	$31,418

A.5 Small Hotel Cost Summary

Small Hotel	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$195	-$240	-$117	$301	-$160	$28,669	$28,669	$28,669	$28,669	$28,669
Maintenance	-$2	-$2	-$2	-$1	-$2					
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
2	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
3	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
4	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
5	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
6	$0	$0	$0	$0	$0	-$100,064	-$100,064	-$100,064	-$100,064	-$100,064
7	$0	$0	$0	$0	$0	-$11,534	-$11,534	-$11,534	-$11,534	-$11,534
8	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
9	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
10	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
11	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
12	$0	$0	$0	$0	$0	-$98,419	-$98,419	-$98,419	-$98,419	-$98,419
13	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
14	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
15	-$984	-$1,017	-$888	-$825	-$759	-$58,975	-$58,975	-$58,975	-$58,975	-$58,975
16	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
17	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
18	$0	$0	$0	$0	$0	-$107,088	-$107,088	-$107,088	-$107,088	-$107,088
19	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
20	$183	$183	$183	$183	$183	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
21	$0	$0	$0	$0	$0	-$49,391	-$49,391	-$49,391	-$49,391	-$49,391
22	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
23	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
24	$0	$0	$0	$0	$0	-$101,390	-$101,390	-$101,390	-$101,390	-$101,390
25	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
26	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
27	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
28	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
29	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
30	-$3,821	-$3,854	-$3,726	-$3,095	-$3,880	-$100,297	-$100,297	-$100,297	-$100,297	-$100,297
31	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
32	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
33	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
34	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
35	$0	$0	$0	$0	$0	-$11,767	-$11,767	-$11,767	-$11,767	-$11,767
36	$0	$0	$0	$0	$0	-$105,443	-$105,443	-$105,443	-$105,443	-$105,443
37	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
38	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
39	$0	$0	$0	$0	$0	-$54,615	-$54,615	-$54,615	-$54,615	-$54,615
40	$2,220	$2,231	$2,188	$1,788	$2,334	$5,759	$5,759	$5,759	$5,759	$5,759

Small Hotel	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,388	$842	$842	$174	$172	$29,862	$29,271	$29,394	$29,143	$28,680
Maintenance	$0	$0	$0	$0	$0	-$2	-$2	-$2	-$1	-$2
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
2	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
3	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
4	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
5	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
6	$0	$0	$0	$0	$0	-$100,064	-$100,064	-$100,064	-$100,064	-$100,064
7	$0	$0	$0	$0	$0	-$11,534	-$11,534	-$11,534	-$11,534	-$11,534
8	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
9	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
10	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
11	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
12	$0	$0	$0	$0	$0	-$98,419	-$98,419	-$98,419	-$98,419	-$98,419
13	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
14	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
15	$0	$0	$0	$0	$0	-$59,958	-$59,992	-$59,863	-$59,799	-$59,733
16	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
17	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
18	$0	$0	$0	$0	$0	-$107,088	-$107,088	-$107,088	-$107,088	-$107,088
19	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
20	$0	$0	$0	$0	$0	-$20,935	-$20,935	-$20,935	-$20,935	-$20,935
21	$0	$0	$0	$0	$0	-$49,391	-$49,391	-$49,391	-$49,391	-$49,391
22	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
23	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
24	$0	$0	$0	$0	$0	-$101,390	-$101,390	-$101,390	-$101,390	-$101,390
25	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
26	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
27	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
28	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
29	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
30	$0	$0	$0	$0	$0	-$104,118	-$104,152	-$104,023	-$103,392	-$104,177
31	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
32	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
33	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
34	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
35	$0	$0	$0	$0	$0	-$11,767	-$11,767	-$11,767	-$11,767	-$11,767
36	$0	$0	$0	$0	$0	-$105,443	-$105,443	-$105,443	-$105,443	-$105,443
37	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
38	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
39	$0	$0	$0	$0	$0	-$54,615	-$54,615	-$54,615	-$54,615	-$54,615
40	$0	$0	$0	$0	$0	$7,979	$7,990	$7,947	$7,547	$8,093

A.6 Mid-rise Apartment Cost Summary

Mid-rise Apartment	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$9,017	$8,864	$7,591	$11,427	$11,720	-$21,989	-$21,989	-$21,989	-$21,989	-$21,989
Maintenance	$480	$480	$480	$480	$480					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
15	$9,684	$9,457	$7,583	$11,986	$12,425	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$533	$533	$533	$533	$533
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$9,684	$9,457	$7,583	$11,986	$12,425	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	-$3,228	-$3,152	-$2,528	-$3,995	-$4,142	$9,971	$9,971	$9,971	$9,971	$9,971

Mid-rise Apartment	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$980	$736	$736	$595	$595	-$11,992	-$12,389	-$13,661	-$9,966	-$9,674
Maintenance	$0	$0	$0	$0	$0	$480	$480	$480	$480	$480
Replacement (Year)						$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
15	$0	$0	$0	$0	$0	$9,684	$9,457	$7,583	$11,986	$12,425
16	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$533	$533	$533	$533	$533
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$10,218	-$10,444	-$12,319	-$7,916	-$7,476
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$6,744	$6,819	$7,444	$5,976	$5,830

Appendix B

Energy Cost and Use

This appendix includes summary energy use, cost, and savings data used in the cost-effectiveness analysis.

Energy cost savings tables show the total building energy cost in dollars per square foot for each prototype in each climate zone analyzed. Annual energy cost for each edition of Standard 90.1 is shown with the cost savings and percentage savings.

Energy use savings tables show the total building site energy use cost in kilowatt-hours, therms, and thousand British thermal units per square foot per year for each prototype in each climate zone analyzed. Annual energy use for each edition of Standard 90.1 is shown with the use, savings, and percentage savings.

Energy end use tables show the end use breakdown of annual electric and gas use per square foot for each prototype in each climate zone analyzed. Results are shown for 90.1-2016 and 90.1-2019.

B.1 Energy Cost and Savings Summary, 90.1-2016 and 90.1-2019

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office												
Electricity	$0.881	$0.830	$0.050	5.7%	$0.805	$0.757	$0.047	5.8%	$0.817	$0.768	$0.049	6.0%
Gas	$0.000	$0.000	$0.000	-	$0.002	$0.002	$0.000	0.0%	$0.000	$0.000	$0.000	-
Totals	$0.881	$0.830	$0.050	5.7%	$0.807	$0.760	$0.047	5.8%	$0.818	$0.768	$0.049	6.0%
Large Office												
Electricity	$1.775	$1.704	$0.071	4.0%	$1.669	$1.603	$0.067	4.0%	$1.749	$1.687	$0.061	3.5%
Gas	$0.011	$0.010	$0.001	9.1%	$0.023	$0.016	$0.007	30.4%	$0.015	$0.016	-$0.001	-6.7%
Totals	$1.786	$1.714	$0.072	4.0%	$1.693	$1.619	$0.073	4.3%	$1.764	$1.704	$0.060	3.4%
Stand-Alone Retail												
Electricity	$1.256	$1.147	$0.109	8.7%	$1.064	$0.964	$0.100	9.4%	$1.082	$0.980	$0.102	9.4%
Gas	$0.037	$0.038	-$0.001	-2.7%	$0.093	$0.099	-$0.006	-6.5%	$0.051	$0.056	-$0.005	-9.8%
Totals	$1.293	$1.185	$0.108	8.4%	$1.157	$1.063	$0.093	8.0%	$1.133	$1.036	$0.097	8.6%
Primary School												
Electricity	$1.238	$1.154	$0.084	6.8%	$1.046	$0.971	$0.075	7.2%	$1.043	$0.951	$0.092	8.8%
Gas	$0.063	$0.062	$0.001	1.6%	$0.095	$0.088	$0.007	7.4%	$0.078	$0.076	$0.002	2.6%
Totals	$1.301	$1.216	$0.085	6.5%	$1.141	$1.058	$0.082	7.2%	$1.121	$1.028	$0.094	8.4%
Small Hotel												
Electricity	$1.079	$0.987	$0.093	8.6%	$0.985	$0.898	$0.087	8.8%	$0.974	$0.885	$0.089	9.1%
Gas	$0.194	$0.194	$0.000	0.0%	$0.213	$0.213	$0.000	0.0%	$0.206	$0.206	$0.000	0.0%
Totals	$1.273	$1.181	$0.093	7.3%	$1.198	$1.111	$0.087	7.3%	$1.180	$1.091	$0.089	7.5%
Mid-Rise Apartment												
Electricity	$1.151	$1.102	$0.049	4.3%	$1.070	$1.046	$0.024	2.2%	$1.080	$1.066	$0.014	1.3%
Gas	$0.003	$0.001	$0.002	66.7%	$0.034	$0.012	$0.022	64.7%	$0.011	$0.003	$0.008	72.7%
Totals	$1.154	$1.102	$0.052	4.5%	$1.104	$1.057	$0.047	4.3%	$1.090	$1.069	$0.022	2.0%

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity	$0.787	$0.744	$0.043	5.5%	$0.791	$0.748	$0.044	5.6%
Gas	$0.005	$0.005	$0.000	0.0%	$0.021	$0.022	-$0.001	-4.8%
Totals	$0.792	$0.749	$0.043	5.4%	$0.812	$0.770	$0.043	5.3%
Large Office								
Electricity	$1.606	$1.550	$0.056	3.5%	$1.566	$1.509	$0.058	3.7%
Gas	$0.028	$0.024	$0.003	10.7%	$0.039	$0.034	$0.005	12.8%
Totals	$1.634	$1.574	$0.060	3.7%	$1.605	$1.543	$0.062	3.9%
Standalone Retail								
Electricity	$0.993	$0.900	$0.093	9.4%	$0.926	$0.836	$0.091	9.8%
Gas	$0.175	$0.186	-$0.011	-6.3%	$0.257	$0.270	-$0.013	-5.1%
Totals	$1.168	$1.086	$0.082	7.0%	$1.183	$1.105	$0.078	6.6%
Primary School								
Electricity	$0.967	$0.900	$0.068	7.0%	$0.907	$0.842	$0.065	7.2%
Gas	$0.105	$0.099	$0.005	4.8%	$0.144	$0.135	$0.009	6.3%
Totals	$1.072	$0.999	$0.073	6.8%	$1.050	$0.977	$0.074	7.0%
Small Hotel								
Electricity	$0.958	$0.880	$0.078	8.1%	$0.958	$0.885	$0.074	7.7%
Gas	$0.233	$0.233	$0.000	0.0%	$0.251	$0.251	$0.001	0.4%
Totals	$1.191	$1.113	$0.078	6.5%	$1.209	$1.135	$0.074	6.1%
Mid-Rise Apartment								
Electricity	$1.056	$1.036	$0.020	1.9%	$1.050	$1.029	$0.021	2.0%
Gas	$0.030	$0.035	-$0.004	-13.3%	$0.058	$0.064	-$0.006	-10.3%
Totals	$1.087	$1.071	$0.016	1.5%	$1.108	$1.093	$0.015	1.4%

B.2 Energy Use and Savings Summary, 90.1-2016 and 90.1-2019

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office												
Electricity, kWh/ft^2	8.285	7.810	0.475	5.7%	7.569	7.124	0.445	5.9%	7.690	7.226	0.464	6.0%
Gas, therm/ft^2	0.000	0.000	0.000	-	0.002	0.003	0.000	0.0%	0.000	0.000	0.000	-
Totals, kBtu/ft^2	28.277	26.657	1.620	5.7%	26.073	24.570	1.503	5.8%	26.273	24.692	1.581	6.0%
Large Office												
Electricity, kWh/ft^2	16.695	16.026	0.668	4.0%	15.705	15.078	0.627	4.0%	16.450	15.875	0.575	3.5%
Gas, therm/ft^2	0.012	0.010	0.001	8.3%	0.024	0.017	0.007	29.2%	0.015	0.016	-0.001	-6.7%
Totals, kBtu/ft^2	58.141	55.738	2.402	4.1%	55.955	53.141	2.814	5.0%	57.677	55.826	1.851	3.2%
Stand-Alone Retail												
Electricity, kWh/ft^2	11.818	10.790	1.029	8.7%	10.011	9.073	0.938	9.4%	10.177	9.222	0.955	9.4%
Gas, therm/ft^2	0.038	0.039	-0.001	-2.6%	0.094	0.101	-0.006	-6.4%	0.052	0.057	-0.005	-9.6%
Totals, kBtu/ft^2	44.091	40.687	3.403	7.7%	43.617	41.053	2.564	5.9%	39.981	37.186	2.795	7.0%
Primary School												
Electricity, kWh/ft^2	11.645	10.855	0.790	6.8%	9.836	9.132	0.703	7.1%	9.816	8.948	0.867	8.8%
Gas, therm/ft^2	0.064	0.063	0.002	3.1%	0.097	0.089	0.008	8.2%	0.080	0.078	0.002	2.5%
Totals, kBtu/ft^2	46.185	43.338	2.847	6.2%	43.268	40.102	3.166	7.3%	41.466	38.333	3.133	7.6%
Small Hotel												
Electricity, kWh/ft^2	10.153	9.281	0.873	8.6%	9.269	8.449	0.820	8.8%	9.166	8.328	0.839	9.2%
Gas, therm/ft^2	0.198	0.198	0.000	0.0%	0.217	0.217	0.000	0.0%	0.210	0.210	0.000	0.0%
Totals, kBtu/ft^2	54.461	51.496	2.965	5.4%	53.349	50.577	2.772	5.2%	52.273	49.455	2.818	5.4%
Mid-Rise Apartment												
Electricity, kWh/ft^2	10.830	10.365	0.465	4.3%	10.066	9.836	0.230	2.3%	10.157	10.025	0.132	1.3%
Gas, therm/ft^2	0.003	0.001	0.002	66.7%	0.035	0.012	0.023	65.7%	0.011	0.003	0.008	72.7%
Totals, kBtu/ft^2	37.254	35.430	1.824	4.9%	37.828	34.756	3.072	8.1%	35.749	34.514	1.235	3.5%

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity, kWh/ft^2	7.404	6.995	0.409	5.5%	7.446	7.033	0.413	5.5%
Gas, therm/ft^2	0.005	0.005	0.000	0.0%	0.021	0.022	-0.001	-4.8%
Totals, kBtu/ft^2	25.764	24.406	1.358	5.3%	27.537	26.249	1.288	4.7%
Large Office								
Electricity, kWh/ft^2	15.109	14.577	0.531	3.5%	14.735	14.192	0.543	3.7%
Gas, therm/ft^2	0.028	0.025	0.004	14.3%	0.040	0.035	0.005	12.5%
Totals, kBtu/ft^2	54.380	52.210	2.170	4.0%	54.269	51.951	2.318	4.3%
Standalone Retail								
Electricity, kWh/ft^2	9.337	8.462	0.875	9.4%	8.714	7.861	0.854	9.8%
Gas, therm/ft^2	0.179	0.190	-0.011	-6.1%	0.262	0.275	-0.013	-5.0%
Totals, kBtu/ft^2	49.767	47.862	1.905	3.8%	55.954	54.335	1.619	2.9%
Primary School								
Electricity, kWh/ft^2	9.101	8.464	0.637	7.0%	8.528	7.920	0.608	7.1%
Gas, therm/ft^2	0.107	0.101	0.006	5.6%	0.147	0.138	0.009	6.1%
Totals, kBtu/ft^2	41.724	38.991	2.733	6.6%	43.775	40.790	2.985	6.8%
Small Hotel								
Electricity, kWh/ft^2	9.010	8.277	0.732	8.1%	9.014	8.322	0.692	7.7%
Gas, therm/ft^2	0.238	0.238	0.000	0.0%	0.256	0.256	0.001	0.4%
Totals, kBtu/ft^2	54.510	52.008	2.502	4.6%	56.394	53.973	2.420	4.3%
Mid-Rise Apartment								
Electricity, kWh/ft^2	9.937	9.745	0.192	1.9%	9.877	9.677	0.201	2.0%
Gas, therm/ft^2	0.031	0.036	-0.004	-12.9%	0.060	0.066	-0.006	-10.0%
Totals, kBtu/ft^2	37.020	36.811	0.209	0.6%	39.676	39.591	0.085	0.2%

B.3 Energy by Usage Category, 90.1-2016 and 90.1-2019

Annual Energy Usage for Buildings in Climate Zone 2A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr
ASHRAE 90.1-2016												
Heating, Humidification	0.013	0.000	0.139	0.003	0.000	0.004	0.000	0.006	0.030	0.001	0.000	0.003
Cooling	2.033	0.000	3.798	0.000	4.393	0.000	3.755	0.000	3.304	0.000	2.118	0.000
Fans, Pumps, Heat Recovery	0.978	0.000	1.533	0.000	1.506	0.000	1.767	0.000	1.097	0.000	0.810	0.000
Lighting, Interior & Exterior	1.913	0.000	1.956	0.000	3.732	0.000	1.422	0.000	2.136	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.604	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.105	2.639	0.000
Total	8.285	0.000	16.695	0.012	11.818	0.038	11.645	0.064	10.153	0.198	10.830	0.003
ASHRAE 90.1-2019												
Heating, Humidification	0.012	0.000	0.154	0.002	0.000	0.005	0.000	0.004	0.036	0.001	0.000	0.001
Cooling	1.957	0.000	3.487	0.000	4.151	0.000	3.469	0.000	3.139	0.000	1.844	0.000
Fans, Pumps, Heat Recovery	0.900	0.000	1.489	0.000	1.428	0.000	1.667	0.000	1.047	0.000	0.775	0.000
Lighting, Interior & Exterior	1.593	0.000	1.627	0.000	3.025	0.000	1.163	0.000	1.472	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.459	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.105	2.637	0.000
Total	7.810	0.000	16.026	0.010	10.790	0.039	10.855	0.063	9.281	0.198	10.365	0.001
Total Savings	0.475	0.000	0.668	0.001	1.029	-0.001	0.790	0.002	0.873	0.000	0.465	0.002

Annual Energy Usage for Buildings in Climate Zone 3A

Energy End-Use	Small Office Electric kWh/ ft^2·yr	Small Office Gas therms/ ft^2·yr	Large Office Electric kWh/ ft^2·yr	Large Office Gas therms/ ft^2·yr	Stand-Alone Retail Electric kWh/ ft^2·yr	Stand-Alone Retail Gas therms/ ft^2·yr	Primary School Electric kWh/ ft^2·yr	Primary School Gas therms/ ft^2·yr	Small Hotel Electric kWh/ ft^2·yr	Small Hotel Gas therms/ ft^2·yr	Mid-Rise Apartment Electric kWh/ ft^2·yr	Mid-Rise Apartment Gas therms/ ft^2·yr
ASHRAE 90.1-2016												
Heating, Humidification	0.260	0.002	0.404	0.013	0.000	0.059	0.000	0.036	0.240	0.005	0.000	0.035
Cooling	1.107	0.000	2.637	0.000	2.439	0.000	2.150	0.000	2.223	0.000	1.145	0.000
Fans, Pumps, Heat Recovery	0.932	0.000	1.432	0.000	1.638	0.000	1.549	0.000	1.075	0.000	0.670	0.000
Lighting, Interior & Exterior	1.923	0.000	1.963	0.000	3.748	0.000	1.437	0.000	2.144	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.119	2.987	0.000
Total	7.569		15.705	0.024	10.011	0.094	9.836	0.097	9.269	0.217	10.066	0.035
ASHRAE 90.1-2019												
Heating, Humidification	0.265		0.439	0.007	0.000	0.066	0.000	0.029	0.276	0.006	0.000	0.012
Cooling	1.052	0.000	2.354	0.000	2.287	0.000	1.966	0.000	2.090	0.000	1.096	0.000
Fans, Pumps, Heat Recovery	0.858	0.000	1.385	0.000	1.554	0.000	1.437	0.000	1.020	0.000	0.647	0.000
Lighting, Interior & Exterior	1.601	0.000	1.632	0.000	3.044	0.000	1.175	0.000	1.477	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.119	2.983	0.000
Total	7.124		15.078	0.017	9.073	0.101	9.132	0.089	8.449	0.217	9.836	0.012
Total Savings	0.445	0.000	0.627	0.007	0.938	-0.006	0.703	0.008	0.820	0.000	0.230	0.023

Annual Energy Usage for Buildings in Climate Zone 3B

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.098	0.000	0.851	0.006	0.000	0.018	0.000	0.020	0.085	0.002	0.000	0.011
Cooling	1.232	0.000	2.708	0.000	2.380	0.000	2.239	0.000	2.230	0.000	1.243	0.000
Fans, Pumps, Heat Recovery	1.090	0.000	1.666	0.000	1.767	0.000	1.429	0.000	1.120	0.000	0.752	0.000
Lighting, Interior & Exterior	1.921	0.000	1.955	0.000	3.843	0.000	1.451	0.000	2.144	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.599	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.116	2.897	0.000
Total	7.690	0.000	16.450	0.015	10.177	0.052	9.816	0.080	9.166	0.210	10.157	0.011
ASHRAE 90.1-2019												
Heating, Humidification	0.102	0.000	0.803	0.007	0.000	0.022	0.000	0.018	0.107	0.002	0.000	0.003
Cooling	1.169	0.000	2.556	0.000	2.228	0.000	2.018	0.000	2.096	0.000	1.252	0.000
Fans, Pumps, Heat Recovery	1.007	0.000	1.620	0.000	1.680	0.000	1.188	0.000	1.062	0.000	0.769	0.000
Lighting, Interior & Exterior	1.599	0.000	1.627	0.000	3.128	0.000	1.188	0.000	1.477	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.457	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.116	2.894	0.000
Total	7.226	0.000	15.875	0.016	9.222	0.057	8.948	0.078	8.328	0.210	10.025	0.003
Total Savings	0.464	0.000	0.575	-0.001	0.955	-0.005	0.867	0.002	0.839	0.000	0.132	0.008

Annual Energy Usage for Buildings in Climate Zone 4A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr
ASHRAE 90.1-2016												
Heating, Humidification	0.503	0.005	0.435	0.017	0.000	0.143	0.000	0.045	0.551	0.013	0.000	0.031
Cooling	0.800	0.000	2.073	0.000	1.613	0.000	1.459	0.000	1.693	0.000	0.811	0.000
Fans, Pumps, Heat Recovery	0.855	0.000	1.370	0.000	1.707	0.000	1.514	0.000	1.054	0.000	0.608	0.000
Lighting, Interior & Exterior	1.897	0.000	1.961	0.000	3.831	0.000	1.429	0.000	2.125	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.016	0.000	0.132	3.256	0.000
Total	7.404	0.005	15.109	0.028	9.337	0.179	9.101	0.107	9.010	0.238	9.937	0.031
ASHRAE 90.1-2019												
Heating, Humidification	0.517	0.005	0.669	0.014	0.000	0.154	0.000	0.039	0.643	0.013	0.000	0.036
Cooling	0.760	0.000	1.705	0.000	1.514	0.000	1.370	0.000	1.583	0.000	0.786	0.000
Fans, Pumps, Heat Recovery	0.786	0.000	1.303	0.000	1.636	0.000	1.357	0.000	0.999	0.000	0.593	0.000
Lighting, Interior & Exterior	1.585	0.000	1.632	0.000	3.126	0.000	1.182	0.000	1.466	0.000	0.900	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.015	0.000	0.132	3.257	0.000
Total	6.995	0.005	14.577	0.025	8.462	0.190	8.464	0.101	8.277	0.238	9.745	0.036
Total Savings	0.409	0.000	0.531	0.004	0.875	-0.011	0.637	0.006	0.732	0.000	0.192	-0.004

Annual Energy Usage for Buildings in Climate Zone 5A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/
	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.855	0.021	0.706	0.028	0.000	0.225	0.000	0.084	0.975	0.022	0.000	0.060
Cooling	0.489	0.000	1.458	0.000	0.938	0.000	0.910	0.000	1.282	0.000	0.543	0.000
Fans, Pumps, Heat Recovery	0.854	0.000	1.341	0.000	1.760	0.000	1.503	0.000	1.047	0.000	0.586	0.000
Lighting, Interior & Exterior	1.899	0.000	1.960	0.000	3.831	0.000	1.416	0.000	2.123	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.142	3.485	0.000
Total	7.446	0.021	14.735	0.040	8.714	0.262	8.528	0.147	9.014	0.256	9.877	0.060
ASHRAE 90.1-2019												
Heating, Humidification	0.860	0.022	0.476	0.023	0.000	0.238	0.000	0.075	1.092	0.021	0.000	0.066
Cooling	0.458	0.000	1.522	0.000	0.873	0.000	0.858	0.000	1.188	0.000	0.510	0.000
Fans, Pumps, Heat Recovery	0.782	0.000	1.294	0.000	1.679	0.000	1.337	0.000	0.991	0.000	0.570	0.000
Lighting, Interior & Exterior	1.585	0.000	1.631	0.000	3.123	0.000	1.169	0.000	1.465	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.142	3.486	0.000
Total	7.033	0.022	14.192	0.035	7.861	0.275	7.920	0.138	8.322	0.256	9.677	0.066
Total Savings	0.413	-0.001	0.543	0.005	0.854	-0.013	0.608	0.009	0.692	0.001	0.201	-0.006

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Energy and Energy Cost Savings Analysis of the 2018 IECC for Commercial Buildings

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U.S. DEPARTMENT OF ENERGY

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Prepared for
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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and related environmental impacts for the life of buildings. As required by federal statute (42 U.S.C. 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2016 would achieve greater energy efficiency in buildings compared to the 2013 edition of the standard. In support of DOE's determination, Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2016 (DOE 2017). While Standard 90.1 is the national model energy standard for commercial buildings (42 U.S.C. 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings.

This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2018 IECC would save energy and energy costs as compared to the 2015 IECC. The Commercial Energy Efficiency chapter in the 2018 IECC allows users to either follow the provisions in the IECC or use Standard 90.1-2016 as an alternative compliance path. PNNL also compared the energy performance of the 2018 IECC with the corresponding Standard 90.1-2016 to help states and local jurisdictions make informed decisions regarding model code adoption.

The analysis builds on previous work done by PNNL that assessed the energy performance of the 2015 IECC compared to the 2012 editions of the IECC (Zhang et al. 2015). For this analysis, PNNL first reviewed all code changes from the 2015 to 2018 IECC and identified those having a quantifiable impact on energy. These changes were then implemented in a suite of 16 prototype building models covering all 16 climate zones in the United States. This results in a total of 512 building models, 256 models each for the 2015 and 2018 editions of the IECC. Prototype models for the 2018 IECC were developed by implementing code changes to the 2015 IECC models. The 16 prototype building models represent more than 80% of the national stock of commercial buildings in the United States.

Whole-building energy simulations were conducted using DOE's *EnergyPlus Version 8.0* (DOE 2015) building simulation software. The resulting energy use from the complete suite of 512 simulation runs was converted to site energy use intensity (EUI, or energy use per unit floor area), and energy cost index (ECI) for each simulation. For each prototype, the resulting EUIs and ECIs in each climate zone were weighted to calculate the aggregate national level EUI and ECI. Weighting factors were developed using commercial construction data and are based on construction floor area of the different building types in each climate zone. Finally, the EUIs were aggregated across building types to the national level using the same weighting data.

Overall, the 2018 edition of the IECC results in site energy savings of 5.1% at the aggregate national level compared to the 2015 IECC edition. Comparatively, on a national weighted average basis, the 2018 IECC is 2.6% *less* efficient for energy use than Standard 90.1-2016 (see Appendix B in this report for the full comparison of the 2018 IECC and Standard 90.1-2016). Savings from the 2015 to 2018 IECC vary

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers (until 2012, then just ASHRAE); IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

significantly by prototype and climate. This is expected because code requirements are different by building type and by climate.

A few high-impact changes resulting in significant energy savings are listed below:

- Heating, ventilation and air conditioning (HVAC): dual maximum control requirements to multiple-zone variable-air volume (VAV) systems with direct digital control (DDC) (C403.6.1); VAV system ventilation optimization when energy recovery ventilator (ERV) is installed (C403.6.6); and HVAC control for hotel guestroom during unoccupied hours (C403.7.6).
- Lighting: high efficacy lighting in dwelling units (C405.1), and lower interior and exterior lighting power allowance (C405.3.2 and C405.4.2).

Table ES.1 summarizes the analysis results. The 16 building prototypes are listed along with their construction weighting factors. Side-by-side comparisons of the site EUI and ECI for the 2015 and 2018 IECC are shown in the table along with their percentage savings. Positive percentage savings indicate a reduction in energy or energy costs from the 2015 IECC. As depicted in Table ES.1, the analysis shows an estimated site energy savings of 5.1% and energy cost savings of 5.3% on a national aggregated basis.

Table ES.1. Site Energy and Energy Cost Savings between the 2015 and 2018 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI (kBtu/ft^2-yr)		Site EUI Savings (%)	ECI ($/ft^2-yr)		ECI Savings (%)
			2015 IECC	2018 IECC		2015 IECC	2018 IECC	
Office	Small Office	5.6	29.6	28.6	3.4%	$0.89	$0.85	4.5%
	Medium Office	6.0	34.2	33	3.5%	$0.97	$0.93	4.1%
	Large Office	3.3	71.1	67.9	4.5%	$2.04	$1.98	2.9%
Retail	Stand-Alone Retail	15.3	47.1	40.9	13.2%	$1.20	$1.04	13.3%
	Strip Mall	5.7	55.4	51.5	7.0%	$1.46	$1.33	9.6%
Education	Primary School	5.0	52.7	48.8	7.4%	$1.31	$1.20	8.4%
	Secondary School	10.4	43.1	40.2	6.7%	$1.11	$1.03	7.2%
Healthcare	Outpatient Health Care	4.4	119.7	115.7	3.3%	$3.09	$2.97	4.2%
	Hospital	3.4	125.6	124.3	1.0%	$2.90	$2.88	0.7%
Lodging	Small Hotel	1.7	60.3	56.4	6.5%	$1.29	$1.17	9.3%
	Large Hotel	5.0	87.7	85.4	2.6%	$1.79	$1.75	1.7%
Warehouse	Non-Refrigerated Warehouse	16.7	16.2	14.4	11.1%	$0.36	$0.30	16.7%
Food Service	Quick Service Restaurant	0.6	575.5	572.2	0.6%	$8.45	$8.35	1.2%
	Full Service Restaurant	0.7	372	368	1.1%	$6.28	$6.14	2.2%
Apartment	Mid-Rise Apartment	7.3	43.6	43	1.4%	$1.25	$1.23	1.6%
	High-Rise Apartment	9.0	47.6	46.6	2.1%	$1.13	$1.10	2.7%
National Weighted Average		**100**	**54.5**	**51.7**	**5.1%**	**$1.31**	**$1.24**	**5.3%**

Figures ES.1 and ES.2 illustrate the weighted EUI and ECI for each prototype and the national weighted average results for the 2015 and 2018 editions of the IECC, respectively.

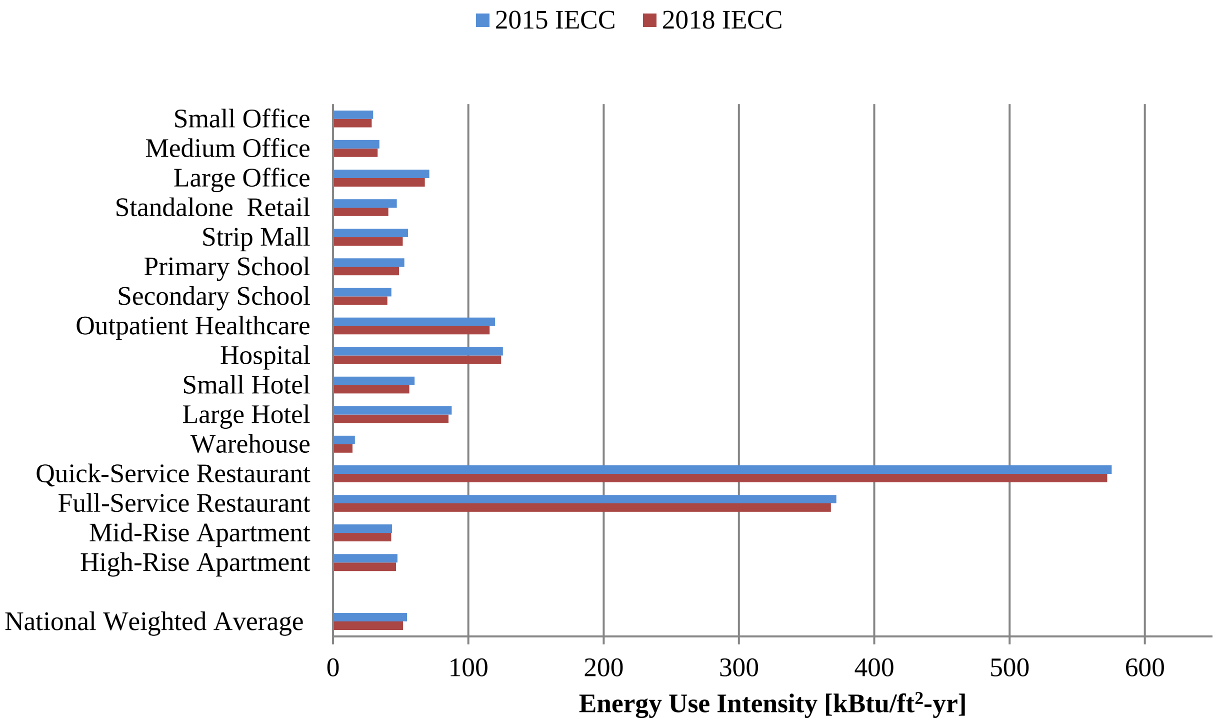

Figure ES.1. National Average Energy Use Intensity for all IECC Prototypes

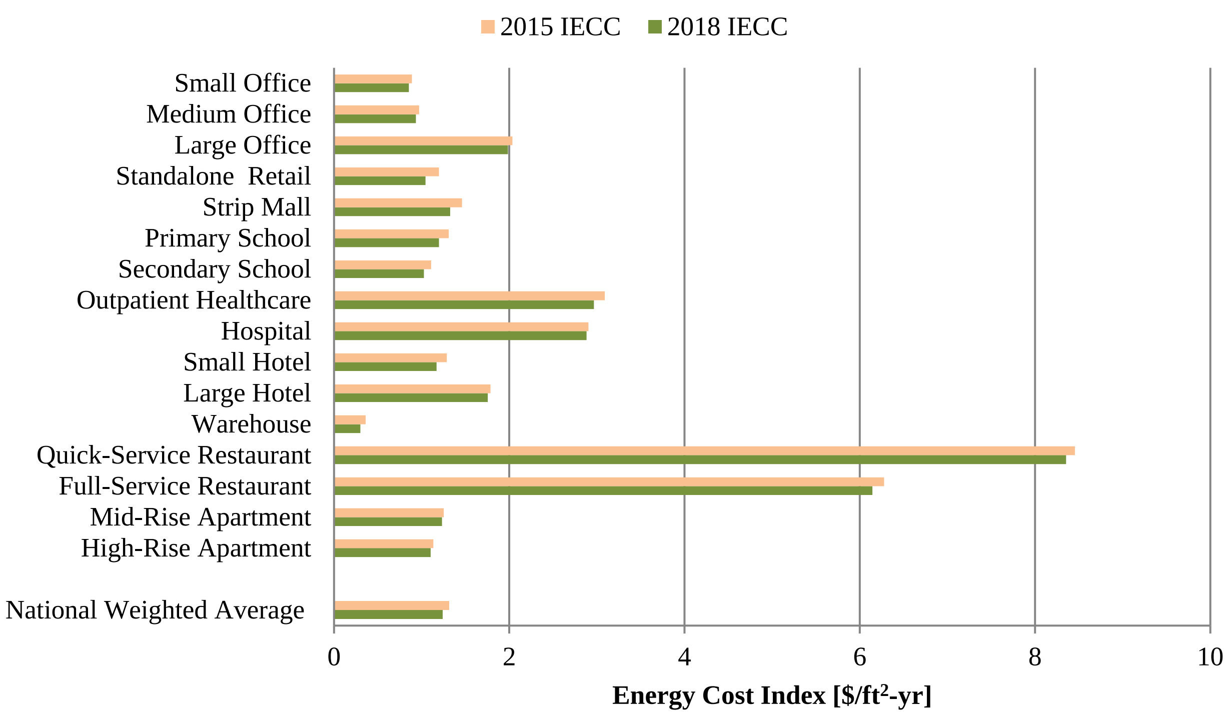

Figure ES. 2. National Average Energy Cost Index for all IECC Prototypes

Acknowledgments

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Pacific Northwest National Laboratory

Acronyms and Abbreviations

AFUE	annual fuel utilization efficiency
ANSI	American National Standards Institute
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BECP	Building Energy Codes Program
Btu/h	British thermal unit(s) per hour
CBECS	Commercial Building Energy Consumption Survey
CFR	Code of Federal Regulations
DDC	direct digital control
DOE	U.S. Department of Energy
ECI	energy cost index
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EMS	energy management system
ERV	energy recovery ventilator
EUI	energy use intensity
ft^2	square feet
hp	horsepower
HVAC	heating, ventilation, and air-conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
$kBtu/ft^2$-yr	thousand British thermal unit(s) per square foot per year
kBtu/h	thousand British thermal unit(s) per hour
kWh	kilowatt hour(s)
LPD	lighting power density
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient
USC	United States Code
VAV	variable air volume
VSD	variable speed drive
WWR	window-to-wall ratio

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1.0 Introduction

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and related environmental impacts for the life of buildings.

As required by federal statute (42 U.S.C. 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2016 would achieve greater energy efficiency in buildings subject to the code compared to the 2013 edition of the standard.[2] Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2016 in support of the determination (DOE 2017). While Standard 90.1 is the national model energy standard for commercial buildings (42 U.S.C. 6833), many states adopt the full suite of International Codes, and thus adopt the International Energy Conservation Code (IECC), which includes energy conservation requirements for both residential and commercial buildings. Of the 43 states with statewide commercial building energy codes currently, 35 use a version of the IECC (BECP 2018). The Commercial Energy Efficiency chapter in the 2018 IECC (International Code Council, ICC 2018) allows users to either follow the provisions in the IECC or use Standard 90.1-2016 as an alternative compliance path. This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2018 IECC would save energy and energy costs compared to the 2015 IECC (ICC 2015). Because PNNL used the same methodology for both this 2018 IECC analysis and the previous Standard 90.1-2016 analysis, comparisons between the estimated energy performance of the 2018 IECC and that of its referenced Standard 90.1-2016 are presented in Appendix B of this report. The goal of this analysis is to help states and local jurisdictions make informed decisions regarding model code adoption.

This report documents the approach and results for PNNL's analysis for energy and energy cost savings of the 2018 IECC for commercial buildings. PNNL first reviewed all code changes from the 2015 to 2018 IECC and identified those having a quantifiable impact. PNNL then compared two suites of building prototypes, each suite complying with one edition of the IECC. Each suite consists of 256 building prototypes; a combination of 16 building prototypes in all 16 U.S. climate zones. The 2015 IECC prototypes were taken from PNNL's previous analysis of the energy performance of the 2015 IECC compared to its previous edition which was documented in *Energy and Energy Cost Savings Analysis of the 2015 IECC for Commercial Buildings* (Zhang et al. 2015), referred to here as *Analysis of the 2015 IECC.*

The remainder of this report is organized as follows: Section 2.0 summarizes the general methodology about the building prototypes, their development, and simulation for their energy use and cost. The same methodology was applied in the previous *Analysis of the 2015 IECC* and the Standard 90.1-2016 determination (DOE 2017). Section 3.0 describes how PNNL developed the 2018 IECC prototypes using the 2015 IECC prototypes as a basis. Finally, Section 4.0 summarizes the results of the comparison of the two editions of the IECC. Appendix A summarizes the identified code changes between the 2015 and 2018 IECC (with quantified energy impacts) and identifies which building prototypes are impacted by each change. Appendix B provides energy and energy cost comparisons

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers (until 2012, then just ASHRAE); IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)
[2] For more information on the DOE Determination of energy savings, see http://www.energycodes.gov/development/determinations

between Standard 90.1-2016 and the 2018 IECC. Appendix C identifies a few amendments to the 2018 IECC that would align the requirements with Standard 90.1-2016 to create equivalency on a nationally aggregated basis.

2.0 Methodology

To support the development and implementation of building energy codes, PNNL researchers have developed building prototypes that comply with various editions of energy codes including both Standard 90.1 and IECC. These building prototypes represent the majority of new commercial building stock and were developed using DOE's *EnergyPlus Version 8.0* building energy simulation software (DOE 2015). The results allow comparison of the national weighted average savings of one code to its earlier edition and the relative performance differences between the codes. This section summarizes the general methodology used for this 2018 IECC analysis, which is consistent with that used for the *Analysis of the 2015 IECC*.

2.1 Building Prototypes

For this analysis, PNNL used a suite of building prototypes (DOE and PNNL 2018) representing the first seven principal building activities in the Commercial Buildings Energy Consumption Survey (CBECS; EIA 2003). These seven principal building activities represent 76% of the building energy usage of commercial buildings. In addition, two multifamily prototypes (Mid-Rise and High-Rise Apartments), which are not included in CBECS, were added into the suite of prototypes. These two prototypes were included in the analysis because they are regulated by the commercial provisions of the IECC. Table 2.1 shows the seven principal activities as defined in CBECS and the added apartment activity. These eight building activities were further divided into 16 building prototypes as listed in Table 2.1 along with their floor area, representing 80% of new construction floor area in the United States. Detailed descriptions of these prototypes and enhancements are documented in Thornton et al. (2011) and Goel et al. (2014).

2.2 Climate Zones

The climate zones and moisture regimes in the 2018 IECC include eight zones and three moisture regimes. Each combination of climate zone and moisture regime defines a climate subzone, resulting in 15 climate subzones in the United States, which are the same as those defined in Standard 90.1-2013. Standard 90.1-2016 adopted an updated climate zone map by referencing ASHRAE Standard 169-2013, *Climatic Data for Building Design Standards* (ASHRAE 2013), which reassigns U.S. counties to climate zones, as shown in Figure 2.1, based on more recently monitored climate data and also added a new, extremely hot climate zone 0. Approximately 300 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones. A sensitivity analysis using prototype building models (Athalye et al. 2016) showed the energy impact of the county-climate zone reassignment to be very small at a national level, with an increase of 0.18% in the site energy consumption of buildings compared to those with previous county-climate assignments. For DOE's recent determination of the energy savings of Standard 90.1-2016 compared to Standard 90.1-2013 (DOE 2017), PNNL decided to focus on energy savings due to the changes in design requirements between the standards instead of the climate zone assignments. To maintain consistency with that approach, the new county-climate zone mapping was used for all codes and standards compared in the present analysis. For the same reason, the new set of 16 representative cities used for the 90.1-2016 Determination (DOE 2017) was also used for this analysis.

Table 2-1. Commercial Prototype Building Models

Building Type	Prototype Building	Floor Area (ft^2)
Office	Small Office	5,502
	Medium Office	53,628
	Large Office	498,588
Retail	Stand-Alone Retail	24,692
	Strip Mall	22,500
Education	Primary School	73,959
	Secondary School	210,887
Healthcare	Outpatient Health Care	40,946
	Hospital	241,501
Lodging	Small Hotel	43,202
	Large Hotel	122,120
Warehouse	Non-Refrigerated Warehouse	52,045
Food Service	Quick Service Restaurant	2,501
	Full Service Restaurant	5,502
Apartment	Mid-Rise Apartment	33,741
	High-Rise Apartment	84,360

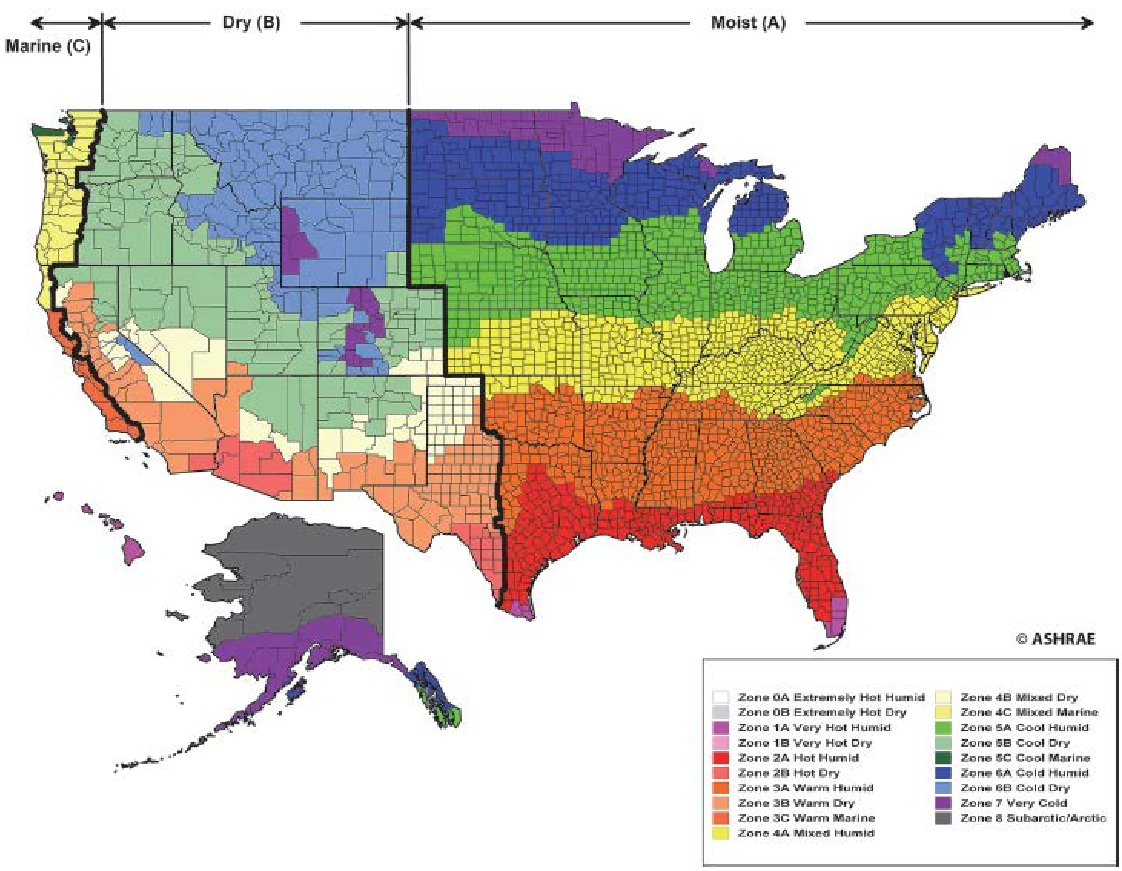

Figure 2.1. United States Climate Zone Map (ASHRAE 2013)

The 16 cities used in the current analysis are:

- 1A: Honolulu, Hawaii (very hot, humid)
- 2A: Tampa, Florida (hot, humid)
- 2B: Tucson, Arizona (hot, dry)
- 3A: Atlanta, Georgia (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Diego, California (warm, marine)
- 4A: New York, New York (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Seattle, Washington (mixed, marine)
- 5A: Buffalo, New York (cool, humid)
- 5B: Denver, Colorado (cool, dry)
- 5C: Port Angeles, Washington (cool, marine)
- 6A: Rochester, Minnesota (cold, humid)
- 6B: Great Falls, Montana (cold, dry)
- 7: International Falls, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

2.3 Comparison Metrics and Construction Weights

Annual electricity and natural gas energy use in each building prototype were simulated across 256 buildings, a combination of 16 prototypes in all 16 U.S. climate zones. This simulated energy use is utility electricity and natural gas delivered and used at the building site. The site energy use was converted to site energy use intensity (site EUI, or energy use per unit floor area).

To calculate the energy cost, PNNL relied on national average commercial building energy prices based on Energy Information Administration (EIA) statistics for 2016 in Table 2, "U.S. Energy Prices," of the March 2017 Short Term Energy Outlook for commercial sector natural gas and electricity[1] of:

- $0.1037/kWh of electricity
- $7.26 per 1000 cubic feet ($0.701/therm) of natural gas

The same set of prices was used for all prototypes and in all climate zones. The annual energy costs for each building were calculated for each fuel type (electricity and natural gas) by using the energy prices for all buildings. These costs were converted to energy cost index (ECI, or energy cost per unit floor area) for each building.

PNNL recognizes that actual energy costs will vary somewhat by building type within a region, and even more across regions. However, the use of national average figures sufficiently illustrates energy cost savings and the effect on energy efficiency in commercial buildings. The same method and the same set of fuel prices were used for the DOE determination for Standard 90.1-2016.

The EUI and ECI results of each building were weighted by construction volume for each building prototype and climate zone to calculate the national weighted average EUI and ECI. Weighting factors developed by building type and climate-related geographic areas in the United States were previously derived from 5 years of recent construction data (Jarnagin and Bandyopadhyay 2010).[2] Table 2.2 lists the weighting factors assigned to each prototype in all 16 U.S. climate zones.

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[1] EIA Short Term Energy Outlook available at http://www.eia.gov/forecasts/steo/report/.

[2] The original weighting factors were based on the climate to county mapping in Standard 169-2006. This analysis uses updated mapping from 169-2013 and the construction weights were updated accordingly (DOE 2017).

Table 2-2. Relative Construction Volume Weights for 16 Prototype Buildings by Climate Zone (percent)

Building Type	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Weights by Bldg Type
Large Office	0.13	0.39	0.06	0.49	0.28	0.12	1.05	0.00	0.15	0.44	0.12	0.00	0.08	0.00	0.01	0.00	3.33
Medium Office	0.21	0.85	0.29	0.83	0.72	0.14	1.16	0.04	0.19	1.00	0.35	0.01	0.21	0.03	0.02	0.01	6.05
Small Office	0.17	1.13	0.29	1.02	0.47	0.08	0.84	0.06	0.12	0.89	0.32	0.01	0.18	0.03	0.02	0.00	5.61
Stand-Alone Retail	0.41	2.33	0.51	2.57	1.25	0.19	2.44	0.13	0.41	3.36	0.79	0.02	0.69	0.08	0.06	0.01	15.25
Strip Mall	0.20	1.08	0.25	1.11	0.63	0.10	0.89	0.02	0.11	0.96	0.20	0.00	0.09	0.01	0.00	0.00	5.67
Primary School	0.16	0.99	0.16	0.96	0.45	0.05	0.87	0.03	0.09	0.82	0.23	0.00	0.12	0.03	0.02	0.00	4.99
Secondary School	0.32	1.59	0.23	1.99	0.82	0.11	1.97	0.06	0.23	2.15	0.45	0.01	0.30	0.08	0.05	0.01	10.36
Hospital	0.06	0.51	0.10	0.49	0.27	0.04	0.66	0.03	0.10	0.80	0.21	0.00	0.12	0.02	0.03	0.00	3.45
Outpatient Health Care	0.08	0.62	0.13	0.63	0.28	0.06	0.81	0.02	0.17	1.06	0.22	0.01	0.23	0.03	0.03	0.00	4.37
Full Service Restaurant	0.02	0.11	0.02	0.12	0.05	0.01	0.12	0.01	0.01	0.13	0.03	0.00	0.02	0.00	0.00	0.00	0.66
Quick Service Restaurant	0.02	0.10	0.02	0.10	0.06	0.01	0.09	0.01	0.01	0.12	0.03	0.00	0.02	0.00	0.00	0.00	0.59
Large Hotel	0.13	0.69	0.12	0.70	0.79	0.11	0.90	0.04	0.12	0.90	0.20	0.00	0.16	0.05	0.03	0.00	4.95
Small Hotel	0.03	0.30	0.03	0.27	0.11	0.02	0.32	0.02	0.04	0.35	0.09	0.00	0.08	0.03	0.02	0.00	1.72
Non-Refrigerated Warehouse	0.51	3.07	0.58	2.70	2.30	0.15	2.84	0.08	0.43	3.01	0.70	0.00	0.29	0.03	0.03	0.00	16.72
High-rise Apartment	1.69	1.48	0.08	0.62	0.74	0.17	2.38	0.00	0.36	1.25	0.12	0.00	0.06	0.02	0.01	0.00	8.97
Mid-rise Apartment	0.34	1.19	0.09	0.82	0.86	0.26	1.58	0.02	0.36	1.15	0.32	0.01	0.23	0.06	0.03	0.00	7.32
Weights by Zone	4.46	16.43	2.98	15.42	10.08	1.61	18.92	0.57	2.92	18.39	4.37	0.07	2.89	0.49	0.37	0.05	100.00

3.0 2018 IECC Building Prototype Development

The starting point for the 2018 prototypes was the 2015 prototypes that were developed for the *Analysis of the 2015 IECC* (Zhang et al. 2015). PNNL reviewed all code changes from the 2015 to 2018 IECC. In this section, PNNL compares code changes in commercial energy efficiency provisions between the 2015 and 2018 IECC and documents how they were implemented in the 2018 IECC prototypes and modeled in *EnergyPlus*.

3.1 Review of Code Changes

Chapter 4 Commercial Energy Efficiency of the IECC provides three alternative paths for a new building to show compliance: (1) the mandatory and prescriptive requirements in the IECC; (2) the mandatory and total building performance requirements in the IECC; or (3) the requirements in the referenced Standard 90.1. This analysis looks only at compliance path (1), comparing the energy performance of the mandatory and prescriptive requirements in the 2015 IECC relative to those in the 2018 IECC, which is consistent with how DOE has traditionally evaluated model code updates when issuing its statutorily-directed *Determinations of Energy Savings*[1].

Of the changes to path (1), PNNL classified them into three categories, including those that 1) provide clarifications, administrative, or updated references to other documents that do not directly impact energy use; 2) result in energy efficiency impacts but are not quantified using the building prototypes; and 3) result in energy efficiency impacts that can be quantified. Only those in the third category were incorporated into the 2018 IECC building prototypes. Changes in the second category were not quantified when they met one of the following criteria:

1. The changes impact features not found in typical building designs. The prototype models include the most common design features found in each building type in the United States. Therefore, there are many less common features that are not represented in the prototypes, such as heated slabs and conditioned (cooled) vestibules. Changes affecting these features of buildings were not captured via the prototypes in order to preserve representation of the typical building stock.

2. The changes adopt standard practice. The systems and their configuration in the prototype models are based on standard practice that has been widely adopted in the United States. When a change is to fix a loophole for an uncommon design practice, the uncommon design is not modeled in the prototypes and thus, has no affect within the analysis.

3. Changes apply only to existing buildings instead of new buildings.

Table 3-1 lists the changes in the third category and Appendix A identifies their location in the IECC and which prototypes are impacted. The following subsections describe these changes in more detail, as well as their modeling strategies in the prototypes.

[1]https://www.energycodes.gov/development/determinations

Table 3-1 Changes Between the 2015 and 2018 IECC with Quantified Energy Impacts

Description of Code Changes
Establishes a new opaque envelope assembly category, garage door <14% glazing, in Table C402.1.4 for garage doors, which is previously under nonswinging opaque door category in Table C402.1.3 in the 2015 IECC.
Prescribes lower SHGC for vertical fenestration in climate zones 4 and 5.
Increases gas boiler efficiency.
Adds control requirements for heating and cooling systems in vestibules.
Reduces the threshold for variable flow pumping requirements for chilled water pumps and adds requirement for heating water pumps. Expands the VSD requirement to heat rejection loops.
Adds dual maximum control requirements to multiple-zone VAV systems with direct digital control (DDC).
Requires VAV system ventilation optimization even when ERV is installed.
Raises minimum threshold for energy recovery.
Requires deeper thermostat setback for networked guestrooms or those unoccupied for more than 16 hours/day. Also requires ventilation be turned off when guestrooms are unoccupied.
Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp and includes the service factor power in the determination of a 5 hp threshold. Eliminates the exception for climate zones 1 and 2.
Updates efficiency requirements for electric water heaters (>12kW) and gas water heaters (<75Kbtu/h) based on the latest federal requirement effective in 2018.
Increases efficacy requirements for lighting installed in dwelling units.
Adds occupancy sensor requirements for open offices.
Changes interior lighting power allowances including display lighting.
Reduces exterior lighting power allowances.
Updates distribution transformer efficiency requirements.

3.2 Building Envelope

3.2.1 U-factor for Garage Door

Code Change Description. The 2018 IECC establishes a new opaque envelope assembly category, garage door <14% glazing, in Table C402.1.4, which is under the nonswinging opaque door category in Table C402.1.3 in the 2015 IECC. A new footnote i to Table C402.1.3 also clarifies that garage doors should no longer follow the nonswinging door requirements, which is the case in the 2015 IECC.

Modeling Strategy. The number of opaque doors modeled in each prototype is summarized in Table 3-2. Swinging doors were assumed to be 7 ft tall by 3 ft wide, and rollup doors were assumed to be 10 ft tall by 8 ft wide.

For this analysis, the garage doors are modeled using the nonswinging door requirement of the 2015 IECC and the garage door <14% glazing requirement of the 2018 IECC. The energy impacts are captured in Large Hotel, Hospital, Stand-alone Retail, and Non-refrigerated Warehouse prototypes.

Table 3-2 Number of Opaque Doors in Prototypes

Prototype	Number of Swinging Doors Modeled	Number of Rollup Doors Modeled
Full Service Restaurant	1	0
Large Hotel	5	1
Hospital	16	1
Large Office	12	0
Medium Office	6	0
Small Hotel	3	0
Outpatient Health Care	17	0
Primary School	25	0
Quick Service Restaurant	1	0
Stand-Alone Retail	8	5
Secondary School	32	0
Small Office	2	0
Strip Mall	0	0
Non-Refrigerated Warehouse	1	12

3.2.2 Vertical Fenestration Solar Heat Gain Coefficient (SHGC)

Code Change Description. The 2018 IECC decreases the maximum SHGC requirement in climate zones 4 and 5 in Table C402.4.

Modeling Strategy. All the prototypes have vertical fenestration; therefore, this code change has energy impacts on all prototypes in these two climate zones. For each prototype building, assumptions were made in previous analyses (Thornton et al. 2011 and Zhang et al. 2015) about the mixed use of vertical fenestration types in each prototype. Weighted U-factor and SHGC were developed using the fenestration type weighting factors (Thornton et al. 2011) and the code requirements in the IECC. The weighting factors remain the same for each prototype between the 2015 and 2018 IECC but different window constructions were selected in EnergyPlus models to reflect the SHGC differences between the two IECC editions.

3.3 Building Mechanical Systems

3.3.1 Gas-Fired Boiler Efficiency

Code Change Description. The IECC contains requirements for specific types of equipment that are regulated by federal efficiency standards for manufacturing and import. Based on the new federal standards, the 2018 IECC updated the annual fuel utilization efficiency (AFUE) requirements for gas- and oil-fired boilers with capacity <300,000 Btu/h in Table C403.3.2(5).

Modeling Strategy. Gas-fired boilers are used in prototypes with hydronic heating systems, including the Large Office, Primary School, Secondary School, Outpatient Health Care, Large Hotel and

High-Rise Apartment. The capacity of the boilers is automatically sized based on the building load. For each prototype building, a sizing simulation run was performed first and then a script was used to assign the appropriate thermal efficiency input based on the code requirement. The impact of this code change was captured for prototypes with boilers sized less than 300,000 Btu/h.

3.3.2 Controls for Heating and Cooling Systems in Vestibules

Code Change Description. The 2018 IECC establishes a new requirement C403.4.1.4 to limit heating and cooling energy use associated with vestibules. It requires heated and cooled vestibules to have controls to limit the heating setpoint to a maximum of 60°F and the cooling setpoint to a minimum of 85°F. The vestibule heating system is also required to include automatic controls configured to shut off the heating system when the outdoor air temperature is above 45°F. Control of heating or cooling provided by site-recovered energy or transfer air is exempted from meeting these requirements.

Modeling Strategy. The new requirement only impacts the Stand-alone Retail prototype, which has a designated thermal zone serving the purpose of a vestibule, heated using a unit heater and not cooled. The gas unit heater follows the same thermostat setpoint and schedule as the rest of the building in the 2015 IECC model. The 2018 IECC requirement was implemented using a two-step approach: (1) the heating setpoint for the vestibule is limited to a maximum of 60°F, and (2) an energy management system (EMS) routine in EnergyPlus was created to shut off the unit heater and fan when the outdoor air temperature is above 45°F.

3.3.3 Modified Threshold for VSD Pumps

Code Change Description. Section C403.4.4 was modified to improve energy efficiency of hydronic systems. The 2018 IECC reduces the threshold of hydronic heating or cooling output capacity from 500,000 Btu/h to 300,000 Btu/h for part-load control requirements to be triggered. It also reduces the threshold that triggers the requirement for variable flow and variable speed drives (VSD) for pumping systems. The pump threshold is reduced from 10 to 2 hp for continuous operation and time schedule controlled pumps. Pumps that have operation controlled by direct digital control based on zone demand result in a varied threshold based on climate zone. Where formerly only chilled water pumps and those in a heat rejection loop serving water-cooled unitary air conditioners were covered, large heating water pumps are now included.

Modeling Strategy. The output capacity of the chilled water systems in the prototypes is over 500,000 Btu/h, so the C403.4.4 Part-load Controls provision is applicable to all chilled water systems. A few hydronic heating systems in the Outpatient Health Care prototype in warmer climates are between 300,000 Btu/h and 500,000 Btu/h. PNNL identified two reasons that the capacity threshold change does not impact these small heating systems:

1) Section C403.4.1.5 Hot Water Boiler Outdoor Temperature Setback Control (Mandatory) already requires supply-water temperature reset regardless of heating output capacity. Therefore, the change in output capacity threshold for C403.4.4 (1), supply-water temperature reset, does not impact hydronic heating systems.

2) All hydronic heating systems are assumed to vary flow by "riding the pump curve" as their typical design. The pump size thresholds are more stringent than the heating output thresholds for the applicability of the part-load controls.

The pump threshold change potentially impacts the following prototypes with hydronic heating or cooling systems: Large Hotel, Large Office, Secondary School, Primary School, Outpatient Health Care, and Hospital. In the recent DOE Standard 90.1-2016 Determination analysis, the baseline hydronic systems in all prototypes were modified to include a pump motor sizing factor of 1.25 times the required brake horsepower with varied pump flow.

The 2015 IECC does not require heating pumps to have VSD, so pumps are assumed to vary flow by "riding the pump curve". In the 2015 IECC prototypes, all chilled water systems have primary-secondary pumping systems and they do not need to have VSD either. For the 2018 IECC, a VSD pump is included when the pump sizes are greater than the values in Table 3-3.

Table 3-3 VSD Requirements for Demand-Controlled Chilled Water and Heating Pumps in the 2018 IECC

Motor Nameplate Horsepower	Chilled Water Pumps in These Climate Zones	Heating Water Pumps in These Climate Zones
≥2 hp	0A, 0B, 1A, 1B, 2B	NR
≥3 hp	2A, 3B	NR
≥5 hp	3A, 3C, 4A, 4B	7, 8
≥7.5 hp	4C, 5A, 5B, 5C, 6A, 6B	3C, 5A, 5C, 6A, 6B
≥10 hp		4A, 4C, 5B
≥15 hp	7, 8	4B
≥25 hp		2A, 2B, 3A, 3B
≥100 hp		1B
≥200 hp		0A, 0B, 1A
NR: not required		

3.3.4 Dual Maximum Control Requirements to Multiple-Zone VAV Systems

Code Change Description. Section C403.4.4 in the 2015 IECC limits zone airflow of multiple zone VAV systems to 30% of the maximum supply air during deadband and before reheating can occur. It also allows a higher reheating airflow rate if a reduction in overall annual energy use can be demonstrated by offsetting reheat/recool energy losses through a reduction in outdoor air intake for the system. In the 2018 IECC, this section is renumbered to C404.6.1 and requires systems with DDC to implement a dual maximum control strategy, in which the minimum zone airflow becomes 20% during deadband and is allowed to increase to 50% during reheating to better control the supply air temperature and improve ventilation effectiveness.

Modeling Strategy. This code change is related to VAV terminal box control and it impacts building prototypes with an air system serving multiple zones: Large Office, Medium Office, Hospital, Outpatient Health Care, Large Hotel, Primary School, and Secondary School. PNNL assumed they all have DDC, which is typical for most multiple-zone VAV systems. For the 2015 IECC prototypes, a simple-maximum control sequence with 30% minimum damper position is used as illustrated in Figure 3.1.

In the 2018 prototypes, the modeled dual-maximum control sequence has one maximum damper position for cooling and one for heating. When the zone is in the deadband mode, the damper stays at the minimum position, which is the higher value of 20% and the minimum position to meet the ventilation requirement. When the zone temperature falls below the heating setpoint and the zone mode changes to the heating mode, the reheating coil valve opens up increasingly while the damper position is still at the minimum position. With increasing heating load, the reheat coil valve can open until the supply air temperature reaches the predefined maximum value. Then, the damper position increases up to the maximum heating airflow setpoint of 50% if more heat is needed for zone heating. Such a control sequence is illustrated in Figure 3.2.

Both the 2015 and 2018 IECC state that a terminal airflow rate higher than 30% (2015 IECC) or 20% (2018 IECC) is allowed if it can be demonstrated to reduce overall system annual energy use by offsetting reheat/recool energy losses through a reduction in outdoor air intake for the system. PNNL has established a modeling strategy to determine the minimum zone supply airflow to meet this requirement. The calculation procedure includes four steps: (1) calculate zone ventilation efficiency; (2) calculate system ventilation efficiency; (3) increase the minimum damper fraction (i.e., ratio of minimum to maximum zone supply airflow) from 30% (2015 IECC) or 20% (2018 IECC) to a new value based on a target value of system ventilation efficiency; and (4) calculate the system design outdoor air intake.

EnergyPlus does not allow dual maximum control (reverse damper control input in the software) for electric reheat VAV terminals, which are in Medium Office and Outpatient Health Care. Therefore, the dual maximum control requirement is not captured in these prototypes.

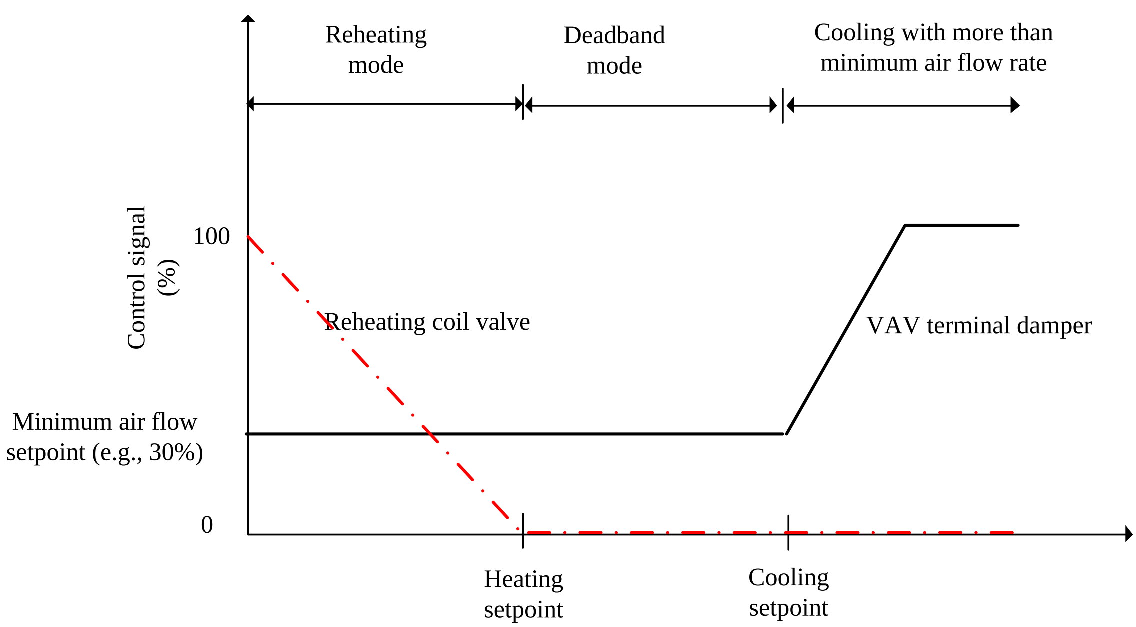

Figure 3.1. Single-maximum Terminal Box Control Sequence

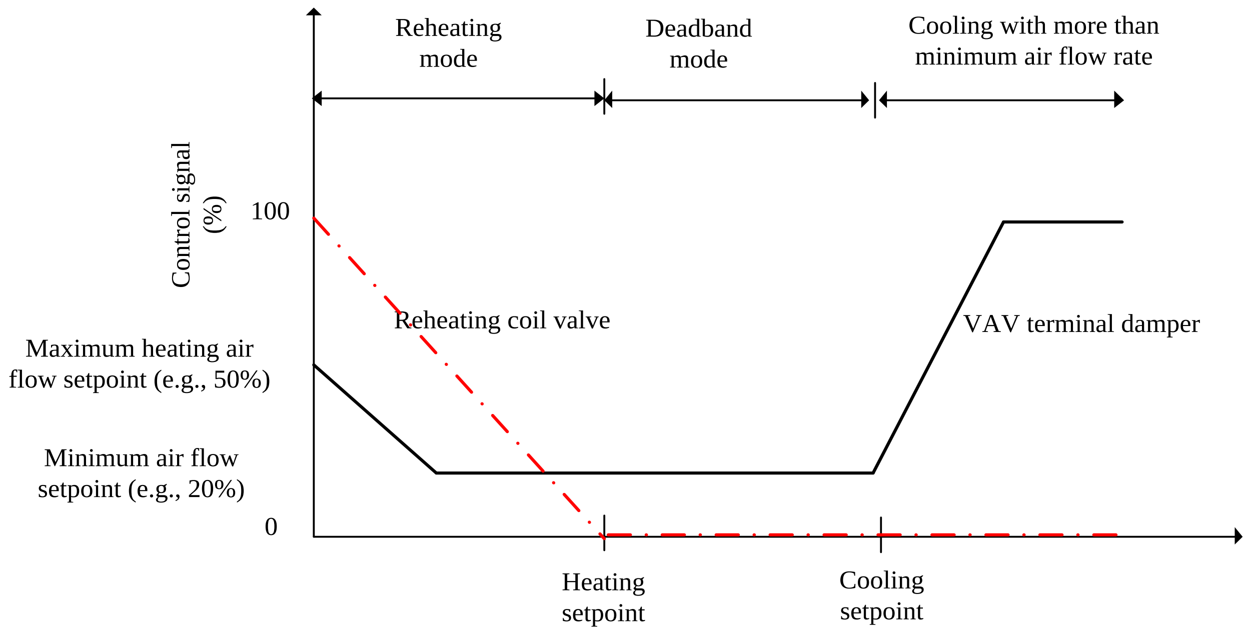

Figure 3.2. Dual-maximum Terminal Box Control Sequence

3.3.5 ERV with Ventilation Optimization

Code Change Description. The 2015 IECC allows systems with exhaust energy recovery to be exempt from the Multi-zone VAV Ventilation Optimization Control provision per Exception 2 to Section C403.4.4.6. This exception is removed in the 2018 IECC (renumbered to C403.6.6).

Modeling Strategy. Dynamic ventilation optimization or dynamic ventilation reset was simulated using the mechanical controller object in EnergyPlus. This object has an option to turn on the ventilation rate procedure calculations for optimizing system outdoor air flow in multi-zone VAV systems. Previously, dynamic ventilation reset was only turned on when there was no energy recovery ventilator (ERV) in the system. In the 2018 IECC models, the ventilation optimization control was modeled for all multiple-zone VAV systems regardless of the use of an ERV.

3.3.6 Raises Minimum Energy Recovery Threshold

Code Change Description. Section C403.7.4 uses supply fan airflow rate and the ratio of design outdoor airflow rate to fan airflow rate to determine if an ERV is required. The 2018 IECC raises the minimum design outdoor airflow rate threshold in Tables C403.2.7(1) and C403.2.7(2) (renumbered to Tables C403.7.4(1) and C403.7.4(2)) from zero cfm to a reasonable amount based on minimum ERV products available on the market. Overall this will have the impact of reducing the requirement for ERVs in certain climates where small size units are not readily available.

Modeling Strategy. In the *Analysis of the 2015 IECC*, air handling units in Mid-Rise and High-Rise Apartment in certain climate zones meet the trigger for the ERV requirements in the 2015 IECC but ERV was not added to these prototypes because products were not available for those small air handing units (AHU).

For this analysis, because the new ERV thresholds in the 2018 IECC are based on the availability of market products, PNNL used the same thresholds for both 2015 (a baseline change) and 2018 IECC to implement the code changes. The inclusion of an ERV in a system in the prototypes depends on the climate zone, system airflow and the design outdoor air fraction. An initial design simulation is performed; and based on the system supply and outdoor air flow rates, a script automatically inserts the ERV into the system where required. The code change impacts systems with small supply and outdoor air flow rates, such as those found in the Mid- and High-rise Apartment prototypes.

3.3.7 Hotel Guestroom Controls

Code Change Description. The 2018 IECC introduces a new set of automatic control requirements for HVAC systems serving guestrooms in large hotels with more than 50 guestrooms. These include:

1) Two levels of thermostat setback for when a room is unrented or rented but not occupied. They require heating and cooling setpoints to be lowered and raised, respectively by 4°F when rented rooms are unoccupied. For unrented unoccupied periods, heating and cooling setpoints are to be lowered to 60°F and raised to 80°F, respectively.

2) Ventilation and exhaust airflow must also be turned off when rooms are unoccupied.

Unrented periods can be determined either by the networked guestroom control system or by a longer unoccupied period up to 16 hours. Key card control systems may be used to indicate occupancy.

Modeling Strategy. This code change only impacts Small and Large Hotel prototypes. The Small Hotel already has separate blocks of vacant guestrooms, while vacancy was managed through an average schedule in the Large Hotel. The baseline of the Large Hotel was modified to have separate blocks of rented and unrented rooms. The Small Hotel has 65% occupancy on average, while the Large Hotel has 58% occupancy. The ventilation for rented rooms is turned off 6 hours per day, and the ventilation for unrented rooms is turned off 23 hours per day, with a 1-hour daily ventilation purge. The baselines had a temperature setback in occupied rooms because this was previously required in the general thermostat requirements. The temperature setpoints and ventilation operation for the various modes are shown in Table 3-4.

Table 3-4. Guestroom Setpoints and Ventilation Control

Guestroom Condition	2015 IECC			2018 IECC		
	Heating	Cooling	Ventilation	Heating	Cooling	Ventilation
Occupied	70°F	70°F	Continuous	70°F	70°F	Continuous
Rented Unoccupied	66°F	74°F	Continuous	66°F	74°F	Off 6 hr/day
Unrented Unoccupied	66°F	74°F	Continuous	60°F	80°F	Off 23 hr/day

3.3.8 Reduced Threshold for Fan Speed Control for Heat Rejection Equipment

Code Change Description. The 2018 IECC has more stringent requirements in C403.9.1 Fan Speed Control for heat rejection equipment than C403.4.3.2 in the 2015 IECC. This code change reduces the threshold where variable speed drives are required for heat rejection fan systems. The fan threshold is reduced from 7.5 to 5 hp. It also eliminates the exception for climate zones 1 and 2 for cooling tower fans. In addition, the new requirement clarifies the maximum motor horsepower based on the service factor that should be used to establish compliance with this requirement.

Modeling Strategy. This code change potentially impacts the following prototypes with water-cooled heat rejection: High-rise Apartment, Large Office, and Hospital. The heat rejection fans serving water-loop heat pumps in High-rise Apartment are close to 5 hp and therefore are impacted by this code change. However, the Hospital and Large Office prototypes have cooling tower fans that are much greater than 7.5 hp; therefore, they are not impacted. These large cooling towers were established as variable speed by standard practice in the baseline prototypes, so there was no change made for removing the exception in climate zones 1 and 2. For High-rise Apartment, the evaporative fluid cooler type in the EnergyPlus model was changed from “SingleSpeed” in the 2015 IECC baseline to “TwoSpeed” for 2018 IECC.

3.4 Service Water Heating

3.4.1 Updates Efficiency Requirements for Water Heaters

Code Change Description. The 2018 IECC includes an updated Table C404.2 Minimum Performance of Water-Heating Equipment based on new federal appliance and equipment standards. The changes impact several water heater categories, such as electric water heaters, gas and oil storage water heaters, and gas and oil instantaneous water heaters.

Modeling Strategy. All water heaters in the prototypes are either electric water heaters or gas storage water heaters by equipment type defined in Table C404.2. The efficiency and tank heat loss for these water heaters in the prototypes are calculated based on their volume and size categories. The electric water heaters (>12kW) and gas water heaters (<75 kBtu/h) in Small Office, Stand-alone Retail, Strip Mall, and Non-refrigerated Warehouse are affected by this code change.

3.5 Electrical Power and Lighting Systems

3.5.1 Dwelling Unit Lighting Efficacy

Code Change Description. The 2018 IECC clarifies that lighting power allowance in dwelling units in multifamily buildings shall comply with R404.1, which was updated to require no less than 90% of permanently installed lighting fixtures to use high-efficacy lamps. The requirement for high-efficacy lamps is 75% in the 2015 IECC.

Modeling Strategy. In the recent DOE Standard 90.1-2016 Determination analysis, a study by Gifford et al. (2012) was used to update the typical lighting usage in the two apartment prototypes. The updated baseline assumption represents typical multifamily homes that are not designed to meet a particular energy code provision.

PNNL calculated changing an apartment unit from using 75% high-efficacy lamps for the 2015 IECC to 90% for the 2018 IECC would reduce their hard-wired lighting energy usage by about 94 W×hr/day or by 12%. This difference was modeled in the Mid-rise and High-rise Apartments using their lighting power density inputs to the apartment zones.

3.5.2 Occupancy Sensor Lighting Control

Code Change Description. There are several changes to Section C405.2.1 Occupant Sensor Controls: 1) clarifying the space names for consistency without changing the stringency, 2) reducing the occupancy sensor time delay from 30 to 20 minutes, and 3) adding occupancy sensor control to open office areas.

Modeling Strategy. The New Commercial Construction Characteristics database (Richman et al. 2008) is used to determine the fraction of open office space type in the Small, Medium, and Large Offices, Large Hotel, and Hospital prototypes. These spaces do not have occupancy sensor lighting control in the 2015 IECC models and the modeled lighting schedules are based on scheduled controls. To implement the new occupancy sensor control, PNNL applied a 10% reduction to the lighting schedule fractions during the occupied hours.

PNNL reviewed some literature and did not find sufficient data to quantify the energy impacts from reducing occupancy sensor time delay from 30 to 20 minutes. A paper from VonNeida (2000) includes data with time delay of 5, 10, 15, and 20 minutes. It was not clear if extrapolating the data to 30 min is reasonable and the data were not available for all the space types required in the 2018 IECC. Therefore, the impact of reducing time delay was not captured.

3.5.3 Interior Lighting Power

Code Change Description. The lighting power density (LPD) allowances for many building area types and space types in Tables C405.3.2(1) and C405.3.2(2) are modified to reduce energy use of lighting systems from 2015 to 2018 IECC. In addition, the additional interior lighting power allowance for specific lighting functions is reduced in C405.3.2.2.1.

Modeling Strategy. The change affects all prototypes. Each thermal zone in the prototypes is either mapped to a single space-by-space category or is assumed to be a mix of two or more space types. Because the three office prototypes do not have detailed thermal zones, the office building LPD from the whole building area method was used.

Section C406 of the IECC requires buildings to comply with the requirements in one of eight high efficiency package options. In the previously developed 2012 and 2015 IECC prototypes, the reduced lighting power option was selected. To be consistent with the previous IECC prototypes, PNNL selected the same option for the 2018 IECC. Some editorial changes to code language for this option (see C406.3) were made but the requirement remains the same, i.e., 10% reduction to the LPD calculated based on Tables C405.3.2(1) and C405.3.2(2). PNNL used the calculated LPD allowances accounting for C406.3 to develop two sets of lighting power inputs to the prototypes for the 2015 and 2018 IECC.

3.5.4 Exterior Lighting Power

Code Change Description. The exterior lighting power allowances for most area types and applications listed in Tables C405.4.2(2) and C405.4.2(3) are reduced in the 2018 IECC compared to the 2015 IECC.

Modeling Strategy. These changes are applicable to all prototypes for only three major exterior lighting applications: uncovered parking areas, building entrances and exits, and building facades. The development of assumptions for exterior lighting in prototypes is described in Thornton et al. (2011). Based on the lighting power allowances in Tables C405.4.2(2) and C405.4.2(3), the total exterior lighting power was calculated for each of the three major applications for all prototypes. During the recent DOE Standard 90.1-2016 Determination Analysis, PNNL updated some baseline assumptions about what exterior lighting zones are applicable to each prototype as shown in Table 3-5. These assumptions allow PNNL to assign the proper power allowance to a prototype based on its exterior lighting zone. Where a prototype is in two or three lighting zones, an average of the lighting power allowances for the multiple zones is used.

Table 3-5. Exterior Lighting Zones for Prototypes

Prototype	Exterior Lighting Zone
Quick Service Restaurant	2,3,4
Full Service Restaurant	2,3,4
Strip Mall	2,3
Large Office	4
Outpatient Health Care	2,3
Non-refrigerated Warehouse	2,3
Stand-Alone Retail	2,3
Small Office	2,3
Medium Office	2,3
Primary School	2
Secondary School	2,3
Hospital	3,4
Small Hotel	3
Large Hotel	3,4
Mid-rise Apartment	2,3
High-rise Apartment	3,4

Table 3-6 summarizes the total exterior lighting power for each prototype for the 2015 and 2018 IECC and they are modeled as exterior lighting objects in the prototypes.

Table 3-6. Exterior Lighting Power in Prototypes for 2015 and 2018 IECC

Prototype	Parking Lot		Building Entrances		Building Façade	
	2015 IECC (W)	2018 IECC (W)	2015 IECC (W)	2018 IECC (W)	2015 IECC (W)	2018 IECC (W)
Small Office	713	446	148	115	38	38
Medium Office	6947	4342	456	376	390	390
Large Office	42265	26027	1037	968	9734	9734
Stand-Alone Retail	2800	1751	1528	1304	238	238
Strip Mall	3390	2120	3240	2520	315	315
Primary School	881	584	2350	1646	113	113
Secondary School	4745	2974	3807	2995	332	332
Outpatient Health Care	6634	4148	1664	1402	131	131
Hospital	8905	5432	1669	1499	2203	2203
Small Hotel	3368	2022	247	225	432	432
Large Hotel	10182	6192	487	444	3755	3755
Non-refrigerated Warehouse	1604	1005	4594	3955	86	86
Quick Service Restaurant	979	608	55	42	92	92
Full Service Restaurant	2154	1337	143	123	116	116
Mid-rise Apartment	2286	1429	0	0	167	167
High-rise Apartment	8227	5011	0	0	1874	1874

3.5.5 Transformer Efficiency

Code Change Description. Table C405.7 Minimum Nominal Efficiency Levels for 10 CFR 431 Low-Voltage Dry-Type Distribution Transformers is updated with more stringent requirements for three-phase transformers, which reflect the federal energy efficiency standards that went into effect on January 1, 2016.

Modeling Strategy. Prototypes with floor areas greater than 50,000 square feet, i.e., Medium Office, Large Office, Primary School, Secondary School, Hospital, and Large Hotel, are assumed to include transformers as documented in Thornton et al. (2011). PNNL captured efficiency changes using the EnergyPlus transformer object, which takes efficiency input and requires electric end use through the transformer to be specified. All miscellaneous plug loads and incandescent lighting are assumed to be fed through the transformers. Assumptions about the fraction of incandescent lighting to total interior lighting in the prototypes are documented in Thornton et al. (2011).

4.0 Site Energy and Energy Cost Savings Results

This section summarizes the estimated site energy and energy cost savings for the 2018 IECC compared to the 2015 IECC. The results of the analysis are summarized in Table 4.1. This table groups the building prototypes by their principal activity and shows the construction weighting factors by building prototype. The table provides a side-by-side comparison of the site EUI and ECI for the 2015 and 2018 editions of the IECC. Site energy is utility electricity and natural gas delivered and used at the building site. The EUI and ECI shown in Table 4.1 for each prototype are national weighted averages across climate zones in the United States. The percent savings (reduction) in EUI and ECI are presented as well. A negative percentage would reflect increases in EUI or ECI. The last row of Table 4.1 shows the national weighted average results from all 16 prototypes and 16 climate zones using the construction weighting factors (see Table 2.2 in this report). As shown in Table 4.1, on a weighted national basis, the 2018 IECC results in 5.1% energy savings and 5.3% energy cost savings over the 2015 IECC. These savings include federally mandated efficiency improvements of appliances and equipment that have taken effect since (but independent of) the publication of the 2015 IECC. The savings attributed to federal appliance and equipment standards are included in the results in Table 4.1.

Table 4-1. Site Energy and Energy Cost Savings between the 2015 and 2018 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI ($kBtu/ft^2$-yr) 2015 IECC	Site EUI ($kBtu/ft^2$-yr) 2018 IECC	Site EUI Savings (%)	ECI ($\$/ft^2$-yr) 2015 IECC	ECI ($\$/ft^2$-yr) 2018 IECC	ECI Savings (%)
Office	Small Office	5.6	29.6	28.6	3.4%	$0.89	$0.85	4.5%
	Medium Office	6.0	34.2	33	3.5%	$0.97	$0.93	4.1%
	Large Office	3.3	71.1	67.9	4.5%	$2.04	$1.98	2.9%
Retail	Stand-Alone Retail	15.3	47.1	40.9	13.2%	$1.20	$1.04	13.3%
	Strip Mall	5.7	55.4	51.5	7.0%	$1.46	$1.33	9.6%
Education	Primary School	5.0	52.7	48.8	7.4%	$1.31	$1.20	8.4%
	Secondary School	10.4	43.1	40.2	6.7%	$1.11	$1.03	7.2%
Healthcare	Outpatient Health Care	4.4	119.7	115.7	3.3%	$3.09	$2.97	4.2%
	Hospital	3.4	125.6	124.3	1.0%	$2.90	$2.88	0.7%
Lodging	Small Hotel	1.7	60.3	56.4	6.5%	$1.29	$1.17	9.3%
	Large Hotel	5.0	87.7	85.4	2.6%	$1.79	$1.75	1.7%
Warehouse	Non-refrigerated Warehouse	16.7	16.2	14.4	11.1%	$0.36	$0.30	16.7%
Food Service	Quick Service Restaurant	0.6	575.5	572.2	0.6%	$8.45	$8.35	1.2%
	Full Service Restaurant	0.7	372	368	1.1%	$6.28	$6.14	2.2%
Apartment	Mid-Rise Apartment	7.3	43.6	43	1.4%	$1.25	$1.23	1.6%
	High-Rise Apartment	9.0	47.6	46.6	2.1%	$1.13	$1.10	2.7%
National Weighted Average		**100.0**	**54.5**	**51.7**	**5.1%**	**$1.31**	**$1.24**	**5.3%**

As can be seen from Table 4.1, the savings vary significantly by prototype. This is expected as code requirements are different by building type and by climate. PNNL did not separately quantify the national impacts of individual code changes. Although this approach does not allow the ranking of all code changes based on their energy savings impacts, a few high impact changes resulting in significant energy savings are listed below (categorized by end use):

a. HVAC: dual maximum control requirements to multiple-zone VAV systems with DDC (see Section 3.3.4); VAV system ventilation optimization when ERV is installed (see Section 3.3.5); HVAC control for hotel guestrooms during unoccupied hours (see Section 3.3.7).

b. Lighting: high efficacy lighting in dwelling units (see Section 3.5.1), lower interior and exterior lighting power allowance (see Sections 3.5.3 and 3.5.4), and extended occupancy sensor controls for open office area (see Section 3.5.2).

Figure 4.1 and Figure 4.2 illustrate the weighted EUI and ECI for each prototype and the national weighted EUI and ECI for the 2015 and 2018 editions of the IECC, respectively.

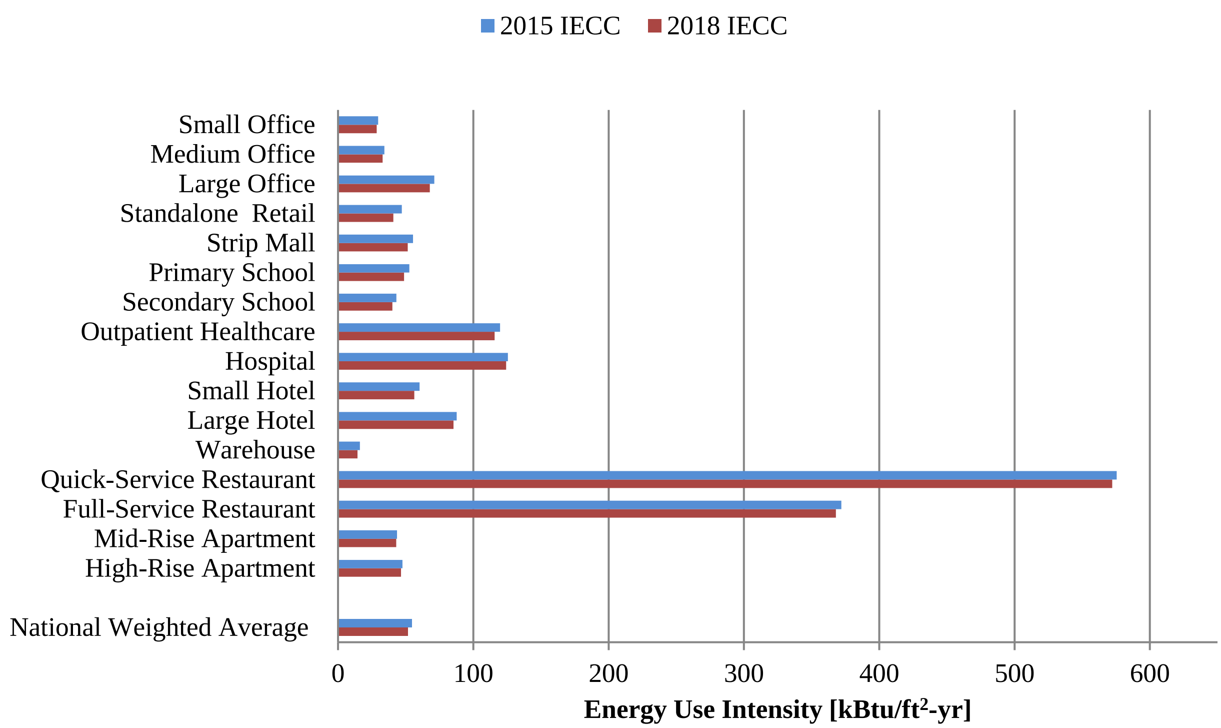

Figure 4.1. National Average Energy Use Intensity for all IECC Prototypes

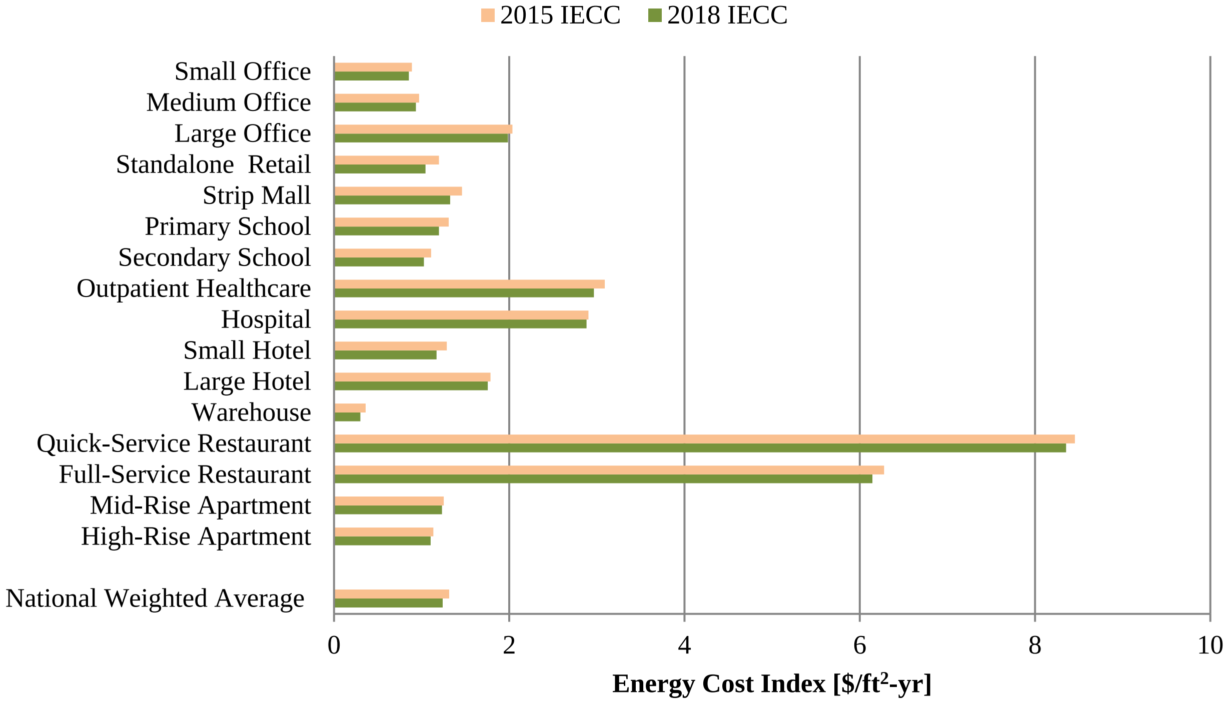

Figure 4.2. National Average Energy Cost Index for all IECC Prototypes

Table 4.2 presents the 2018 IECC savings for all prototype buildings aggregated by climate zone. The energy and energy cost savings vary by climate zone. The energy savings in 10 climate zones are greater than 5% and the savings in the remaining six climate zones (i.e., 1A, 3B, 3C, 4B, 4C, and 5B) are between 3.6 and 5%. The energy cost savings in all climate zones are over 5% except for climate zones 1A and 3C. For all climate zones, the percentages of energy cost savings are greater than the energy savings. The savings variance is attributed to the applicability of the code changes to different climate zones and the construction weights of the building types within the climate zones.

Table 4-2. Site Energy and Energy Cost Savings between the 2015 and 2018 IECC by Climate Zone

Climate Zones	Site EUI (kBtu/ft²-yr)		Site EUI Savings (%)	ECI ($/ft²-yr)		ECI Savings (%)
	2015 IECC	2018 IECC		2015 IECC	2018 IECC	
1A	49.4	47.6	3.6%	1.33	1.27	4.5%
2A	51.6	48.9	5.2%	1.36	1.28	5.9%
2B	51.3	48.5	5.5%	1.35	1.27	5.9%
3A	52.1	49.2	5.6%	1.29	1.21	6.2%
3B	48.2	46.1	4.4%	1.22	1.15	5.7%
3C	47.2	45.3	4.0%	1.22	1.16	4.9%
4A	55.4	52.6	5.1%	1.31	1.24	5.3%
4B	56.4	54.2	3.9%	1.33	1.26	5.3%
4C	51.0	48.9	4.1%	1.20	1.14	5.0%
5A	60.4	57.1	5.5%	1.32	1.24	6.1%
5B	57.0	54.8	3.9%	1.32	1.25	5.3%
5C	53.4	50.3	5.8%	1.28	1.20	6.3%
6A	69.8	66.0	5.4%	1.49	1.39	6.7%
6B	65.1	61.8	5.1%	1.43	1.35	5.6%
7	78.0	73.8	5.4%	1.60	1.50	6.3%
8	75.4	69.5	7.8%	1.44	1.31	9.0%
National Weighted Average	**54.5**	**51.7**	**5.1%**	**1.31**	**1.24**	**5.3%**

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Appendix A

Code Changes from the 2015 to 2018 IECC Included in Analysis and their Impact on Building Prototypes

Appendix A

Code Changes from the 2015 and 2018 IECC Included in Analysis and their Impact on Building Prototypes

The following table lists the code changes to the 2015 IECC that result in energy savings that were quantified in the analysis, as well as what section of the IECC is impacted and which prototypes were affected.

Table A.1. Changes between the 2015 and 2018 IECC with Quantified Energy Impacts and Impacted Prototypes

Section Number in the 2018 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Stand-Alone Retail	Strip Mall	Primary School	Secondary School	Outpatient Health Care	Hospital	Small Hotel	Large Hotel	Non-refrigerated Warehouse	Quick Service Restaurant	Full Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C402.1.4 Assembly U-factor, C-factor or F-factor-based method	Establishes a new opaque envelope assembly category, garage door <14% glazing, in Table C402.1.4 for garage doors, which is previously under nonswinging opaque door category in Table C402.1.3 in the 2015 IECC.				x					x		x	x				
C402.4 Fenestration (Prescriptive)	Prescribes lower SHGC for vertical fenestration in climate zones 4 and 5.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C403.3.2 HVAC equipment performance requirements	Increases gas boiler efficiency.		x	x			x	x	x	x		x					x

Section Number in the 2018 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Stand-Alone Retail	Strip Mall	Primary School	Secondary School	Outpatient Health Care	Hospital	Small Hotel	Large Hotel	Non-refrigerated Warehouse	Quick Service Restaurant	Full Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.4.1.4 Heated or cooled vestibules (Mandatory)	Adds control requirements for heating and cooling systems in vestibules.				x												
C403.4.4 Part-load controls	Reduces the threshold for variable flow pumping requirements for chilled water pumps and adds requirement for heating water pumps. Expands the VSD requirement to heat rejection loops.			x			x	x		x		x					x
C403.6.1 Variable air volume and multiple zone systems	Adds dual maximum control requirements to multiple-zone VAV systems with DDC.			x			x	x	x	x		x					
C403.6.6 Multiple-zone VAV system ventilation optimization control	Requires VAV system ventilation optimization even when ERV is installed.		x	x			x	x	x	x		x					
C403.7.4 Energy recovery ventilation systems (Mandatory)	Raises minimum threshold for energy recovery.															x	x
C403.7.6 Automatic control of HVAC systems serving guestrooms (Mandatory)	Requires deeper thermostat setback for networked guestrooms or those unoccupied for more than 16 hours/day. Also requires ventilation be turned off when guestrooms are unoccupied.										x	x					

Section Number in the 2018 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Stand-Alone Retail	Strip Mall	Primary School	Secondary School	Outpatient Health Care	Hospital	Small Hotel	Large Hotel	Non-refrigerated Warehouse	Quick Service Restaurant	Full Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.9.1 Fan speed control	Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp and includes the service factor power in the determination of a 5 hp threshold. Eliminates the exception for climate zones 1 and 2.																x
C404.2 Service water-heating equipment performance efficiency	Updates efficiency requirements for electric water heaters (>12kW) and gas water heaters (<75Kbtu/h) based on the latest federal requirement effective in 2018.	x			x	x							x				
C405.1 General (Mandatory)	Increases efficacy requirements for lighting installed in dwelling units.															x	x
C405.2.1.3 Occupant sensor control function in open plan office areas	Adds occupancy sensor requirements for open offices.	x	x	x						x		x					
C405.3.2 Interior lighting power allowance	Changes interior lighting power allowances including display lighting.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C405.4.2 Exterior lighting power allowance	Reduces exterior lighting power allowances.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Section Number in the 2018 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Stand-Alone Retail	Strip Mall	Primary School	Secondary School	Outpatient Health Care	Hospital	Small Hotel	Large Hotel	Non-refrigerated Warehouse	Quick Service Restaurant	Full Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C405.6 Electrical transformers (Mandatory)	Updates transformer efficiency requirements.			x			x	x	x	x			x				

Appendix B

Energy and Energy Cost Savings for the 2018 IECC and Corresponding Standard 90.1-2016

Appendix B

Energy and Energy Cost Savings for the 2018 IECC and Corresponding Standard 90.1-2016

Section 304(b) of the ECPA (Energy Conservation and Production Act), as amended, requires the Secretary of Energy to make a determination each time a revised edition of Standard 90.1 is published with respect to whether the revised standard would improve energy efficiency in commercial buildings. When DOE issues an affirmative determination on Standard 90.1, states are statutorily required to certify within two years that they have reviewed and updated the commercial provisions of their building energy code, with respect to energy efficiency, to meet or exceed the revised standard (42 U.S.C. 6833).

In support of DOE's determination, PNNL conducted an energy savings analysis for Standard 90.1-2016 compared to Standard 90.1-2013 (DOE 2017). Based on that analysis, DOE issued a determination that Standard 90.1-2016 would achieve greater energy efficiency in buildings compared to the 2013 edition of the standard.

As many states have historically adopted the IECC for both residential and commercial buildings, PNNL has also compared energy performance of Standard 90.1-2016 with the 2018 IECC to help states and local jurisdictions make informed decisions regarding model code adoption. Of the 43 states with statewide commercial building energy codes currently, 35 use a version of the IECC (BECP 2018).

Table B.1 shows side-by-side comparisons of the site EUI and ECI for Standard 90.1-2016 and the 2018 IECC for each of 16 prototype buildings along with the percent difference between the two. The national weighted average of all prototypes combined is also shown. Negative percentage differences indicate higher energy usage or energy costs for buildings designed to the 2018 IECC compared to those designed to Standard 90.1-2016.

Table B.1. Site Energy and Energy Cost Savings between Standard 90.1-2016 and the 2018 IECC

Building Prototype	Site EUI			ECI		
	Standard 90.1-2016 (kBtu/ft²/yr)	2018 IECC (kBtu/ft²/yr)	2018 IECC compared to 90.1-2016 (%)	Standard 90.1-2016 ($/ft²/yr)	2018 IECC ($/ft²/yr)	2018 IECC compared to 90.1-2016 (%)
Small Office	26.0	28.6	-10.0%	$0.78	$0.85	-9.0%
Medium Office	31.8	33.0	-3.8%	$0.90	$0.93	-3.3%
Large Office	67.0	67.9	-1.3%	$1.95	$1.98	-1.5%
Stand-Alone Retail	41.8	40.9	2.2%	$1.07	$1.04	2.8%
Strip Mall	52.1	51.5	1.2%	$1.35	$1.32	2.2%
Primary School	43.6	48.8	-11.9%	$1.03	$1.20	-16.5%
Secondary School	36.6	40.2	-9.8%	$0.90	$1.03	-14.4%
Outpatient Health Care	112.1	115.7	-3.2%	$2.87	$2.96	-3.1%
Hospital	120.1	124.3	-3.5%	$2.74	$2.88	-5.1%
Small Hotel	55.0	56.4	-2.5%	$1.12	$1.17	-4.5%
Large Hotel	85.2	85.4	-0.2%	$1.73	$1.75	-1.2%
Non-refrigerated Warehouse	14.8	14.4	2.7%	$0.30	$0.30	0.0%
Quick Service Restaurant	564.6	572.2	-1.3%	$8.27	$8.35	-1.0%
Full Service Restaurant	366.1	368.0	-0.5%	$6.08	$6.14	-1.0%
Mid-Rise Apartment	41.9	43.0	-2.6%	$1.20	$1.23	-2.5%
High-Rise Apartment	45.3	46.6	-2.9%	$1.05	$1.10	-4.8%
National Weighted Average	**50.4**	**51.7**	**-2.6%**	**$1.19**	**$1.24**	**-4.2%**

Figures B.1 and B.2 show the same results graphically. For most prototypes, both EUIs and ECIs were lower using Standard 90.1-2016 except for Stand-alone Retail and Strip Mall prototypes where the 2018 IECC resulted in lower energy use and energy costs. The 2018 IECC results in lower energy use and energy cost than Standard 90.1-2016 in the two retail prototypes because of two main reasons: 1) the design lighting power density for Sales Area space type in the 2018 IECC (with reduced lighting power per C406.3, a selected Additional Efficiency Package Option for this analysis) is lower than that in Standard 90.1-2016; and 2) the 2018 IECC requires all buildings to have optimum start controls where Standard 90.1-2016 (Section 6.4.3.3.3) does not require them to do so because the two prototypes are assumed not to have DDC controls.

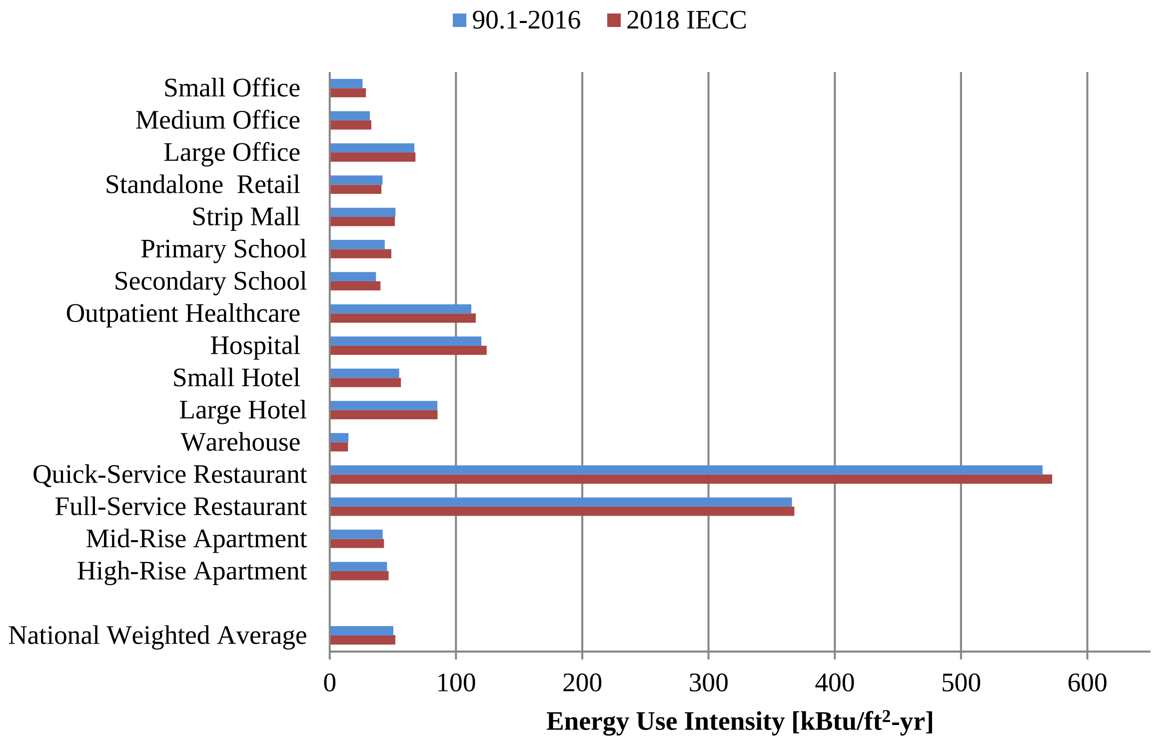

Figure B.1. National Average Energy Use Intensity for Standard 90.1 and IECC Prototypes

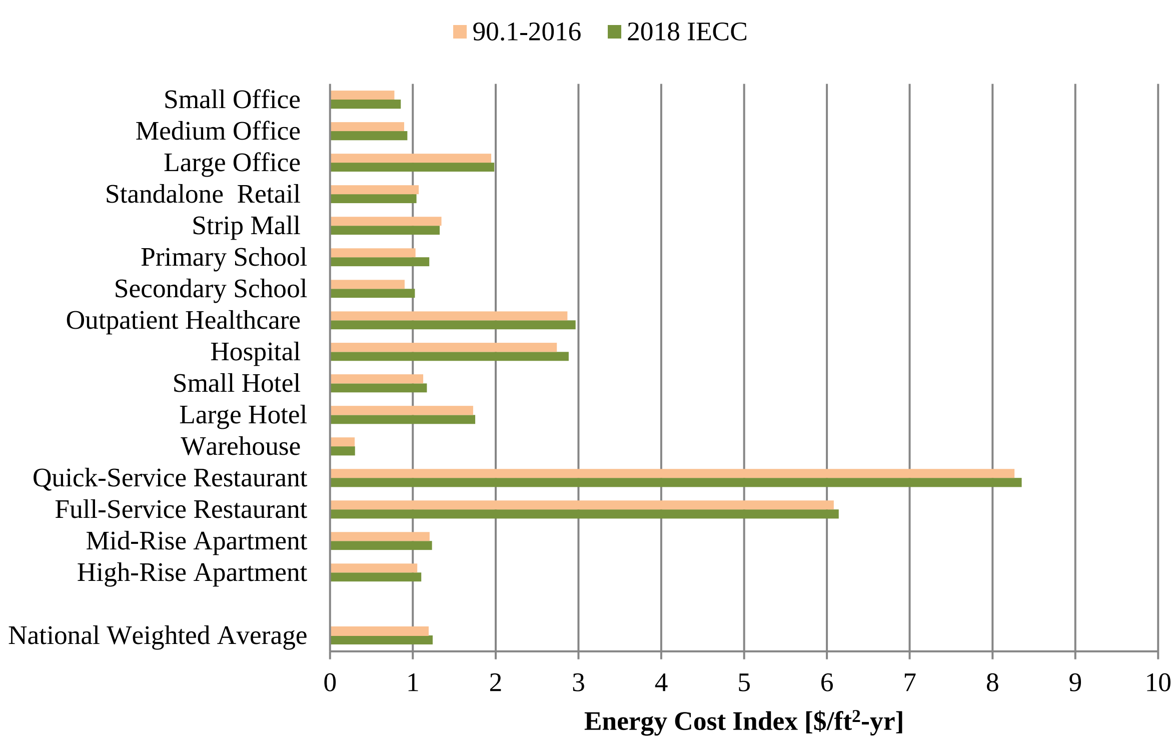

Figure B.2. National Average Energy Cost Index for Standard 90.1 and IECC Prototypes

The comparisons show the combined energy impacts of differences between the 2018 IECC and Standard 90.1-2016. Although the current analysis does not compare or rank the individual differences based on their energy savings, a few high impact differences by category can be identified as follows:

a. Envelope
    - Prescriptive window-to-wall ratio (WWR) limit: the 2018 IECC allows a WWR up to 30% unless a significant portion of the building is equipped with daylight responsive controls, in which case up to 40% is allowed. Standard 90.1-2016 requires WWR less than 40%.
    - Semi-heated space envelope requirements: the 2018 IECC does not have separate envelope requirements for semi-heated spaces. Semi-heated spaces are required to follow conditioned space requirements. Standard 90.1-2016 has less stringent insulation requirements for semi-heated spaces.
    - Vertical fenestration U-factor independent of frame material: the U-factor requirements for vertical fenestration in the 2018 IECC are independent of the frame material. Standard 90.1-2016 has higher U-factors for metal-framed fenestration than for nonmetal-framed fenestration.
    - Vestibule exceptions: the 2018 IECC exempts building entrance doors that open up to a space less than 3,000 square feet; Standard 90.1-2016 does not. The 2018 IECC also includes an exception from vestibule requirements if an air curtain is installed instead; Standard 90.1-2016 does not have such an exception.
    - Fenestration orientation: the 2018 IECC does not limit the distribution of fenestration area. Standard 90.1-2016 limits the fenestration area on the east and west façades.

b. Building mechanical systems
    - Transfer air: the 2018 IECC requires the use of transfer air to kitchen exhaust systems. Standard 90.1-2016 expands the requirement to more exhaust systems, including restroom and laundry exhaust.
    - Door switch connected to HVAC: Standard 90.1-2016 requires doors opening to the outside, which do not close automatically, to have switches that connect to the HVAC system, such that the HVAC system is put into deep setback (55°F for heating and 90°F for cooling) automatically 5 minutes after the door is opened. The requirement attempts to reduce the HVAC energy spent in satisfying the unintentional infiltration load from operable doors. The 2018 IECC does not have such a requirement.

c. Lighting
    - Dwelling unit (apartment) lighting power: the 2018 IECC requires 90% of all permanently installed luminaires in dwelling units to be high efficacy. Standard 90.1-2016 requires 75%.
    - Controls for secondary daylight zone: the 2018 IECC does not require secondary daylight zones to have daylight responsive controls; Standard 90.1-2016 does.
    - Egress lighting control: Standard 90.1-2016 requires lighting connected to emergency circuits to be turned off in spaces that comply with the automatic full off or scheduled off requirements when there are no occupants. It provides an exception to the automatic full off and scheduled off requirements for egress lighting by allowing 0.02 W/ft^2 or less lighting power to remain on during the unoccupied period. The 2018 IECC does not have such a requirement.

- Parking area luminaire control: Standard 90.1-2016 requires activity-sensing controls for pole-mounted lighting in parking lots with mounting heights lower than 24 feet and with lighting power greater than 78 W. The 2018 IECC does not have such a requirement.

d. Additional efficiency package options

- The interior lighting power allowances in Tables C405.3.2(1) and C405.3.2(2) in the 2018 IECC are almost the same as the corresponding requirements in Standard 90.1-2016. As discussed in Section 3.5.3, of the six additional efficiency package options, PNNL selected the reduced lighting power option to develop the 2018 IECC prototypes. Standard 90.1-2016 does not have such a requirement and therefore the modeled lighting power in the 90.1-2016 prototypes is about 10% more than the 2018 IECC prototypes.

Table B2 show the comparison of the analysis results for Standard 90.1-2016 and the 2018 IECC by climate zone. The EUI and ECI shown in the table for each climate zone are weighted averages across the 16 prototypes within that climate zone in the United States. For all climate zones, the table shows buildings designed to the 2018 IECC have higher energy consumption and costs than those designed to Standard 90.1-2016 based on a weighted average.

Table B.2. Site Energy and Energy Cost Savings between Standard 90.1-2016 and the 2018 IECC by Climate Zone

Climate Zone	Site EUI			ECI		
	Standard 90.1-2016 (kBtu/ft²/yr)	2018 IECC (kBtu/ft²/yr)	2018 IECC compared to 90.1-2016 (%)	Standard 90.1-2016 ($/ft²/yr)	2018 IECC ($/ft²/yr)	2018 IECC compared to 90.1-2016 (%)
1A	46.0	47.6	-3.5%	1.22	1.27	-4.1%
2A	47.6	48.9	-2.7%	1.23	1.28	-4.1%
2B	47.0	48.5	-3.2%	1.22	1.27	-4.1%
3A	48.4	49.2	-1.7%	1.17	1.21	-3.4%
3B	44.7	46.1	-3.1%	1.11	1.15	-3.6%
3C	44.0	45.3	-3.0%	1.11	1.16	-4.5%
4A	51.4	52.6	-2.3%	1.20	1.24	-3.3%
4B	52.5	54.2	-3.2%	1.21	1.26	-4.1%
4C	47.6	48.9	-2.7%	1.10	1.14	-3.6%
5A	55.9	57.1	-2.1%	1.20	1.24	-3.3%
5B	53.0	54.8	-3.4%	1.19	1.25	-5.0%
5C	48.9	50.3	-2.9%	1.16	1.20	-3.4%
6A	64.6	66.0	-2.2%	1.35	1.39	-3.0%
6B	59.3	61.8	-4.2%	1.28	1.35	-5.5%
7	71.8	73.8	-2.8%	1.44	1.50	-4.2%
8	67.2	69.5	-3.4%	1.26	1.31	-4.0%
National Weighted Average	**50.4**	**51.7**	**-2.6%**	**1.19**	**1.24**	**-4.2%**

On a national average basis for all prototypes combined, the 2018 IECC is 2.6% less efficient for energy use and 4.2% less for energy costs than Standard 90.1-2016. Based on the key differences listed above, PNNL identified a few amendments to the 2018 IECC that would better align the requirements with Standard 90.1-2016 to create parity on a nationally aggregated basis. Those amendments are located in Appendix C.

Appendix C

Amendments to the 2018 IECC to Align with Standard 90.1-2016

Appendix C

Amendments to the 2018 IECC to Align with Standard 90.1-2016

C.1 Proposed Amendments to Align the 2018 IECC with Standard 90.1-2016

PNNL identified a few amendments to the 2018 IECC that would better align the requirements with Standard 90.1-2016 to create parity on a nationally aggregated basis. States can use these amendments as they engage individual processes to review and update their building codes with respect to energy efficiency. Amendments provided are a resource for each state's consideration as they tailor their state building code to their individual needs. DOE provides the amendments to allow each state options and ease the burden of meeting the statutory requirement. A summary of each suggested amendment is provided below along with specific code change language to be applied to the 2018 IECC shown with inserted and deleted text. Tables C.1 and C.2 show the impact of adding these amendments to the 2018 IECC and the difference with Standard 90.1-2016 by building type and climate zone, respectively. The tables show that the addition of this package of amendments will result in both national weighted site energy cost and energy use for the 2018 IECC of within 1% of Standard 90.1-2016.

Table C.1. Site Energy Savings and Energy Cost Savings for the 2018 IECC with Amendments and Standard 90.1 2016 by Prototype

	Site Energy Use			Site Energy Cost		
Building Prototype	Standard 90.1-2016 (kBtu/ft²/yr)	2018 IECC with amendments (kBtu/ft²/yr)	2018 IECC with amendments compared to 90.1 2016 (%)	Standard 90.1-2016 Cost ($/ft²/yr)	2018 IECC with amendments Cost ($/ft²/yr)	2018 IECC with amendments compared to 90.1 2016 (%)
Small Office	26.0	25.7	1.2%	$0.78	$0.77	1.3%
Medium Office	31.8	31.4	1.3%	$0.90	$0.89	1.1%
Large Office	67.0	66.4	0.9%	$1.95	$1.94	0.5%
Stand-Alone Retail	41.8	40.2	3.8%	$1.07	$1.02	4.7%
Strip Mall	52.1	50.5	3.1%	$1.35	$1.29	4.4%
Primary School	43.6	44.2	-1.4%	$1.03	$1.05	-1.9%
Secondary School	36.6	36.9	-0.8%	$0.90	$0.92	-2.2%
Outpatient Health Care	112.1	114.6	-2.2%	$2.87	$2.93	-2.1%
Hospital	120.1	123.7	-3.0%	$2.74	$2.86	-4.4%
Small Hotel	55.0	56.4	-2.5%	$1.12	$1.17	-4.5%
Large Hotel	85.2	85.3	-0.1%	$1.73	$1.75	-1.2%
Non-refrigerated Warehouse	14.8	13.9	6.1%	$0.30	$0.28	6.7%
Quick Service Restaurant	564.6	570.9	-1.1%	$8.27	$8.32	-0.6%
Full Service Restaurant	366.1	366.9	-0.2%	$6.08	$6.11	-0.5%
Mid-rise Apartment	41.9	42.9	-2.4%	$1.20	$1.23	-2.5%
High-rise Apartment	45.3	46.6	-2.9%	$1.05	$1.10	-4.8%
National Weighted Average	**50.4**	**50.5**	**-0.2%**	**$1.19**	**$1.20**	**-0.8%**

Table C.2. Site Energy Savings and Energy Cost Savings for the 2018 IECC with Amendments and Standard 90.1 2016 by Climate Zone

	Site Energy Use			Site Energy Cost		
Climate Zone	Standard 90.1-2016 (kBtu/ft²/yr)	2018 IECC with Amendments (kBtu/ft²/yr)	2018 IECC with Amendments Compared to 90.1 2016 (%)	Standard 90.1-2016 Cost ($/ft²/yr)	2018 IECC with Amendments Cost ($/ft²/yr)	2018 IECC with Amendments Compared to 90.1 2016 (%)
1A	46.0	46.6	-1.3%	1.22	1.24	-1.6%
2A	47.6	47.5	0.2%	1.23	1.23	0.0%
2B	47.0	47.1	-0.2%	1.22	1.22	0.0%
3A	48.4	47.8	1.2%	1.17	1.16	0.9%
3B	44.7	44.9	-0.4%	1.11	1.12	-0.9%
3C	44.0	44.2	-0.5%	1.11	1.13	-1.8%
4A	51.4	51.5	-0.2%	1.20	1.20	0.0%
4B	52.5	52.8	-0.6%	1.21	1.22	-0.8%
4C	47.6	48.0	-0.8%	1.10	1.11	-0.9%
5A	55.9	56.0	-0.2%	1.20	1.20	0.0%
5B	53.0	53.5	-0.9%	1.19	1.21	-1.7%
5C	48.9	49.1	-0.4%	1.16	1.16	0.0%
6A	64.6	64.9	-0.5%	1.35	1.35	0.0%
6B	59.3	60.6	-2.2%	1.28	1.31	-2.3%
7	71.8	72.7	-1.3%	1.44	1.46	-1.4%
8	67.2	68.6	-2.1%	1.26	1.27	-0.8%
National Weighted Average	**50.4**	**50.5**	**-0.2%**	**1.19**	**1.20**	**-0.8%**

C.1.1 Exterior Lighting Controls

Purpose:

Require activity-sensing controls for parking lot lighting with low mounting heights (below 24 ft) and luminaire rated wattage greater than 78 W. These controls would reduce lighting power by at least 50% per luminaire when no activity is detected in the zone served by the lighting.

Specific Amendment to the 2018 IECC:

C405.2.6.3 Lighting setback. Lighting that is not controlled in accordance with Section C405.2.6.2 shall be controlled so that the total wattage of such lighting is automatically reduced by not less than ~~30~~ 50 percent by selectively switching off or dimming luminaires at one of the following times:

1. From not later than midnight to not earlier than 6 a.m.

2. From not later than one hour after business closing to not earlier than one hour before business opening.

3. During any time where activity has not been detected for 15 minutes or more.

4. Luminaires serving outdoor parking areas and having a rated input wattage of greater than 78 W and a mounting height of 24 ft (7.3 m) or less above the ground, shall be controlled to automatically reduce the power of each luminaire by a minimum of 50% when no activity has been detected in the area illuminated by the controlled luminaires for a time of no longer than 15 minutes. No more than 1,500 W of lighting power shall be controlled together.

C.1.2 Egress Lighting Controls

Purpose:

Require interior lights to have scheduled shutoff control except for egress lighting, up to a maximum of 0.02 W/ft^2 multiplied by the gross lighted area of the building.

Specific Amendment to the 2018 IECC:

C405.2 Lighting controls (Mandatory). Lighting systems shall be provided with controls that comply with one of the following.

1. Lighting controls as specified in Sections C405.2.1 through C405.2.7~~6~~.
2. Luminaire level lighting controls (LLLC) and lighting controls as specified in Sections C405.2.1, C405.2.4, ~~and~~ C405.2.5, and C405.2.6. The LLLC luminaire shall be independently capable of:

2.1. Monitoring occupant activity to brighten or dim to off lighting when occupied or unoccupied, respectively.

2.2. Monitoring ambient light, both electric light and daylight, and brighten or dim artificial light to maintain desired light level.

2.3. For each control strategy, configuration and reconfiguration of performance parameters including: bright and dim setpoints, timeouts, dimming fade rates, sensor sensitivity adjustments, and wireless zoning configurations.

Exceptions: Lighting controls are not required for the following:

1. Areas designated as security or emergency areas that are required to be continuously lighted.
2. Interior exit stairways, interior exit ramps and exit passageways up to a maximum of 0.02 W/ft^2 multiplied by the gross lighted area of the building.
3. Emergency egress lighting that is normally off.

C405.2.6 Scheduled shutoff. All lighting in the building not meeting requirements of C405.2.1, including lighting connected to emergency circuits, shall be automatically shut off during periods when the space is scheduled to be unoccupied using either (1) a time-of-day operated control device that automatically turns the lighting off at specific programmed times or (2) a signal from another automatic control device or alarm/security system. The control device or system shall provide independent control sequences that (1) control the lighting for an area of no more than 25,000 square feet (2322 m^2), (2) include no more than one floor, and (3) shall be programmed to account for weekends and holidays. Any manual control installed to provide override of the scheduled shutoff control shall not turn the lighting on for more than 2 hours per activation during scheduled off periods and shall not control more than 5000 square feet (465 m^2).

Exceptions: Lighting controls are not required for the following:

1. Lighting in spaces where lighting is required for 24/7 continuous operation.
2. Lighting in spaces where patient care is rendered.
3. Lighting in spaces where automatic shutoff would endanger the safety or security of the room or building occupants.
4. Lighting load not exceeding 0.02 W/ft^2 multiplied by the gross lighted area of the building.

C405.2.7~~6~~ Exterior lighting controls. Exterior lighting systems shall be provided with controls that comply with Sections C405.2.~~6~~7.1 through C405.2.6.4. Decorative lighting systems shall comply with Sections C405.2.~~6~~7.1, C405.2.~~6~~7.2 and C405.2.~~6~~7.4.

RENUMBER ALL SUBSECTIONS UNDER C405.2.6.1, C405.2.6.2, C405.2.6.3, AND C405.2.6.4 TO C405.2.7.1, C405.2.7.2, C405.2.7.3, AND C405.2.7.4, RESPECTIVELY.

C.1.3 Automatic Receptacle Control

Purpose:

Require automatic receptacle controls to reduce previously unregulated plug and process loads consumed by electric equipment in offices and other smaller spaces.

Specific Amendment to the 2018 IECC:

C405.10 Automatic Receptacle Control (Mandatory)

The following shall be automatically controlled:

a. At least 50% of all 125 V, 15 and 20 amp receptacles in all private offices, conference rooms, rooms used primarily for printing and/or copying functions, break rooms, classrooms, and individual workstations.

b. At least 25% of branch circuit feeders installed for modular furniture not shown on the construction documents.

This control shall function on

a. a scheduled basis using a time-of-day operated control device that turns receptacles off at specific programmed times—an independent program schedule shall be provided for controlled areas of no more than 5000 square feet and not more than one floor (the occupant shall be able to manually override the control device for up to two hours);
b. an occupant sensor that shall turn receptacles off within 20 minutes of all occupants leaving a space; or
c. an automated signal from another control or alarm system that shall turn receptacles off within 20 minutes after determining that the area is unoccupied.

All controlled receptacles shall be permanently marked to visually differentiate them from uncontrolled receptacles and are to be uniformly distributed throughout the space. Plug-in devices shall not be used to comply with Section C405.10.

Exceptions to Section C405.10

Receptacles for the following shall not require an automatic control device:

1. Receptacles specifically designated for equipment requiring continuous operation (24/day, 365 days/year).
2. Spaces where an automatic control would endanger the safety or security of the room or building occupants.

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ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis

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August 2014

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Executive Summary

Section 304(b) of the Energy Conservation and Production Act (ECPA), as amended, requires the Secretary of Energy to make a determination each time a revised version of ASHRAE Standard 90.1 is published with respect to whether the revised standard would improve energy efficiency in commercial buildings. When the U.S. Department of Energy (DOE) issues an affirmative determination on Standard 90.1, states are statutorily required to certify within two years that they have reviewed and updated the commercial provisions of their building energy code, with respect to energy efficiency, to meet or exceed the revised standard.

To meet these statutory requirements, the DOE Building Energy Codes Program (BECP) and Pacific Northwest National Laboratory (PNNL) conduct two types of analysis in a determination of energy savings for a revised Standard 90.1:

- **Qualitative Analysis**: This is a detailed textual analysis that identifies all the changes made to the previous edition of Standard 90.1 and categorizes the changes as having a positive, negative, or neutral impact on energy efficiency in commercial buildings. In the qualitative analysis, no attempt is made to estimate a numerical impact using whole building simulation. Three steps are typically undertaken in the qualitative analysis: identify all changes made to Standard 90.1, characterize the impact of each change on the energy efficiency of Standard 90.1, and identify those changes that can be incorporated into the subsequent quantitative analysis.
- **Quantitative Analysis**: This analysis uses the results of the qualitative analysis to identify which changes should be incorporated into the building simulation models to estimate the energy impact resulting from the changes to Standard 90.1.

This report provides the quantitative analysis to assess whether buildings constructed according to the requirements of ANSI/ASHRAE/IES Standard 90.1-2013 would result in improved energy efficiency in commercial buildings. The analysis considered each of the addenda to Standard 90.1-2010 that were included in Standard 90.1-2013. PNNL reviewed all addenda included by ASHRAE in creating Standard 90.1-2013 from Standard 90.1-2010, and considered their combined impact on a suite of prototype building models across all U.S. climate zones. . Out of the 110 total addenda, 30 were identified as having a measureable and quantifiable impact.

The present analysis builds on previous work by PNNL to assess the energy performance of recent editions of Standard 90.1.[1] A suite of 240 computer energy simulations for prototype buildings complying with Standard 90.1-2010 was developed, a combination of 16 prototype buildings in all15 U.S. climate zones. These prototypes were then modified in accordance with the addenda with quantifiable impacts on energy efficiency to create a second suite of corresponding building simulations reflecting the same buildings complying with Standard 90.1-2013. The building simulations were conducted using the DOE *EnergyPlus Version 8.0*[2] building simulation software. The resulting energy use from the complete suite of 480 simulation runs was then converted to energy use intensity (EUI, or energy use per unit floor

[1] Thornton et al. 2011. *Achieving 30% Goal: Energy and Cost Saving Analysis of ASHRAE/IES Standard 90.1-2010*. Pacific Northwest National Laboratory, Richland, Washington. Available at http://www.energycodes.gov/publications/research/documents/codes/PNNL-20405.pdf.
[2] DOE. 2013. *Energy Plus Energy Simulation Software, Version 8.0*. U.S. Department of Energy, Washington, D.C. Available at http://apps1.eere.energy.gov/buildings/EnergyPlus/.

area) metrics (site EUI, primary EUI), and energy cost intensity (ECI) results for each simulation. For each edition of the standard, these EUIs and ECIs were then aggregated to a national basis for each prototype using weighting factors based on construction floor area developed for each of the 15 U.S. climate zones using commercial construction data (Jarnagin and Bandyopadhyay 2010). When compared, the resulting weighted EUIs indicated that each of the 16 prototype buildings used less energy under Standard 90.1-2013 than under Standard 90.1-2010 on a national basis when considering site energy, primary energy, or energy cost. The EUIs were also aggregated across building types to a national commercial building basis using the same weighting data.

On a national basis, the quantitative analysis estimated a floor-space-weighted national average reduction in new building energy consumption of 8.5% for source energy and 7.6% when considering site energy. An 8.7% savings in energy cost, based on national average commercial energy costs for electricity and natural gas, was also estimated. National savings results by building type are shown in Figure E-1 and Tables E1, E2, and E3.

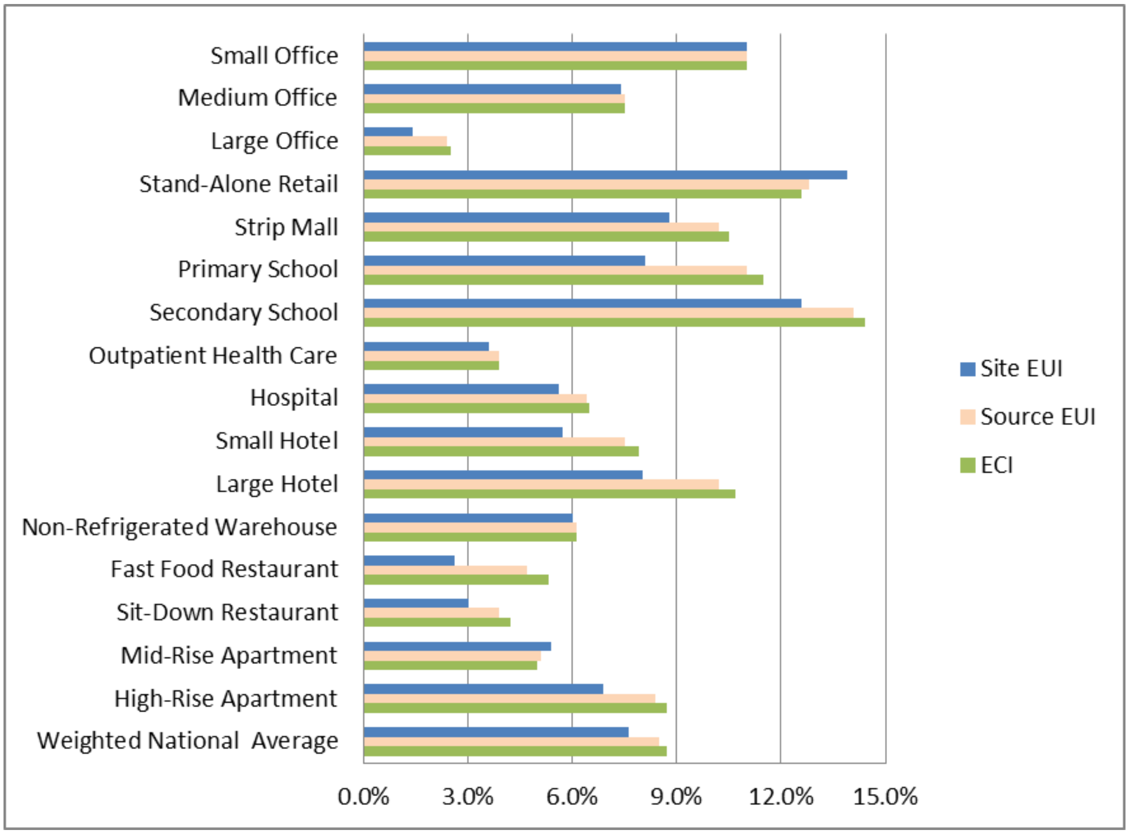

Figure E.1. Percentage Savings by Building Type from 90.1-2010 to 90.1-2013

Table E.1. Estimated Energy Use Intensity by Building Type – Standard 90.1-2010

Building Type	Prototype building	Building Type Floor Area Weight (%)	Whole Building EUI Data for Building Population		
			Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)
Office	Small Office	5.61	33.0	100.4	$0.99
	Medium Office	6.05	36.8	105.9	$1.03
	Large Office	3.33	71.9	210.7	$2.06
Retail	Stand-Alone Retail	15.25	53.4	142.9	$1.38
	Strip Mall	5.67	60.4	164.1	$1.58
Education	Primary School	4.99	59.0	151.1	$1.44
	Secondary School	10.36	47.7	130.3	$1.26
Healthcare	Outpatient Health Care	4.37	120.0	324.3	$3.13
	Hospital	3.45	131.0	321.1	$3.04
Lodging	Small Hotel	1.72	63.6	148.8	$1.40
	Large Hotel	4.95	96.7	217.7	$2.03
Warehouse	Non-Refrigerated Warehouse	16.72	18.2	43.2	$0.41
Food Service	Fast-Food Restaurant	0.59	591.5	1051.7	$9.27
	Sit-Down Restaurant	0.66	383.9	742.7	$6.69
Apartment	Mid-Rise Apartment	7.32	46.3	131.4	$1.28
	High-Rise Apartment	8.97	50.4	124.9	$1.19
National		**100**	**58.5**	**148.9**	**$1.42**

Table E.2. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013

Building Type	Prototype building	Building Type Floor Area Weight (%)	Whole Building EUI Data for Building Population		
			Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)
Office	Small Office	5.61	29.4	89.3	$0.88
	Medium Office	6.05	34.1	97.9	$0.95
	Large Office	3.33	70.8	205.8	$2.01
Retail	Stand-Alone Retail	15.25	45.9	124.6	$1.20
	Strip Mall	5.67	55.1	147.3	$1.42
Education	Primary School	4.99	54.2	134.4	$1.28
	Secondary School	10.36	41.7	111.9	$1.08
Healthcare	Outpatient Health Care	4.37	115.8	311.8	$3.00
	Hospital	3.45	123.7	300.7	$2.85
Lodging	Small Hotel	1.72	60.0	137.6	$1.29
	Large Hotel	4.95	89.0	195.4	$1.81
Warehouse	Non-Refrigerated Warehouse	16.72	17.1	40.6	$0.38
Food Service	Fast-Food Restaurant	0.59	576.4	1001.9	$8.78
	Sit-Down Restaurant	0.66	372.5	713.5	$6.41
Apartment	Mid-Rise Apartment	7.32	43.9	124.8	$1.21
	High-Rise Apartment	8.97	46.9	114.4	$1.08
National		**100**	**54.1**	**136.2**	**$1.30**

Table E.3. Estimated Percent Energy Savings between 2010 and 2013 Editions of Standard 90.1 – by Building Type

Building Type	Prototype building	Building Type Floor Area Weight (%)	Percent Savings in Whole Building Energy Use Intensity (%)		
			Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.0	11.0	11.0
	Medium Office	6.05	7.4	7.5	7.5
	Large Office	3.33	1.4	2.4	2.5
Retail	Stand-Alone Retail	15.25	13.9	12.8	12.6
	Strip Mall	5.67	8.8	10.2	10.5
Education	Primary School	4.99	8.1	11.0	11.5
	Secondary School	10.36	12.6	14.1	14.4
Healthcare	Outpatient Health Care	4.37	3.6	3.9	3.9
	Hospital	3.45	5.6	6.4	6.5
Lodging	Small Hotel	1.72	5.7	7.5	7.9
	Large Hotel	4.95	8.0	10.2	10.7
Warehouse	Non-Refrigerated Warehouse	16.72	6.0	6.1	6.1
Food Service	Fast Food Restaurant	0.59	2.6	4.7	5.3
	Sit-Down Restaurant	0.66	3.0	3.9	4.2
Apartment	Mid-Rise Apartment	7.32	5.4	5.1	5.0
	High-Rise Apartment	8.97	6.9	8.4	8.7
National		**100**	**7.6**	**8.5**	**8.7**

Acronyms and Abbreviations

AEDG	Advanced Energy Design Guide
AEO	Annual Energy Outlook
AFUE	annual fuel utilization efficiency
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AHU	air handling unit
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
bhp	brake horsepower
BECP	Building Energy Codes Program
Btu	British thermal unit(s)
Btu/h	British thermal unit(s) per hour
Btu/kWh	British thermal unit per kilowatt-hour
CBECS	Commercial Building Energy Consumption Survey
COP	coefficient of performance
CRRC	Cool Roof Rating Council
CZ	climate zone
DCV	demand-controlled ventilation
DDC	direct digital control(s)
DOE	U.S. Department of Energy
DX	direct expansion
E_c	combustion efficiency
EC	electronically commutated
ECB	energy cost budget
ECI	energy cost intensity
ECPA	Energy Conservation and Production Act
EER	energy efficiency ratio
EIA	Energy Information Administration
EMS	energy management system
EPAct	Energy Policy Act
ER	emergency room
ERV	energy recovery ventilator
E_t	thermal efficiency
EUI	energy use intensity
hp	horsepower
HSPF	heating seasonal performance factor

HVAC	heating, ventilation, and air-conditioning
ICU	intensive care unit
IEAD	insulation entirely above deck
IEER	integrated energy efficiency ratio
IES	Illuminating Engineering Society of North America
kBtu	thousand British thermal unit(s)
kWh	kilowatt hour(s)
LABS	laboratories
LPD	lighting power density
MAT	mixed air temperature
MBH	thousand Btu per hour
NC3	New Commercial Construction Characteristics database
NEMA	National Electrical Manufacturers Association
NFRC	National Fenestration Rating Council
OR	operating room
PATRMS	patient rooms
PBA	principal building activity
PBAplus	detailed principal building activity
PLR	part load ratio
PNNL	Pacific Northwest National Laboratory
PSC	permanent-split capacitor
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
RH	relative humidity
SAT	supply air temperature
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SPVAC	single package vertical air conditioners
SPVHP	single package vertical heat pumps
VAV	variable air volume
VT	visible transmittance
w.c.	water column

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1.0 Introduction

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for the Building Energy Efficiency Standards Program (42 U.S.C. 6831 et seq.). Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA[1] 90.1-1989 (Standard 90.1-1989 or 1989 edition), or any successor to that code, is revised, the Secretary must make a determination, not later than 12 months after such revision, whether the revised code would improve energy efficiency in commercial buildings and must publish notice of such determination in the Federal Register (42 U.S.C. 6833 (b)(2)(A)). The Secretary may determine that the revision of Standard 90.1-1989, or any successor thereof, improves the level of energy efficiency in commercial buildings. If so, then not later than 2 years after the date of the publication of such affirmative determination, each State is required to certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency with respect to the revised or successor code (42 U.S.C. 6833(b)(2)(B)(i)). The State must include in its certification a demonstration that the provisions of its commercial building code, regarding energy efficiency, meet or exceed the revised standard (42 U.S.C. 6833(b)(2)(B)(i)).

If the Secretary makes a determination that the revised standard will not improve energy efficiency in commercial buildings, State commercial codes shall meet or exceed the last revised standard for which the Secretary has made a positive determination (42 U.S.C. 6833(b)(2)(B)(ii)). ECPA also requires the Secretary to permit extensions of the deadlines for the State certification if a State can demonstrate that it has made a good faith effort to comply with the requirements of Section 304(c) of ECPA and that it has made significant progress in doing so (42 U.S.C. 6833(c)).

On October 9, 2011, DOE issued an affirmative determination of energy savings for Standard 90.1-2010, which concluded that Standard 90.1-2010 would achieve greater energy efficiency in buildings subject to the code, than Standard 90.1-2007 (76 FR 64904). Consequently, DOE has determined that Standard 90.1-2010 represents the baseline to which Standard 90.1-2013 requirements are compared for the purpose of a determination of energy savings for Standard 90.1-2013. To meet these statutory requirements, the DOE Building Energy Codes Program (BECP) and Pacific Northwest National Laboratory (PNNL) conduct two types of analysis in a determination of energy savings for a revised Standard 90.1[2]:

- **Qualitative Analysis**: This is a detailed textual analysis that identifies all the changes made to the previous edition of Standard 90.1 and categorizes the changes as having a positive, negative, or neutral impact on energy efficiency in commercial buildings. In the qualitative analysis, no attempt is made to estimate a numerical impact using whole building simulation. Three steps are typically undertaken in the qualitative analysis: identify all changes made to Standard 90.1, characterize the impact of each change on the energy efficiency of Standard 90.1, and identify those changes that can be incorporated into the subsequent quantitative analysis.
- **Quantitative Analysis**: This analysis uses the results of the qualitative analysis to identify which changes should be incorporated into the building simulation models to estimate the energy impact resulting from the changes to Standard 90.1.

[1] American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers/Illuminating Engineering Society of North America
[2] Standard 90.1-2010 Determination available at http://www.energycodes.gov/regulations/determinations

In support of the U.S. Department of Energy (DOE) Determination of Energy Savings for ANSI/ASHRAE/IES[1] Standard 90.1-2013 (referred to as ASHRAE Standard 90.1-2013, Standard 90.1-2013, 90.1-2013, or 2013 edition) (ASHRAE 2013b), Pacific Northwest National Laboratory (PNNL) prepared this quantitative analysis of the relative energy use for commercial buildings designed to meet requirements found in Standard 90.1-2013 compared to meeting requirements found in ANSI/ASHRAE/IES Standard 90.1-2010 (referred to as ASHRAE Standard 90.1-2010, Standard 90.1-2010, 90.1-2010, or 2010 edition) (ASHRAE 2010b).

This evaluation is carried out using computer simulations of prototype buildings constructed to Standard 90.1-2010 and Standard 90.1-2013 across the range of U.S. climates. Each prototype building used in the simulation analysis was first developed as a computer model in accordance with design and construction requirements found in Standard 90.1-2010. Changes to the building model, consistent with addenda published to Standard 90.1-2010 in the development of Standard 90.1-2013, are made to reflect the building as it would be constructed under the requirements of Standard 90.1-2013. The set of Standard 90.1-2010 and Standard 90.1-2013 buildings are simulated, and energy use statistics are extracted from each building model in the form of annual energy use by energy type. The annual energy use is then converted to energy use intensity (EUI) figures expressed in annual energy use per square foot. Using weighting factors by building type and geographic area developed using the past 5 years of construction data, these energy use results are then aggregated to national levels for each revision of Standard 90.1. DOE relies upon these data and analysis to assess whether an affirmative determination can be made for Standard 90.1-2013.

The ensuing sections of this document describe:

- determination process,
- characterization of the addenda to be modeled for Standard 90.1-2013,
- characterization of the building models,
- simulation methodology,
- use of building construction weights to aggregate results from simulations across building types and locations into national results,
- translation of the addenda into modeling inputs used in the computer simulations, and
- results of the analysis with regard to the overall EUI for buildings under both standards and the energy and energy cost savings of Standard 90.1-2013 over Standard 90.1-2010.

Review Under the Information Quality Act

This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. Though this report does not constitute “influential” information, as that term is defined in DOE’s information quality guidelines or the Office of Management and Budget's Information Quality Bulletin for Peer Review (Bulletin), the current report builds upon methods of analysis that have been subjected to

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[1] American National Standards Institute/American Society of Heating, Refrigerating, and Air Conditioning Engineers/Illuminating Engineering Society of North America

peer review and public dissemination. In addition, this work has been subject to internal peer review and external review through the public comment process as part of the DOE Determination for Standard 90.1-2013.

2.0 Addenda Included in Standard 90.1-2013

In assessing the energy savings included in Standard 90.1-2013, PNNL prepared a qualitative analysis of the addenda to Standard 90.1-2010 (Halverson et al. 2014). Standard 90.1-2013 incorporates Standard 90.1-2010 and all approved addenda. Appendix A lists all 110 addenda processed by ASHRAE for inclusion in Standard 90.1-2013. The addenda included in Standard 90.1-2013 may also be found in the published supplements to Standard 90.1-2010 on the ASHRAE website (ASHRAE 2012, ASHRAE 2013a).

The list of addenda in Appendix A of this report is taken from Appendix F to Standard 90.1-2013. Appendix A lists each addendum and describes the way in which the text is affected by the change, as well as ASHRAE, IES, and ANSI approval dates. Appendix A is a copy of Appendix F to Standard 90.1-2013 with minor edits to define some of the acronyms used in Appendix F and to make the format of the descriptions the same. The description of addendum 90.1-2010j was also modified in this report as it was a repeat of the description of addendum 90.1-2010k. The section affected by addendum 90.1-2010bo was also modified to indicate that this addendum is associated with the Service Water Heating section and not the Heating, Ventilating, and Air-Conditioning section.

Note that the table numbers called out in Appendix A refer to Standard 90.1-2010. In Standard 90.1-2013, tables have been renumbered from a format of “Table (Section Number) Letter” to “(Table Section Number)-Number.” Thus, for example, Table 6.8.1A in Standard 90.1-2010 is now Table 6.8.1-1 in Standard 90.1-2013. Notes have been added to the discussion throughout this report to show both the original Standard 90.1-2010 table numbers and the Standard 90.1-2013 table numbers.

ASHRAE Standard 90.1-2013 includes addenda that:

- are purely editorial or update references to other documents,
- update prescriptive design and construction requirements for the envelope, lighting, mechanical, power, and other equipment sections of the standard,
- update the performance path option to compliance (the energy cost budget and performance rating method sections of Standard 90.1 [Appendix G]), or
- affect informative appendix material that is provided in Standard 90.1-2013 but is not part of the design and construction requirements of the standard.

For the quantitative analysis, PNNL includes in the analysis only those addenda that modified the prescriptive and mandatory requirements of Standard 90.1. In specific circumstances, particularly with regard to requirements for certain heating, ventilation, and air-conditioning (HVAC) equipment, addenda to Standard 90.1-2010 reflect changes to national manufacturing standards previously developed by DOE or enacted independently through federal legislation. Because the energy savings that are attributable to these national manufacturing standards would accrue no matter what edition of Standard 90.1 is complied with and regardless of whether they are reflected in the text of the standards, PNNL has not incorporated these as changes contributing to energy savings for the purpose of the determination.

3.0 Prototype Buildings and Simulation Methodology

The purpose of the quantitative analysis described here is to provide DOE with an evaluation of the relative energy efficiency of ASHRAE Standard 90.1-2010 and Standard 90.1-2013 when taken as a whole. To the degree that it can be considered representative of all commercial building construction, the analysis estimates the impact of the change in standards on commercial building energy efficiency. The quantitative comparison of energy codes is based on whole building energy simulation of buildings whose characteristics match either Standard 90.1-2010 or Standard 90.1-2013. It is not feasible to simulate all possible permutations of building design. Further, data are simply not available to correctly weigh each possible permutation in each U.S. climate zone as a fraction of the national building construction mix. Hence, the quantitative analysis focuses on the use of prototype buildings that reflect a representative mix of typical construction practices.

The present analysis builds on previous work conducted by PNNL to assess the energy performance of the three most recent editions of Standard 90.1 in (Thornton et al. 2011), referred to here as *Analysis of 90.1-2010*. The individual building models for each climate are modified as needed to correctly reflect the prescriptive requirements for Standard 90.1-2010 as required for each climate zone. In addition, for each of these Standard 90.1-2010 compliant building models, a second, corresponding building with the same basic design and use patterns, but which reflects the prescriptive requirements of Standard 90.1-2013, is developed. This process is completed by reviewing each addendum; first establishing whether that addendum would affect a given prototype building (based on the assumptions and descriptions of the prototype building components) and in which climates.

Each of the 480 building models (16 prototypes, 15 climate locations, and two standards) is simulated using *EnergyPlus Version 8.0* (DOE 2013), and the resulting energy use is extracted by energy type and by end use. The energy use data is then aggregated by energy type and, using the floor space for each prototype, converted to EUI metrics for each energy type by prototype building by climate and standard edition.

3.1 Building Types and Model Prototypes

Sixteen prototype buildings are shown in Table 3.1 and used in the quantitative analysis. Each prototype building model is defined as characteristic of a certain class of buildings, mostly corresponding to a classification scheme established in the 2003 DOE/Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) (EIA 2003). CBECS categorizes commercial buildings using the two variables “variable principal building activity” (PBA) and “detailed principal building activity” (PBAplus) for more specific activities, separating the commercial sector into 29 PBA categories and 51 subcategories. PNNL relied heavily on these classifications in determining the buildings to be represented by the set of prototype building models. By mapping CBECS observations to each prototype building, PNNL also used the CBECS building characteristics data to develop prototypes that could best typify the building stock.

Multi-family housing buildings are not included in CBECS but are covered by Standard 90.1, if more than three stories high. Consequently, PNNL developed mid-rise and high-rise multi-family prototype building to add to the original prototype buildings identified through the review of CBECS. The characteristics of the mid-rise and high-rise multi-family buildings were developed from data in a separate study by PNNL (Gowri et al. 2007).

Details on the development of all the prototype buildings that are used in this analysis may be found in the technical support document for the *Analysis of 90.1-2010* (Thornton et al. 2011). The prototype models described in that report have since been modified as described in the document *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014). This document is available at https://www.energycodes.gov/development/commercial/90.1_models.

Table 3.1. ASHRAE Commercial Prototype Building Models

Building Type	Prototype building	Prototype Floor Area (ft^2)
Office	Small Office	5,502
	Medium Office	53,628
	Large Office	498,588
Retail	Stand-Alone Retail	24,692
	Strip Mall	22,500
Education	Primary School	73,959
	Secondary School	210,887
Healthcare	Outpatient Health Care	40,946
	Hospital	241,501
Lodging	Small Hotel	43,202
	Large Hotel	122,120
Warehouse	Non-Refrigerated Warehouse	52,045
Food Service	Fast Food Restaurant	2,501
	Sit-Down Restaurant	5,502
Apartment	Mid-Rise Apartment	33,741
	High-Rise Apartment	84,360

In the case of office buildings, one of the largest PBA categories in terms of floor area out of the total stock, PNNL determined that the wide variation in building design and equipment use made determining a "typical" office design difficult. Consequently, PNNL developed three sizes and form factors characteristic of small, medium, and large office buildings to reflect the wide variation in office building design. Similarly, retail, education, healthcare, lodging, food service, and apartments have two representative prototypes each.

To keep the building set manageable, the basic form factor and equipment selection for each prototype building was developed to be most typical of construction on a national basis. Regional variations in form factor, size, or design differences such as equipment selection are not represented in the group of prototype buildings.

The 16 prototypes used in the quantitative analysis together reflect approximately 80% of the total square footage of commercial construction, including multi-family buildings more than three stories tall, covered under ASHRAE Standard 90.1 (Jarnagin and Bandyopadhyay 2010).

3.2 Climate Zones

Standardized climate zones originally developed by DOE are used for the determination analysis. These climate zones have since been adopted by the International Energy Code Council as well as ASHRAE for both residential and commercial building applications. The common set of climate zones includes eight thermal zones covering the entire United States, as shown in Figure 3.1 (Briggs et al. 2003). Climate zones are categorized from 1 to 8, with increasing heating degree days and decreasing cooling degree days. These thermal climate zones may be mapped to other climate locations for international use. Most thermal climate zones are further divided into moist (A), dry (B), and marine (C) regions. For this analysis, a specific climate location (city) is selected as a representative of each climate zone. A set of 15 cities is used that represents the 15 climate zones identified in Standard 90.1 that exist in the United States. Two other climate zones are identified by ASHRAE but are not included because the climate subzones they represent do not exist in the U.S. Riyadh, Saudi Arabia represents climate zone 1B (very hot, dry) and Vancouver B.C., Canada represents climate zone 5C (cool, marine).

The 15 cities representing the climate zones are:

- 1A: Miami, Florida (very hot, humid)
- 2A: Houston, Texas (hot, humid)
- 2B: Phoenix, Arizona (hot, dry)
- 3A: Memphis, Tennessee (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Francisco, California (warm, marine)
- 4A: Baltimore, Maryland (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Salem, Oregon (mixed, marine)
- 5A: Chicago, Illinois (cool, humid)
- 5B: Boise, Idaho (cool, dry)
- 6A: Burlington, Vermont (cold, humid)
- 6B: Helena, Montana (cold, dry)
- 7: Duluth, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

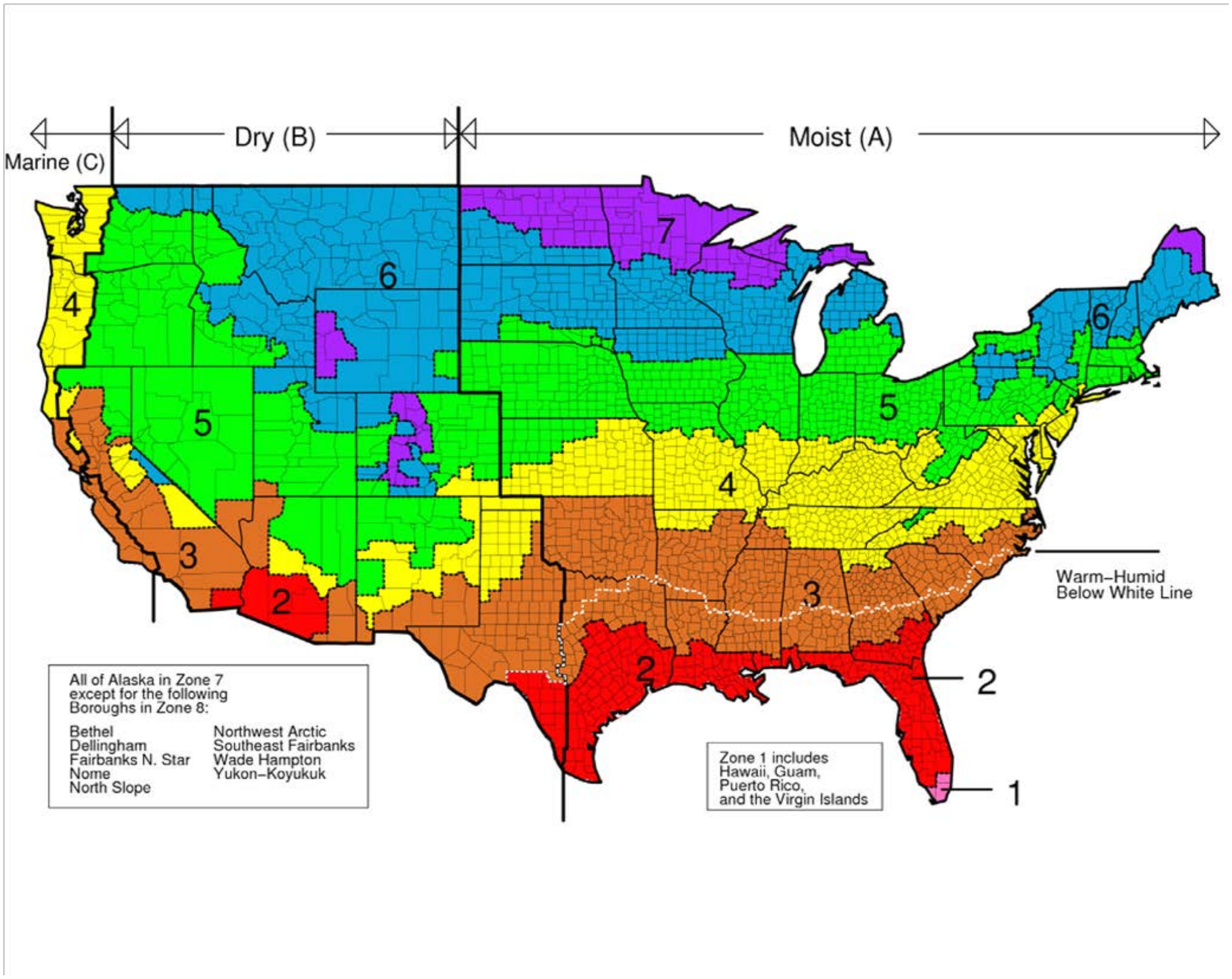

Figure 3.1. DOE-Developed Climate Zone Map

3.3 Development of Weighting Factors and National Savings Estimates

Weighting factors were developed based on 5 years' of construction data purchased from McGraw Hill's construction data set. Development of the weighting factors is discussed in a PNNL report (Jarnagin and Bandyopadhyay 2010), which details weighting factors for 16 prototype buildings, including the high-rise apartment commercial prototype building. Table 3.2 lists the resulting weighting factors by climate and by prototype building in the final determination.

PNNL developed estimates of the new construction floor space that correspond to each prototype/climate zone combination. These data are used to develop the relative fractions of new construction floor space represented by prototype building and within the 15 climate zones. Using the energy use index (EUI) statistics from each building simulation and the corresponding relative fractions of new construction floor space, PNNL developed floor-space-weighted national EUI statistics by energy type for each building type and standard level. PNNL then added these energy-specific EUI estimates to obtain the national site energy EUI by building type and standard level. PNNL also applied national data for average energy prices and average primary energy conversion rates to the energy-specific EUI data to obtain estimates of national primary energy EUI and national energy cost intensity (ECI), again by building type and by standard level. PNNL examined the national results by prototype building to determine which building types would show reduced energy use under Standard 90.1-2013.

Finally, PNNL weighted the EUI and ECI statistics by building type to arrive at national site EUI, primary energy EUI, and ECI values for buildings constructed under both editions of Standard 90.1. The approach taken is not comprehensive for all buildings. The analysis assesses the relative energy impact of the standard by simulating prototypical examples of buildings of various types reflected in the overall building population. It is recognized that some specific requirements of the standard will not be amenable to simulation within the scope of this analysis. For most of these requirements, any differences in requirements will suggest an obvious stringency change between the standards, and this has been explored in the qualitative analysis done in parallel to this quantitative assessment (Halverson et al. 2014).

Table 3.2. Relative Construction Volume Weights for 16 Prototype buildings by Climate Zone

Building Type	1	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8	Weights by Bldg Type
Large office	0.102	0.326	0.061	0.445	0.285	0.117	1.132	0.000	0.154	0.442	0.121	0.133	0.000	0.011	0.000	3.33
Medium office	0.129	0.813	0.292	0.766	0.715	0.136	1.190	0.036	0.196	1.060	0.342	0.298	0.035	0.033	0.007	6.05
Small office	0.084	1.064	0.289	0.963	0.475	0.078	0.936	0.047	0.123	0.920	0.322	0.241	0.030	0.032	0.005	5.61
Standalone retail	0.224	2.220	0.507	2.386	1.250	0.191	2.545	0.119	0.428	3.429	0.792	0.948	0.091	0.109	0.014	15.25
Strip mall retail	0.137	0.991	0.254	1.021	0.626	0.103	1.008	0.023	0.107	1.023	0.201	0.153	0.016	0.007	0.001	5.67
Primary school	0.064	0.933	0.164	0.944	0.446	0.048	0.895	0.030	0.094	0.920	0.224	0.168	0.037	0.023	0.003	4.99
Secondary school	0.160	1.523	0.230	1.893	0.819	0.109	2.013	0.063	0.243	2.282	0.438	0.415	0.086	0.075	0.012	10.36
Hospital	0.040	0.479	0.096	0.468	0.273	0.039	0.615	0.022	0.106	0.812	0.218	0.221	0.024	0.034	0.001	3.45
Outpatient health care	0.037	0.567	0.134	0.581	0.275	0.061	0.818	0.023	0.181	1.058	0.218	0.342	0.033	0.039	0.002	4.37
Full-service restaurant	0.009	0.106	0.025	0.111	0.047	0.006	0.127	0.006	0.010	0.143	0.031	0.031	0.004	0.004	0.000	0.66
Quick-service restaurant	0.008	0.092	0.020	0.102	0.063	0.007	0.089	0.005	0.014	0.128	0.026	0.025	0.003	0.004	0.000	0.59
Large hotel	0.109	0.621	0.125	0.635	0.793	0.106	0.958	0.037	0.123	0.919	0.200	0.227	0.058	0.038	0.004	4.95
Small hotel	0.010	0.288	0.030	0.268	0.114	0.022	0.315	0.020	0.039	0.365	0.089	0.107	0.031	0.020	0.004	1.72
Warehouse	0.349	2.590	0.580	2.966	2.298	0.154	2.446	0.068	0.435	3.580	0.688	0.466	0.049	0.043	0.002	16.72
High-rise apartment	1.521	1.512	0.076	0.652	0.741	0.173	2.506	0.000	0.358	1.163	0.115	0.125	0.016	0.008	0.000	8.97
Mid-rise apartment	0.257	1.094	0.093	0.825	0.862	0.260	1.694	0.022	0.371	1.122	0.318	0.313	0.056	0.032	0.000	7.32
Weights by Zone	3.24	15.22	2.98	15.03	10.08	1.61	19.29	0.52	2.98	19.37	4.34	4.21	0.57	0.51	0.06	100.00

4.0 Inclusion of Addenda in the Quantitative Analysis

PNNL examined each of the 110 addenda included in Standard 90.1-2013 and identified 57 of those as having a direct impact on energy efficiency and 53 that did not. Of those 57 addenda that had a direct impact on energy efficiency, 30 could be quantified using the simulation methodology for the quantitative analysis. The most common reason why an addendum with energy efficiency impacts was not included in the quantitative analysis was because the class of equipment or the particular requirements impacted by the addendum was not represented in the prototype buildings. Examples of this include addendum 90.1-2010bp – efficiency improvements for evaporative condensers with ammonia refrigerant, addendum 90.1-2010o – air leakage requirements for glazed sectional garage doors, and addendum 90.1-2010dq – sizing requirements for pipes greater than 24 inches in diameter. Other reasons for not including energy savings addenda were if they applied only to retrofit situations (e.g., addendum 90.1-2010bg – retrofit storm window efficiency) or if they enhanced quality assurance (e.g., addendum 90.1-2010dw – economizer high limit requirements for improved accuracy).

As discussed in Section 2.0, Standard 90.1 contains requirements for specific types of equipment, many of which are related to minimum federal efficiency standards. In some instances, a revised edition of Standard 90.1 will adopt a federal efficiency standard. Because that mandated equipment efficiency will be enforced as a manufacturing standard regardless of whether it is represented in Standard 90.1, the inclusion of the requirement in the ASHRAE standard is assumed to have no real energy impact due to the ASHRAE update. To address this issue, energy savings is not accounted for PNNL's quantitative analysis methodology for equipment efficiency improvements mandated by federal equipment efficiency standards. This avoids attributing energy savings in the quantitative analysis that would occur in new building construction regardless of the use of Standard 90.1, and it prevents an incorrect biasing of the quantitative analysis toward positive energy savings that would have occurred, and is accounted for, through federally mandated equipment efficiency improvements. Excluding energy savings for these addenda in the quantitative analysis is consistent with the approach used in previous DOE determinations.

5.0 Modeling of Specific Addenda

This section details the modeling of the 30 addenda to Standard 90.1-2010 simulated for the quantitative analysis. Where individual addenda modify the same section of Standard 90.1, these addenda are discussed together.

5.1 Addenda Characterization

Figure 5.1 shows the number of addenda without energy impact, addenda with energy impact that are quantified, and addenda with energy impact that are not quantified. For the addenda with quantified savings, the figure shows the number of addenda associated with each chapter of Standard 90.1-2010. There are no addenda associated with Chapter 7, Service Water Heating, or with Chapter 10, Other Equipment that have quantified energy impact.

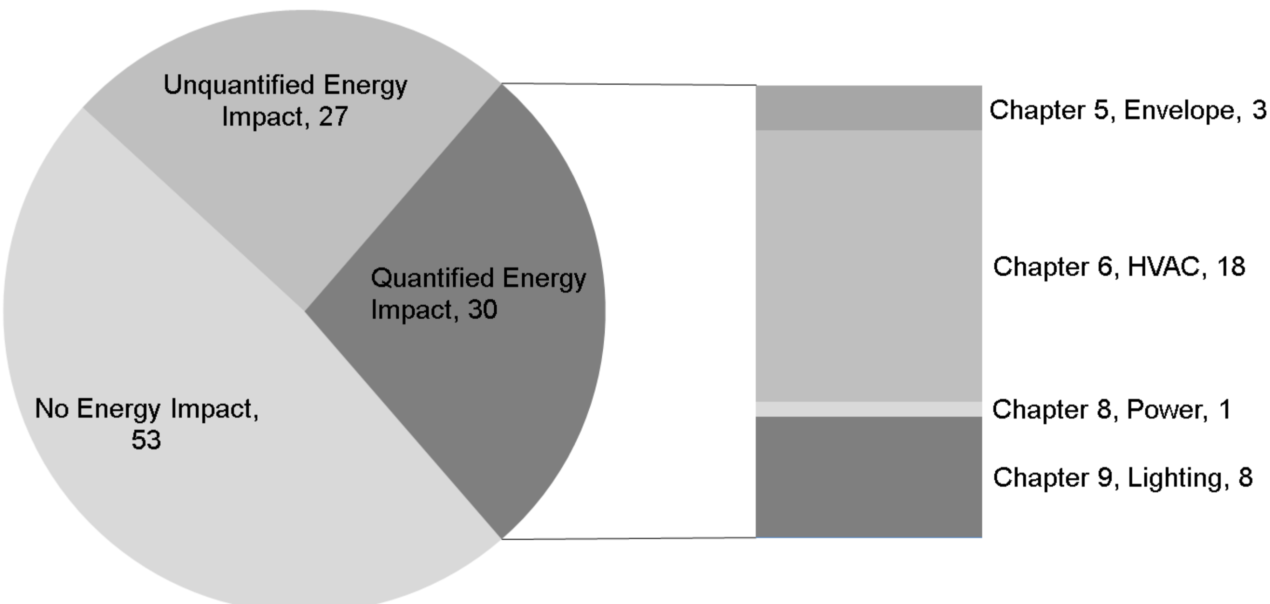

Figure 5.1. Addenda by Category and Quantity

Table 5.1lists addenda that have an energy impact on the prototype buildings and have been captured in the analysis. Appendix B provides additional details about these addenda. Addenda listed in Appendix B are in a sorted hierarchy: (1) by the relevant Standard 90.1 chapter, and (2) sequential by alphabetical letter name of the addenda with two letter designations following single letter designations (e.g., “t” before “aa”). Addenda that affect more than one chapter in Standard 90.1, for example, those changing the building envelope and lighting controls for daylighting, are sorted into the Standard 90.1 chapter that is primarily responsible for the energy savings. Appendix B also identifies which prototype building is impacted by each of the quantified addenda.

Table 5.1. Addenda with Quantified Energy Impacts

Addendum	Description	Addendum	Description
h	Water-to-air heat pump efficiency	bk	Increased PTAC efficiency
af	Heat rejection flow turndown	bs	Reduce threshold for DCV
aj	Small motor efficiency	bt	Reduces threshold for ERV
am	Boiler turndown requirements	bw	Orientation SHGC tradeoff
aq	Fan control and DX staging	by	Improved lighting controls
as	Humidification and pre-heat control	ca	Vestibule heating controls
au	Fan power credit adjustments	cb	Night setback and optimum start
ay	Enhances daylighting requirements	ch	Chiller efficiency
az	Cooling tower efficiency	co	Building area LPD update
ba	HVAC setback when doors are open	cr	Space-by-space lighting power update
bb	Comprehensive envelope upgrade	cy	Energy recovery for 24/7 occupancies
bc	Enhances daylighting requirements	di	Limits humidity controls
bf	Automatic receptacle controls	dj	Additional lighting power for electrical/mechanical rooms
bh	Space-by-space lighting power	dl	Increases lighting power for guest rooms
bi	Small heat pump and air conditioner efficiency	dv	Chiller/boiler isolation

5.2 Addenda Implementation in Modeling

The procedures for implementing the addenda into the Standard 90.1-2010 and 90.1-2013 prototype models include identifying the changes to the prototypes required by each addendum, developing model inputs to simulate those changes, applying those changes to the prototype models, running the simulations, and extracting and post-processing the results. This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for *EnergyPlus*. Descriptions include identifying the change introduced by the addendum, the prototypes affected by the change, and a high-level summary of how the change was implemented in the prototype models. The terms “baseline” and “advanced” are used in some cases to describe the implementation of the addenda. The baseline is Standard 90.1-2010 and the advanced case is Standard 90.1-2013.

5.2.1 Building Envelope

5.2.1.1 Addendum 90.1-2010bb: Opaque Envelope and Fenestration Performance

Addendum 90.1-2010bb makes extensive changes to the opaque envelope and fenestration requirements in Chapter 5 of Standard 90.1-2010. It also introduces new requirements and makes editorial changes to the standard. The following list describes the changes from addendum 90.1-2010bb that have an impact on the energy consumption of buildings:

1. Tables 5.5-1 through 5.5-8, the tables of prescriptive criteria for the building envelope, are updated. For opaque elements, minimum insulation levels are increased for most assemblies in most climate zones. For vertical fenestration, the U-factor requirements are more stringent for most framing types in most climate zones.
2. The fenestration framing types are changed from Standard 90.1-2010 to include non-metal framing, fixed metal framing, operable metal framing, and entrance door metal framing.
3. A minimum visible transmittance to solar heat gain coefficient ratio (VT/SHGC) is introduced in a new section, 5.5.4.6, to enhance daylighting while minimizing solar gain.
4. An exception is added to allow the skylight area to be increased to 6% where skylights are designed and utilized as part of a daylighting scheme. In Section 5.5.4.3, an exception is added to allow the skylight U-factor to be increased where skylights are designed and utilized as part of a daylighting scheme.
5. In Section 5.5.4.4, an exception is added that allows the SHGC criteria for vertical fenestration that faces north to be modified to account for the reduced solar heat gain on the north side of buildings in northern latitudes.

All the prototype buildings are impacted by the changes from addendum 90.1-2010bb. The change in opaque envelope and fenestration assembly requirements are captured in the prototype models, as is the new requirement for minimum VT/SHGC ratio. Other requirements having an energy impact are either optional (added for designed flexibility) or are not represented in the prototype buildings (for example, insulation requirements of heated slab-on-grade floors). A side-by-side comparison between Standard 90.1-2010 and addendum 90.1-2010bb opaque envelope and fenestration requirements is shown in Appendix C of this report.

To model the changes in wall and roof insulation requirements, U-factor requirements from addendum 90.1-2010bb are used to calculate the R-value of the insulation layer in the construction assembly, which is built using the assembly descriptions from Appendix A of Standard 90.1-2013. For the slab-on-grade assembly, the R-value insulation requirements are modeled directly using the slab preprocessor in *EnergyPlus*.

The fenestration requirements are determined by weighting the U-factor of different framing types for each prototype building model. The weighted U-factor together with the SHGC (SHGC requirements are the same for all framing types) and VT from prescriptive tables is used to find a matching assembly in the *EnergyPlus* fenestration library that complies with the requirements. The framing type weights are taken from the *Analysis of 90.1-2010* (Thornton et al. 2011). The fixed metal framing and operable metal framing types introduced by addendum 90.1-2010bb use the same weights as those used in 90.1-2010 for curtain wall/storefront metal framing and all other metal framing, respectively.

5.2.1.2 Addendum 90.1-2010bw: Fenestration Orientation

Addendum 90.1-2010bw modifies the fenestration orientation requirements in Section 5.5.4.5 of Standard 90.1-2010. The new requirements allow compliance through one of two methods:

1. by making each of the west- and east-oriented fenestration area less than or equal to a quarter of the total building fenestration area, or,

2. by making each of the product of west- and east-oriented fenestration area and SHGC less than or equal to a quarter of the product of the total building fenestration area and the SHGC criteria established in Tables 5.5-1 through 5.5-8.

Buildings in climate zone 8 are exempt from these requirements. The addendum introduces a new exception, exception (e), for buildings where, if the window-to-wall ratio of the east or west facade is less than 20%, the requirement is considered to be met if the SHGC is reduced by 10% over the prescribed value for that facade.

To model the Standard 90.1-2010 fenestration orientation requirements, prototype models were rotated by 90 degrees (Small Hotel and Hospital) because SHGC trade-off was not allowed. Addendum 90.1-2010bw allows trading-off the SHGC with the fenestration area, and this path is most likely to be used by designers for compliance. This is the path chosen for modeling the requirements. Rotated prototype models that were modeled to meet 90.1-2010 requirements are used to check whether the new requirements are met (the Standard 90.1-2010 models are the starting point for the Standard 90.1-2013 models). For those prototype buildings that do not meet the simpler area requirements of addendum 90.1-2010bw, the SHGC trade-off equation is used to calculate a new SHGC for the west- or east-oriented fenestration that would meet the requirements.

There are four prototypes that do not meet the fenestration area requirement: Hospital, Quick-service Restaurant, Full-service Restaurant, and Warehouse. For these prototypes, the SHGCs required for compliance are calculated separately for east- and west-oriented fenestration. The calculated SHGCs are applied only to the west- and east-oriented fenestration of the impacted prototypes. The office space in the Warehouse prototype causes non-compliance, but it is ignored because the fenestration area is very small. For the Hospital prototype, the east-oriented fenestration area is less than 20% of the gross wall area, allowing exception (e) in the addendum to be used. Table 5.2 shows the new SHGC values calculated for the east- and west-oriented fenestration by climate zone (CZ).

Table 5.2. New SHGC Values Meeting Addendum 90.1-2010bw Fenestration Orientation Requirements

	Hospital			Quick-service Restaurant			Full-service Restaurant		
SHGC	CZ 1-3	CZ 4-6	CZ 7	CZ 1-3	CZ 4-6	CZ 7	CZ 1-3	CZ 4-6	CZ 7
90.1-2013 Prescriptive SHGC	0.25	0.4	0.45	0.25	0.4	0.45	0.25	0.4	0.45
Calculated East SHGC	0.23	0.36	0.41	0.25	0.40	0.45	0.21	0.34	0.38
Calculated West SHGC	-	-	-	0.25	0.40	0.45	0.21	0.34	0.38

5.2.1.3 Addendum 90.1-2010ca: Vestibule Heating

Addendum 90.1-2010ca adds two requirements for heated vestibules to Section 6.4.3.9 in Standard 90.1-2013. Section 6.4.3.9 is a new section resulting from the renumbering of sections in Section 6.4 of Standard 90.1-2013. The new vestibule heating requirements are discussed here because vestibules are an integral part of the envelope requirements in Chapter 5 of Standard 90.1. Addendum 90.1-2010ca requires heated vestibules to have controls to limit the heating setpoint to a maximum of 60°F and the vestibule heating system is required to include automatic controls configured to shut off the heating system when the outdoor air temperature is above 45°F. Vestibules without heating systems or the ones heated by transfer air are exempted from meeting these requirements.

Addendum 90.1-2010ca only impacts the Standalone Retail prototype building, which has a designated thermal zone serving the purpose of a vestibule, heated using a unit heater. The unit heater is fitted with a gas heating coil and follows the same thermostat setpoint and schedule as the rest of the building.

The requirements of addendum 90.1-2010ca are implemented using a two-step approach: (1) a new thermostat schedule is created for the vestibule zone, such that the heating setpoint is limited to a maximum of 60°F, and (2) an energy management system (EMS) routine is created to shut off the unit heater heating coil and fan when the outdoor air temperature is above 45°F. The EMS in *EnergyPlus* is a user-accessible programming functionality that can adjust parameters during program simulation. Figure 5.2 shows the original and the new thermostat heating setpoint schedule for the vestibule zone.

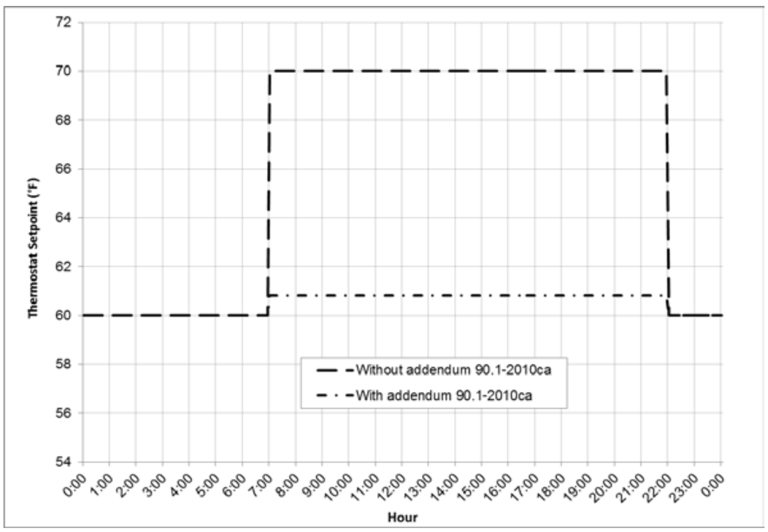

Figure 5.2. Heating Setpoints for Vestibule Zone in the Standalone Retail Prototype Building

5.2.2 Heating, Ventilating, and Air-Conditioning

5.2.2.1 Addendum 90.1-2010g: Reach-in Refrigerators and Freezer Equipment

DOE has defined maximum energy consumption requirements for selected commercial refrigerators and freezers that went into effect on 1/1/2010. Additional requirements for commercial refrigeration equipment have also been defined and approved per 10 CFR part 431 and went into effect on 1/1/2012. Addendum 90.1-2010g adds these requirements through two new tables in Chapter 6 (Tables 6.8.1-12 and 6.8.1-13) of Standard 90.1. Among the equipment listed in the two tables, commercial reach-in refrigerators with solid doors and commercial reach-in freezers with solid doors are modeled in prototype buildings with commercial kitchens: Quick-service Restaurant, Full-service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. Navigant (2009) provided a summary of typical sizes and numbers of the applicable equipment in the prototype buildings. Table 5.3 shows the typical sizes and numbers of commercial freezers and refrigerators in the prototype buildings.

Table 5.3. Typical number of Commercial Refrigerators and Freezers in Prototype Models

Prototype	Building Type	Number of commercial freezers with solid doors (typical volume V=24 ft^3)	Number of commercial refrigerators with solid doors (typical volume V=48 ft^3)
Quick-service Restaurant	Food Service	1	2
Full-service Restaurant	Food Service	1	2
Hospital	Health Care	2	3
Large Hotel	Lodging	1	1
Primary School	Education	2	2
Secondary School	Education	2	2

Table 6.8.1-12 in addendum 90.1-2010g defines the energy use limits in kWh/day as a function of the volume (V) in ft^3. These limits are converted to input power and are modeled as a plug load with a constant operation schedule in *EnergyPlus*. To develop baseline inputs for the prototype models, the California Title 20 requirement (CEC 2008), effective 3/1/2003, is used to calculate the energy use limits without addendum 90.1-2010g. Table 5.4 shows the energy use limits used to calculate the input power of commercial refrigerators and freezers for the baseline and advanced models. For the Standard 90.1-2013 determination analysis, both the 90.1-2010 and 90.1-2013 models include the impact of addendum 90.1-2010g because it is a federally mandated requirement and there is no credit to Standard 90.1-2013 from the requirement.

Table 5.4. Summary of Energy Use Limits for Commercial Refrigerators and Freezers in Prototypes

Equipment	Energy Use Limits Before Addendum 90.1-2010g (kWh/day)	Energy Use Limits After Addendum 90.1-2010g (kWh/day)
Reach-in refrigerators with solid doors	0.125V+4.22	0.10V + 2.04
Reach-in freezers with solid doors	0.398V+2.83	0.40V + 1.38

5.2.2.2 Addendum 90.1-2010h: Water to Air Heat Pump Efficiency

Addendum 90.1-2010h improves the minimum energy efficiency standards for water-to-air heat pumps (water loop, ground water, and ground loop) listed in Table 6.8.1B of Standard 90.1-2010 (now Table 6.8.1-2 of Standard 90.1-2013). .

Table 5.5 shows the minimum energy efficiency ratio (EER) and coefficient of performance (COP) requirements for water-to-air heat pump as required by Standard 90.1-2010 (before addendum 90.1-2010h) and by addendum 90.1-2010h.

Table 5.5. Impacted Equipment and Efficiency Changes Required by Addendum 90.1-2010h

Equipment Type	Size Category	Rating Condition	Minimum Efficiency 90.1-2010	Minimum Efficiency Addendum 90.-2010h
Water to Air: Water Loop (cooling mode)	<17,000 Btu/h	86 °F entering water	11.2 EER	12.2 EER
	≥17,000 Btu/h and <65,000 Btu/h	86 °F entering water	12.0 EER	13.0 EER
	≥65,000 Btu/h and <135,000 Btu/h	86 °F entering water	12.0 EER	13.0 EER
Water to Air: Ground Water (cooling mode)	<135,000 Btu/h	59 °F entering water	16.2 EER	18.0 EER
Brine to Air: Ground Loop (cooling mode)	<135,000 Btu/h	77 °F entering fluid	13.4 EER	14.1 EER
Water to Air: Water Loop (heating mode)	<135,000 Btu/h (cooling capacity)	68 °F entering water	4.2 COP	4.3 COP
Water to Air: Ground Water (heating mode)	<135,000 Btu/h (cooling capacity)	50 °F entering water	3.6 COP	3.7 COP
Brine to Air: Ground Loop (heating mode)	<135,000 Btu/h (cooling capacity)	32 °F entering fluid	3.1 COP	3.2 COP

Of the 16 prototype buildings, only the High-rise Apartment Building uses water-loop heat pumps. The other two water-to-air heat pumps (ground water and ground loop) are not used in any of the 16 prototype buildings. Therefore, High-rise Apartment Building is the only building type affected by addendum 90.1-2010h.

For each building model in each climate zone simulated, the heat pumps are sized using the design day sizing analysis, and the efficiency of the heat pump is determined for the model based on the design capacity and the required efficiency from each version of Standard 90.1. The conversion of efficiency from EER and COP to *EnergyPlus* inputs is documented in the *Analysis of 90.1-2010* (Thornton et al. 2011).

5.2.2.3 Addendum 90.1-2010af: Heat Rejection Equipment

Addendum 90.1-2010af includes two major changes to Standard 90.1-2010: fan control for multi-cell heat rejection equipment (Section 6.5.5.2) and open-circuit cooling tower flow turndown (Section 6.5.5.4). The addendum requires that the maximum number of fans operate in a multi-cell heat rejection equipment installation to minimize energy. It is more energy efficient to operate all fans in tandem at the same (lower) fan speed than to have an on/off or sequenced fan operation (operating a select number of cells at full speed to meet load). Using more cells also increases heat transfer area and more heat can be rejected with less airflow and fan speed.

The fan control requirement applies to air cooled chillers that have fans 7.5 horsepower (hp) or larger. A review of the largest chiller required for either the large hotel or the secondary school shows that a typical fan is in the 3 hp to 5 hp range, so would not trigger the fan control requirement.

The tower flow turndown requirement states that open-circuit cooling towers used on water-cooled chiller systems that are configured with multiple or variable speed condenser water pumps shall be designed so that all open circuit cooling tower cells can be run in parallel with the larger of either the flow that is produced by the smallest pump at its minimum expected flow rate, or 50% of the design flow for each cell.

The Large Office and Hospital are the two prototype buildings using open-circuit cooling towers. For these two prototype buildings, the model has two variable-speed cooling towers. Each tower has one dedicated condenser water pump and two cells. Because the two cooling towers are equally sized, the two condenser water pumps have the same design flow rate. Before implementing addendum 90.1-2010af, the number of operating cooling towers and condenser water pumps corresponded to the number of operating chillers. When one chiller was operating, one cooling tower was operating and the corresponding condenser water pump was also operating. When both chillers were running, both cooling towers and both condenser water pumps were running.

Addendum 90.1-2010af requires that the maximum number of fans operate to minimize fan energy. This means that when one chiller is running, all four cell fans in the two cooling towers shall be operating unless the fan in one cooling tower already runs at its minimum speed. Running two towers implies that the condenser water flow will be reduced by 50% for each cell in comparison with running one tower.

Major elements of the strategy for modeling addendum 90.1-2010af include the following:

1. Change the cell control strategy for variable speed cooling towers in *EnergyPlus* from “minimum cells” to “maximum cells.”
2. For each time step, find the number of operating chillers.
3. If one chiller is running and the current airflow ratio is greater than the minimum, run the two towers in parallel. Use the *EnergyPlus* EMS to halve the airflow ratio, which is then used to calculate the fan power according to the cubic power law. The EMS control is necessary because *EnergyPlus* native control algorithms cannot run both towers in parallel while delivering the condenser water flow just for one chiller if there are two chillers in the plant.
4. If two chillers are running or the current airflow is at the minimum when one chiller is running, the EMS routine will not override the tower fan curve input and output.

5.2.2.4 Addendum 90.1-2010aj: Fractional HP Motors

Addendum 90.1-2010aj adds a new Section 6.5.3.5 to Standard 90.1-2010 and requires motors from 1/12 horsepower (hp) to under 1 hp to be electronically commutated (EC) motors or have a minimum efficiency of 70%. The intention is to replace standard permanent-split capacitor (PSC) motors having efficiencies in the range of 15% to 65% with more-efficient EC motors. The intended applications are toilet exhaust fans, small kitchen exhaust fans, series fan-powered variable air volume (VAV) boxes, and fan-coil units. The following motors are exempted under addendum 90.1-2010aj: motors in airstream where only heating is provided, motors in packaged equipment, poly-phase small motors, and capacitor-start capacitor-run and capacitor-start induction-run motors that are covered by Table 10.8-4 and Table 10.8-5 in Standard 90.1-2013.

In the prototype building models, this addendum will apply to fan-coil units, exhaust fans, kitchen exhaust fans, and elevator fans. Of the 16 prototype buildings, only the Small Office, Standalone Retail, and Strip Mall prototypes have no impact from addendum 90.1-2010aj. Table 5.6 provides details on the prototype buildings and fans to which this addendum applies.

Table 5.6. Prototype buildings Affected by Addendum 90.1-2010aj

Prototype Building	Fan-Coil Unit	Exhaust Fan	Kitchen Exhaust fan	Elevator Fan
Highrise Apartment				Yes
Midrise Apartment				Yes
Hospital			Yes	Yes
Large Hotel	Yes	Yes	Yes	Yes
Small Hotel				Yes
Large Office				Yes
Medium Office				Yes
Outpatient Healthcare		Yes		Yes
Quick Service Restaurant		Yes	Yes	
Full Service Restaurant		Yes	Yes	
Primary School		Yes	Yes	
Secondary School		Yes		Yes

To determine the motors whose efficiency must be changed, a set of criteria is established based on motor size. From a review of catalogs, motors in the smallest fans are selected from standard fractional horsepower motor sizes even if the required brake horsepower (bhp) is much lower. Therefore, maximum bhp is set at 90% of 3/4 hp or 560 W (above 90% of 3/4 hp, a 1 hp or larger motor would be used) and minimum bhp is set at 25% of 1/12 hp, or 14 W. Motors between the minimum and maximum bhp are considered to be applicable to the requirements of addendum 90.1-2010aj.

To implement the requirements of addendum 90.1-2010aj, motor efficiency is changed. Before applying this change, fan properties in different prototypes were reviewed and unified for consistent application across prototypes. This baseline change is documented in *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014). As part of this change, the fan mechanical efficiency is set to 55%, and the baseline or PSC motor efficiency is set to 29%. To capture the impact of addendum 90.1-2010aj, the advanced or EC motor efficiency is set to 70%.

For Standard 90.1-2010 models, the baseline motor efficiency is used, whereas for Standard 90.1-2013 models, the advanced motor efficiency is used. .

Table 5.7 summarizes the baseline and advanced fan properties for the fan systems affected by addendum 90.1-2010aj.

Table 5.7. Baseline and Advanced Fan Assumptions for Different Fan Systems

Type of Fan System	Static Pressure, in. w.c.	Fan Mech. Efficiency	Motor Efficiency	Total Fan Efficiency	Motor Efficiency	Total Fan Efficiency	Modeling Approach in *EnergyPlus*
	All	All	Baseline		Advanced		
Fan-Coil Units	1.088	55%	29%	16%	70%	39%	Modeled as fan system
Exhaust Fans	0.500	55%	29%	16%	70%	39%	Modeled as fan system
Kitchen Fans	0.500	55%	29%	16%	70%	39%	Modeled as plug load
Elevator Exhaust	0.4480	55%	29%	16%	70%	39%	Modeled as plug load

5.2.2.5 Addendum 90.1-2010am: Boiler Turndown

Addendum 90.1-2010am adds a new Section, 6.5.4.6 to Standard 90.1-2013, and requires that boiler systems with design input of at least 1,000,000 Btu/h comply with a turndown ratio as specified in Table 6.5.4.6. Table 5.8 shows the boiler turndown requirements of addendum 90.1-2010am.

Table 5.8. Boiler Turndown Required by Addendum 90.1-2010am

Boiler System Design Input (Btu/h)	Minimum Turndown Ratio
≥ 1,000,000 and less than or equal to 5,000,000	3 to 1
> 5,000,000 and less than or equal to 10,000,000	4 to 1
> 10,000,000	5 to 1

The following prototype buildings use boilers that may be affected by the turndown requirements: Large Office, Hospital, Primary School, Secondary School, Large Hotel, High-rise Apartment, and Outpatient Healthcare.

The baseline control type for the prototype models is assumed to be single-stage capacity control (PNNL 2014). Compared with the single-stage capacity control, modulating boiler capacity as required by addendum 90.1-2010am will improve the boiler performance at part-load conditions. Part-load curves are developed for single-stage capacity control and modulating capacity control (PNNL 2014).

The following steps describe the logic in implementing the requirements of addendum 90.1-2010am into the baseline and advanced models:

1. For the baseline models, the following part load efficiency curve is used:

$$Single\ Stage\ Curve = 0.907 + 0.320 * PLR - 0.420 * PLR^2 + 0.193 * PLR^3$$

2. For the advanced models, boiler systems with input capacity <1,000 MBH use the single stage curve, whereas boiler systems with input capacity >1,000 MBH, use the following curve:

$$\mathrm{ModCurve} = 0.975 + 0.305 * \mathrm{PLR} - 0.527 * \mathrm{PLR}^2 + 0.249 * \mathrm{PLR}^3$$

3. When the part load ratio (PLR) is below the minimum turndown ratio, the curve output will be calculated by

$$\mathrm{Curve}_{\mathrm{PLR}} = \frac{\mathrm{PLR}}{\mathrm{PLR} + 2\%} * \frac{\mathrm{Ec}_{\mathrm{min}}}{\mathrm{Et}_{\mathrm{rated}}}$$

4. Step 3 applies to both baseline and advanced models.

5.2.2.6 Addendum 90.1-2010aq: Staged Cooling and Economizer Integration

Addendum 90.1-2010aq introduced several new requirements related to direct expansion (DX) cooling capacity control, air economizer integration and fan airflow control to Chapter 6, and modified the requirements in both the mandatory requirements (Section 6.4) and the prescriptive requirements (Section 6.5) of Standard 90.1-2010. The requirements of addendum 90.1-2010aq (effective 1/1/2016) can be summarized as follows:

1. For DX units ≥65,000 Btu/h that control cooling capacity directly based on space temperature (usually serving a single zone), a minimum of two stages of mechanical cooling capacity is required. DX units ≥65,000 and <240,000 Btu/h that modulate airflow shall have three stages of cooling with minimum compressor displacement ≤35% while DX units ≥240,000 Btu/h that modulate airflow shall have four stages of cooling with minimum compressor displacement ≤25%

2. For DX units that control cooling capacity directly based on space temperature (usually serving a single zone), a minimum of two stages of fan control is required. Low or minimum speed is not allowed to exceed 66% of full speed.

3. DX cooling capacity control is required to be interlocked with air economizer controls such that 100% outdoor air can be supplied when mechanical cooling is on and outdoor airflow is only reduced after the discharge air temperature has dropped below 45°F.

A new method of simulating economizer operation is introduced to improve the modeling of partial economizer operation and to capture the difference in partial economizer operation between single-stage cooling and two-stage cooling as required by addendum 90.1-2010aq. This new method is described in *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014).

Modeling Cooling Capacity Control

The following prototype building models use packaged single-zone DX cooling units: Standalone Retail, Strip Mall, Quick-service Restaurant, Full-service Restaurant, Primary School, Secondary School, Small Hotel, and Warehouse. Except for the single-zone systems in Small Hotel and Warehouse buildings, the cooling capacity of DX units found in the prototypes is larger than 65,000 Btu/h in most climate zones. DX units larger than 65,000 Btu/h have been installed with two-stage compressors for a long period in the market. Therefore, it is assumed that all packaged single-zone DX cooling units in Standard 90.1-2010 models and 90.1-2013 models, except those Small Hotel and Warehouse, have two-stage compressors. DX cooling in these prototypes is modeled using the two-stage cooling object (*Coil:Cooling:DX:TwoSpeed*) in *EnergyPlus*. For Standard 90.1-2010 and 90.1-2013 models, the low-stage capacity is assigned to be half the high-stage capacity.

Improved economizer integration is a source of savings from staged cooling. When the cooling capacity thresholds for requiring staged cooling are exceeded in Standard 90.1-2010 and 90.1-2013 models, economizer operation is modified to represent increased economizer effectiveness. The fraction of time spent by the system in each mode—full economizer, partial economizer, and full mechanical cooling—is used to calculate an average economizer effectiveness for a given time step. Economizer effectiveness is adjusted by changing the maximum outside air schedule that controls the amount of outside air available at a time step. Economizer effectiveness calculations are described in greater detail in *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014).

Packaged DX cooling units for multiple zones are used in the following prototype models: Medium Office, Primary School, and Outpatient Healthcare. These units are currently modeled as two-stage DX cooling for discharge air temperature control. Based on addendum 90.1-2010aq, the number of cooling stages is required to be increased to three for those units with cooling capacity in between 65,000 and 240,000 Btu/h and increased to four for those units with cooling capacity more than 240,000 Btu/h. In *EnergyPlus*, the multi-speed DX cooling object (*Coil:Cooling:DX:Multispeed*) cannot be used to model unitary air conditioners. In addition, the cooling capacity cannot be overridden with EMS control. Although it might be possible to consider the impact via the part-load performance curve, the challenge is the lack of data to support the curve development. Therefore, the impact of reduced compressor cycling for packaged VAV units is not captured.

Modeling Fan Airflow Control

For packaged DX cooling units serving single zones, the threshold of cooling capacity is reduced from 110,000 Btu/h to 65,000 Btu/h for fan speed control by addendum 90.1-2010aq. Previously, while modeling the requirements for single-zone VAV in Standard 90.1-2010, a workaround was used to emulate single-zone VAV control. Because this workaround could not capture the required fan speed control very well, the EMS is used to capture the impact of fan speed control. Using the EMS, the percentage of time for different operation modes (ventilation, economizing, first-stage DX cooling, and second-stage DX cooling) is calculated.

In each time step, the compressor speed ratio is used to determine the percentage of time when the compressor runs at its rated speed. The DX coil runtime fraction is then used to determine the percentage of time in ventilation mode and economizing mode. The logic works as follows:

1. If the compressor speed ratio is greater than 0, the percentage of first-stage DX cooling is equal to 1 minus compressor speed ratio.

2. If the compressor speed ratio is equal to 0, the DX cooling coil runtime fraction is the percentage of time for first-stage DX cooling.

3. Next, if the DX coil runtime fraction is greater than 0, the percentage of time for ventilation mode is equal to 1 minus DX coil runtime fraction.

4. If the DX coil runtime fraction is equal to 0, the unit is in either ventilation mode or economizing mode for the whole time step.

5. To differentiate between ventilation and economizing mode, the current outdoor airflow is compared to the minimum. If it is higher than minimum, the unit is in the economizing mode; otherwise, it is in the ventilation mode.

Addendum 90.1-2010aq also requires that units with air economizer shall have a minimum of two speeds of fan control during economizer operation. The fan speed control in economizing mode intends to avoid using excess fan energy when outside air is cold enough to provide cooling at partial air flow. In the model, the desired discharge air temperature is calculated to meet the space load assuming the fan runs at its low speed. If the outdoor air temperature is lower than the desired discharge air temperature, the fan is assumed to run at its low speed; otherwise, the fan runs at its high speed.

There are no changes on airflow control from this addendum for packaged VAV systems. Therefore, prototype buildings with packaged VAV systems (Medium Office, Primary School, and Outpatient Healthcare) do not have model changes on supply fan airflow control.

Implementation of Addendum 90.1-2010aq in Prototype building Models

As described earlier, the EMS is used to implement improved economizer effectiveness with two-stage cooling and fan-speed control. The applicable HVAC systems in each model are checked to determine the cooling capacity and whether the capacity thresholds are exceeded. Depending on the capacity, each system is assigned single-stage or two-stage operation. The economizer effectiveness and fan speed are calculated by the EMS routines for each time-step.

5.2.2.7 Addendum 90.1-2010ar: Refrigeration Equipment

Addendum 90.1-2010ar expands the scope of Standard 90.1 to cover requirements for refrigeration equipment including walk-in coolers and freezers and refrigeration systems. The new requirements for walk-in coolers and freezers have been defined and legislated as the national manufacturing standard and described in 10 Code of Federal Regulations (CFR) 431.306. They are added to Standard 90.1 in a new Section, 6.4.5. The requirements are for walk-ins cover doors, insulation, evaporator fan motor, lighting, anti-sweat heater, condenser fan motor, and their controls. The requirements for refrigeration systems include fan-powered condenser controls and a minimum saturated condensing temperature setpoint.

Six prototype buildings with commercial kitchens are affected by addendum 90.1-2010ar: Quick-service Restaurant, Full Service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. Because the walk-in coolers and freezers in these prototype buildings are assumed to be packaged and without remote compressors and condensers, the refrigeration system requirements of addendum 90.1-2010ar do not apply to these prototype buildings.

Navigant (2009) developed characteristics of baseline walk-in coolers and freezers while evaluating potential energy savings from the equipment. It is found that the baseline characteristics either meet or exceed most requirements in addendum 90.1-2010ar except the evaporator fan motor and the lighting requirements. To capture these new requirements, the evaporator fan motors in baseline models are assumed to be shaded pole motors (1/20 hp) for walk-in coolers and shaded pole motors (1/40 hp) for walk-in freezers with a motor efficiency of 20%. The motors are changed to EC motors in the advanced models with a motor efficiency of 70%. The average efficiencies of shaded pole and EC motors are determined by surveying typical efficiencies listed in manufacturer catalogs. The differences in efficiency are reflected in the fan power inputs in *EnergyPlus*.

Light sources with a minimum efficacy of 40 lumens per Watt are assumed to be in the baseline walk-ins, although this minimum efficacy is required by addendum 90.1-2010ar. The impact of the lighting control requirement is modeled as a 10% reduction in the hourly lighting schedule in the advanced models. This simulates the energy saving benefits from an occupancy sensor based lighting control.

Both the EC fan motor efficiency and lighting schedule reduction are applied to the Standard 90.1-2010 models because addendum 90.1-2010ar introduces federally mandated requirements that do not provide credit to Standard 90.1-2013.

5.2.2.8 Addendum 90.1-2010as: Humidification System Requirements

Addendum 90.1-2010as makes changes to Sections 6.5.2.4.1, 6.5.2.4.2, 6.5.2.4.3 and 6.5.2.5 of Standard 90.1-2010. The requirements in Sections 6.5.2.4.1 and 6.5.2.4.2 already exist in 90.1-2010; they are marked as changes because their location in Section 6.5 is changed. Sections 6.5.2.4.3 and 6.5.2.5 are new requirements. Section 6.5.2.4.3 requires a minimum of R-0.5 insulation on humidifier steam dispersion assemblies. Section 6.5.2.5 requires preheat coils to stop operation during cooling or economizing. Modeling approaches to the two sections are discussed below.

Impact of Insulation on Humidifier Steam Dispersion Assembly

The insulation requirement on humidifier steam dispersion assembly affects those air systems with humidifiers. These systems occur in the Hospital (VAV_ER, VAV_OR, VAV_ICU, VAV_PATRMS, VAV_LABS), Outpatient Healthcare (AHU-1), and Large Office (AirLoop Datacenter Basement) prototype buildings.

Assuming the humidifier is of electric steam type, the impact of added insulation is modeled by adding an electric heating coil to the affected air handling units (AHUs). When the humidifier is on, the electric coil is on. The coil outputs differ between the baseline and the advanced case to capture the impact of insulation on the steam dispersion assembly. In the baseline, the coil output causes the supply air temperature rise of 2.58°F (PNNL 2014). In the advanced case with humidifier insulation, the coil output causes the supply air temperature rise of 0.65°F (Wasner and Lundgreen, 2007).

Impact of Preheat Coil Control

Section 6.5.2.5 intends to avoid uncontrolled heat transfer from the preheat coil to the bypass air when AHUs are in cooling mode, including economizing mode. This heat transfer can occur on face and bypass coils even when the face dampers are completely closed. The requirements have an impact on systems in the Hospital (VAV_ER, VAV_OR, VAV_ICU, VAV_PATRMS, VAV_LABS) and

Outpatient Healthcare (AHU-1) prototype buildings. To capture the impact of steam preheat coil control, a hot water coil is added to the affected AHUs.

In the baseline case, the hot water coil is on when the outdoor air temperature is below 50°F regardless of whether the AHU is in cooling or heating mode. When the hot water coil is on, it has a heating output of 8.5 Btu/h per cooling cfm for the operating room AHU and 3.0 Btu/h per cooling cfm for other medical area AHUs (PNNL 2014). In the advanced case, the hot water coil is only on when the outdoor air temperature is below 50°F and the AHU is in heating mode. The supply air temperature rise is calculated from the heating output and the airflow rate.

Implementation Approach

In *EnergyPlus*, heating coils located in the AHUs are controlled to a predefined temperature setpoint. This means that the heating output normally varies to satisfy the controlled temperature setpoint. This control method does not meet the requirement of modeling a constant heating output for a given system. The EMS is used to achieve the control strategy described above. When the added heating coil is on, the controlled temperature setpoint is reset based on the inlet node temperature and the air temperature rise.

5.2.2.9 Addendum 90.1-2010au: Fan Power Limitation Adjustment Credits

Addendum 90.1-2010au adds deductions to pressure drop credits specified in Table 6.5.3.1B of Standard 90.1-2010 (now Table 6.5.3.1-2 in Standard 90.1-2013), used to calculate the fan power limits for a system. The deductions apply to systems without any central heating or cooling device. Systems without a central cooling device are required to deduct 0.6 inches water column (in. w.c.) from the allowed fan pressure drop, systems without a central heating device are required to deduct 0.3 in. w.c. from the allowed fan pressure drop, and systems with a central electric resistance heating element are required to deduct 0.2 in. w.c. from the allowed fan pressure drop. Another requirement allows an adjustment for sound attenuation for fans in systems serving spaces with background noise criteria requirements, although this change does not affect the prototype building models.

All prototype buildings have central cooling coils but none of them have central electric resistance coils. Therefore, the new requirements only impact those prototype buildings without central heating coils. This applies to multi-zone VAV systems: Hospital, Large Hotel, Large Office, Medium Office, Outpatient Healthcare, Primary School, and Secondary School located in warm climates. To determine the systems that must take the fan pressure deduction, additional calculations are required. A central heating device is needed only when the mixed air temperature (MAT) is below the supply air temperature (SAT) setpoint at design conditions.

Assuming a return air temperature of 75°F and a supply air temperature of 55°F, and using the heating design outdoor air temperature for each climate location, the critical outdoor air fraction at which mixed air temperature would be equal to the supply air temperature setpoint is calculated. If the modeled outdoor air fraction—calculated based on multi-zone ventilation and dynamic ventilation reset requirements—is larger than the critical outdoor air fraction calculated earlier, the MAT would be lower than the SAT and a heating coil is required. Accordingly, when a central heating coil is not required, the fan pressure drop is reduced by 0.3 in. w.c. in the advanced models.

5.2.2.10 Addendum 90.1-2010az: Cooling Tower Efficiency

Addendum 90.1-2010az increases the minimum efficiency of open circuit axial fan cooling towers from 38.2 to 40.2 gpm/hp at rated conditions. Additionally, a note “f” is added to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) clarifying that the required minimum efficiency rating for all types of cooling towers applies to models with options and accessories that affect the thermal performance of the whole unit, and not just the base model.

The addendum applies to the Hospital and Large Office prototype buildings that use water cooled chillers. The impact of footnote “f” to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) cannot be captured because the cooling towers in prototype building models do not account for add-ons that may impact the efficiency of the whole unit. The impact of addendum 90.1-2010az is captured by converting the efficiency (gpm/hp) to fan power based on the design flow rate and inputting the fan power into *EnergyPlus*.

5.2.2.11 Addendum 90.1-2010ba: Door Switches

Addendum 90.1-2010ba adds a new Section, 6.5.10, to Standard 90.1-2010 and requires doors opening to the outside, which do not close automatically, to have switches that connect to the HVAC system, such that the HVAC system is put into deep setback (55°F for heating and 90°F for cooling) automatically 5 minutes after the door is opened. Doors in spaces that are not being heated or cooled as well as loading dock doors are exempted. Operable doors, such as those that open to balconies in apartments and hotel guestrooms that are operated by the occupants for fresh air, are the types of doors targeted by the addendum. The addendum attempts to reduce the HVAC energy spent in satisfying the unintentional infiltration load from operable doors.

Apartments in the two apartment prototypes and guestrooms in the two hotel prototypes are likely to have doors opening to the outside that do not have automatic closing devices. To capture the impact of this addendum, several unknowns needed to be resolved:

1. the fraction of apartments and guestrooms in prototype buildings that have operable doors,
2. ambient conditions when doors are likely to be open,
3. the probability of operable doors being operated during favorable conditions,
4. the time for which doors stay open after conditions become unfavorable,
5. the time of day when doors may be open, and,
6. the fraction of door area that is open to the outdoor conditions.

The New Commercial Construction Characteristics (NC3) database[1] (Richman et al. 2008) is used to determine the fraction of spaces with operable doors in the two apartment and the two hotel prototypes. The fractions are based on a review of groups of building plans. Of the plans reviewed for mid-rise

[1] NC3 is a database developed by Pacific Northwest National Laboratory based on building characteristics taken from McGraw Hill commercial building plans submitted for bidding. The database includes over 160 buildings.

apartment buildings, not all buildings had operable doors and balconies. Similarly, not all the guestrooms in a group of reviewed hotels had operable doors to the outside. To simulate savings from this addendum the following assumptions are made:

1. Assume that outdoor conditions are considered favorable between outdoor temperatures of 60°F and 80°F.
2. Assume one-third of operable doors are opened when conditions are favorable.
3. Assume doors stay open for 1 hour after conditions become unfavorable.
4. Assume doors are allowed to be open only from 6 a.m. to 10 p.m. After 10 p.m., doors are unlikely to be operated.
5. Assume area of door opening is on average 25% of fully open. The doors are assumed to be 7 feet tall and 6 feet wide, a common sliding door dimension.
6. Assume doors are closed when the indoor temperature falls below 66°F or rises above 78°F.

In the baseline models, the HVAC system continues to operate normally after the doors have been opened. In the advanced models, the thermostat is set back to 55°F for heating and 90°F for cooling 5 minutes after the door is opened. Table 5.9 summarizes the assumptions used in modeling addendum 90.1-2010ba.

Table 5.9. Prototype Building Properties and Assumptions for Modeling Door Switches

	Prototype Buildings			
Assumptions	High-rise Apartment	Mid-rise Apartment	Small Hotel	Large Hotel
Number of buildings in the NC3 Database	3	4	8	18
Fraction of operable doors in living areas	36.7%	11.6%	0.7%	9.6%
Fraction of doors operated when conditions are favorable	0.33	0.33	0.33	0.33
Fraction of door area that is open	25%	25%	25%	25%
Operable door dimension	7 ft x 6 ft	7 ft x 6 ft	7 ft x 6 ft	7 ft x 6 ft
Operable door opening area (ft^2)	1.27	0.40	0.02	0.22
Operable door availability	6 a.m. to 10 p.m.	6 a.m. to 10 p.m.	6 a.m. to 10 p.m.	6 a.m. to 10 p.m.
Building height (ft)	100	40	38	63
Height difference (ft)	50	20	19	31.5
Min indoor temp (°F)	66	66	66	66
Max indoor temp (°F)	78	78	78	78
Min outdoor temp (°F)	60	60	60	60
Max outdoor temp (°F)	80	80	80	80
Fraction of living spaces in prototypes that are occupied	100%	100%	65%	65%

The *ZoneVentilation:WindandStackOpenArea* object in *EnergyPlus* is used to control infiltration from the operable door. This object allows the opening area to be defined and indoor and outdoor temperature limits to be established for the operation of the door, and takes into account the effect of wind and stack on the infiltration through the opening. The EMS is used to detect whether the door is open. If the door has been open for one time-step (the time-step for all models is longer than 5 minutes), the thermostat setback is enabled by changing the thermostat schedule.

5.2.2.12 Addendum 90.1-2010bi: Air Conditioner and Heat Pump Efficiency

Section 6.4.1.1 in Standard 90.1-2010 and its related tables include mandatory minimum efficiency values for HVAC equipment. Table 6.8.1A in Standard 90.1-2010 (now Table 6.8.1-1 in Standard 90.1-2013) applies to unitary air conditioners and condensing units and Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013) applies to unitary and applied heat pumps. Minimum efficiency values are provided for equipment with different cooling capacities and different manufacturing time periods. Addendum 90.1-2010bi increases the efficiency values for unitary air conditioners and heat pumps under 65,000 Btu/h cooling capacity manufactured on or after January 1, 2015. Table 5.10 shows the Standard 90.1-2010 values and the amended values from addendum 90.1-2010bi for this size equipment manufactured on or after January 1, 2015. Values not shown in the table remain the same as in Standard 90.1-2010.

Table 5.10. Unitary HVAC Equipment Efficiency (<65,000 Btu/h)

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	90.1-2010 Minimum Efficiency Before 1/1/2015[a]	Addendum 90.1-2010bi Minimum Efficiency As of 1/1/2015
Air Conditioners, Air-Cooled	<65,000 Btu/h	All	Split System	13.0 SEER	13.0 SEER
			Single Package	13.0 SEER	14.0 SEER
Heat Pumps, Air-Cooled (cooling mode)	<65,000 Btu/h	All	Split System	13.0 SEER	13.0 SEER
			Single Package	13.0 SEER	14.0 SEER
Heat Pumps, Air-Cooled (heating mode)	<65,000 Btu/h (cooling capacity)	All	Split System	7.7 HSPF	8.2 HSPF
			Single Package	7.7 HSPF	8.0 HSPF

(a) HSPF is heating seasonal performance factor; SEER is seasonal energy efficiency ratio.

The changes are implemented in the advanced models by modifying a script routine that extracts the equipment cooling capacity and assigns the corresponding equipment efficiency based on that capacity. For the advanced models, higher efficiency values are applied for the applicable unit type and capacity. This affects the HVAC units in prototype buildings with unitary HVAC equipment, including the Small Office, Medium Office, Standalone Retail, Strip Mall, Primary School, Outpatient Healthcare, Small Hotel, Warehouse, Quick-service Restaurant, Full-service Restaurant, and Mid-rise Apartment. Only those systems with air conditioners and heat pumps having capacities smaller than 65,000 Btu/h are affected.

5.2.2.13 Addendum 90.1-2010bk: PTAC Cooling Efficiency

The current federal minimum cooling efficiency levels for standard-size packaged terminal air conditioners (PTACs) established by DOE rulemaking are lower than those for packaged terminal heat pumps (PTHPs). These requirements came into effect on October 8, 2012. Addendum 90.1-2010bk modifies Table 6.8.1D (now Table 6.8.1-4 in Standard 90.1-2013) by raising the minimum cooling efficiency requirements for standard-size PTACs manufactured on or after January 1, 2015, to the same level as the PTHPs. Table 5.11shows the change in PTAC efficiency required as per addendum 90.1-2010bk.

Table 5.11. Standard-size PTAC Efficiency

Equipment Type	Size Category	Minimum Efficiency Effective before 1/1/2015	Minimum Efficiency Effective as of 1/1/2015
PTAC (cooling mode)	All Capacities	13.8 – (0.3 x Cap/1000) EER	14.0 – (0.3 × Cap/1000) EER

The addendum only applies to the Small Hotel prototype building, which has guestrooms and corridors served by PTACs. The addendum is modeled by assigning the higher efficiency level to the advanced models. The calculation of *EnergyPlus* COP from EER is shown in the *Analysis of 90.1-2010* (Thornton et al. 2011).

5.2.2.14 Addendum 90.1-10bs: Demand Controlled Ventilation

Demand controlled ventilation (DCV) requirements were first introduced in Standard 90.1-2004. Since then, DCV requirements have become more stringent mainly by reducing the design occupancy threshold at which the requirements are triggered. Addendum 90.1-2010bs reduces the threshold at which DCV is required from >40 to >25 people per 1000 ft^2 and also lowers the minimum system outdoor air threshold from 1200 to 750 cfm. Due to the renumbering of sections in Section 6.4, the DCV requirements now appear in Section 6.4.3.8.

The impact of this addendum is captured by first identifying prototype buildings with spaces that have design occupancy of more than 25 people per 1000 ft^2 and meeting other DCV requirements. Spaces meeting all the DCV requirements and the lower design occupancy threshold are identified in Large Hotel, Primary School, and Secondary School prototype buildings.

For the Primary and Secondary School prototypes, DCV controllers are implemented for the classroom pods, which previously did not require them. For the Large Hotel prototype, DCV controller has been implemented for the multi-zone VAV system, but new spaces are added to the controller as part of the new requirements. DCV is implemented in *EnergyPlus* by using a mechanical controller to control turn down of the outdoor air intake (based on occupancy) in spaces required to have DCV. Only the people component of the total outdoor air intake is allowed to be reduced by the DCV controller. Even though DCV controls are added to new spaces, DCV will be enabled only if it is required for the particular prototype building model in a given climate zone.

DCV is not required in the presence of an energy recovery ventilator (ERV). A preliminary simulation is conducted to determine whether ERV is required for each prototype building model. After the final ERV and DCV assignments are made and the system layout is finalized, the final sizing and annual runs are conducted.

5.2.2.15 Addendum 90.1-2010bt and Addendum 90.1-2010cy: Energy Recovery Ventilation

Table 6.5.6.1 in Standard 90.1-2010 specified energy recovery requirements as a function of percent outdoor air and design supply fan airflow. The requirements were for systems with outdoor air ventilation ratios above 30%. Many buildings operate with ventilation ratios below 30%. Addendum 90.1-2010bt establishes energy recovery for outdoor ventilation rates above 10% in climate zones 1A, 2A, 3A, 4A, 5A, 6A, 6B, 7, and 8. Additionally, the requirements for zones 3B, 3C, 4B, 4C, and 5B for systems with outdoor ventilation rates above 70% are removed because it was determined that energy recovery would not be cost-effective for ventilation systems that do not operate continuously.

Addendum 90.1-2010cy separates the energy recovery requirements for ventilation systems operating less than 8,000 hours per year and more than 8,000 hours per year in two tables: Table 6.5.6.1-1 and 6.5.6.1-2 of Standard 90.1-2013. Table 6.5.6.1-1 carries the requirements introduced by addendum 90.1-2010bt, whereas Table 6.5.6.1-2 includes requirements for ventilation systems running more than 8,000 hours per year, enabling the requirements that were removed by addendum 90.1-2010bt to be reintroduced together with the new requirements.

Table 5.12 and Table 5.13 show the requirements introduced by addendum 90.1-2010bt and addendum 90.1-2010cy. Blank cells in Table 5.12 indicate that the requirement did not change from Standard 90.1-2010.

Table 5.12. New ERV Requirements for Ventilation Systems Operating Less than 8000 Hours per Year

Climate Zone	% Outdoor Air at Full Design Airflow Rate			
	≥10% and <20%	≥20% and <30%	≥70% and <80%	≥80%
	Design Supply Fan Airflow Rate (cfm)			
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR
1B, 2B, 5C	NR	NR		
6B	≥28,000	≥26,500		
1A, 2A, 3A, 4A, 5A, 6A	≥26,000	≥16,000		
7,8	≥4500	≥4000		

Table 5.13 ERV Requirements for Ventilation Systems Operating Greater than 8,000 Hours per Year

Climate Zone	% Outdoor Air at Full Design Airflow Rate							
	≥10% and <20%	≥20% and <30%	≥30% and <40%	≥40% and <50%	≥50% and <60%	≥60% and <70%	≥70% and <80%	≥80%
	Design Supply Fan Airflow Rate (cfm)							
3C	NR	NR	NR	NR	NR	NR	NR	NR
1B, 2B, 3B, 4C, 5C	NR	≥19500	≥9000	≥5000	≥4000	≥3000	≥1500	>0
1A, 2A, 3A, 4B, 5B	≥2500	≥2000	≥1000	≥500	>0	>0	>0	>0
4A, 5A, 6A, 6B, 7, 8	>0	>0	>0	>0	>0	>0	>0	>0

ERV requirements are not applied to the two apartment prototypes or the Small Hotel prototype even though they meet the trigger for the requirement because ERVs are not available for these small systems. Based on the system sizing information from the *EnergyPlus* simulation, each air system of the other 13 prototype buildings in each climate location is checked to determine whether energy recovery is applicable. Other energy recovery modeling details have been described previously in the *Analysis of 90.1-2010* (Thornton et al. 2011).

5.2.2.16 Addendum 90.1-2010cb: Optimum Start

Addendum 90.1-2010cb introduces several changes to the setback control (Section 6.4.3.3.2) and optimum start control requirements (Section 6.4.3.3.3) in Standard 90.1-2010. New setback control requirements include the following: heating and cooling setback is required in all climate zones, heating setback is required to be at least 10°F below occupied heating setpoint, cooling setback is required to be at least 5°F above occupied cooling setpoint, and radiant heating systems are required to have a setback of at least 4°F below occupied heating setpoint. New optimum start control requirements include the following: removal of the 10,000 cfm threshold, requiring optimum start for only those systems with direct digital control (DDC) and setback control requirements, and requiring the control algorithm to be a function of outside air temperature and of floor temperature for radiant floor systems.

Because optimum start is now required for systems with DDC instead of for systems with a minimum of 10,000 cfm of design supply air, all systems in all prototype buildings are reexamined to determine whether DDC would be required for the system. Another addendum, 90.1-2010aa, introduced new requirements that clearly spelled out the situations in which DDC is required. This addendum was assumed to not have an energy impact because DDC by itself is assumed to not save energy in the models. The requirements of addendum 90.1-2010cb do interact with the requirements of addendum 90.1-2010aa when considering savings from 90.1-2010cb.

Addendum 90.1-2010aa adds a new Section, 6.4.3.10, to Standard 90.1-2010 for DDC with three parts: 1) DDC applications that require DDC for three new building situations and five existing building situations; 2) new requirements for DDC controls to have four capabilities—monitor zone and system demand for five parameters, transfer zone and system demand information to appropriate controllers, automatically detect those zones and systems that may be excessively driving the reset logic and generate an alarm to the system operator, and allow operator to remove zones from the reset algorithm (addendum 90.1 2010s also required the last two items for VAV static pressure reset—placing these requirements in a mandatory DDC section expands their scope to all resets, including chilled water and supply air); and 3) a requirement for DDC trending and graphically displaying input and output. With the clarity added for when DDC is required, it is possible to determine systems in the prototype models that are required to have DDC.

Table 5.14 lists systems in prototype building models required to have DDC controls per addendum 90.1-2010aa. These systems are not required to run continuously. Only packaged single-zone systems in the Standalone Retail prototype require DDC due to the requirements of addendum 90.1-2010aa; all other systems would have required DDC to operate and are assumed to have DDC in all models.

Table 5.14. Systems in Prototype building Models Requiring DDC and Setback Controls in Standard 90.1-2013

Prototypes with DDC	Systems with Setback Controls and DDC
Highrise Apartment	AirLoop Office DXAC Heat Pump
Hospital	None
Large Hotel	None
Large Office	CAV_BAS, VAV_BOT WITH REHEAT, VAV_mid WITH REHEAT, VAV_top WITH REHEAT
Medium Office	All systems
Outpatient Healthcare	All systems
Standalone Retail	All systems
Primary School	All systems
Secondary School	All systems

The new setback control requirements are captured as follows:

1. Heating and cooling setback are expanded to all climate zones. In Standard 90.1-2010 models, heating setback was exempt in climate zone 1 and cooling setback was required only in climate zones 1b, 2b, and 3b. Setback controls are applied only to systems that do not run continuously.

2. Optimum start controls are applied to those systems in Standard 90.1-2013 prototype building models that are required to have DDC and have setback controls regardless of system airflow. In the baseline models, standard optimum start control is applied only if the design fan airflow rate is higher than 10,000 cfm. The standard optimum start control does not include the effect of outside air temperature on the system start time.

3. For Standard 90.1-2013, the optimum start control algorithm is modified to include outside air temperature in calculating how the control is operated. The EMS within *EnergyPlus* is used to detect the outside air temperature. Based on the outside air temperature, the time at which the system should turn on to reach the occupied setpoint is determined. If the system is required to start 2 hours prior to the occupied thermostat setpoint, then the thermostat setpoint goes through two steps. If the system is required to start only 1 hour prior to the occupied setpoint, then the thermostat setpoint goes through just one step. In real buildings, optimum start controls could be based on a learning algorithm that starts the building optimally given the outdoor air temperature, space temperature, and the time before occupied setpoint. Figure 5.3 shows an example of how the optimum start control functions on a warm morning. The control operation is fully described in *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (PNNL 2014).

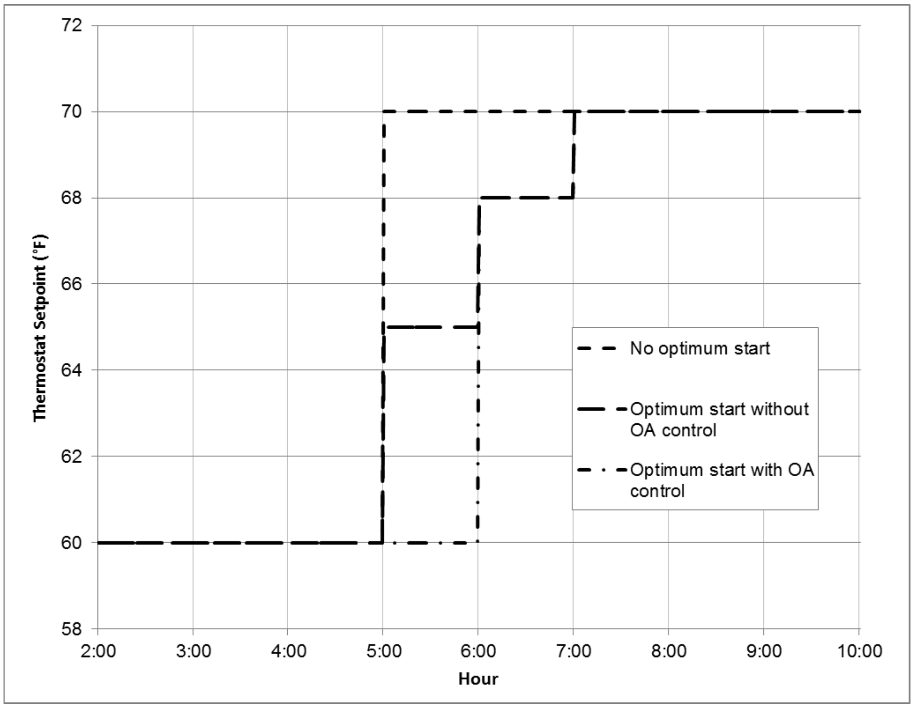

Figure 5.3. Example of Optimum Start Control Operation for a Warm Morning

5.2.2.17 Addendum 90.1-10ch: Chiller Efficiency

Addendum 90.1-2010ch changes the minimum efficiency requirements for air- and water-cooled chillers in Table 6.8.1C of Standard 90.1-2010 (now Table 6.8.1-3 of Standard 90.1-2013). Table 5.15 shows the minimum efficiency requirements, in terms of COP, for water-cooled positive displacement chillers, water-cooled centrifugal chillers, and air-cooled chillers.

Table 5.15. Efficiency in COP for Chillers

	Standard 90.1-2010				Addendum 90.1-2010ch			
	Path A		Path B		Path A		Path B	
Size (tons)	Full Load	Part Load	Full Load	Part Load	Full Load	Part Load	Full Load	Part Load
Water-cooled Positive Displacement Chillers								
<75	4.51	5.58	4.39	5.86	4.69	5.86	4.51	7.03
75-150	4.54	5.72	4.45	6	4.88	6.28	4.69	7.18
150-300	5.17	6.06	4.9	6.51	5.33	6.51	5.17	7.99
300-600	5.67	6.51	5.5	7.18	5.76	6.76	5.63	8.58
> 300	5.67	6.51	5.5	7.18	6.28	7.03	6.01	9.25
Water-cooled Centrifugal Chillers								
<150	5.55	5.9	5.5	7.81	5.76	6.39	5.06	7.99
150-300	5.55	5.9	5.5	7.81	5.76	6.39	5.54	8.79
300-400	6.1	6.4	5.86	8.79	6.28	6.76	5.91	9.02
400-600	6.1	6.4	5.86	8.79	6.28	7.03	6.01	9.25
>600	6.17	6.52	5.96	8.79	6.28	7.03	6.01	9.25
Air-cooled Chillers								
<150	2.8	3.66	NA	NA	2.96	4.01	2.84	4.63
150-300	2.8	3.74	NA	NA	2.96	4.1	2.84	4.72

This addendum involves both full-load and part-load efficiency changes. Because of the lack of reliable performance curves used to model part-load efficiency, only the impact of full-load efficiency changes is captured. This is the same approach used previously for addendum 90.1-2007m when modeling the Standard 90.1-2010 requirements in the *Analysis of 90.1-2010* (Thornton et al. 2011).

The Secondary School and Large Hotel prototypes use air-cooled chillers, while the Hospital and Large Office prototypes use water-cooled chillers. Path A is followed for all four prototype buildings. The full-load efficiency changes are implemented through the sizing routine by changing the capacity thresholds and corresponding efficiency levels.

5.2.2.18 Addendum 90.1-2010cz: Residential-size Boiler Efficiency

Addendum 90.1-2010cz increases the minimum efficiency for boilers with capacities less than 300,000 Btu/h by updating Table 6.8.1F in Standard 90.1-2010 (now Table 6.8.1-6 in Standard 90.1-2013). This increase in efficiency reflects the minimum federally mandated equipment efficiency for these types of boilers. Efficiency improvements in terms of annual fuel utilization efficiency (AFUE), combustion efficiency, or thermal efficiency are seen for gas-fired and oil-fired boilers with capacities less than 300,000 Btu/h. Boilers of this size are typically found in residential building applications. Table 5.16 shows the boiler efficiency requirements modified by addendum 90.1-2010cz.

Table 5.16. Boiler Efficiency Requirements in Addendum 90.1-2010cz

Equipment Type	Subcategory	Size Category (Input)	Minimum Efficiency Before Addendum 90.1-2010cz As of 3/2/2010	Minimum Efficiency After Addendum 90.1-2010cz: After Addendum 90.1-2010cz	Minimum Efficiency After Addendum 90.1-2010cz: As of 3/2/2020
Boilers, Hot Water	Gas Fired	<300,000 Btu/h	80% AFUE	82% AFUE	82% AFUE
		≥300,000 Btu/h and <2,500,000 Btu/h	80% Et	80% Et	80% Et
		>2,500,000 Btu/h	82% Ec	82% Ec	82% Ec
	Oil Fired	<300,000 Btu/h	80% AFUE	84% AFUE	84% AFUE
		≥300,000 Btu/h and <2,500,000 Btu/h	82% Et	82% Et	82% Et
		>2,500,000 Btu/h	84% Ec	84% Ec	84% Ec
Boilers, Steam	Gas Fired	<300,000 Btu/h	75% AFUE	80% AFUE	80% AFUE
	Gas-Fired all, except Natural Draft	≥300,000 Btu/h and <2,500,000 Btu/h	79% Et	79% Et	79% Et
		>2,500,000 Btu/h	79% Et	79% Et	79% Et
	Gas Fired-Natural Draft	≥300,000 Btu/h and <2,500,000 Btu/h	77% Et	77%Et	79%Et
		>2,500,000 Btu/h	77% Et	77% Et	79% Et
	Oil Fired	<300,000 Btu/h	80% AFUE	82% AFUE	82% AFUE
		≥300,000 Btu/h and <2,500,000 Btu/h	81% Et	81% Et	81% Et
		>2,500,000 Btu/h	81% Et	81% Et	81% Et

The following prototypes use gas-fired hot water boilers: Large Office, Primary School, Secondary School, Outpatient Healthcare, Hospital, and Large Hotel. There are no oil-fired or steam boilers in any of the prototype buildings. Only the Outpatient Healthcare prototype building has boilers smaller than 300,000 Btu/h.

The efficiency of gas-fired hot water boilers smaller than 300,000 Btu/h is increased from 80% AFUE to 82% AFUE by addendum 90.1-2010cz. To capture this impact, the efficiency must be expressed in terms of thermal efficiency for inputting into *EnergyPlus*. AFUE is similar to SEER and represents average annual efficiency. To calculate the thermal efficiency from AFUE, jacket losses must be subtracted. Jacket losses of up to 0.75% are allowed for furnaces smaller than 225,000 Btu/h. This assumption is used for boilers smaller than 300,000 Btu/h. Thus, the updated thermal efficiency as per addendum 90.1-2010cz is calculated to be 81.25%.

The new efficiency is input using the sizing routine that detects the size of the boiler after the sizing run is complete, and provides the appropriate efficiency for the annual run. Note that the higher boiler efficiency is applied to the Standard 90.1-2013 models as well as the Standard 90.1-2010 models because addendum 90.1-2010cz introduces federally mandated requirements that do not provide credit to Standard 90.1-2013.

5.2.2.19 Addendum 90.1-2010di: Humidity Controls

Addendum 90.1-2010di modifies Section 6.4.3.7 in Standard 90.1-2010 (now Section 6.4.3.6 in Standard 90.1-2013) by prohibiting the use of fossil fuel and electricity for humidification above 30%

relative humidity (RH) and dehumidification below 60% RH, except in special circumstances. A dead-band of at least 10% is required when a specific humidity level needs to be maintained for special spaces. Addendum 90.1-2010di also modifies Section 6.5.2.3 in Standard 90.1-2010 by requiring at least 75% of the annual energy used for reheat to be from recovered or site-generated solar energy when specific humidity levels are set and dehumidification control is needed. Other systems that dehumidify and reheat but do not maintain specific humidity levels are required to have 90% of the annual energy used for reheat to be recovered or sourced from site-generated solar energy.

In prototype building models, humidity control is required in the Hospital and Outpatient Healthcare prototype buildings and also in systems serving the data center zones in the Large Office prototype building. The changes in Section 6.5.2.3 due to addendum 90.1-2010di do not have an impact because exception (a) to Section 6.5.2.3 allows reheating if the airflow is supplied to meet ventilation requirement, and this is true for the particular prototype building models.

The changes to Section 6.4.3.7 from addendum 90.1-2010di affect all air systems with humidity control in the Hospital and Outpatient Healthcare prototype buildings. The air system for the data center in the Large Office prototype is not affected because it serves only one zone that already has a setpoint of 30% RH for humidification.

To implement the changes from addendum 90.1-2010di, two changes are applied:

1. The lower humidification limit is set to 30% RH for the advanced models, except for the ICU zone in the Hospital prototype, where it is set to 35% RH considering that some of the zones under the ICU system are for burn units with 40% RH requirement. For the baseline models, the lower humidification limit is left at 40% RH.
2. For advanced models, the AHU’s humidity control strategy is changed to the warmest zone for humidification and the coldest zone for dehumidification. In baseline models, the humidity control strategy continues to be based on pre-defined critical zones.

5.2.2.20 Addendum 90.1-2010dv: Chiller/Boiler Fluid Flow Isolation

Addendum 90.1-2010dv modifies Section 6.5.4.2 of Standard 90.1-2010 to clarify that when multiple chillers or boilers are used, fluid flow through the chillers or boilers that are not operating should be automatically shut off. Addendum 90.1-2010dv also requires that when pumps are used to serve multiple chillers or boilers, the number of pumps shall be equal to the number of chillers or boilers and the pumps will be cycled on and off with the chiller or boiler they serve.

The Hospital and Large Office prototypes are each modeled with two chillers. Other prototypes having chillers or boilers are modeled with only a single piece of equipment. A single constant speed pump serves the two chillers in both the 90.1-2010 Hospital and Large Office prototypes. To model the requirements of addendum 90.1-2010dv, two constant speed pumps (one for each chiller) are used in the advanced models. The pumps cycle on and off with the operation of the chiller they are serving, thus meeting both the requirements of addendum 90.1-2010dv.

5.2.3 Power

5.2.3.1 Addendum 90.1-2010bf: Automatic Receptacle Control

Addendum 90.1-2010bf adds to the requirements previously established by addenda 90.1-2007bs and 90.1-2007cs. This addendum modifies Section 8.4.2 of Standard 90.1-2010 and adds more spaces to the requirement: conference rooms, print/copy rooms, break rooms, and classrooms other than computer classrooms. Open offices required receptacle controls in Standard 90.1-2010, and appear to have been taken off the list of spaces in this addendum; however, the new requirement requires control of individual workstations, which are interpreted as workstations in open offices.

There are other changes made by addendum 90.1-201bf to the original requirement. Independent controls are required for every 5,000 ft^2 instead of 25,000 ft^2 in Standard 90.1-2010 and manual override lasting for 2 hours is allowed. Receptacles are required to be uniformly distributed throughout the space and permanently labeled to visually differentiate the controlled receptacles. These additions are intended to improve compliance and increase energy savings, but compliance rate improvements are not captured in the prototype building models. Occupancy-controlled turn-off is required to turn off power to the receptacle within 20 minutes, instead of 30 minutes in Standard 90.1-2010. Definitive data for the difference in energy savings between a 30- and 20-minute turn off could not be found in the literature and the potential energy savings from this change are not captured in the prototype building models.

The following prototype buildings include spaces that are affected by the new receptacle control requirements: Large Hotel, Small Hotel, Hospital, Medium Office, Large Office, Small Office, Standalone Retail, Full-service Restaurant, Primary School, Secondary School, Outpatient Healthcare, and Warehouse.

Because occupancy sensors are required by lighting control requirements in the new spaces added by addendum 90.1-2010bf, it is assumed that the same occupancy sensors would be used to meet the receptacle control requirement. The addition of new spaces to the receptacle control requirement is captured by following the steps below:

1. The area of each space type in each prototype is determined using the NC3 database. Table 5.17 shows the area fractions for spaces added by addendum 90.1-201bf.
2. The time each space type is unoccupied during normally occupied hours is found. Table 5.18 shows the unoccupied fraction during regularly occupied hours. This fraction is the ratio of the time a space is unoccupied during regular hours. For example, a classroom may be unoccupied during lunch time (12 noon to 1 p.m.), which is within the regular business hours (8 a.m. to 5 p.m.).
3. The fraction of plug-in equipment that is likely to be plugged into a controlled receptacle in each space type is calculated. Table 5.18 shows the fraction of equipment that could be turned off using occupancy sensors. For example, computer monitors could be turned off, but the computers are likely to be plugged into uncontrolled receptacles. The equipment makeup from the Advanced Energy Design Guides is used to determine the equipment that can be unplugged. A diversity factor is added to account for equipment that could be turned off but is not plugged into a controlled receptacle.

The factors and area fractions are combined to produce two reduction fractions, one for occupied periods and another for unoccupied periods, which will be applied to the occupied and unoccupied periods in the equipment schedule for that space. The two factors for the baseline and advanced models are shown in Table 5.19.

Table 5.17. Area Fractions for Space Types Added by Addendum 90.1-2010bf

	Space/Prototype Area Fraction		
Prototype	Classroom	Break Room	Conference Room
Large Hotel	0.60%	3.10%	5.20%
Small Hotel[(a)]	0.00%	100%	100%
Hospital	0.25%	1.24%	2.16%
Large Office	0.38%	0.23%	1.55%
Medium Office	0.50%	1.80%	5.20%
Standalone Retail	0.40%	1.10%	0.10%
Full-service Restaurant	0.00%	0.70%	0.00%
Small Office	0.00%	2.00%	8.00%
Warehouse	0.00%	2.00%	8.00%
Primary School	48.44%	0.13%	0.51%
Secondary School	35.28%	0.11%	0.43%
Outpatient HealthCare	0.00%	2.93%	0.82%

(a) Small Hotel has separate zones and equipment schedules for the break room and conference room space types. These spaces are assigned 100% area fraction because the reduction fraction from receptacle control will be applied only to the equipment schedules for those zones.

Table 5.18. Factors Used to Calculate Reduction Fraction for Equipment Schedule

Factor	Classroom	Break Room	Conference Room
Unoccupied fraction during occupied hours	0.32	0.15	0.33
Fraction of plug loads that could be turned off	0.55	0.37	0.45
Diversity factor	0.75	0.75	0.75

Table 5.19. Reduction Factors for Baseline and Advanced Models

Prototype	Standard 90.1-2010 Occupied Hours Reduction Fraction	Standard 90.1-2010 Unoccupied Hours Reduction Fraction	Standard 90.1-2013 Occupied Hours Reduction Fraction	Standard 90.1-2013 Unoccupied Hours Reduction Fraction
Large Hotel	0.9604	0.7938	0.9524	0.7652
Small Hotel - Private Office[(a)]	0.9258	-	0.9258	-
Small Hotel - Break Room	1.0000	1.0000	0.9584	0.7228
Small Hotel - Conference Room	1.0000	1.0000	0.8873	0.6625
Fast Food Restaurant	0.9989	0.9951	0.9989	0.9951
Retail Strip Mall	0.9963	0.9831	0.9963	0.9831
High-rise Apartment	0.9258	0.6625	0.9258	0.6625
Mid-rise Apartment	0.9258	0.6625	0.9258	0.6625
Hospital	0.9773	0.8849	0.9740	0.8732
Large Office	0.9515	0.7444	0.9491	0.7369
Medium Office	0.9604	0.7938	0.9531	0.7692
Retail Standalone	0.9983	0.9919	0.9972	0.9869
Sit Down Restaurant	0.9992	0.9963	0.9989	0.9943
Small Office	0.9694	0.8515	0.9595	0.8190
Warehouse	0.9694	0.8515	0.9595	0.8190
Primary School	0.9952	0.9816	0.9306	0.7797
Secondary School	0.9983	0.9919	0.9512	0.8446
Outpatient HealthCare	0.9926	0.9664	0.9905	0.9555

(a) The private office space in Small Hotel is a 24-hour occupied space. It does not have unoccupied hours.

5.2.4 Lighting

5.2.4.1 Addendum 90.1-2010ay: Daylighting Requirements

Addendum 90.1-2010ay makes several modifications to the daylighting requirements in Chapter 9 and the daylight area definitions in Chapter 3 of Standard 90.1-2010. Due to the change in format of Chapter 9, the requirements of addendum 90.1-2010ay appear in Section 9.4.1.1 and Table 9.6.1 of Standard 90.1-2013. The new requirements are summarized as follows:

1. In Standard 90.1-2010, daylighting controls were required when the primary sidelighted area was greater than 250 ft^2. Addendum 90.1-2010ay modifies the area threshold to a controlled power threshold, such that, daylighting controls are required when the amount of lighting power in the sidelighted area is larger than 150 W. Daylighting controls are also required in the secondary daylight area when the controlled power is above 300 W in the primary and secondary daylight area. The secondary daylight area is required to be controlled independently of the primary sidelighted area.
2. Daylighting control requirements for daylight areas under skylights and roof monitors are also changed from an area threshold to a controlled power threshold of 150 W. This change does not have an impact on the prototype models because all the toplighted spaces are already under daylighting control. The addendum requires overlapping sidelighted and toplighted areas to be controlled as toplighted areas. This was already the case in the prototype building models.
3. The daylighting controls are required to turn off the lights completely when the illuminance target is met.

4. The addendum modified the definition of primary and secondary sidelighted areas. Instead of a fixed 2 ft added width in Standard 90.1-2010, the sidelighted area width is defined as one-half the head height on either side of the fenestration plus the width of the fenestration.
5. The controlled power threshold requirement eliminates the need for the effective aperture exception.
6. Daylighting documentation is required to identify the luminaires in daylight areas. This is intended to help code officials determine if the daylighting control requirements have been met.
7. The definitions of terms related to daylight area (primary sidelighted area, secondary sidelighted area, daylight area under roof monitors, and daylight area under skylights) are combined in a single portion in the definitions section.

Retail spaces and spaces where the fenestration area is less than 20 ft^2 are exempt from sidelighting control requirements. Dwelling units are exempt from the requirements of Chapter 9 altogether. Sidelighting controls are not applied to zones in prototype building models that are classified as retail spaces (Standalone Retail, Strip Mall) or dwelling units (High-rise Apartment, Mid-rise Apartment, Small Hotel, and Large Hotel guestrooms).

Calculating the Controlled Power in Spaces with Sidelighted Areas

The primary sidelighted area and secondary sidelighted area for each space are calculated using window dimensions in those spaces. The controlled power in the sidelighted area is calculated by multiplying the sidelighted area with the Standard 90.1-2013 lighting power density (LPD) for the space. If the controlled power exceeds the threshold, daylighting controls are applied.

In Standard 90.1-2010, daylighting controls were modeled such that lights turned off completely when the illuminance target was met. While this control feature is made mandatory by addendum 90.1-2010ay, it was assumed that this type of control was already in practice when the daylighting control requirements were introduced in Standard 90.1-2010. Therefore, additional savings due to the off-step control requirement are not reflected in the implementation of addendum 90.1-2010ay.

Lighting in the primary and secondary sidelighted areas needs to be controlled independently. This is implemented in *EnergyPlus* by using two sensors per zone when secondary sidelighted areas are required to have daylighting controls. The two sensors are located at two-thirds the depth of the primary sidelighted area and two-thirds the depth of the secondary sidelighted area from the perimeter wall. Sensors are 30 inches off the floor. The fraction of lighting controlled by each sensor will depend on the ratio of lighting power in the sidelighted area controlled by the sensor to the total lighting power in the zone. Target illuminance levels are based on the recommendations from the IES Handbook (DiLaura et al. 2011).

All prototype building zones are evaluated for sidelighting controls based on the requirements of addendum 90.1-2010ay. Table 5.20 lists the prototype buildings and zones with daylighting controls and shows the fraction of lighting power that is controlled by daylighting sensors in those zones.

Table 5.20. Fraction of Lighting Power Controlled by Daylighting Sensors in Zones in Prototype building Models

Prototype building/Zone	Fraction of Zone Controlled by Primary Sidelighted Area Sensor	Fraction of Zone Controlled by Secondary Sidelighted Area Sensor	Target Illuminance (lux)
Small Hotel			
Front Lounge Flr1	0.29	0.29	300
MeetingRoomFlr1	0.28	0.28	375
FrontOfficeFlr1	0.26	0.26	375
LaundryRoomFlr1	0.26	0.26	300
Large Hotel			
LobbyFlr1	0.07	0.07	300
Café	0.39	0.39	300
Dining_Flr6	0.20	0.20	300
Banquet_Flr6	0.20	0.20	300
Warehouse			
Office	0.29	0.10	375
Quick-service Restaurant			
Dining	0.38	0.38	300
Full-service Restaurant			
Dining	0.25	0.25	300
Primary School			
Corner_Class_1_Pod_1_ZN_1_FLR_1	0.56	0.20	500
Mult_Class_1_Pod_1_ZN_1_FLR_1	0.28	0.28	500
Mult_Class_2_Pod_3_ZN_1_FLR_1	0.28	0.28	500
Computer_Class_ZN_1_FLR_1	0.28	0.28	500
Lobby_ZN_1_FLR_1	0.28	0.28	300
Offices_ZN_1_FLR_1	0.24	0.18	375
Cafeteria_ZN_1_FLR_1	0.34	0.16	300
Library_Media_Center_ZN_1_FLR_1	0.26	0.18	500
Secondary School			
Corner_Class_1_Pod_1_ZN_1_FLR_1	0.56	0.20	500
Mult_Class_1_Pod_1_ZN_1_FLR_1	0.28	0.28	500
Lobby_ZN_1_FLR_1	0.18	0.18	300
Offices_ZN_1_FLR_1	0.36	0.08	375
Cafeteria_ZN_1_FLR_1	0.21	0.15	300
LIBRARY_MEDIA_CENTER_ZN_1_FLR_2	0.21	0.11	500
Outpatient Healthcare			
Floor 3 Lounge	0.24	0.24	300
Floor 3 Office	0.19	0.19	375
Floor 2 Office	0.57	0.43	375
Floor 2 Conference	0.67	0.33	300
Floor 2 Reception	0.23	0.54	300
Hospital			
Office1_Flr_5, Office3_Flr_5	0.56	0.21	375
Lobby_Records_Flr_1	0.08	0.08	375
Office2_Mult5_Flr_5	0.23	0.23	375
Office4_Mult6_Flr_5	0.47	0.47	375
Dining_Flr_5	0.09	0.09	300

PNNL analyzed typical daylight areas in medium office buildings (Athalye et al. 2013). Findings from the analysis are used to calculate the size of the daylight areas in perimeter zones in the Medium and

Large Office prototype buildings. Data from the Medium Office prototype is used for the Large Office prototype. For the Small Office prototype, data from NC3 database is used. In both the baseline and advanced cases, daylighting controls are required because the sidelighted areas and the controlled lighting power exceed the respective thresholds. In Standard 90.1-2010, however, daylighting controls are not required for the secondary sidelighted area. The steps for calculating the fraction of perimeter zone that is controlled by the primary sidelighted area sensor and the secondary sidelighted area sensor are shown in Table 5.21. The major assumptions are summarized as follows:

1. For medium and large office buildings, 80% of perimeter has access to daylight and has spaces that could be daylighted, out of which 40% are open offices and 60% are enclosed offices. At least 75% of enclosed spaces are larger than 170 ft^2 and would require daylighting controls as per addendum 90.1-2010ay (given private office LPD). There are no secondary sidelighted areas in enclosed spaces.
2. For small office buildings, 43% of the perimeter has access to daylight and has spaces that could be daylighted, out of which 66% are enclosed offices and 33% are open offices. All the enclosed spaces are assumed to be larger than 170 ft^2.

Table 5.21. Fraction of Each Perimeter Zone under Daylighting Control in Office Prototype buildings

Assumption	Small Office	Medium Office	Large Office
Total primary sidelighted area as a fraction of perimeter Zone Area	0.56	0.56	0.57
Total secondary sidelighted area as a fraction of perimeter zone area	0.21	0.44	0.43
Fraction of primary sidelighted area that can be daylighted	0.43	0.68	0.68
Fraction of secondary sidelighted area that can be daylighted	0.14	0.32	0.32
Fraction of perimeter zone controlled by sensor 1 (primary sidelighted area)	0.24	0.38	0.39
Fraction of perimeter zone controlled by sensor 2 (secondary sidelighted area)	0.03	0.14	0.14

5.2.4.2 Addendum 90.1-2010bc: Guestroom Lighting Control

Addendum 90.1-2007aw added automatic shut off control to the bathroom lights of guestrooms in hotels. Addendum 90.1-2010bc modifies Chapter 9 and extends the automatic shut off to other lights and switched receptacles in the guestroom, except when the lights and receptacles are controlled by captive key systems. The changes from addendum 90.1-2010bc appear in Section 9.4.1.3 of Standard 90.1-2013. The implementation of addendum 90.1-2007aw assumes 10% reduction in lighting energy in bathroom lighting (Standard 90.1-2010, Appendix G) and that the bathroom lighting contributes 31% of the guestroom lights.

This addendum only impacts the two hotel prototypes. Using the hourly reduction fraction for guestroom lighting in the advanced case in the 50% AEDG for Highway Lodging (Jiang et al. 2009), a new schedule for guestroom lighting is calculated. The daily weighted reduction in the lighting power using this schedule is 38%. For Standard 90.1-2010, only the bathroom lights are assumed to be turned off (31% of guestroom lights) but the full reduction of 38% is applied.

Besides lighting control, addendum 90.1-2010bc also applies to the switched receptacles in guestrooms. Again, the hourly reduction fraction for guestroom equipment in advanced models from the 50% AEDG for Highway Lodging is used to calculate the advanced schedule. This results in a daily weighted reduction of 17% in equipment energy consumption. Both lighting and receptacle control are implemented by using different schedules for the advanced and baseline models.

5.2.4.3 Addenda 90.1-2010bh, 90.1-2010cr, 90.1-2010dj, and 90.1-2010dl: Lighting Power Density (Space-by-Space Method)

Addenda 90.1-2010bh, 90.1-2010cr, 90.1-2010dj, and 90.1-2010dl impact the space-by-space method LPD table (Table 9.6.1) in Standard 90.1-2010. These four addenda are discussed together here for clarity and to show the impact on Table 9.6.1 of Standard 90.1-2010 as a whole.

Addendum 90.1-2010bh reformats and makes extensive changes to the space-by-space LPD table, Table 9.6.1, of Standard 90.1-2010, to account for the recommended light levels published in the IES Handbook (DiLaura et al. 2011). While some LPDs have increased and some have decreased, the average reduction in LPDs is approximately 6%. New space types are added to the table and some space types are renamed for consistency.

Addendum 90.1-2010cr changes the LPD set by addendum 90.1-2010bh for corridors in hospitals, dining areas in special facilities for the visually impaired, and sales areas. Additionally, it segregates storage rooms by size and proposes a separate, higher LPD for storage rooms smaller than 50 ft^2.

Addendum 90.1-2010dj adds a provision for additional lighting allowance for electrical and mechanical rooms provided the additional lighting is controlled separately from the base allowance and is not used for other purposes. This allowance ensures sufficient horizontal and vertical illuminance levels for challenging configurations of electrical and mechanical rooms. The addition of this allowance brings the allowable LPD for electrical and mechanical rooms back to the same level as in Standard 90.1-2010.

Addendum 90.1-2010dl combines the guestrooms in hotels and motels into a single category and sets the guestroom LPD to 0.91 W/ft^2. This is higher than the LPD for motel guestrooms and lower than the LPD for hotel guestrooms specified in Standard 90.1-2010.

All prototypes, except the three office prototype buildings, use the space-by-space LPD table. Addenda 90.1-2010bh, 90.1-2010cr, 90.1-2010dj, and 90.1-2010dl affect a number of spaces in these prototypes. The collective impact of these addenda on the prototype building models is summarized in Table 5.22.

Table 5.22. Combined Impact of Addenda 90.1-2010bh, 90.1-2010cr, 90.1-2010dj, and 90.1-2010dl on Spaces Affected in Simulation Analysis

Prototype building	Zone	Standard 90.1-2010 Space-by-Space LPD (W/ft^2)	Standard 90.1-2013 Space-by-Space LPD (W/ft^2)
Hospital	Corridor	0.89	0.99
	Operating Room	1.89	2.48
	Nurses' Station	0.87	0.71
	Radiology	1.32	1.51
	Food Preparation	0.99	1.21
Large Hotel	Mechanical room	0.95	0.42
	Guest rooms	1.11	0.91
	Food Preparation	0.99	1.21
Small Hotel	Mechanical room	0.95	0.42
	Guest rooms	0.75	0.47
Outpatient HealthCare	Lounge	1.07	0.92
	Nurses' Station	0.87	0.71
	Operating Room	1.89	2.48
	Radiology	1.32	1.51
Quick-service Restaurant	Food Preparation	0.99	1.21
	Dining Area	0.89	0.65
Full-service Restaurant	Food Preparation	0.99	1.21
Standalone Retail	Sales Area	1.68	1.44
Strip-mall	Sales Area	1.68	1.44
Primary School	Mechanical room	0.95	0.42
	Food Preparation	0.99	1.21
Secondary School	Mechanical room	0.95	0.42
	Food Preparation	0.99	1.21
	Audience Seating Area	0.79	0.63

5.2.4.4 Addendum 90.1-2010by: Lighting Controls

Addendum 90.1-2010by represents a complete overhaul of the way interior lighting control requirements are expressed in Chapter 9. In addition to a new format, addendum 90.1-2010by adds new requirements, expands some of the existing requirements to more spaces, and adds new spaces to the list of spaces in the space-by-space method table (Table 9.6.1). Changes from addendum 90.1-2010by are discussed in further detail below:

1. Format: The new format maps control requirements to individual spaces. This is done by adding columns to the existing LPD table (Table 9.6.1) for different control requirements and by defining the individual control requirements in Section 9.4.1.1. The controls requirements are split into 9 individual requirements as follows: (a) manual control, (b) restricted to manual on, (c) restricted to partial automatic on, (d) bi-level control, (e) sidelighting controls, (f) toplighting controls, (g) automatic partial off, (h) automatic full off, and (i) scheduled shutoff.
2. Manual control (a) is required in all spaces. Requirements (b) and (c) restrict the automatic turn on of lights. For most spaces, the user is allowed to pick either (b) or (c). Automatic partial off (g) requires lighting power to be turned down by 50% within 20 minutes of all occupants leaving the space. This is a new requirement and is not optional in some spaces. Requirements (h) and (i) have been included in 90.1-2010. The daylighting control requirements, (e) and (f), are the same as in addendum 90.1-2010ay, just formatted into the new table.

3. New space types: New space types have been added, and some existing space types have been expanded to differentiate spaces. For example, stairwells have been split into stairways and stairwells, to indicate the difference between a stairway inside another space and a stairwell that is used to enter or exit a building.
4. New control requirements: A new control requirement for partial automatic turn-off has been added.
5. Shorter time for automatic turn off: Lights are now required to be turned off, either partially or fully, by automatic sensors within 20 minutes, instead of 30 minutes, of occupants leaving the space.

Of all the changes introduced by addendum 90.1-2010by, only a few changes affect energy consumption and are applicable to the prototype building models. The affected space types are as follows:

1. Partial automatic turn off: corridor (other than hospital), laboratory classrooms, lobby (other than hotels and elevator lobbies), storage (> 1000 ft^2), stairwell, library stacks, and warehouse.
2. Scheduled turn off: stairwell.
3. Full automatic turn off: stairwell, healthcare spaces (exam/treatment room, imaging room, physical therapy room).

All prototypes are affected by this addendum because each prototype has at least one space type that has a new control requirement. Savings assumptions exist from previous requirements for all the lighting controls. The partial auto-off controls use the same savings assumptions as those for full off controls, except for the partial auto-off, only half the installed lighting power will be turned off.

To implement the lighting control changes, the following steps are taken:

1. Spaces with new control requirements are mapped to zones in the prototype building models.
2. Savings fractions for each control type are applied to the zones. Savings fractions from each control are accumulated to come up with a reduction fraction for each zone.
3. The accumulated reduction fraction is applied to the lighting schedule for the zone. Sometimes, one lighting schedule is applied to multiple zones with different reduction fractions. In such cases, reduction fractions from different space types and control types are weighted to determine the single reduction fraction. Table 5.23 shows the savings assumptions for the affected space types and the source of the assumptions.

Table 5.23. Lighting Control Reduction Fraction for Space Types

Space Types	Unoccupied Fraction During Occupied Hours	Occupied Hours Savings Fraction - Automatic Partial OFF (g)	Occupied Hours Savings Fraction - Automatic Full OFF (h)	Source
General Spaces				
Corridor – other than hospital corridors	0.7	0.35	0.7	Thornton et al. (2011)
Laboratory classroom	0.32	0.16	0.32	Same as classroom
Lobby – other than in hotels and elevator lobbies	0.1	0.05	0.1	Appendix G default
Stairwell	0.9	0.45	0.9	Thornton et al. (2011)
Storage – other (greater than 1000 ft^2)	0.48	0.24	0.48	Thornton et al. (2011)
Healthcare Facility				
in an Exam/Treatment Room	0.22	0.11	0.22	Same as private office in Thornton et al. (2011)
in an Imaging Room	0.22	0.11	0.22	Same as private office in Thornton et al. (2011)
in a Physical Therapy Room	0.22	0.11	0.22	Same as private office in Thornton et al. (2011)
Library				
in the Stacks	0.3	0.15	0.3	CASE (2011)
Warehouse – Storage Area				
for medium to bulky, palletized items	0.2	0.1	0.2	CASE (2011)
for smaller, hand-carried items	0.2	0.1	0.2	CASE (2011)

5.2.4.5 Addendum 90.1-2010co: Lighting Power Density (Building Area Method)

Addendum 90.1-2010co makes a number of modifications to Table 9.5.1 (Building Area Method LPD) of Standard 90.1-2010 based on the recommended light levels published in the IES Lighting Handbook (DiLaura et al. 2011). While some LPDs have increased and some have decreased, the average reduction in LPDs is approximately 5%.

The building area table is used by the three office prototype buildings, the library zones in the two school prototypes, office zones in the Warehouse and Hospital prototypes, and the large basement zone in the Large Hotel prototype, which is assumed to be similar to a medium office building. Table 5.24 shows the change in LPD for the affected prototype building models compared to Standard 90.1-2010.

Table 5.24. Impact of Addendum 90.1-2010co on Prototypes

Prototype building	Zone	Standard 90.1-2010 Building Area LPD (W/ft^2)	Standard 90.1-2013 Building Area LPD (W/ft^2)
Primary School	Library	1.18	1.19
Secondary School	Library	1.18	1.19
Small, Medium and Large Office	Office	0.9	0.82
Warehouse	Office	0.9	0.82
Hospital	Office	0.9	0.82
Large Hotel	Basement office	0.9	0.82

6.0 Results

Table 6.1 and Table 6.2 list the national EUI by building type for the 16 prototype buildings analyzed. The results are aggregated on a national basis for the 2010 and 2013 editions of Standard 90.1, respectively, based on the weighting factors discussed in Section 3.3. For each edition of Standard 90.1, the national building floor area weight used to calculate the national impact on building EUI or building ECI is presented.

Using the weighting factors by climate zone and building type, PNNL was able to estimate the relative reductions in building site energy use. Site energy refers to the energy consumed at the building site. In a corresponding fashion, PNNL was also able to calculate a reduction in terms of weighted average primary EUI, and in terms of weighted average ECI in dollars per square foot of building floor space per year. Primary energy, as used here, refers to the energy required to generate and deliver energy to the site. To estimate primary energy, all electrical EUIs were first converted to primary energy using a factor of 10,469 Btu of primary energy per kilowatt-hour (based on the 2013 estimated values reported in Table 2 of the EIA 2013 *Annual Energy Outlook* [AEO][1].

Table 6.1. Estimated Energy Use Intensity by Building Type – Standard 90.1-2010

Building Type	Prototype building	Building Type Floor Area Weight (%)	Whole Building EUI Data for Building Population		
			Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)
Office	Small Office	5.61	33.0	100.4	$0.99
	Medium Office	6.05	36.8	105.9	$1.03
	Large Office	3.33	71.9	210.7	$2.06
Retail	Stand-Alone Retail	15.25	53.4	142.9	$1.38
	Strip Mall	5.67	60.4	164.1	$1.58
Education	Primary School	4.99	59.0	151.1	$1.44
	Secondary School	10.36	47.7	130.3	$1.26
Healthcare	Outpatient Health Care	4.37	120.0	324.3	$3.13
	Hospital	3.45	131.0	321.1	$3.04
Lodging	Small Hotel	1.72	63.6	148.8	$1.40
	Large Hotel	4.95	96.7	217.7	$2.03
Warehouse	Non-Refrigerated Warehouse	16.72	18.2	43.2	$0.41
Food Service	Fast-Food Restaurant	0.59	591.5	1051.7	$9.27
	Sit-Down Restaurant	0.66	383.9	742.7	$6.69
Apartment	Mid-Rise Apartment	7.32	46.3	131.4	$1.28
	High-Rise Apartment	8.97	50.4	124.9	$1.19
National		**100**	**58.5**	**148.9**	**$1.42**

[1] Available at http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2013&subject=0-AEO2013&table=2-AEO2013&region=1-0&cases=ref2013-d102312a)

Table 6.2. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013

Building Type	Prototype building	Building Type Floor Area Weight (%)	Whole Building EUI Data for Building Population: Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)
Office	Small Office	5.61	29.4	89.3	$0.88
	Medium Office	6.05	34.1	97.9	$0.95
	Large Office	3.33	70.8	205.8	$2.01
Retail	Stand-Alone Retail	15.25	45.9	124.6	$1.20
	Strip Mall	5.67	55.1	147.3	$1.42
Education	Primary School	4.99	54.2	134.4	$1.28
	Secondary School	10.36	41.7	111.9	$1.08
Healthcare	Outpatient Health Care	4.37	115.8	311.8	$3.00
	Hospital	3.45	123.7	300.7	$2.85
Lodging	Small Hotel	1.72	60.0	137.6	$1.29
	Large Hotel	4.95	89.0	195.4	$1.81
Warehouse	Non-Refrigerated Warehouse	16.72	17.1	40.6	$0.38
Food Service	Fast-Food Restaurant	0.59	576.4	1001.9	$8.78
	Sit-Down Restaurant	0.66	372.5	713.5	$6.41
Apartment	Mid-Rise Apartment	7.32	43.9	124.8	$1.21
	High-Rise Apartment	8.97	46.9	114.4	$1.08
National		**100**	**54.1**	**136.2**	**$1.30**

The conversion factor of 10,469 was calculated from AEO Table 2 by summing the commercial electricity value of 4.47 quads with the electricity losses value of 9.24 quads and then dividing that sum by the commercial value ((4.47 + 9.24) / 4.47 = 3.07). This yields a ratio of 3.07 for converting how much primary (source) energy is required per unit of site required electricity. This ratio of 3.07 is then multiplied by 3,412 Btu/kWh, producing a value of 10,469 Btu of primary energy per kilowatt-hour of site energy.[1] Natural gas EUIs in the prototype buildings were converted to primary energy using a factor of 1.093 Btu of primary energy per Btu of site natural gas use (based on the 2014 national energy use estimated shown in Table 2 of the AEO2013). This natural gas source energy conversion factor was calculated by dividing the natural gas subtotal of 25.87 quads (sum of all natural gas usage, including usage for natural gas field production, leases, plant energy, and pipeline [compression] supply) by the delivered natural gas total of 23.67 quads (sum of four primary energy sectors (residential, commercial, industrial, and transportation).

To estimate the reduction in energy cost index, PNNL relied on national average commercial building energy prices of $0.1029/kWh of electricity and $8.17 per 1000 cubic feet ($0.796/therm) of natural gas, based on EIA statistics for 2013 (the last complete year of data available) in Table 2, “U.S. Energy Prices,” of the February 2014 Short Term Energy Outlook for commercial sector natural gas and electricity[2]. DOE recognizes that actual energy costs will vary somewhat by building type within a region, and will in fact vary more across regions. Nevertheless, DOE believes that the use of simple

[1] The final conversion value of 10,469 is calculated using the full seven digit values available in Table 2 of AEO2013. Other values shown in the text are rounded.
[2] EIA Short Term Energy Outlook available at http://www.eia.gov/forecasts/steo/report/.

national average figures illustrates whether there will be energy cost savings sufficient for the purposes of the DOE determination. The resulting EUI statistics for site and primary energy are listed in Table 6.1 and Table 6.2 for Standard 90.1-2010 and Standard 90.1-2013, respectively. In terms of energy expenditures per square foot per year, ECI statistics are provided as well in these tables. Table 6.3 presents the estimated percent energy savings (based on change in EUIs) between the 2010 and 2013 editions of Standard 90.1.

Considering those differences that can be reasonably quantified, the 2013 edition will increase the energy efficiency of commercial buildings. On a national basis, the quantitative analysis estimated a floor-space-weighted national average reduction in new building energy consumption of 8.5% for source energy and 7.6% when considering site energy. An 8.7% savings in energy cost, based on national average commercial energy costs for electricity and natural gas, was also estimated. National savings results by building type are shown in Figure 6.1.

Table 6.3. Estimated Percent Energy Savings between 2010 and 2013 Editions of Standard 90.1 – by Building Type

Building Type	Prototype building	Building Type Floor Area Weight (%)	Percent Savings in Whole Building Energy Use Intensity (%)		
			Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.0	11.0	11.0
	Medium Office	6.05	7.4	7.5	7.5
	Large Office	3.33	1.4	2.4	2.5
Retail	Stand-Alone Retail	15.25	13.9	12.8	12.6
	Strip Mall	5.67	8.8	10.2	10.5
Education	Primary School	4.99	8.1	11.0	11.5
	Secondary School	10.36	12.6	14.1	14.4
Healthcare	Outpatient Health Care	4.37	3.6	3.9	3.9
	Hospital	3.45	5.6	6.4	6.5
Lodging	Small Hotel	1.72	5.7	7.5	7.9
	Large Hotel	4.95	8.0	10.2	10.7
Warehouse	Non-Refrigerated Warehouse	16.72	6.0	6.1	6.1
Food Service	Fast Food Restaurant	0.59	2.6	4.7	5.3
	Sit-Down Restaurant	0.66	3.0	3.9	4.2
Apartment	Mid-Rise Apartment	7.32	5.4	5.1	5.0
	High-Rise Apartment	8.97	6.9	8.4	8.7
National		**100**	**7.6**	**8.5**	**8.7**

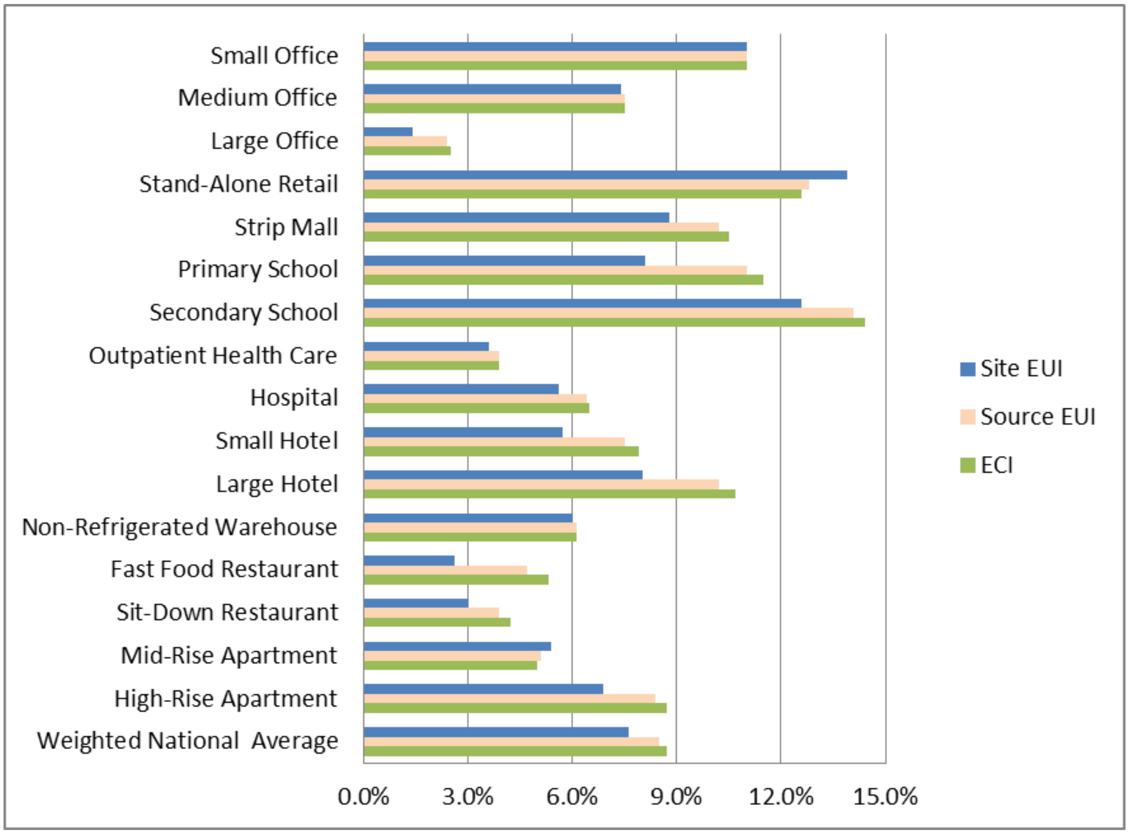

Figure 6.1. Percentage Savings by Building Type from 90.1-2010 to 90.1-2013

7.0 References

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Appendix A. Addenda Processed for ANSI/ASHRAE/IES Standard 90.1-2013

Table A.1. Complete List of Addenda Processed for ASHRAE Standard 90.1-2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
bb (formerly addendum bb to 90.1-2007)	5.Building Envelope, Appendix A	This addendum modifies the building envelope requirements for opaque assemblies and fenestration in Tables 5.5-1 through 5.5-8 and the associated text in Section 5.5.4.5. It also updates the National Fenestration Rating Council (NFRC) 301 reference and modifies two metal building roof assemblies in Table A.2.3.	3/23/2012	4/4/2012	3/23/2012	5/11/2012
bz (formerly addendum bz to 90.1-2007)	6. Heating, Ventilating, and Air-Conditioning	This addendum adds a Section 8.4.2 which specifies requirements for installation of basic electrical metering of major end uses (total electrical energy, HVAC systems, interior lighting, exterior lighting and receptacle circuits) to provide basic reporting of energy consumption data to building occupants.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
cg (formerly addendum cg to 90.1-2007)	11.Energy Cost Budget and Appendix G	This addendum modifies the simulation requirements for modeling mandatory automatic daylighting controls as well as automatic lighting controls. It also modifies the simulation requirements for automatic lighting controls in the proposed design, beyond the minimum mandatory requirements. Table G3.2, which provided power adjustment percentages for automatic lighting controls, has been deleted and savings through automatic control devices are now required to be modeled in building simulation through schedule adjustments for the proposed design.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
ci (formerly addendum ci to 90.1-2007)	3.Definitions, 11.Energy Cost Budget and Appendix G	This addendum modifies requirements for the cooling tower in Chapter 11, from two-speed to variable speed. A formula has been specified to calculate the condenser water design supply temperature. Similar revisions have been made to Appendix G for the cooling tower requirements. Definitions for cooling design wet-bulb temperature and heating design wet-bulb temperature have been added to Chapter 3.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
cj (formerly addendum cj to 90.1-2007)	Appendix G	Creates modeling rules for computer rooms in Appendix G.	6/26/2012	41086	6/28/2013	7/24/2013
cm (formerly addendum cm to 90.1-2007)	5. Building Envelope	The proposed text clarifies how to interpret the use of dynamic glazing products given the requirements in addendum bb (envelope requirements).	7/20/2010	7/23/2010	7/24/2010	7/26/2010

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
dm (previously from 2007)	5. Building Envelope	This addendum modifies Section 5.4.3.4 for vestibules. It adds a size limit for large buildings, exemptions for semiheated spaces and elevator lobbies in parking garages.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
ds (formerly addendum ds to 90.1-2007)	5.Building Envelope	This addendum corrects the definitions of primary sidelighted area, secondary sidelighted area, and sidelighting effective area to use the term “vertical fenestration” instead of “window” to clarify that glazed doors and other fenestration products are included as well as windows. Additionally, the definition of daylight area under rooftop monitors is corrected to include the spread of light beyond the width of the rooftop monitor glazing.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
a	10.Other Equipment and 12.Normative References	This addendum specifies that nominal efficiencies for motors are required to be established in accordance with 10 CFR 431 instead of National Electrical Manufacturers Association (NEMA) Standards. It modifies the footnotes to Tables 10.8A, 10.8B, 10.8 C. The corresponding reference for 10 CFR 431 has also been added.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
b	10.Other Equipment and 12.Normative References	This addendum requires escalators and moving walkways to automatically slow when not conveying passengers. The corresponding reference to American Society of Mechanical Engineers (ASME) A17.1/ Canadian Standards Association (CSA) B44 has also been added to the Normative References.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
c	Appendix G	This addendum adds requirements for laboratory exhaust fans to Section G3.1.1, Baseline HVAC System Type and Definition. Lab exhaust fans are required to be modeled as constant horsepower, reflecting constant volume stack discharge with outside air bypass.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
e	Appendix G	This addendum updates language in Section G3.1, part 5 'Building Envelope', to require that existing buildings use the same envelope baseline as new buildings with the exception of fenestration area.	6/27/2012	6/27/2012	6/18/2012	7/26/2012
f	Appendix G	This addendum modifies Section G.3.1, Building Envelope. It specifies the vertical fenestration area for calculating baseline building performance for new buildings and additions.	6/26/2013	6/26/2013	6/28/2013	7/24/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
g	6. Heating, Ventilating, and Air-Conditioning and 12.Normative References	This addendum adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment. Table 6.8.1L and Table 6.8.1M (now Tables 6.8.1-12 and 6.8.1-13 in Standard 90.1-2013) have been added which specify the energy use limits for refrigerators and freezers. The corresponding references to federal standards have also been added in Chapter 12.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
h	6. Heating, Ventilating, and Air-Conditioning.	This addendum modifies the minimum efficiency standards for water to air heat pumps (water loop, ground water and ground loop). The proposed cooling energy efficiency ratios (EERs) and heating coefficients of performance (COPs) are more stringent than the present values. This addendum also removes the small duct high velocity product class from Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013).	6/25/2011	6/29/2011	6/30/2011	6/30/2011
i	6. Heating, Ventilating, and Air-Conditioning.	This addendum increases the minimum efficiency standards for single package vertical air conditioners (SPVAC) and single package vertical heat pumps (SPVHP). It also creates a new product class for SPVAC and SPVHP used in space constrained applications. This new product class only applies to non-weatherized products with cooling capacities <36,000 Btu/h and intended to replace an existing AC.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
j	6. Heating, Ventilating, and Air-Conditioning.	Modifies the minimum efficiency requirements of evaporatively cooled units, of size category 240,000 Btu/h to 760,000 Btu/h and heating type-other, in Table 6.8.1A (now Table 6.8.1-1 in Standard 90.1-2013). The value is reduced to account for increased pressure drop in such system types. The product class, small duct high velocity, has been eliminated.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
k	8. Power and 12. Normative References	This addendum modifies notes to Table 8.1 and specifies that nominal efficiencies would be established in accordance with the 10 CFR 431 test procedure for low- voltage dry-type transformers. The corresponding references have also been added in Chapter 12.	6/25/2011	6/29/2011	6/30/2011	6/30/2011
l	6. Heating, Ventilating, and Air-Conditioning.	This addendum fixes the error with 90.1-2010 fan power limitations, which required the user to perform calculations for fan brake horsepower (bhp) even if the simplified nameplate hp option was being used.	6/27/2012	6/27/2012	6/18/2012	6/28/2012

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
m	9.Lighting	This addendum adds some control requirements for lighting alterations, for interior and exterior applications. It adds a section for submittals and includes loading docks as a tradable surface. It modifies the provisions for additional interior lighting power, which would now be calculated on the basis of controlled wattage.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
n	10.Other Equipment	This addendum clarifies that the total lumens/watt for the entire elevator cab is required to meet the efficiency requirement and it is not required for each individual light source.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
o	5.Building Envelope and 3.Definitions	This addendum adds the definition for sectional garage doors. It also modifies Section 5.4.3.2 (d), fenestration air leakage provisions for doors, to include requirements for glazed sectional garage doors.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
p	5.Building Envelope and 12.Normative References	This addendum modifies Section 5.5.3.1 and requires roof solar reflectance and thermal emittance testing to be in accordance with Cool Roof Rating Council (CRRC)-1 Standard. It also modifies Section 12 by adding the reference for CRRC.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
q	5. Building Envelope, 3.Definitions and 12.Normative References	This addendum modifies Section 5.8.2.2, by clarifying the requirements for labeling of fenestration and door products. The corresponding references to NFRC in Chapter 12 have also been updated.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
r	Appendix G and 12.Normative References	This addendum clarifies the requirements related to temperature and humidity control in Appendix G and relocates all related wording to the Schedules section of Table 3.1. Additionally, clarity is provided for modeling systems that provide occupant thermal comfort via means other than other than directly controlling the air dry-bulb and wet-bulb temperature (i.e., radiant cooling/heating, elevated air speed, etc.). It permits the use of ASHRAE Standard 55 for calculation of PMV-PPD. This addendum also updates the Normative References by including a reference to ASHRAE Standard 55-2010.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
s	6. Heating, Ventilating, and Air-Conditioning.	This addendum modifies the requirement for the static pressure sensor location and the control requirements for set point reset for systems with direct digital control (DDC) of individual zones. Ensures that savings from previously required static pressure reset will be realized.	1/21/2012	1/23/2012	1/18/2012	1/26/2012

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
u	6. Heating, Ventilating, and Air-Conditioning.	This addendum adds new definition for Fan Efficiency Grade (FEG) and requires each fan has a FEG of 67 or higher as defined by Air Movement and Control Association (AMCA) 205-10 (Energy Efficiency Classification for Fans).	1/26/2013	1/29/2013	2/11/2013	2/12/2013
v	8.Power	This addendum clarifies the requirement for controlled receptacles in open offices. It also requires the automatically controlled receptacles to be appropriately identified for the users benefit.	1/26/2013	1/29/2013	2/11/2013	2/28/2013
w	3.Definitions, 11.Energy Cost Budget Method and Appendix G.	This addendum adds definitions for on-site renewable energy and purchased energy. It clarifies the process for accounting for on-site renewable energy and purchased energy as well as calculating the annual energy costs in the energy cost budget (ECB) approach and Appendix G.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
y	3.Definitions and 10.Other Equipment	This addendum revises the definitions of general purpose electric motors (subtype I &II) based on information from NEMA. It also updates the standard to include the new federal energy efficiency standards used in HVAC equipment, to be in effect from 2015. It adds Table 10.8D (now Table 10.8-4 in Standard 90.1-2013), which specifies minimum average full-load efficiency for Polyphase Small Electric Motors; and Table 10.8E (now Table 10.8-5 in Standard 90.1-2013), which specifies minimum average full-load efficiency for Capacitor-Start Capacitor-Run and Capacitor-Start Induction-Run Small Electric Motors.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
z	6. Heating, Ventilating, and Air-Conditioning.	This addendum relocates the requirements for water economizers into the main economizer section, Section 6.5.1.5.	1/21/2012	1/23/2012	1/18/2012	1/26/2012
aa	6. Heating, Ventilating, and Air-Conditioning.	Prior to this addendum certain controls requirements were only required when the controls were provided by a DDC system. This addendum eliminates that contingency for set point overlap restrictions, humidification and dehumidification controls, variable air volume (VAV) fan control set point reset, multiple-zone VAV system ventilation optimization control, hydronic system design and control, and instead specifies how the system must perform. This will in effect require DDC for systems where these controls are needed.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
ad	12.Normative References	Adds reference to specific addenda to Air-Conditioning, Heating, and Refrigeration Institute (AHRI) standards 340/360 and 1230 being referenced.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
ae	12.Normative References	Adds reference to specific addenda to AHRI standards 210/240 and 550/590 being referenced.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
af	6. Heating, Ventilating, and Air-Conditioning	Modifies heat rejection equipment (cooling tower) requirements to require variable speed drives on fans, operate all fans at the same speed instead of sequencing them, and require that systems with multiple condenser water pumps operate those pumps in parallel at reduced flow.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ag	Appendix G	Establishes a method for gaining credit in Appendix G for buildings that undergo whole building air leakage testing to demonstrate that they have an air-tight building.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ah	Appendix G	Sets system sizing requirements in Appendix G for humid climates based on humidity ratio instead of Supply Air Temperature Differential. Sets baseline system dehumidification requirements.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
ai	Appendix G	Modifies Appendix G to account for 3 prescriptive addenda that were incorporated in to Standard 90.1-2010, but did not make it into Appendix G in time for publication. Updates economizer requirements to match addendum cy, establishes baseline transformer efficiency requirements to match addendum o, and establishes path A for centrifugal chiller baselines from addendum m.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
aj	6. Heating, Ventilating, and Air-Conditioning	Requires fractional horsepower motors >= 1/22 hp to EC motors or minimum 70% efficient in accordance with10 CFR 431. Also requires adjustable speed or other method to balance airflow.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
al	Appendix G	Establishes a consistent fuel source for space heating for baseline systems based on climate zone. Establishes a consistent fuel source for service water heating based on building type.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
am	6. Heating, Ventilating, and Air-Conditioning	Establishes minimum turndown for boilers and boiler plants with of at least 1,000,000 Btu/h.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
an	Appendix C	Rewrites entire Appendix C to use a simulation based approach for envelope trade-offs.	7/26/2013	7/30/2013	7/29/2013	8/28/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
ap	6. Heating, Ventilating, and Air-Conditioning	Adds Power Utilization Effectiveness (PUE) as an alternative compliance methodology for data centers.	1/26/2013	1/29/2013	2/11/2013	5/3/2013
aq	6. Heating, Ventilating, and Air-Conditioning and 11.Energy Cost Budget	This addendum makes changes to the requirements for fan control for both constant volume and VAV units including extending the fan part load power requirements down to ¼ hp. In addition it defines the requirements for integrated economizer control and defines direct expansion (DX) unit capacity staging requirements	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ar	6. Heating, Ventilating, and Air-Conditioning	Adds mandatory and prescriptive requirements for walk-in coolers and freezers and refrigerated display cases.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
as	6. Heating, Ventilating, and Air-Conditioning	Avoidance of simultaneous heating and cooling at air handling unit (AHU). Requires humidifiers mounted in the airstream to have an automatic control valve shutting off preheat when humidification is not required, and insulation on the humidification system dispersion tube surface.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
at	3. Definitions, 5.Building Envelope, and 9. Lighting	Deletes the term clerestory and instead adds roof monitor and clarifies the definition. Changes the references in Chapters 5 and 9 from clerestory to roof monitor.	6/27/2012	6/27/2012	6/18/2012	6/28/2012
au	6. Heating, Ventilating, and Air-Conditioning	This addendum modifies Table 6.5.3.1.1B (now Table 6.5.3.1-2 in Standard 90.1-2013) which addresses fan power limitation pressure drop adjustment credits. Deductions are added for systems without any central heating or cooling as well as systems with electric resistance heating. Sound attenuation credit is modified to be available only when there are background noise criteria requirements.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
av	6. Heating, Ventilating, and Air-Conditioning	This addendum modifies Section 6.5.1, exception k, applicable to Tier IV data centers, in an attempt to make economizer exceptions stricter and in agreement with ASHRAE TC 9.9.	6/26/2013	6/26/2013	6/28/2013	7/24/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
aw	11. Energy Cost Budget and Appendix G	This addendum updates the reference year for ASHRAE Standard 140 and exempts software used for ECB and Appendix G compliance from having to meet certain sections of ASHRAE Standard 140.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
ax	Appendix G	Table G3.1, Part 14 of Appendix G is modified to exclude the condition that permits a building surface, shaded by an adjacent structure, to be simulated as north facing if the simulation program is incapable of simulating shading by adjacent structures.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ay	3. Definitions, 9. Lighting	This addendum modifies daylighting requirements. It modifies definitions for daylight area under skylights, daylight area under roof monitors, primary sidelighted area, and secondary sidelighted area. It modifies the thresholds for applying automatic daylighting control for sidelighting and toplighting, to a wattage basis and provides characteristics for the required photo controls. It modifies Table 9.6.2 to include continuous dimming in secondary sidelighted areas, which is now based on a Watts level rather than area of the space. It eliminates the need for effective aperture calculation.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
az	6. Heating, Ventilating, and Air-Conditioning	This addendum increases the minimum efficiency of open circuit axial fan cooling towers. An additional requirement has been added which states that the minimum efficiency requirements for all types of cooling towers also applies to accessories that affect the thermal performance of the unit. An additional footnote clarifies that the certification requirements do not apply to field erected cooling towers.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
ba	6. Heating, Ventilating, and Air-Conditioning	Adds requirements for door switches to disable or reset mechanical heating or cooling when doors are left open.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
bc	9. Lighting	Modifies requirements for automatic lighting control for guestroom type spaces. Exceptions to this requirement are lighting and switched receptacles controlled by captive key systems.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
bd	9. Lighting	This addendum adds more specific requirements for the functional testing of lighting controls, specifically, occupancy sensors, automatic time switches and daylight controls.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
be	9. Lighting	Minor revisions to Section 9.7.2.2, which addresses the scope of the operating and maintenance manuals required for lighting equipment and controls.	1/26/2013	1/29/2013	2/11/2013	2/12/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
bf	8. Power	This addendum addresses Section 8.4.2 on automatic receptacle control and increases the spaces where plug shutoff control is required. It also clarifies the application of this requirement for furniture systems, states a labeling requirement to distinguish controlled and uncontrolled receptacles and restricts the use of plug-in devices to comply with this requirement.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
bg	5.Building Envelope	Requirements for low-E storm window retrofits.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bh	9. Lighting	Modifies Table 9.6.1 Space-By-Space Lighting Power Density allowance.	7/26/2013	7/30/2013	8/12/2013	9/4/2013
bi	6. Heating, Ventilating, and Air-Conditioning	Increase seasonal energy efficiency ratio (SEER) and heating season performance factor (HSPF) for air-cooled commercial air conditioners and heat pumps below 65,000 Btu/h. Effective 1/1/2015.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bj	6. Heating, Ventilating, and Air-Conditioning.	Re-establishes the product class for Small Duct High Velocity (SDHV) air conditioners and heart pumps. Adds efficiency requirements for systems at <65.000 Btu/h.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bk	6. Heating, Ventilating, and Air-Conditioning	Increases cooling efficiency for packaged terminal air conditioners (PTACs).	1/26/2013	1/29/2013	2/11/2013	2/12/2013
bl	11.Energy Cost Budget and Appendix G	Provide rules for removing fan energy from efficiency metrics when modeling in ECB or Appendix G.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bn	8. Power and 10. Other Equipment	Establishes electric and fuel metering requirements.	7/26/2013	7/30/2013	7/29/2013	9/4/2013
bo	7. Service Water Heating	Requires buildings with service water heating capacity >= 1million Btu/h to have average efficiency of at least 90%. Updates Table 7.8 to reflect federal requirements for electric water heaters. Updates the reference standard for swimming pool water heaters to ASHRAE Standard 146.	7/26/2013	7/30/2013	7/29/2013	9/4/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
bp	6. Heating, Ventilating, and Air-Conditioning	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with ammonia refrigerants.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bq	6. Heating, Ventilating, and Air-Conditioning	Improve efficiency of commercial refrigeration systems.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
br	10. Other Equipment	Updates motor efficiency tables.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bs	6. Heating, Ventilating, and Air-Conditioning	Reduce occupancy threshold for demand controlled ventilation from greater than 40 people per 1000 ft^2 to equal to or greater than 25 people per 1000 ft^2 with exemptions for certain occupancies.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
bt	6. Heating, Ventilating, and Air-Conditioning	Reduces the threshold at which energy recovery is required. Relaxed in some climate zones.	6/26/2013	6/26/2013	6/28/2013	7/24/2013
bv	9. Lighting	Reduces the threshold at which skylights and daylighting controls are required for high bay spaces.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
bw	5.Building Envelope	Modifies orientation requirements and adds solar heat gain coefficient (SHGC) tradeoff.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
bx	9. Lighting	Clarification of exceptions to occupancy sensor requirements.	1/26/2013	1/29/2013	2/11/2013	2/12/2013
by	9.Lighting	Improves and enhances lighting controls requirements. Establishes table of lighting controls applicable to each space type. Corrects daylighting threshold.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ca	5.Building Envelope	Adds control requirements for heating systems in vestibules.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cb	6. Heating, Ventilating, and Air-Conditioning	This addendum requires night setback 10°F heating and 5°F cooling and removes exception for systems less than 10,000 cfm min for optimum start.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
cc	6. Heating, Ventilating, and Air-Conditioning	Adds efficiency requirements (Btu/h-hp) to Table 6.8.1G (now Table 6.8.1-7 in Standard 90.1-2013) for evaporative condensers with R-507A.	6/26/2013	6/26/2013	6/28/2013	7/1/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
cd	6. Heating, Ventilating, and Air-Conditioning	Provides definition for piping to include all accessories in series with pipe such as pumps, valves, strainers, air separators, etc. This is meant to clarify that these accessories need to be insulated.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ce	Appendix G	Establishes a baseline system type for retail occupancies less than 3 stories in Appendix G.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cf	Appendix G	Establishes baseline window-to-wall ratio in Appendix G for strip malls.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
ch	6. Heating, Ventilating, and Air-Conditioning	Improved air and water cooled chiller efficiencies in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). Exempts water cooled positive displacement chillers with leaving condenser temperature ≥ 115°F. (typically heat reclaim chillers).	6/26/2013	6/26/2013	6/28/2013	7/1/2013
ck	6. Heating, Ventilating, and Air-Conditioning	Requires VAV dual maximum damper position when DDC system is present.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cl	6. Heating, Ventilating, and Air-Conditioning	Table 6.8.1A and B. (Now Tables 6.8.1-1 and 6.8.1-2 in Standard 90.1-2013) Improves integrated energy efficiency ratio (IEER) requirements for air-cooled air conditioners and heat pumps and EER requirements for water and evaporatively cooled air conditioners and heat pumps.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cn	Appendix G	Establishes modeling rules for laboratories with 100% outdoor air in Appendix G.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
co	9.Lighting	Comprehensive update of lighting power densities (LPDs) in Table 9.5.1 - Building Area Method.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cp	5.Building Envelope	Corrects non-residential U-factor and R-value requirements for steel joist floors in CZ3.	6/26/2013	6/26/2013	6/28/2013	7/1/2013
cr	9.Lighting	Makes a number of adjustments to Table 9.6.1 Space-by-space LPD.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
ct	Appendix G	Identifies heated only storage systems 9 and 10 in Appendix G as being assigned one system per thermal zone.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cv	Appendix G	Establishes baseline system types in Appendix G for Assembly occupancies.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
cy	6. Heating, Ventilating, and Air-Conditioning	More stringent energy recovery for 24/7 occupancies.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
cz	6. Heating, Ventilating, and Air-Conditioning	Increases boiler efficiency for residential sized (National Appliance Energy Conservation Act (NAECA) covered) equipment, <3,000 Btu/h.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
da	5.Building Envelope	Relaxes air leakage requirements for high-speed doors for vehicle access and material transport.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
db	5.Building Envelope	Corrects residential U-factor and R-value requirements for steel joist floors in CZ3.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dc	9. Lighting	Clarifies automatic lighting and switched receptacle control in guest rooms as applied to individual spaces.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dd	5.Building Envelope	Clarifies roof insulation requirements, differentiating between roof recovering (on top of existing roof covering) and replacement of roof covering.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
de	6. Heating, Ventilating, and Air-Conditioning	Relaxes design requirements for waterside economizers for computer rooms.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dg	5.Building Envelope	Updates reference to ANSI/CRRC-l Standard 2012 (cool roof ratings).	7/26/2013	7/30/2013	7/29/2013	7/31/2013
di	6. Heating, Ventilating, and Air-Conditioning	Establishes limits on using electric or fossil fuel to humidify or dehumidify between 30% and 60% relative humidity (RH) except certain applications. Requires deadband on humidity controls.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dj	9.Lighting	Additional lighting power allowance for electrical/mechanical rooms provided there is separate control for additional lighting.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dk	9.Lighting	Eliminates the exemption for wattage used in spaces where lighting is specifically designed for those with age-related eye conditions or other medical conditions related to the eye, where special lighting or light levels might be needed.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
dl	9.Lighting	Modifies hotel and motel guest room LPD.	7/26/2013	7/30/2013	7/29/2013	8/28/2013
dn	6. Heating, Ventilating, and Air-Conditioning	Reduces the limits on hot gas bypass as a means of cooling capacity control.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Addendum	Section(s) Affected	Description of Changes	ASHRAE Standards Committee Approval	ASHRAE BOD	IES BOD Approval	ANSI Approval
do	6. Heating, Ventilating, and Air-Conditioning	Update references to AHRI 550, AMCA 500, ANSI Z21.10.3 & Z21.47, ASHRAE 90.1 & 62.1, NEMA MG 1, & National Fire Protection Association (NFPA) 70 & 96.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dp	6. Heating, Ventilating and Air Conditioning	Corrects the definition of walk-in-coolers to be consistent with federal requirements.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dq	6. Heating, Ventilating, and Air-Conditioning	Deletes sizing requirements for pipes >24".	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dr	5.Building Envelope	Clarifies definition of building entrances to exclude electrical room, mechanical rooms, and other utility service entrances.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dt	9.Lighting	Added exceptions for control of exterior lighting integral to signage. Requires certain types of exterior lighting exempt from LPD requirements to be separately controlled.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dv	6. Heating, Ventilating, and Air-Conditioning	Establishes chiller and boiler fluid flow isolation requirements so there is no flow through the equipment when not in use.	7/26/2013	7/30/2013	7/29/2013	7/31/2013
dw	6. Heating, Ventilating, and Air-Conditioning	Revises high limit shutoff for air economizers. Add sensor accuracy requirements.	7/26/2013	7/30/2013	7/29/2013	7/31/2013

Appendix B. Addenda Included in Quantitative Analysis and their Impact on Prototype Buildings

Table B.1. Addenda Included in Quantitative Analysis and their Impact on Prototype Buildings

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010bb	5.5	Modifies the building envelope requirements for opaque assemblies and fenestration in Tables 5.5-1 through 5.5-8. Adds and modifies text in Section 5. Adds new visible transmittance (VT) requirement through Section 5.5.4.5. Also updates the NFRC 301 reference, references in Section 11 and modifies two metal building roof assemblies in Table A2.3.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
90.1-2010bw	5.5.4.5	Modifies orientation requirements and adds SHGC tradeoff.			X								X	X				
90.1-2010ca	6.4.3.9	Adds control requirements for heating systems in vestibules.							X									
90.1-2010g*	6.8.1	Adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment. Table 6.8.1L and Table 6.8.1M (now Tables 6.8.1-12 and 6.8.1-13 in Standard 90.1-2013) have been added which specify the energy use limits for refrigerators and freezers. The corresponding references have also been added in Chapter 12.			X						X	X	X	X		X		

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010h	6.8.1	Modifies the minimum efficiency standards for water-to-air heat pumps (water loop, ground water and ground loop). The proposed cooling EERs and heating coefficients of performance are more stringent than the present values. Also removes the small duct high velocity heat pump product class from Table 6.8.1B (now Table 6.8.1-2 in Standard 90.1-2013).																X
90.1-2010af	6.5.5	Modifies heat rejection equipment (cooling tower) requirements to require that variable speed drive controlled fans operate all fans at the same speed instead of sequencing them, and require that open-circuit towers with multiple cells operate all cells in parallel down to 50% of design flow.	X		X													
90.1-2010aj	6.5.3.5	Requires fractional horsepower motors ≥1/12 hp to be electronically-commutated motors or have a minimum 70% efficiency in accordance with10 CFR 431. Also requires adjustable speed or other method to balance airflow.	X	X	X		X				X	X	X	X	X	X	X	X
90.1-2010am	6.5.4	Establishes minimum turndown for boilers and boiler plants with design input power of at least 1,000,000 Btu/h.	X		X							X				X	X	X

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010aq	6. 4.3.10, 6.5.1.3, 6.5.3.2.1	Expands the requirements for fan speed control for both chilled water and unitary direct expansion systems. In addition enhances the requirements for integrated economizer control and defines DX unit capacity staging requirements.							X	X	X	X	X	X				
90.1-2010ar[(a)]	6.8.1	Adds mandatory and prescriptive requirements for walk-in coolers and freezers and refrigerated display cases.			X						X	X	X	X		X		
90.1-2010as	6.5.2.4	Requires humidifiers mounted in the airstream to have an automatic control valve shutting off preheat when humidification is not required, and insulation on the humidification system dispersion tube surface. (Avoidance of simultaneous heating and cooling at air handling unit.)			X												X	
90.1-2010au	6.5.3.1.1	Modifies Table 6.5.3.1.1B (now Table 6.5.3.1.1-2 in Standard 90.1-2013) which addresses fan power limitation pressure drop adjustment credits. Deductions from allowed fan power are added for systems without any central heating or cooling as well as systems with electric resistance heating. Sound attenuation credit is modified to be available only when there are background noise criteria requirements.	X	X	X						X	X				X	X	

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010az	6.8.1	Increases the minimum efficiency of open circuit axial fan cooling towers. An additional requirement has been added for all types of cooling towers which states that the minimum efficiency requirements applies to the tower including the capacity effect of accessories which affect thermal performance. An additional footnote clarifies that the certification requirements do not apply to field erected cooling towers.	X		X													
90.1-2010ba	6.5.10	Adds requirements for door switches to disable or reset mechanical heating or cooling when doors without automatic door closers are left open.					X								X	X		X
90.1-2010bi	6.8.1	Increase seasonal energy efficiency ratio and heating seasonal performance factor for air-cooled commercial air conditioners and heat pumps below 65,000 Btu/h. Effective 1/1/2015.				X	X	X	X	X	X		X	X	X		X	
90.1-2010bk	6.8.1	Increases cooling efficiency for packaged terminal air conditioners.													X			
90.1-2010bs	6.4.3.9	Reduces occupancy threshold for demand controlled ventilation from greater than 40 people per 1000 ft^2 to equal to or greater than 25 people per 1000 ft^2 with exemptions for certain occupancies.									X	X				X		

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010bt	6.5.6.1	Reduces the system size and outdoor air thresholds at which energy recovery is required. Relaxed in some climate zones.	X	X	X				X	X	X	X	X	X		X	X	
90.1-2010cb	6.4.3.3.2, 6.4.3.3.3	Revises night setback requirements to a reset of 10°F heating & 5°F cooling and removes exceptions for climate zones. Changes optimum start requirement from > 10,000 cfm to any DDC system and adds a requirement that outside air temperature be used in optimum algorithms.	X	X	X				X		X	X				X	X	X
90.1-2010ch	6.8.1	Increases air- and water-cooled chiller efficiencies in Table 6.8.1C (now Table 6.8.1-3 in Standard 90.1-2013). Exempts water-cooled positive displacement chillers with leaving condenser temperature ≥ 115°F (typically heat reclaim chillers).	X		X							X				X		
90.1-2010cy	6.5.6.1	Reduces the design supply fan air flow rate for which energy recovery is required for systems that operate more than 8000 hours per year.			X											X		
90.1-2010cz[(a)]	6.8.1	Increases boiler efficiency for residential sized (NAECA covered) equipment, <3,000 Btu/h.															X	
90.1-2010di	6.4.3.7, 6.5.2.3	Establishes limits on using electricity or fossil fuel to humidify or dehumidify between 30% and 60% RH except certain applications.			X											X	X	

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
		Requires deadband on humidity controls.																
90.1-2010dv	6.5.4.2	Establishes chiller and boiler fluid flow isolation requirements so there is no flow through the equipment when not in use.	X		X													
90.1-2010bf	8.4.2	Addresses Section 8.4.2 on automatic receptacle control and increases the spaces where plug shutoff control is required. Clarifies the application of this requirement for furniture systems, lowers the threshold for turn off from 30 to 20 minutes, states a labeling requirement to distinguish controlled and uncontrolled receptacles and restricts the use of plug-in devices to comply with this requirement.	X	X	X	X		X	X		X	X		X	X	X	X	

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010ay	9.4.1.4, 9.4.1.5	Modifies daylighting requirements. Modifies definitions for daylight area under skylights, daylight area under roof monitors, primary sidelighted area, and secondary sidelighted area. Changes the criterion for applying automatic daylighting control for sidelighting and toplighting to a controlled lighting power basis and provides characteristics for the required photo controls. Adds control requirements for secondary sidelighted areas. Modifies Table 9.6.2 to include continuous dimming in secondary sidelighted areas, which is now based on an installed wattage rather than area of the space. Eliminates the need for effective aperture calculation.	X	X	X	X		X			X	X	X	X	X	X	X	
90.1-2010bc	9.4.1.6	Modifies requirements for automatic lighting control for guestroom type spaces. Exceptions to this requirement are lighting and switched receptacles controlled by captive key systems.													X	X		
90.1-2010bh	9.6.1	Modifies Table 9.6.1 Space-By-Space Lighting Power Density allowance.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Addenda to 90.1-2010	90.1-2010 Sections Affected	Description of Changes	Large Office	Medium Office	Hospital	Warehouse	Mid-rise Apartment	Small Office	Stand Alone Retail	Strip Mall Retail	Primary School	Secondary School	Quick-service Restaurant	Full-service Restaurant	Small Hotel	Large Hotel	Outpatient Health	High-rise Apartment
90.1-2010by	9.4.1	Significantly modifies the way requirements are presented in Section 9. Requires the use of certain lighting controls in more space types. Reduces the amount of time after occupants vacate a space for lights to be automatically reduced or shut off. Establishes table of lighting controls applicable to each space type.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
90.1-2010co	9.5.1	Comprehensive update of lighting power densities (LPDs) in Table 9.5.1 - Building Area Method.	X	X	X	X		X			X	X				X		
90.1-2010cr	9.6.1	Makes a number of adjustments to Table 9.6.1, Space-by-space LPD.							X	X					X	X	X	
90.1-2010dj	9.6.1	Additional lighting power allowance for electrical/mechanical rooms made available to match 2010 level provided there is separate control for the additional lighting.									X	X			X	X		
90.1-2010dl	9.6.1	Modifies hotel and motel guest room lighting power density.													X	X		

(a) Addendum is included in modeling for both Standard 90.1-2010 and Standard 90.1-2013 prototypes. Addenda 90.1-2010g, 90.1-2010ar, and 90.1-2010cz are included in this category

.

Appendix C. Comparison of Building Envelope Requirements in Standard 90.1-2010 and Addendum 90.1-2010bb

This appendix compares building envelope requirements from Standard 90.1-2010 and those required by addendum 90.1-2010bb.

Abbreviations used in tables below:

2010	Requirements in 90.1-2010
bb	Requirements in addendum 90.1-2010bb

Table C.1. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Non-Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
IEAD Roof[(a)]	0.063	0.048	0.048	0.039	0.048	0.039	0.048	0.032	0.048	0.032	0.048	0.032	0.048	0.028	0.048	0.028
Metal Building Roof	0.065	0.041	0.055	0.041	0.055	0.041	0.055	0.037	0.055	0.037	0.049	0.031	0.049	0.029	0.035	0.026
Attic Roof	0.034	0.027	0.027	0.027	0.027	0.027	0.027	0.021	0.027	0.021	0.027	0.021	0.027	0.017	0.021	0.017
Mass Wall	0.580	0.580	0.151	0.151	0.123	0.123	0.104	0.104	0.090	0.090	0.080	0.080	0.071	0.071	0.071	0.048
Metal Building Wall	0.093	0.094	0.093	0.094	0.084	0.094	0.084	0.060	0.069	0.050	0.069	0.050	0.057	0.044	0.057	0.039
Steel-Frame Wall	0.124	0.124	0.124	0.077	0.084	0.077	0.064	0.064	0.064	0.055	0.064	0.049	0.064	0.049	0.064	0.037
Wood-Frame Wall	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.064	0.064	0.051	0.051	0.051	0.051	0.051	0.036	0.032
Below Ground Wall[(b)]	1.140	1.140	1.140	1.140	1.140	0.119	1.140	0.119	0.119	0.119	0.119	0.092	0.119	0.063	0.119	0.063
Mass Floor	0.322	0.322	0.107	0.107	0.107	0.074	0.087	0.057	0.074	0.057	0.064	0.051	0.064	0.042	0.057	0.038
Steel-Joist Floor	0.350	0.350	0.052	0.038	0.052	0.052	0.038	0.038	0.038	0.038	0.038	0.032	0.038	0.032	0.032	0.032
Wood-Framed Floor	0.282	0.282	0.051	0.033	0.051	0.033	0.033	0.033	0.033	0.033	0.033	0.027	0.033	0.027	0.033	0.027
Unheated Slab on Grade[(c)]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.520	0.730	0.520	0.540	0.510	0.520	0.510	0.520	0.434
Heated Slab on Grade[(c)]	1.020	1.020	1.020	0.900	0.900	0.860	0.860	0.843	0.860	0.688	0.860	0.688	0.843	0.671	0.688	0.671

U-factors are expressed in Btu/h-ft^2-°F.

(a) IEAD: insulation entirely above deck.

(b) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F)

(c) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F)

Table C.2. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
IEAD Roof[(a)]	0.048	0.039	0.048	0.039	0.048	0.039	0.048	0.032	0.048	0.032	0.048	0.032	0.048	0.028	0.048	0.028
Metal Building Roof	0.065	0.041	0.055	0.041	0.055	0.041	0.055	0.037	0.055	0.037	0.049	0.029	0.049	0.029	0.035	0.026
Attic Roof	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.021	0.027	0.021	0.027	0.021	0.027	0.017	0.021	0.017
Mass Wall	0.151	0.151	0.123	0.123	0.104	0.104	0.090	0.090	0.080	0.080	0.071	0.071	0.071	0.071	0.052	0.048
Metal Building Wall	0.093	0.094	0.093	0.094	0.084	0.072	0.084	0.050	0.069	0.050	0.069	0.050	0.057	0.044	0.057	0.039
Steel-Frame Wall	0.124	0.124	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.055	0.064	0.049	0.042	0.049	0.037	0.037
Wood-Frame Wall	0.089	0.089	0.089	0.089	0.089	0.064	0.064	0.064	0.051	0.051	0.051	0.051	0.051	0.051	0.036	0.032
Below Ground Wall[(b)]	1.140	1.140	1.140	1.140	1.140	0.119	0.119	0.092	0.119	0.092	0.119	0.063	0.092	0.063	0.075	0.063
Mass Floor	0.322	0.322	0.087	0.087	0.087	0.074	0.074	0.051	0.064	0.051	0.057	0.051	0.051	0.042	0.051	0.038
Steel-Joist Floor	0.350	0.350	0.052	0.038	0.052	0.032	0.038	0.038	0.038	0.038	0.032	0.032	0.032	0.032	0.032	0.032
Wood-Framed Floor	0.282	0.282	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.027	0.033	0.027	0.033	0.027
Unheated Slab on Grade[(c)]	0.730	0.730	0.730	0.730	0.730	0.540	0.540	0.520	0.540	0.510	0.520	0.434	0.520	0.434	0.510	0.424
Heated Slab on Grade[(c)]	1.020	1.020	1.020	0.860	0.900	0.860	0.860	0.688	0.860	0.688	0.688	0.671	0.688	0.671	0.688	0.373

U-factors are expressed in Btu/h-ft^2-°F.

(a) IEAD: insulation entirely above deck.

(b) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F).

(c) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F).

Table C.3. Addendum 90.1-2010bb Changes to Opaque Envelope U-factor Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
IEAD Roof[(a)]	0.218	0.218	0.218	0.173	0.173	0.119	0.173	0.093	0.119	0.063	0.093	0.063	0.093	0.039	0.063	0.039
Metal Building Roof	0.167	0.115	0.097	0.096	0.097	0.096	0.097	0.082	0.083	0.082	0.072	0.060	0.072	0.037	0.065	0.037
Attic Roof	0.081	0.081	0.081	0.053	0.053	0.053	0.053	0.034	0.053	0.034	0.034	0.034	0.034	0.027	0.034	0.027
Mass Wall	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.151	0.151	0.151	0.151	0.123	0.123	0.104	0.104
Metal Building Wall	0.113	0.352	0.113	0.162	0.113	0.162	0.113	0.162	0.113	0.094	0.113	0.094	0.113	0.072	0.113	0.060
Steel-Frame Wall	0.352	0.352	0.124	0.124	0.124	0.124	0.124	0.124	0.124	0.084	0.124	0.084	0.124	0.064	0.084	0.064
Wood-Frame Wall	0.292	0.292	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.064	0.089	0.051
Below Ground Wall[(b)]	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	1.140	0.119	1.140	0.119	1.140	0.119
Mass Floor	0.322	0.322	0.322	0.322	0.322	0.137	0.137	0.107	0.137	0.107	0.137	0.087	0.107	0.074	0.087	0.064
Steel-Joist Floor	0.350	0.350	0.069	0.069	0.069	0.052	0.069	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
Wood-Framed Floor	0.282	0.282	0.066	0.066	0.066	0.051	0.066	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.033	0.033
Unheated Slab on Grade[(c)]	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.740	0.540
Heated Slab on Grade[(c)]	1.020	1.020	1.020	1.020	1.020	1.020	1.020	0.900	1.020	0.900	1.020	0.860	0.900	0.860	0.900	0.860

U-factors are expressed in Btu/h-ft^2-°F.

(a) IEAD: insulation entirely above deck.

(b) Below ground wall requirements are expressed in terms of C-factor (Btu/h-ft^2-°F).

(c) Unheated and heated slab on grade requirements are expressed in terms of F-factor (Btu/h-ft-°F).

Table C.4. Addendum 90.1-2010bb Changes to Fenestration Requirements for Nonresidential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.50	0.75	0.40	0.65	0.35	0.40	0.35	0.35	0.32	0.35	0.32	0.35	0.32	0.35	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	0.57	0.70	0.57	0.60	0.50	0.50	0.42	0.45	0.42	0.45	0.42	0.40	0.38	0.40	0.38
Metal Framing (entrance door)	1.20	1.10	1.10	0.83	0.90	0.77	0.85	0.77	0.80	0.77	0.80	0.77	0.80	0.77	0.8	0.77
Metal Framing (all other)/ Operable Metal Framing	1.20	0.65	0.75	0.65	0.65	0.60	0.55	0.50	0.55	0.50	0.55	0.50	0.45	0.40	0.45	0.40
Vertical Fenestration, SHGC																
All framing types	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.45	0.45	0.45

Table C.5. Addendum 90.1-2010bb Changes to Fenestration Requirements for Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.50	0.75	0.40	0.65	0.35	0.40	0.35	0.35	0.32	0.35	0.32	0.35	0.32	0.35	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	0.57	0.70	0.57	0.60	0.50	0.50	0.42	0.45	0.42	0.45	0.42	0.40	0.38	0.40	0.38
Metal Framing (entrance door)	1.20	1.10	1.10	0.83	0.90	0.77	0.85	0.68	0.80	0.68	0.80	0.68	0.80	0.68	0.80	0.68
Metal Framing (all other)/ Operable Metal Framing	1.20	0.65	0.75	0.65	0.65	0.6	0.55	0.50	0.55	0.50	0.55	0.50	0.45	0.40	0.45	0.40
Vertical Fenestration, SHGC																
All framing types	0.25	0.25	0.25	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	1.00	0.45	1.00	0.45

Table C.6. Addendum 90.1-2010bb Changes to Fenestration Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Vertical Fenestration, U-factor																
Non-metal Framing	1.20	0.93	1.20	0.93	1.20	0.87	1.20	0.51	1.20	0.45	0.65	0.45	0.65	0.32	0.65	0.32
Metal Framing (curtainwall/storefront)/ Fixed Metal Framing	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.73	1.20	0.62	0.60	0.51	0.60	0.38	0.60	0.38
Metal Framing (entrance door)	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.81	1.20	0.70	0.90	0.59	0.90	0.44	0.90	0.44
Metal Framing (all other)/ Operable Metal Framing	1.20	1.10	1.20	0.83	1.20	0.77	1.20	0.77	1.20	0.77	0.65	0.77	0.65	0.77	0.65	0.77
Vertical Fenestration, SHGC																
All framing types	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Table C.7. Addendum 90.1-2010bb Changes to Skylight Requirements for Non-Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Skylights, U-factor, 0-3% skylight area[a]																
Skylights with curb – glass	1.98	0.75	1.98	0.65	1.17	0.55	1.17	0.50	1.17	0.50	1.17	0.50	1.17	0.50	0.98	0.50
Skylights with curb – plastic	1.90	0.75	1.90	0.65	1.30	0.55	1.30	0.50	1.10	0.50	0.87	0.50	0.87	0.50	0.61	0.50
Skylights without curb – all	1.36	0.75	1.36	0.65	0.69	0.55	0.69	0.50	0.69	0.50	0.69	0.50	0.69	0.50	0.58	0.50
Skylights, SHGC, 0-2% skylight area																
Skylights with curb – glass	0.36	0.35	0.36	0.35	0.39	0.35	0.49	0.40	0.49	0.40	0.49	0.40	0.68	1.00	1.00	1.00
Skylights with curb – plastic	0.34	0.35	0.39	0.35	0.65	0.35	0.65	0.40	0.77	0.40	0.71	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.36	0.35	0.36	0.35	0.39	0.35	0.49	0.40	0.49	0.40	0.49	0.40	0.68	1.00	1.00	1.00
Skylights, SHGC, 2-3% skylight area[a]																
Skylights with curb – glass	0.19	0.35	0.19	0.35	0.19	0.35	0.39	0.35	0.39	0.35	0.49	0.35	0.64	0.35	1.00	0.35
Skylights with curb – plastic	0.27	0.35	0.34	0.35	0.34	0.35	0.34	0.35	0.62	0.35	0.58	0.35	0.71	0.35	1.00	0.35
Skylights without curb – all	0.19	0.35	0.19	0.35	0.19	0.35	0.39	0.35	0.39	0.35	0.49	0.35	0.64	0.35	1.00	0.35

(a) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

Table C.8. Addendum 90.1-2010bb Changes to Skylight Requirements for Residential Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Skylights, U-factor, 0-3% skylight area[a]																
Skylights with curb – glass	1.98	0.75	1.98	0.65	1.17	0.55	1.17	0.50	1.17	0.50	0.98	0.50	1.17	0.50	0.98	0.50
Skylights with curb – plastic	1.90	0.75	1.90	0.65	1.30	0.55	1.30	0.50	1.10	0.50	0.74	0.50	0.61	0.50	0.61	0.50
Skylights without curb – all	1.36	0.75	1.36	0.65	0.69	0.55	0.69	0.50	0.69	0.50	0.58	0.50	0.69	0.50	0.58	0.50
Skylights, SHGC, 0-2% skylight area																
Skylights with curb – glass	0.19	0.35	0.19	0.35	0.36	0.35	0.36	0.40	0.49	0.40	0.46	0.40	0.64	1.00	1.00	1.00
Skylights with curb – plastic	0.27	0.35	0.27	0.35	0.27	0.35	0.62	0.40	0.77	0.40	0.65	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.19	0.35	0.19	0.35	0.36	0.35	0.36	0.40	0.49	0.40	0.49	0.40	0.64	1.00	1.00	1.00
Skylights, SHGC, 2-3% skylight area[a]																
Skylights with curb – glass	0.16	0.35	0.19	0.35	0.19	0.35	0.19	0.40	0.39	0.40	0.36	0.40	0.64	1.00	1.00	1.00
Skylights with curb – plastic	0.27	0.35	0.27	0.35	0.27	0.35	0.27	0.40	0.62	0.40	0.55	0.40	0.77	1.00	1.00	1.00
Skylights without curb – all	0.19	0.35	0.19	0.35	0.19	0.35	0.19	0.40	0.39	0.40	0.49	0.40	0.64	1.00	1.00	1.00

(a) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

Table C.9. Addendum 90.1-2010bb Changes to Skylight Requirements for Semi-heated Buildings

	Climate Zone															
	1		2		3		4		5		6		7		8	
	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb	2010	bb
Skylights, U-factor, 0-3% skylight area[(a)]																
Skylights with curb - glass	1.98	1.80	1.98	1.80	1.98	1.70	1.98	1.15	1.98	0.98	1.98	0.85	1.98	0.85	1.30	0.85
Skylights with curb - plastic	1.90	1.80	1.90	1.80	1.90	1.70	1.90	1.15	1.90	0.98	1.90	0.85	1.90	0.85	1.10	0.85
Skylights without curb - all	1.36	1.80	1.36	1.80	1.36	1.70	1.36	1.15	1.36	0.98	1.36	0.85	1.36	0.85	0.81	0.85
Skylights, SHGC, 0-2% skylight area																
Skylights with curb - glass	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights with curb - plastic	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights without curb - all	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights, SHGC, 2-3% skylight area[(a)]																
Skylights with curb - glass	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights with curb - plastic	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Skylights without curb - all	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

(a) For 90.1-2010, U-factor requirements and SHGC requirements apply to skylight areas of up to 5%.

Appendix D. Impact of the DOE Determination on State and Local Government

The Unfunded Mandates Reform Act of 1995 (Pub. L. 104-4) generally requires Federal agencies to examine closely the impacts of regulatory actions on State, local, and tribal governments. Subsection 101(5) of Title I of that law defines a Federal intergovernmental mandate to include any regulation that would impose upon State, local, or tribal governments an enforceable duty, except a condition of Federal assistance or a duty arising from participating in a voluntary Federal program. Title II of that law requires each Federal agency to assess the effects of Federal regulatory actions on State, local, and tribal governments, in the aggregate, or to the private sector, other than to the extent such actions merely incorporate requirements specifically set forth in a statute. Section 202 of that title requires a Federal agency to perform an assessment of the anticipated costs and benefits of any rule that includes a Federal mandate that may result in costs to State, local, or tribal governments, or to the private sector, of $100 million or more. Section 204 of that title requires each agency that proposes a rule containing a significant Federal intergovernmental mandate to develop an effective process for obtaining meaningful and timely input from elected officers of State, local, and tribal governments.

Upon publication of an affirmative determination, each State would be required under Section 304 of ECPA to review and update, as necessary, the provisions of its commercial building energy code to meet or exceed the revised provisions of Standard 90.1. (42 USCU.S.C. 6833(b)(2)(B)(i)) Section 304 of ECPA requires State action in response to this affirmative determination by DOE, and the statutory requirements of ECPA require DOE to provide a determination irrespective of costs. While the processes that States may undertake to update their codes vary widely, as a general rule, a State (at a minimum) needs to:

- Evaluate Standard 90.1-2013 using the background material provided by DOE;
- Compare the existing State commercial building energy code to Standard 90.1-2013 to determine if an update is needed; and
- Update the State commercial building energy code to meet or exceed Standard 90.1-2013.

DOE evaluated the potential for State activity to exceed $100 million in any one year. The approach looked at the three steps for minimum activity listed in the previous paragraph: evaluate, compare, and update. An additional potential step, providing training on the new code, was also considered as some States might consider training on the new code to be an integral part of adopting the new code. For the steps of minimum activity, DOE estimated the following:

1. Evaluate Standard 90.1-2013: DOE estimated a minimum of 8 hours of review per State and a maximum review time of 500 hours of review per State (12.5 work weeks). The minimum review time of 8 hours (1 day) is the estimated minimum amount of time DOE can see States taking to review Standard 90.1-2013. Reading and reviewing the Federal Register notice, the qualitative analysis document and the quantitative analysis document will take the average person several hours. Deciding on whether or not to upgrade to Standard 90.1-2013 may take additional time. An upper boundary based on a maximum review time of 500 hours (62.5 days or 3 working months) was estimated as the time it would take a State not familiar with energy codes at all, or that has a particularly arduous review process to review these documents.

A cost of $100 per hour in 2010 dollars was assumed based on actual rates proposed in subcontracts associated with compliance studies in late 2010 funded by DOE in support of the American Recovery and Reinvestment Act of 2009. The average rate calculated from these subcontracts for ten types of building officials from six States was $93.41 (in 2010 dollars). DOE chose to round this up to $100 per hour (2010 dollars), and then update the costs to 2014 dollars for this analysis using the Consumer Price Index from the U.S. Department of Labor, Bureau of Labor Statistics, adjusted for inflation. The 2014 cost estimate for hourly rates of the building officials is $107.27.

a. Low estimate: 8 hours * 50 states*$107.27 per hour = $42,908
b. High estimate: 500 hours*50 states*$107.27 per hour = $2,681,750

2. Compare Standard 90.1-2013 to existing State code: Assuming the State is familiar with its code and has effectively evaluated Standard 90.1 in the first step, the range of potential costs should be similar to Step 1. (See Step 1 for discussion of 8 hour and 500 hour times and $107.27 per hour cost estimate.)

a. Low estimate: 8 hours*50 states*$107.27 per hour = $42,908
b. High estimate: 500 hours*50 states*$107.27 per hour = $2,681,750

3. Update the State codes to meet or exceed Standard 90.1-2013: Adopting a new energy code could be as simple as updating an order within the State, or it could be very complex involving hearings, testimony, etc. Again, the range of potential costs are anticipated to be similar to Step 1. (See Step 1 for discussion of origin of 8 hour and 500 hour times and $107.27 per hour cost estimate.)

a. Low estimate: 8 hours*50 states*$107.27 per hour = $42,908
b. High estimate: 500 hours*50 states*$107.27 per hour = $2,681,750

The estimated range of total costs to States under these assumptions would be $129,000 to $8.0 million. This range is well below the $100 million threshold specified by the Unfunded Mandates Act.

4. Train Code Officials on New Code: DOE has also considered potential costs for States to provide training on the new code. There are roughly 40,000 general purpose local governments, or jurisdictions, in the U.S., however, the total number of jurisdictions in the U.S. that enforce energy codes is not known with any degree of certainty. The National League of Cities (NLC) publishes an estimate of the number of local governments in the U.S. The most recent NLC summary (from 2007) indicates that there are 39,044 general purpose governments, including counties, municipalities, and townships. The U.S. Census Bureau also conducts a periodic census of governments (latest version is 2012). A press release on this census of governments indicates that there are:

- 3,031 counties;

- 19,522 municipalities; and
- 16,364 townships.

This estimate from the U.S. Census Bureau equates to 38,917, which is reasonably agrees with the estimate provided by the NLC, and it is therefore assumed that there are approximately 39,000 local governments. (Note that the U.S. Census Bureau Census of Governments also tracks special districts and independent school districts, which are considered unlikely to have to adopt Standard 90.1-2013.)

In estimating maximum potential impact, DOE believes it is reasonable to assume that at least one person in all of the municipal governments, township governments, and county governments could be required to acquire some form of training on the updated Standard 90.1 in order to enforce the Standard as an adopted energy code. In addition, the 50 State governments would be required to acquire training (equates to 39,044+50 = 39,094 local jurisdictions). Another widely referenced total number of code adopting jurisdictions in the U.S. is 44,000, which is based on an estimate developed by the National Conference of States on Building Codes and Standards (NCSBCS) in 1992, and repeated in many sources. (Note that there is a difference between “code adopting jurisdictions” as estimated by NCSBCS and “municipal, township, and county governments” as estimated by NLC and the U.S. Census Bureau, as local governments can have multiple code jurisdictions within them.) All these estimates are in reasonable agreement, and therefore DOE assumes that there are 40,000 jurisdictions that would potentially need training on a new energy code.

Based on experiences with conducting training sessions for jurisdictional staff, one full-day (8 hours) of training is most typical for those seeking basic training on Standard 90.1. Therefore, DOE has used 8 hours as a low estimate and 16 hours as a high estimate for training required if a jurisdiction were to adopt Standard 90.1-2013.

a. Low estimate: 8 hours*40,000 jurisdictions*$107.27 per hour = $34,326,400

b. High Estimate: 16 hours*40,000 jurisdictions*$107.27 per hour = $68,652,800

Adding these estimated training costs, ranging from $34 million to $68 million, to the previously outlined State costs indicates total costs ranging from $34.5 million to $76.7 million. The high end of this estimate is less than the $100 million threshold in the Unfunded Mandates Act. Accordingly, no further action is required under the Unfunded Mandates Reform Act of 1995

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From: Ned B. Heminger
To: BBS, BBSOfficAsst3
Subject: Comment on Adoption of ASHRAE 90.1-2016 and IECC 2018
Date: Wednesday, December 29, 2021 1:53:54 PM
Attachments: image001.jpg

To the BBS:

I recommend adding language to Ohio's Energy Code so that Data Centers can comply with "ASHRAE 90.4-2016 – Energy Standard for Data Centers", provided they are within the scope of this standard.

Some history behind this, in the 2010 version of 90.1 a change was made that no longer exempted data centers from the standard. This created a significant problem for the industry because 90.1 was primarily written around comfort cooling systems. While some patchwork was done in the 2010 standard, it was not a good solution. Additional patchwork was done in later editions, until such time that a new energy standard was developed by ASHRAE specifically for Data Centers. This occurred with the new publication 90.4-2016. Even at that time, 90.1 did not recognized this new 90.4 standard until the 90.1-2019 standard was published. Until such time that Ohio recognizes 90.1-2019 or a later version, it would be very beneficial to include 90.4-2016 as a compliance path for Data Centers in Ohio.

Thank you for your consideration. If you have any questions, please do not hesitate to call.

Ned Heminger, PE, LEED AP, HBDP
Vice President
Chief Engineer

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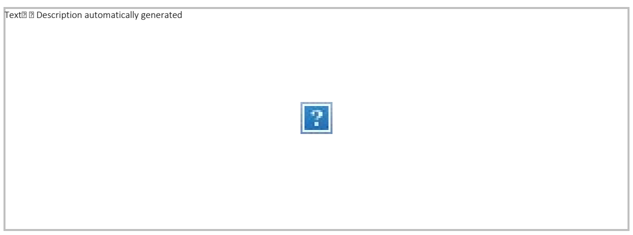
From: Jim Schrader
To: BBS, BBSOfficAsst3
Cc: Jim Schrader
Subject: Comment on Adoption of ASHRAE 90.1-2016 and IECC 2018
Date: Thursday, January 13, 2022 1:23:58 PM
Attachments: image001.png

To BBS:

I recommend that language be added to Ohio’s Energy Code to allow Data Centers to comply with ASHRAE 90.4 – 2016 - Energy Standard for Data Centers.

Jim Schrader, President
TechSite
Phone: (614) 873-7800 x 103 | Mobile: (614) 361-9037
Email: jim.schrader@techsiteplan.com
Web: http://www.techsiteplan.com/
8188 Business Way, Plain City, OH 43064



From:	Nicole Westfall - MEEA
To:	BBS, BBSOfficAsst3
Subject:	MEEA Comments on Ohio"s Building Code Updates
Date:	Friday, January 14, 2022 2:25:44 PM
Attachments:	image001.png MEEA comments on Ohio"s Building Code Update - 1.14.2022.pdf

Ms. Hanshaw and the Ohio Board of Building Standards,

Thank you for the opportunity to comment on Ohio's Building Code update. Please find attached comments from the Midwest Energy Efficiency Alliance. If you have any questions about the attached, please do not hesitate to reach out to me.

Kind regards,
Nicole Westfall

Nicole Westfall
(she/her/hers)
Building Policy Manager
Midwest Energy Efficiency Alliance (MEEA)
312.374.0918 | www.mwalliance.org

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January 14, 2022

Ohio Board of Building Standards Members
Attn: Regina Hanshaw
6606 Tussing Rd
Reynoldsburg, OH 43068

RE: Comments of the Midwest Energy Efficiency Alliance (MEEA) Supporting the Adoption of the 2021 International Energy Conservation Code

Dear Ms. Hanshaw and Members of the Board of Building Standards,

Thank you for opportunity to comment on Ohio's commercial energy code update. The Midwest Energy Efficiency Alliance (MEEA) is a member-based non-profit organization promoting energy efficiency to optimize energy generation, reduce consumption, create jobs and decrease carbon emissions in all Midwest communities. MEEA has previously worked in Ohio on energy codes and provided technical assistance to the Ohio Board of Building Standards in previous energy code adoption cycles.

MEEA supports the adoption of the most recent model energy code, the 2021 IECC, without weakening amendments for commercial and multifamily residential buildings in Ohio. While the adoption of the unamended 2018 IECC will improve commercial construction in the state, the 2021 IECC provides the most up to date cost effective standards and guidance on best practices for commercial construction and will ensure Ohio is capitalizing on the energy savings that come with the adoption of the latest model energy code. We urge the Board adopt the unamended 2021 IECC to ensure the people of Ohio receive the wide-ranging benefits of improved building efficiency. Doing so will make commercial buildings more resilient, reduce costs for owners and occupants, help promote local job creation, and improve the state's building infrastructure for generations to come.

The 2021 IECC provides a cost-effective way for Ohioans to save money and energy

Buildings account for roughly 40% of all energy used and over 70% of all electricity used in the United States. Updated building energy codes have consistently shown to be the most cost-effective way to reduce that energy consumption – putting significant monetary savings back into pockets of building owners, businesses and residents. The US Department of Energy (DOE) conducts state-specific energy savings and cost-effectiveness analyses for each new model commercial energy code1. Using DOE research, updating Ohio's current code, based on the 2012 IECC, to the 2021 IECC

[1] DOE's analysis is based on ASRAHE 90.1-2019. The 2021 IECC incorporates ASHRAE Standard 90.1 by reference as a compliance option and the commercial requirements are typically very close to ASHRAE for overall efficiency. Because these codes are the same in terms of efficiency, we reference the 2021 IECC for clarity. See U.S. Dep't of Energy, *Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019 for Ohio* , at vi (July 2021), available at https://www.energycodes.gov/sites/default/files/2019-09/Cost-effectiveness_of_ASHRAE_Standard_90-1-2013-Ohio.pdf

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would result in a nearly 19% improvement in building energy efficiency.[2] The update on an unamended 2021 IECC would provide significantly more energy savings than can be attributed to the 2018 IECC. Results show that updating Ohio's commercial energy code from the 2018 IECC to the 2021 ICC is cost-effective for every building type in Ohio – meaning the cost of energy saved is higher than cost of compliance and will reduce building energy use and costs when compared to the current commercial energy code in Ohio[3]. On average, building owners and occupants can expect to save an average of $0.05 per square foot in just the first year. This analysis only compares the two most recent version of the code for Ohio – because the state has adopted the 2012 IECC with several weakening amendments, expected energy and cost savings would be significantly higher.

Strong Energy Codes Make Ohio's Buildings More Resilient

In addition, the adoption of the 2021 IECC would lead to more energy efficient buildings in Ohio but would also result in the construction of more resilient buildings. Improving the resiliency and preparedness of Ohio's buildings from blizzards, floods, heatwaves, and power outages will bring obvious benefits to communities across the state, including increased safety, greater ability to safely shelter in place and improved health outcomes. Updating energy codes can also significantly reduce the stress on the grid, and improve reliability, by reducing peak demand from commercial buildings in the state. This is critical during times of extreme weather, when energy resources from the grid can be strained. The most cost-effective time to prevent future damage from extreme weather is during initial building construction and Ohio has an opportunity to instill long-term resiliency planning with the adoption of the 2021 IECC.

Efficient buildings make for healthier and more productive environments

The adoption of a strong commercial building energy code would result in healthier and more productive indoor environments for Ohioans. Improvements in the building envelope and mechanical systems found in the unamended 2021 IECC would positively improve the indoor environmental quality of commercial buildings. The COVID-19 pandemic clearly demonstrated the importance of providing controlled fresh air in our businesses, workspaces, and homes. However, while critically important, increasing ventilation can also increase the energy use in our buildings. Energy efficient construction can ensure that buildings are able to cost-effectively provide appropriate levels of fresh air without increasing costs.[4]

Energy efficiency supports Ohio jobs.

In 2020, the clean energy sector supported more than 103,400 jobs in Ohio, of which 71% are in energy efficiency.[5] Of those energy efficiency jobs, all are interdependent

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[2] See https://www.energycodes.gov/development/determinations for more information.
[3] *See* U.S. DOE, State Fact sheet – Ohio, at vi (July 2021), available at https://www.energycodes.gov/sites/default/files/2021-07/EED_1365_BROCH_StateEnergyCodes_states_OHIO.pdf
[4] See: https://energynews.us/2021/06/25/energy-efficiency-can-rein-in-costs-from-healthy-building-air-quality-projects/
[5] See Clean Energy Jobs Midwest: https://www.cleanjobsmidwest.com/state/ohio

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with the building industry, whether it be HVAC, insulation, or lighting. These are good, in-state jobs in a vital, growing sector of Ohio's economy. By updating the state's commercial energy code, Ohio has an opportunity to build on this foundation and continue to spur local construction and manufacturing jobs while improving the livability and resiliency of new building and reducing energy waste.

The 2021 IECC includes achievable, cost-effective standards that many states across the Midwest are considering. The adoption of the unamended 2021 IECC would result in energy efficient commercial buildings that are more affordable to operate and maintain for years to come in Ohio. However, the full value of the energy and cost savings, and other benefits associated with updating to the 2021 IECC will be substantially reduced if weakening amendments or a weaker model energy code are adopted in the final Ohio Commercial Building Code. The adoption of the unamended 2021 IECC will reduce the cost of utility bills for residents, businesses and building owner's, create more comfortable and healthier indoor environments and improve the resilience of buildings in the state. Adopting the newest/strongest building standards will ensure long-lasting benefits for all Ohioans. If you have any additional questions, please contact MEEA's Building Policy Manager, Nicole Westfall at nwestfall@mwalliance.org.

Thank you for your time and consideration.

Sincerely,

Stacey Paradis

Stacey Paradis
Executive Director

From: Eric Lacey
To: BBS, BBSOfficAsst3
Cc: Hanshaw, Regina
Subject: RECA Comments Supporting Commercial Energy Code Update in OH
Date: Wednesday, January 12, 2022 2:47:08 PM
Attachments: Supplemental RECA Comments Supporting 2021 IECC in OH 1-12-22.pdf
RECA Comments Supporting 2021 IECC in OH 7-14-21.pdf

Regina,

I hope you are doing well. Please see the attached supplemental comments of the Responsible Energy Comments in support of Ohio's proposed commercial energy code update, along with a copy of our July 2021 letter. If you have any questions, please call or email me. I will also plan on participating virtually in the January 27 Board of Building Standards meeting in case Board members have any questions.

Thank you,
Eric

Eric Lacey, Chairman
Responsible Energy Codes Alliance
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Submitted Via Email

July 16, 2021

Regina Hanshaw
Executive Secretary
Ohio Board of Building Standards
P.O. Box 4009
6606 Tussing Road
Reynoldsburg, OH 43068

RE: Comments of the Responsible Energy Codes Alliance (RECA) Supporting the Adoption of the 2021 International Energy Conservation Code for Commercial and Multifamily Residential Buildings

Dear Ms. Hanshaw,

We understand that the Ohio Board of Building Standards is in the process of reviewing the 2021 *International Building Code* (*IBC*) for adoption as the Ohio Building Code. The Responsible Energy Codes Alliance supports the full adoption of the 2021 *IBC*, including Chapter 13, which would incorporate the 2021 *International Energy Conservation Code* (*IECC*) for commercial and multifamily residential construction. The 2021 version of the *IECC* is a clear and substantial improvement over the 2015 and 2018 versions of the *IECC* and will provide a range of energy efficiency, resiliency, and environmental benefits for the owners and occupants of commercial and multifamily residential buildings.

The need for decisive action to reduce energy demands is clearer than ever before. Buildings are a significant source of energy use and emissions, and the 2021 *IECC* provides a solution focused on improving the energy performance of buildings that will save money, promote local job creation, and improve the state's building infrastructure for generations to come. Updating Chapter 13 of the Ohio Building Code from the 2012 *IECC* to the 2021 *IECC* presents an important leadership opportunity that will place Ohio on the forefront of building efficiency. As a result, we recommend that the Board consider the full range of long-term benefits of adopting the 2021 *IECC* for commercial and multifamily residential buildings in the state.

Energy and Cost Savings

The *IECC* is the most widely adopted model energy code for residential and commercial construction, and earlier versions have been adopted in Ohio and nearly every state that has a statewide energy code. For the last fifteen years, the *IECC* has improved in efficiency with every new edition, providing straightforward energy and cost savings for the owners of homes and commercial buildings, and providing an important policy tool for state and local governments to achieve energy efficiency goals.

Like previous editions of the code, the 2021 *IECC* incorporates *ASHRAE* Standard 90.1 by reference as a compliance option, providing additional flexibility for design professionals and builders without sacrificing energy efficiency. In accordance with federal law, the U.S. Department of Energy analyzes efficiency improvements in each edition of *ASHRAE* Standard 90.1. The *IECC* commercial requirements are historically similar to Standard 90.1 in terms of overall efficiency, and the vast majority of states adopt the *IECC* (including the reference to Standard 90.1) and allow design professionals to use both codes. The table below summarizes DOE's analyses of national average energy savings, showing that building owners and occupants stand to benefit from over 20% lower energy costs, on average, with the adoption of the three most recent editions of the model codes.

Model Code	National Avg. Energy Cost Savings over previous model code		National Avg. Energy Cost Savings over previous model code
***ASHRAE* 90.1-2013**	**8.7%[1]**	**2015 *IECC***	**11.5%[2]**
***ASHRAE* 90.1-2016**	**8.3%[3]**	**2018 *IECC***	**5.3%[4]**
***ASHRAE* 90.1-2019**	**4.3%[5]**	**2021 *IECC***	**Not yet released**

[1] *See* U.S. Dep't of Energy, *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis*, at iv (Aug. 2014), *available at* https://www.energycodes.gov/sites/default/files/documents/901-2013_finalCommercialDeterminationQuantitativeAnalysis_TSD.pdf.

[2] *See* U.S. Dep't of Energy, *Energy and Energy Cost Savings Analysis of the 2015 IECC for Commercial Buildings*, at vi (Aug. 2015), *available at* https://www.energycodes.gov/sites/default/files/documents/2015_IECC_Commercial_Analysis.pdf.

[3] *See* U.S. Dep't of Energy, *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016*, at iv (Oct. 2017), *available at* https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf.

[4] *See* U.S. Dep't of Energy, *Energy and Energy Cost Savings Analysis of the 2018 IECC for Commercial Buildings*, at vi (Dec. 2018), *available at* https://www.energycodes.gov/sites/default/files/documents/2018_IECC_Commercial_Analysis_Final.pdf.

By adopting the 2021 *IECC*, Ohio can capture the important energy-saving improvements incorporated into the 2015, 2018, and 2021 versions of the *IECC*.[6]

State-Specific Weakening Amendments

As noted earlier, in the most recent update to Chapter 13 of the Ohio Building Code, several state-specific weakening amendments were adopted, leaving the statewide code short of its full potential for energy and cost savings. Weakening amendments make the code less efficient by watering down specific code requirements and substituting requirements from previous codes for more up-to-date provisions. The *IECC* has undergone a considerable number of interrelated changes since the 2012 edition, so carrying forward the current Ohio amendments could create conflicts (in addition to lost energy savings).

The most straightforward approach to address such potential amendments in this code update would be to start with a clean slate by eliminating all state-specific amendments at the start and then add back only the administrative amendments necessary to align section numbers and other necessary state amendments. If substantive amendments are to be considered, each such amendment to the model code should be carefully analyzed to determine if it is an improvement to the 2021 *IECC.* In our view, only improvements should be adopted and incorporated into Chapter 13 of the Ohio Building Code. For example, the current amendment to Section 1301.2 allows new multifamily residential buildings to be air leakage tested to ≤4 ACH50, whereas the *IECC* has required these buildings to be tested to ≤3 ACH50 since the 2012 edition. In Ohio's varying climate conditions, tighter envelopes provide energy savings and comfort benefits for occupants. And since the current requirement has been in place for several years now, we expect that builders could easily achieve improved air tightness levels in the next edition of the code. We recommend that Ohio adopt the air tightness testing requirement and other improvements as they are published in the 2021 *IECC* so that owners and occupants of these buildings can enjoy the full benefits of the latest model energy codes.

Broad Support for the 2021 *IECC*

Like previous versions of the *IECC*, the 2021 edition was developed with the direct input of the nation's leading architects, building code officials, builders, manufacturers, environmental groups, and sustainability experts in a consensus-based code development

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[5] *See* U.S. Dep't of Energy, *Preliminary Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019*, at vi (Apr. 2021), *available at* https://www.energycodes.gov/sites/default/files/documents/20210407_Standard_90.1-2019_Determination_TSD.pdf.

[6] For an estimate of energy and carbon savings associated with the latest model energy codes, download the Building Energy Codes Emissions Calculator at https://www.imt.org/resources/building-energy-codes-emissions-calculator/.

process. During this process, the efficiency improvements proposed for the 2021 *IECC* were endorsed by a broad range of organizations, including mayors, code officials, state energy officials, sustainability directors, and other governmental representatives from every region of the U.S. For example, the U.S. Conference of Mayors unanimously adopted a Resolution endorsing proposals that would achieve a 10% improvement in the 2021 *IECC*, finding that:

> "… building energy codes, by setting minimum efficiency requirements for all newly constructed and renovated residential, multi-family, and commercial buildings, provide measurable and permanent energy savings and carbon emissions reductions over the century-long life spans of these buildings …"[7]

The 2021 *IECC* is the result of voting by governmental members who participated directly in the ICC process. These members voted in record numbers to improve almost every aspect of the *IECC*, paving the way for a more efficient, more sustainable future.

The 2021 *IECC* contains reasonable energy-saving improvements for the entire building, including:

- Improved building envelopes, providing year-round energy savings and comfort for occupants;
- Improved requirements for verification, certificates, and other consumer protections;
- More efficient mechanical and lighting systems and automated controls designed with occupant health and safety in mind;
- Additional flexibility for builders and design professionals to optimize their design choices without reducing efficiency;
- Improved resilience, protecting occupants from environmental and climate-related risks and helping protect the investment of building owners; and
- A framework for jurisdictions to customize efficiency and net-zero requirements to adapt the *IECC* to meet energy and climate goals.

Delaying the adoption of potential efficiency improvements in the energy code could also have significant long-lasting negative consequences. Buildings constructed today are expected to last 70 years or more, and the vast majority of features that affect efficiency will be chosen and set in place at construction. The failure to grasp the opportunity to build more efficient buildings at the outset is a tremendous loss; any delay in adoption will result in the

[7] *See* U.S. Conference of Mayors, *Meeting Mayors' Energy and Climate Goals by Putting America's Model Energy Code on a Glide Path to Net Zero Energy Buildings by 2050*, USCM Resolution 59 (July 1, 2019) (emphasis added), *available at* https://energyefficientcodes.org/wp-content/uploads/2019-07-1-Putting-the-*IECC*-on-a-Glide-Path-to-Net-Zero-Energy-Buildings-by-2050.pdf.

construction of buildings with less efficiency, a condition that will last for many years and possibly for the life of such buildings. The owners and occupants of commercial and multifamily residential buildings depend on the state to regulate buildings in a way that optimizes energy and cost savings and that will be consistent with Ohio's long-term energy goals. The 2021 *IECC* provides a consensus-driven, adaptable blueprint for Ohio's future.

Conclusion

RECA's members and supporters have been involved in energy code development and adoption for decades, and we offer our assistance and experience as you work to maximize building energy efficiency. Please contact us if you have any questions or would like to discuss how RECA can be of assistance.

Sincerely,

Eric Lacey
RECA Chairman

RECA is a broad coalition of energy efficiency professionals, regional efficiency organizations, product and equipment manufacturers, trade associations, and environmental organizations with expertise in the development, adoption, and implementation of building energy codes nationwide. RECA is dedicated to improving the energy efficiency of homes throughout the U.S. through greater use of energy efficient practices and building products. It is administered by the Alliance to Save Energy, a non-profit coalition of business, government, environmental and consumer leaders that supports energy efficiency as a cost-effective energy resource under existing market conditions and advocates energy-efficiency policies that minimize costs to society and individual consumers. Below is a list of RECA Members that endorse these comments.

Air Barrier Association of America

Alliance to Save Energy

American Chemistry Council

American Council for an Energy-Efficient Economy

CertainTeed LLC

EPS Industry Alliance

Extruded Polystyrene Foam Association

Institute for Market Transformation

Johns Manville Corporation

Knauf Insulation

National Fenestration Rating Council

Natural Resources Defense Council

North American Insulation Manufacturers Association

Owens Corning

Polyisocyanurate Insulation Manufacturers Association

Submitted Via Email

January 12, 2022

Regina Hanshaw
Executive Secretary
Ohio Board of Building Standards
P.O. Box 4009
6606 Tussing Road
Reynoldsburg, OH 43068

RE: Comments of the Responsible Energy Codes Alliance (RECA) Supporting the Adoption of the 2018 *IECC/ASHRAE* 90.1-2016 and Supplementing July 16, 2021 RECA Letter Supporting the Adoption of the 2021 *IECC/ASHRAE* 90.1-2019

Dear Ms. Hanshaw,

We are writing in response to the Ohio Board of Building Standards' December 10, 2021 request for comments on the adoption of the 2018 *International Energy Conservation Code* (*IECC*) and *ASHRAE* Standard 90.1-2016 (*ASHRAE*) for commercial and multifamily residential construction. RECA submitted comments to the Board supporting an update to the most recent edition of the model energy codes on July 16, 2021 (a full copy of which is attached to these comments). **As discussed in more detail below, we strongly recommend adoption of the 2018 *IECC/ASHRAE* 90.1-2016, and ideally the 2021 *IECC/ASHRAE* 90.1-2019, as soon as reasonably practicable.** We submit the following supplemental comments to provide additional information requested by the Board.

1. **RECA supports the proposed adoption of the 2018 *IECC/ASHRAE* 90.1-2016 in Ohio.**

RECA supports the adoption of the 2018 *IECC and ASHRAE* 90.1-2016, which would be a substantial improvement over the current commercial energy code in Ohio (based on the 2012 *IECC*). As we noted in our July letter, the 2018 *IECC/ASHRAE* 90.1-2016 provide clear, cost-effective energy savings for commercial and residential multifamily buildings in Ohio's climate zones. U.S. DOE has found that on a national basis, the 2018 *IECC* saves an average 5.3% in energy cost over the 2015 *IECC* and an additional 11.5% over the 2012 *IECC.* Similarly, *ASHRAE* 90.1-2016 saves 8.3% in energy cost over the 2013 version and an additional 8.7% over the previous version. (A more complete discussion of energy savings can be found in the attached July 2021 letter, page 2).

The Board's request for comments asks for specific details on the impact of the latest codes on building design. The update from the 2012 to the 2018 edition of the *IECC* will provide a number of key improvements for commercial buildings, including the following:

- **System Efficiency** – Heating, cooling, and water heating system efficiency requirements have been improved to maintain pace with federal requirements and market transformation, and new system control requirements will help further optimize efficiency.
- **Permanent Envelope** – The opaque envelope requirements and fenestration efficiency requirements are improved, helping to ensure long-term occupant comfort and energy savings, reducing electric peak demands, and contributing overall to a more durable and resilient building stock. A building that is insulated well and includes reasonably efficient fenestration will provide these benefits over the useful lifetime of the building.
- **Lighting Efficiency** – Lighting efficiency requirements and controls have been updated nearly every cycle to keep pace with rapid advancement in lighting efficiency and market trends. Interior and exterior lighting power densities have been adjusted to match the improving performance of lighting products. The 2018 *IECC* also updates requirements for lighting in multifamily residential dwelling units.
- **Additional Efficiency Options** – The 2018 *IECC* updates and increases the number of efficiency options in section C406, giving design professionals and builders more flexibility in compliance.

2. **Each edition of the *IECC* and *ASHRAE* 90.1 published since the 2012 *IECC* has been carefully reviewed by the U.S. Department of Energy and found to be an improvement in energy efficiency and to be life-cycle cost-effective for Ohio buildings.**

The U.S. Department of Energy reviews each edition of the national model energy codes pursuant to its federal statutory mandate. As part of this work, DOE has released state-specific energy savings and cost-effectiveness analyses for the most recent three editions of the model codes. For commercial buildings, U.S. DOE analyzes *ASHRAE* Standard 90.1 (which is a compliance option referenced in the *IECC*). For Ohio commercial construction specifically, DOE found clear cost-effectiveness over the useful lifetime of commercial buildings for each edition.

By adopting the 2018 *IECC*/*ASHRAE* 90.1-2016, Ohio can benefit from the energy- and cost-saving improvements incorporated into two published versions of the model energy codes. (Adoption of the 2021 *IECC* provides additional cost savings.)

U.S. DOE Analyses of Cost Savings for Commercial Buildings in Ohio			
Model Code	**Average Annual Cost Savings Over Previous Model Code**	**Avg. Life Cycle Cost Savings (Public Bldgs)**	**Avg. Life Cycle Cost Savings (Private Bldgs)**
ASHRAE 90.1-2013[1]	$0.144/sq.ft.	$2.38/sq.ft.	$1.97/sq.ft.
ASHRAE 90.1-2016[2]	$0.118/sq.ft.	$7.62/sq.ft.	$6.31/sq.ft.
ASHRAE 90.1-2019[3]	$0.054/sq.ft.	$4.02/sq.ft.	$3.57/sq.ft.

3. **RECA also encourages the Board to take the next step and adopt the 2021 *IECC/ASHRAE* 90.1-2019 as soon as practicable.**

As noted in our July comments to the Board, while a move to the 2018 *IECC/ASHRAE* 90.1-2016 would certainly be a major improvement and should not be delayed, adoption of the 2021 *IECC* (which includes *ASHRAE* 90.1-2019 as a compliance option) would yield even more energy savings and provide the widest range of benefits for building owners and occupants. The owners and occupants of commercial buildings constructed to the 2021 *IECC/ASHRAE* 90.1-2019 would see, on average, over a 20% reduction in energy costs as compared to buildings constructed to Ohio's current code. The latest model codes have demonstrated clear energy savings and will contribute to Ohio's greenhouse gas reduction goals; additionally, buildings will be more comfortable and more resilient for generations to come.

A move to the 2021 *IECC* provides significant additional improvements for commercial buildings at all levels as compared with the 2018 *IECC:*

1. **Further Improvements in Envelope Efficiency.** The 2021 *IECC* improves nearly all aspects of the permanent envelope, including more efficient fenestration and opaque envelope requirements.

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[1] *See* U.S. Dep't of Energy, *Cost-Effectiveness of ASHRAE Standard 90.1-2013 for the State of Ohio*, at 2 (Dec. 2015) *available at* https://www.energycodes.gov/sites/default/files/2019-09/Cost-effectiveness_of_*ASHRAE*_Standard_90-1-2013-Ohio.pdf.

[2] *See* U.S. Dep't of Energy, *Cost-Effectiveness of ASHRAE Standard 90.1-2016 for the State of Ohio*, at 1 (Aug. 2020) *available at* https://www.energycodes.gov/sites/default/files/2021-03/Cost-effectiveness_of_*ASHRAE*_Standard_90-1-2016-Ohio.pdf.

[3] *See* U.S. Dep't of Energy, *Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019 for Ohio*, at 1 (July 2021) *available at* https://www.energycodes.gov/sites/default/files/2021-07/Cost-effectiveness_of_*ASHRAE*_Standard_90-1-2019-Ohio.pdf.

2. **Tighter Building Envelopes.** New air leakage testing for most building types will save energy, improve mechanical system performance, and help maintain healthy indoor air quality.

3. **Heating, Cooling, and Lighting Improvements.** Increased mechanical system and lighting system efficiencies will help maintain occupant health and reduce costs.

4. **Increased Flexibility for Design Professionals.** A new points-based system of code compliance replaces the package-based Additional Efficiency Options and will provide additional flexibility for design professionals to demonstrate compliance with the code based on specific building occupancy types.

5. **Streamlined Compliance and Enforcement.** Reorganized compliance paths will facilitate code compliance and enforcement.

6. **Improved Transparency for Building Owners.** New certificate and other disclosure requirements will provide information to building owners and operators and improve transparency in the design and building process.

7. **Reference to Most Current and Up-to date Version of *ASHRAE* 90.1.** The 2021 *IECC* references the improved *ASHRAE* 90.1-2019 as an alternate compliance path.

8. **Consistency with other I-Codes.** Section numbers and internal references will align with other 2021 International Codes under consideration in Ohio.

Adopting a code that meets or exceeds *ASHRAE* Standard 90.1-2019 would also be an important step in meeting the Federal Law that requires states to adopt a commercial energy code that meets or exceeds the most recent edition of *ASHRAE* on which U.S. DOE has found increased energy savings.[4] Because U.S. DOE made a positive determination on *ASHRAE* Standard 90.1-2019 on July 28, 2021, states have until July 28, 2023 to make that certification to the Secretary of Energy.[5]

The 2021 *IECC* (and *ASHRAE* Standard 90.1-2019) are the most current and up-to-date options available for adoption and, like previous editions of the model codes, benefit from the latest input of the nation's architects, engineers, efficiency experts, builders, product and equipment manufacturers, and other stakeholders who prioritize safe, healthy, efficient buildings.

[4] *See* 42 U.S.C. § 6833 (b)2(B).

[5] *See* U.S. Dep't of Energy, *Final Determination Regarding Energy Efficiency Improvements in ANSI/ASHRAE/IES Standard 90.1-2019*, 86 Fed. Reg. 40543 (July 28, 2021).

Conclusion

RECA supports the work of the Board of Building Standards to improve the health and safety of the built environment for Ohio citizens. We strongly recommend adoption of the 2018 *IECC/ASHRAE* 90.1-2016, and ideally the 2021 *IECC/ASHRAE* 90.1-2019, as soon as practicable. Please contact us if you have any questions or would like to discuss how RECA can help.

Sincerely,

Eric Lacey
RECA Chairman

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Institute for Market Transformation

Johns Manville Corporation

Knauf Insulation

National Fenestration Rating Council

Natural Resources Defense Council

North American Insulation Manufacturers Association

Owens Corning

Polyisocyanurate Insulation Manufacturers Association

From: Ohler, Deborah
To: Aaron Dearth
Cc: Denk, Joseph
Subject: RE: Energy Code
Date: Friday, February 18, 2022 7:57:00 AM
Attachments: image003.png

Good morning, Aaron-
Thank you for taking the time to provide comments to the BBS Code Committee at their January meeting.

Thank you, too, for taking the time to help me understand your position and to clarify which standard you are using to demonstrate compliance. It was clear to me that you were using the COMcheck software to enable trade-offs. However, I thought I heard you say that you were selecting the 2018 IECC option within the COMcheck software to demonstrate compliance.

Thank you, again, for the clarification.
Have a good day and a great weekend!
Debbie

Ohio | Board of Building Standards

Deborah D. Ohler, P.E., Construction Codes Administrator
Ohio Board of Building Standards
PO Box 4009, 6606 Tussing Rd.
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http://www.com.ohio.gov/dico/BBS/
Better Codes, Better Buildings, Safer Ohio

-
http://coronavirus.ohio.gov
Thanks for your patience while our staff works remotely to stop the community spread of COVID-19.

From: Aaron Dearth <adearth@simonsonconstruction.com>
Sent: Wednesday, February 16, 2022 2:22 PM
To: Ohler, Deborah <debbie.ohler@com.state.oh.us>
Cc: Joe Denk <Joseph.Denk@denkassoc.com>
Subject: Re: Energy Code

Debbie,
thank you for taking the time to call me today. After our conversation, I wanted to look up the codes

and follow up with the information we discussed. You stated that you were confused as to how ComCheck was showing different values, when it appeared that the insulation values had not changed. I believe the confusion lies in the difference between the tabular prescriptive values (for example ICC table C402.2) and the appendix used for the trade-off method. To clarify, we have (3) options for energy code compliance. #1- strictly following or surpassing the prescriptive values, #2- the trade-off method via software such as ComCheck which allows benefits from high performing spaces to allow savings in others, and #3 complex full building modeling which would allow savings between disciplines such as solar lighting allowing decrease in insulation. In general, most of our projects, and those whom I have business with, continue to utilize the trade-off method via ComCheck. The prescriptive values are simply too restricting and don't allow for any variance to things like continuous insulation. I see what you are saying that the prescriptive values appear the same, however these are already the high end insulation values and not the values they allow for use in the trade-off method.

The comcheck software utilizes Ashrae appendix A for its roof and wall calculations. This appears to be where they implemented the changes in the code to inflate the insulation values. For example, in 90.1:2010 a single layer of R-13 in a metal building wall calculated to a U-value of 0.113, in 2016 that changed to a U value of 0.162. This equates to a 30% decrease in the benefit they will allow you to document for that insulation. (Table A3.2) It's the same story for roofing, in 90.1:2010 a double layer of R19 was U0.046, and in 2016 that changed to U0.060, or a 23% decrease in benefit.

Hopefully that helps clear up some of the confusion. It would appear that the changes they made are less obvious. They altered the allowable U-values in the appendix for anything less than the prescriptive values. This effectively artificially inflates the insulation requirements to force them closer to the prescriptive despite being the same R-value previously calculated at better U-values.

As I mentioned, although this was the confusion, this is not my primary concern. My primary issue remains that these changes will primarily be forcing additional upfront costs on businesses with little to no future savings. I admit that as a design-build contractor, factories and warehouses utilizing pre-engineered metal buildings are a major part of our business. And it's these clients I don't see recouping anything in the long run. For just about any facility in the F or S use group, the HVAC system is sized almost entirely for equipment, processes, and ventilation requirements of the space. Additional insulation value won't likely cause any change in the sizing, output or energy use of the large air handling units needed for these facilities. When you are changing over the air in factory space 10-15 times an hour, external influences are negligible. In a way, it could be said that by requiring more raw materials, more labor, without decreasing the utility usage, for F and S uses this change could actually use more energy overall than the previous.

Thanks again for your call, and feel free to reach out to me if you have any further questions. As before, I would recommend you reach out to Mike Halapy and Bill Beals if you would like any input from the insulation industry or Ashrae.

Aaron Jay Dearth, RA, AIA, NCARB
Simonson Construction Services, Inc.
Cell: (419) 565-1898

On Mon, Jan 31, 2022 at 10:45 AM Aaron Dearth <adearth@simonsonconstruction.com> wrote:

> No problem at all Joe. In fact I was very pleasantly surprised by the openness to comments of your board. As well as your appreciation and concern for the real world effect on businesses in Ohio that these changes could affect.
> I have spoken with Mike both before and after the meeting, and he is updating Bill as well. Mike has expressed interest in speaking at the March meeting if that would benefit you.
>
> If you have any other questions, or would like to discuss what we are seeing/hearing from clients in this region, on even the current energy code, I would welcome the conversation. Let me know if you need anything from me.
>
> **Aaron Jay Dearth, RA, AIA, NCARB**
> Simonson Construction Services, Inc.
>
> 2112 Troy Rd, Ashland, OH 44805
>
> Cell: (419) 565-1898
> Office: (419) 281-8299
> Fax: (419) 281-6150
>
> Simonson Construction Services, Inc. is an Equal Opportunity Employer
>
> On Mon, Jan 31, 2022 at 10:15 AM Joe Denk <Joseph.Denk@denkassoc.com> wrote:
>
>> Aaron:
>>
>> Thank you again for your input at our recent Board of Building Standards Code Committee meeting. Please make Mike Halapy and Bill Beals aware that we are considering an update of the Energy Code. We would welcome any input they are inclined to provide.
>>
>> Joe Denk, PE, LEED AP
>>
>> **Denk Associates, Inc.**
>> 503 East 200th Street
>> Cleveland, Ohio 44119
>> 216-531-8880, ext. 205
>> Cell: 216-339-1274
>> Email: jdenk@denkassoc.com

DENK ASSOCIATES
CONSULTING ENGINEERS

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