Board of Building Standards

RESIDENTIAL CONSTRUCTION ADVISORY COMMITTEE MEETING AGENDA

DATE: AUGUST 09, 2023
TIME: 9:00 AM
LOCATION: TRAINING RM 3, 6606 TUSSING RD, REYNOLDSBURG, OHIO 43068
Click here to join the meeting

Call to Order

Roll Call

Agenda – Changes or Additions

Consideration of Minutes

MIN-1 May 10, 2023 Meeting Minutes

Old Business

OB-1 2023 NEC and Analysis of Changes – No action requested
OB-2 Petition #23-04 - RCO 311.7.1 Two handrails - Robert Kramer – Referred back from Board

New Business

NB-1 Review of 2021 IECC Residential Provisions

Reports from Chairperson

Reports from Executive Secretary

Public Comments

Comments from Committee Members

Future Meeting Schedule

October 18
December 20
*More as needed

Motion to Adjourn

MINUTES
RESIDENTIAL CONSTRUCTION ADVISORY COMMITTEE MEETING
MAY 10, 2023

Call to Order
Mr. Phillips called the meeting to order at 9:00 am on May 10, 2023 at 6606 Tussing Rd, Reynoldsburg.

Roll Call
Committee members present: Don Phillips, Ric Johnson, Mike Boeckermann, Andre Frasier, Bill Kaufholz, Roger Puzzitiello, and Dan Spada.

Staff members present: Jay Richards & Regina Hanshaw

Visitors present: Kris Klaus, OHBA

Agenda – Changes or Additions

Mr. Johnson moved and Mr. Puzzitiello seconded to approve the agenda.

Consideration of Minutes
MIN-1 March 22, 2023 Meeting Minutes

Mr. Johnson and Mr. Spada seconded to approve the March 22, 2023 meeting minutes. Motion passed unanimously.

Old Business
OB-1 2023 NEC
Following presentation of 2023 NEC by Tom Moore and Tim McClintock, Mr. Boeckermann moved and Mr. Spada seconded to recommend adoption of the 2023 NEC instead of the 2020 NEC carrying forward the previously approved Ohio changes.

Motion passed unanimously by roll call vote.

OB-2 2019 RCO Proposed Amendments Stakeholder Comments

Mr. Richards presented the stakeholder comments received on the draft amendments to the RCO. Mr. Essary submitted a comment requesting to removal of the Ohio exception for surge protection requirements in the NEC. Following discussion, Mr. Frazier moved and Mr. Boeckermann seconded to retain the proposed Ohio exception for surge protection requirements as part of the NEC adoption.

Motion passed unanimously by roll call vote.

New Business
NB-1 Petition 23-04 Section 311.7.1 (Handrails)

Mr. Richards presented the petition submitted by Robert Kramer proposing second handrail in stairways. Mr. Puzzitiello moved and Mr. Kaufholz seconded to deny petition because lack of information justifying the additional requirement. Under discussion, Mr. Johnson stated that he would like to learn more from the petitioner before the taking action.

Motion passed by roll call vote with Mr. Johnson and Mr. Boeckermann voting no.

Reports from Chairperson
No report.

Reports from Executive Secretary
No report.

Public Comments
There were no public comments.

Comments from Committee Members
Mr. Johnson updated the committee on the development of the 2024 IECC.

Future Meeting Schedule
August 9
October 18
December 20
*More as needed

Motion to Adjourn
Mr. Johnson moved and Mr. Puzzitiello seconded to adjourn. Motion passed unanimously.

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Don Phillips, Chair
Residential Construction Advisory Committee

____
Regina Hanshaw, Executive Secretary
Board of Building Standards

Distribution:
File
Committee Members and Staff

APPLICATION
FOR
RULE CHANGE

Pursuant to section 3781.12 of the Revised Code and rules adopted by the Board of Building Standards, application is herewith submitted to adopt, amend, or annul a rule adopted by the Board pursuant to section 3718.10 of the Revised Code.

BOARD OF BUILDING STANDARDS
6606 Tussing Road, P.O. Box 4009
Reynoldsburg, Ohio 43068-9009
(614) 644-2613
bbs@ohio.gov
www.com.state.oh.us/dico/bbs/default.aspx

For BBS use:	
Petition #:	23-04
Date Recv'd:	03/27/2023

Submitter: ROBERT KRAMER (Contact Name) CITIZEN (Organization/Company)

Address: 5690 GENEVIEVE PLACE (Include Room Number, Suite, etc.)

FAIRFIELD (City) OHIO (State) 45014 (Zip)

Telephone Number: 513-885-4600 **Fax Number:**

Date: MARCH 26, 2023 **E-mail Address:** KEYNOTEMAN@HOTMAIL.COM

Code Section: 101

General Explanation of Proposed Change (attach additional sheets if necessary):

311.7.1 Stairways shall not be less than 36 inches (914 mm) in clear width at all points above the permitted handrail height and below the required headroom height. Handrails must be installed on both sides of all stairways and shall not project more than 4.5 inches (114 mm) on either side of the stairway and the minimum clear width of the stairway at and below the handrail height, including treads and landings, shall not be less than ~~31½ inches (787 mm) where a handrail is installed on one side and~~ 27 inches (698 mm). ~~where handrails are provided on both sides~~

1. Around 24,760,843 patients were admitted to emergency departments due to staircase-related injury during a 23 year-long study by NEISS.
2. In an average year, 1,076,558 people in the US suffer from a staircase-related injury.
3. More than 12,000 people meet death from falling down stairs every year. This itself tells how fatal a fall could be. Simple tripping down stairs or falling off the stairs can rewrite one's destiny. Since the fall will be very fast, the speed of impacting your head or back will occur in a fraction of a second.

The cost should be no more than $200.00 per home.

Explanation of Cost Impact of Proposed Code Change*:

*Attach additional cost information as necessary to justify any statement of cost increase or cost decrease.

SECTION 311 MEANS OF EGRESS

311.1 Means of egress. Dwellings shall be provided with a means of egress in accordance with this section. The means of egress shall provide a continuous and unobstructed path of vertical and horizontal egress travel from all portions of the dwelling to the required egress door without requiring travel through a garage. The required egress door shall open directly into a public way or to a yard or court that opens to a public way.

311.2 Egress door. Not less than one egress door shall be provided for each dwelling unit. The egress door shall be side-hinged, and shall provide a clear width of not less than 32 inches (813 mm) where measured between the face of the door and the stop, with the door open 90 degrees (1.57 rad). The clear height of the door opening shall be not less than 78 inches (1981 mm) in height measured from the top of the threshold to the bottom of the stop. Other doors shall not be required to comply with these minimum dimensions. Egress doors shall be readily openable from inside the dwelling without the use of a key or special knowledge or effort.

311.2.1 Garage access doors. Garages shall be served by at least one side hinged door not less than 2 feet 6 inches (760 mm) in width and 6 feet 8 inches (2032 mm) in height. Such door located between a dwelling and an attached garage shall be acceptable for meeting this requirement.

311.3 Floors and landings at exterior doors. There shall be a landing or floor on each side of each exterior door. The width of each landing shall be not less than the door served. Landings shall have a dimension of not less than 36 inches (914 mm) measured in the direction of travel. The slope at exterior landings shall not exceed 1/4 unit vertical in 12 units horizontal (2 percent). Exception: Exterior balconies less than 60 square feet (5.6 m2) and only accessed from a door are permitted to have a landing that is less than 36 inches (914 mm) measured in the direction of travel.

311.3.1 Floor elevations at the required egress doors. Landings or finished floors at the required egress door shall be not more than 11/2 inches (38 mm) lower than the top of the threshold. Exception: The landing or floor on the exterior side shall be not more than 8 1/4 -inches (209 mm) below the top of the threshold provided that the door does not swing over the landing or floor. Where exterior landings or floors serving the required egress door are not at grade, they shall be provided with access to grade by means of a ramp in accordance with Section 311.8 or a stairway in accordance with Section 311.7.

311.3.2 Floor elevations at other exterior doors. Doors other than the required egress door shall be provided with landings or floors not more than 8 1/4 -inches (209 mm) below the top of the threshold.

Exception: A top landing is not required for the stairway located on the exterior side of the door, provided that the threshold of the door is not more than 30" above the adjacent grade and the door does not swing over the stairway.

311.3.3 Storm and screen doors. Storm and screen doors shall be permitted to swing over exterior stairs and landings.

311.4 Vertical egress. Egress from habitable levels including habitable attics and basements that are not provided with an egress door in accordance with Section 311.2 shall be by a ramp in accordance with Section 311.8 or a stairway in accordance with Section 311.7.

311.5 Landing, deck, balcony and stair construction and attachment. Exterior landings, decks, balconies, stairs and similar facilities shall be positively anchored to the primary structure to resist both vertical and lateral forces or shall be designed to be self-supporting. Attachment shall not be accomplished by use of toenails or nails subject to withdrawal.

311.6 Hallways. The width of a hallway shall be not less than 3 feet (914 mm).

311.7 Stairways.

311.7.1 Width. Stairways shall be not less than 36 inches (914 mm) in clear width at all points above the permitted handrail height and below the required headroom height. The clear width of stairways at and below the handrail height, including treads and landings, shall be not less than 31 1/2 inches (787 mm) where a handrail is installed on one side and 27 inches (698 mm) where handrails are installed on both sides *in accordance with 311.7.8*. Exception: The width of spiral stairways shall be in accordance with Section 311.7.10.1.

311.7.2 Headroom. The headroom in stairways shall be not less than 6 feet 8 inches (2032 mm) measured vertically from the sloped line adjoining the tread nosing or from the floor surface of the landing or platform on that portion of the stairway.

Exceptions:

1. Where the nosings of treads at the side of a flight extend under the edge of a floor opening through which the stair passes, the floor opening shall not project horizontally into the required headroom more than 4 3/4 inches (121 mm).

2. The headroom for spiral stairways shall be in accordance with Section 311.7.10.1.

311.7.3 Vertical rise. A flight of stairs shall not have a vertical rise larger than 148 1/2 -inches (3772 mm) between floor levels or landings.

311.7.4 Walkline. The walkline across winder treads and landings shall be concentric to the turn and parallel to the direction of travel entering and exiting the turn. The walkline shall be located 12 inches (305 mm) from the inside of the turn. The 12-inch (305 mm) dimension shall be measured from the widest point of the clear stair width at the walking surface. Where winders are adjacent within a flight, the point of the widest clear stair width of the adjacent winders shall be used.

311.7.5 Stair treads and risers. Stair treads and risers shall meet the requirements of this section. For the purposes of this section, dimensions and dimensioned surfaces shall be exclusive of carpets, rugs or runners.

311.7.5.1 Risers. The riser height shall be not more than 8 1/4 -inches (209 mm). The riser shall be measured vertically between leading edges of the adjacent treads. The greatest riser height within any flight of stairs shall not exceed the smallest by more than 3/8 inch (9.5 mm). Risers shall be vertical or sloped from the underside of the nosing of the tread above at an angle not more than 30 degrees (0.51 rad) from the vertical. At open risers, openings located more than 30 inches (762 mm), as measured vertically, to the floor or grade below shall not permit the passage of a 4-inch-diameter (102 mm) sphere. Exceptions: 1. The opening between adjacent treads is not limited on spiral stairways. 2. The riser height of spiral stairways shall be in accordance with Section 311.7.10.1.

311.7.5.2 Treads. The tread depth shall be not less than 9 -inches (229 mm). The tread depth shall be measured horizontally between the vertical planes of the foremost projection of adjacent treads and at a right angle to the tread's leading edge. The greatest tread depth within any flight of stairs shall not exceed the smallest by more than 3/8 inch (9.5 mm).

311.7.5.2.1 Winder treads. Winder treads shall have a tread depth of not less than 9 -inches (229 mm) measured between the vertical planes of the foremost projection of adjacent treads at the intersections with the walkline. Winder treads shall have a tread depth of not less than 6 inches (152 mm) at any point within the clear width of the stair. Within any flight of stairs, the largest winder tread depth at the walkline shall not exceed the smallest winder tread by more than 3/8 inch (9.5 mm). Consistently shaped winders at the walkline shall be allowed within the same flight of stairs as rectangular treads and shall not be required to be within 3/8 inch (9.5 mm) of the rectangular tread depth. Exception: The tread depth at spiral stairways shall be in accordance with Section 311.7.10.1.

311.7.5.3 Nosings. Nosings at treads, landings and floors of stairways shall have a radius of curvature at the nosing not greater than 9/16 inch (14 mm) or a bevel not greater than 1/2 inch (12.7 mm). A nosing projection not less than 3/4 inch (19 mm) and not more than 11/4 inches (32 mm) shall be provided on stairways. The greatest nosing projection shall not exceed the smallest nosing projection by more than 3/8 -inch (9.5 mm) within a stairway. Exception: A nosing projection is not required where the tread depth is not less than 11 inches (279 mm).

311.7.5.4 Exterior plastic composite stair treads. Plastic composite exterior stair treads shall comply with the provisions of this section and Section 507.2.2.

311.7.6 Landings for stairways. There shall be a floor or landing at the top and bottom of each stairway. The width perpendicular to the direction of travel shall be not less than the width of the flight served. For landings of shapes other than square or rectangular, the depth at the walk line and the total area shall be not less than that of a quarter circle with a radius equal to the required landing width. Where the stairway has a straight run, the depth in the direction of travel shall be not less than 36 inches (914 mm). Exception: A floor or landing is not required at the top of an interior flight of stairs, including stairs in an enclosed garage, provided that a door does not swing over the stairs.

311.7.7 Stairway walking surface. The walking surface of treads and landings of stairways shall be sloped not steeper than one unit vertical in 48 inches horizontal (2-percent slope).

311.7.8 Handrails. Handrails shall be provided on not less than one side of each flight of stairs with four or more risers. *Where the stairway width exceeds (36, 54, 60) inches, a handrail is to be provided on both sides of the flight of stairs.*

311.7.8.1 Height. Handrail height, measured vertically from the sloped plane adjoining the tread nosing, or finish surface of ramp slope, shall be not less than 34 inches (864 mm) and not more than 38 inches (965 mm) Exceptions: 1. The use of a volute, turnout or starting easing shall be allowed over the lowest tread. 2. Where handrail fittings or bendings are used to provide continuous transition between flights, transitions at winder treads, the transition from handrail to guard, or used at the start of a flight, the handrail height at the fittings or bendings shall be permitted to exceed 38 inches (956 mm).

311.7.8.2 Handrail projection. Handrails shall not project more than 41/2 inches (114 mm) on either side of the stairway. Exception: Where nosings of landings, floors or passing flights project into the stairway reducing the clearance at passing handrails, handrails shall project not more than 61/2 inches (165 mm) into the stairway, provided that the stair width and handrail clearance are not reduced to less than that required.

311.7.8.3 Handrail clearance. Handrails adjacent to a wall shall have a space of not less than 11/2 inches (38 mm) between the wall and the handrails.

311.7.8.4 Continuity. Handrails shall be continuous for the full length of the flight, from a point directly above the top riser of the flight to a point directly above the lowest riser of the flight. Handrail ends shall be returned or shall terminate in newel posts or safety terminals. Exceptions: 1. Handrail continuity shall be permitted to be interrupted by a newel post at a turn in a flight with winders, at a landing, or over the lowest tread. 2. A volute, turnout or starting easing shall be allowed to terminate over the lowest tread. 3. Two or more separate rails shall be considered continuous if the termination of the rails occurs over a single tread and positioned within 4 inches of each other. If the transition occurs between a wall mounted handrail and handrail/guardrail combination, the wall mounted handrail shall return into the wall.

311.7.8.5 Grip size. Required handrails shall be of one of the following types or provide equivalent graspability. 1. Type I. Handrails with a circular cross section shall have an outside diameter of not less than 11/4 inches (32 mm) and not greater than 2 inches (51 mm). If the handrail is not circular, it shall have a perimeter of not less than 4 inches (102 mm) andnot greater than 61/4 inches (160 mm) and a cross section of not more than 21/4 inches (57 mm). Edges shall have a radius of not less than 0.01 inch (0.25 mm). 2. Type II. Handrails with a perimeter greater than 61/4 -inches (160 mm) shall have a graspable finger recess area on both sides of the profile. The finger recess shall begin within 3/4 -inch (19 mm) measured vertically from the tallest portion of the profile and have a depth of not less than 5/16 -inch (8 mm) within 7/8 -inch (22 mm) below the widest portion of the profile. This required depth shall continue for not less than 3/8 -inch (10 mm) to a level that is not less than 13/4 -inches (45 mm) below the tallest portion of the profile. The width of the handrail above the recess shall be not less than 11/4 -inches (32 mm) and not more than 23/4 -inches (70 mm). Edges shall have a radius of not less than 0.01 inch (0.25 mm).

311.7.8.6 Exterior plastic composite handrails. Plastic composite exterior handrails shall comply with the requirements of Section 507.2.2.

311.7.9 Illumination. Stairways shall be provided with illumination in accordance with Sections 303.7 and 303.8.

311.7.10 Special stairways. Spiral stairways and bulkhead enclosure stairways shall comply with the requirements of Section 311.7 except as specified in Sections 311.7.10.1 and 311.7.10.2.

311.7.10.1 Spiral stairways. The clear width at and below the handrails at spiral stairways shall be not less than 26 inches (660 mm) and the walkline radius shall be not greater than 241/2 inches (622 mm). Each tread shall have a depth of no less than 63/4 inches (171 mm) at the walkline. Treads shall be identical, and the rise shall be not more than 91/2 inches (241 mm). Headroom shall be not less than 6 feet 6 inches (1982 mm).

311.7.10.2 Bulkhead enclosure stairways. Stairways serving bulkhead enclosures, not part of the required building egress, providing access from the outside grade level to the basement shall be exempt from the requirements of Sections 311.3 and 311.7 where the height from the basement finished floor level to grade adjacent to the stairway is not more than 8 feet (2438 mm) and the grade level opening to the stairway is covered by a bulkhead enclosure with hinged doors or other approved means.

311.7.11 Alternating tread devices. Alternating tread devices shall not be used as an element of a means of egress. Alternating tread devices shall be permitted provided that a required means of egress stairway or ramp serves the same space at each adjoining level or where a means of egress is not required. The clear width at and below the handrails shall be not less than 20 inches (508 mm). Exception: Alternating tread devices are allowed to be used as an element of a means of egress for lofts, mezzanines and similar areas of 200 gross square feet (18.6m2) or less where such devices do not provide exclusive access to a kitchen or bathroom.

311.7.11.1 Treads of alternating tread devices. Alternating tread devices shall have a tread depth of not less than 5 inches (127 mm), a projected tread depth of not less than 81/2 inches (216 mm), a tread width of not less than 7 inches (178 mm) and a riser height of not more than 91/2 inches (241 mm). The tread depth shall be measured horizontally between the vertical planes of the foremost projections of adjacent treads. The riser height shall be measured vertically between the leading edges of adjacent treads. The riser height and tread depth provided shall result in an angle of ascent from the horizontal of between 50 and 70 degrees (0.87 and 1.22 rad). The initial tread of the device shall begin at the same elevation as the platform, landing or floor surface.

311.7.11.2 Handrails of alternating tread devices. Handrails shall be provided on both sides of alternating tread devices and shall comply with Sections 311.7.8.2 to 311.7.8.6. Handrail height shall be uniform, not less than 30 inches (762 mm) and not more than 34 inches (864 mm).

311.7.12 Ships ladders. Ships ladders shall not be used as an element of a means of egress. Ships ladders shall be permitted provided that a required means of egress stairway or ramp serves the same space at each adjoining level or where a means of egress is not required. The clear width at and below the handrails shall be not less than 20 inches (508 mm). Exception: Ships ladders are allowed to be used as an element of a means of egress for lofts, mezzanines and similar areas of 200 gross square feet (18.6 m2) or less that do not provide exclusive access to a kitchen or bathroom.

311.7.12.1 Treads of ships ladders. Treads shall have a depth of not less than 5 inches (127 mm). The tread shall be projected such that the total of the tread depth plus the nosing projection is not less than 81/2 inches (216 mm). The riser height shall be not more than 91/2 inches (241 mm).

311.7.12.2 Handrails of ships ladders. Handrails shall be provided on both sides of ships ladders and shall comply with Sections 311.7.8.2 to 311.7.8.6. Handrail height shall be uniform, not less than 30 inches (762 mm) and not more than 34 inches (864 mm).

311.8 Ramps.

311.8.1 Maximum slope. Ramps serving the egress door required by Section 311.2 shall have a slope of not more than 1 unit vertical in 8 units horizontal (12.5 -percent slope).

311.8.2 Landings required. There shall be a floor or landing at the top and bottom of each ramp, where doors open onto ramps, and where ramps change directions. The width of the landing perpendicular to the ramp slope shall be not less than 36 inches (914 mm).

311.8.3 Handrails required. Handrails shall be provided on not less than one side of ramps exceeding a slope of one unit vertical in 12 units horizontal (8.33percent slope). *Where the ramp width exceeds (36, 54, 60) inches, a handrail is to be provided on both sides of the ramp.*

311.8.3.1 Height. Handrail height, measured above the finished surface of the ramp slope, shall be not less than 34 inches (864 mm) and not more than 38 inches (965 mm).

311.8.3.2 Grip size. Handrails on ramps shall comply with Section 311.7.8.5.

311.8.3.3 Continuity. Handrails where required on ramps shall be continuous for the full length of ramp. Handrail ends shall return or shall terminate in newel posts or safety terminals. Handrails adjacent to a wall shall have a space of not less than 11/2 -inches (38 mm) between the wall and the handrails.

Significant changes 2018-2021 IECC Residential Provisions

[Sources: IECC 2021]

- Changes climate zone maps resulting in 15 Ohio counties moving from Climate Zone 5 to Climate Zone 4 [Table R301.1]
- Requires that the energy compliance path be identified on the construction documents and the Energy Efficiency certificate [R103.2]
- Requires an insulation certificate identifying the installed R-value of insulation when the insulation of the manufacturer is not readily observable upon inspection [R303.1.2]
- Expands the information required on the Energy Efficiency Certificate that is required to be posted in an approved location [R401.3]
- Eliminates all “Mandatory” and “Prescriptive” labels and moves all code requirements into the respective compliance path section
- Clarifies the different compliance paths and adds additional efficiency requirements that are applicable regardless of which compliance path is chosen [R401.2]

Definitions [R202]

- Adds or modifies definitions of “Access (to)”, “Cavity Insulation”, “Demand Recirculation Water System”, “Dimmer”, “Dwelling Unit Enclosure Area”, “Fenestration, Skylights”, “High-Efficacy Light Sources”, “Occupant Sensor Control”, “On-site Renewable Energy”, “Ready Access (to)”, “Renewable Energy Certificate (REC)”, “Renewable Energy Resources”, “Thermal Distribution Efficiency (TDE)”

Building Envelope [R402]

- Establishes the U-factor as the primary insulation metric. R-value is an alternative.
- Increased envelope stringency in the prescriptive U-factor and R-value tables for windows, ceilings, and slab depth [Tables R402.1.2 and R402.1.3]
- Expands and clarifies the conditions that allow for an unconditioned basement [R402.2.8]
- Clarifies and adds insulation requirements for conditioned sunrooms and heated garages [R402.2.12]
- Adds envelope air leakage testing exceptions for heated attached and detached private garages [R402.4.1.2]
- Adds an exception that allows an alternative testing metric for attached single and multi-family dwelling units and smaller homes [R402.4.1.2]
- Electrical and communication outlet boxes installed in the thermal envelope are required to meet NEMA OS4 [R402.4.6]
- Adds an exception for storm shelter fenestration [R402.5]

Systems [R403]

- Clarified insulation requirements for ducts located outside conditioned space, in conditioned space, and buried [R403.3]
- Requires duct testing for all heating and cooling systems, regardless of whether the ducts are located inside conditioned space [R403.3.5 and R403.3.6]
- Requires controls for demand recirculation water systems, when installed [R403.5.1.1.1]
- Requires balanced heat or energy recovery ventilation for CZ 7-8 [R403.6.1]
- Requires fans to be tested and listed to HVI 916 and prescribes minimum fan efficacy [R403.6.2]
- Requires testing of all mechanical ventilation systems, except kitchen range hoods ducted to the outside and having 6 inch or larger ducts and not more than one elbow [R403.6.3]

Electrical Power and Lighting Systems [R404]

- Requires that all permanently installed residential lighting be high-efficacy lighting [R404.1]
- Regulates exterior lighting of low-rise Group R occupancies [R404.1.1 and R404.3]
- Adds interior lighting controls and some exceptions for permanently installed lighting fixtures [R404.2]

Total Building Performance [R405]

- Clarifies requirements by eliminating "mandatory" and "prescriptive" terms and providing a new table that outlines the code requirements that must be met when using the Total Building Performance method [Table R405.2]
- Simplifies the compliance report and clarifies the documentation and plan review requirements [R405.3.2]

Energy Rating Index (ERI) Compliance Alternative [R406]

- Clarifies requirements by eliminating "mandatory" and "prescriptive" terms and providing a new table that outlines the code requirements that must be met when using the ERI compliance path [Table R406.2]
- Recognizes and prescribes ERI path requirements when on-site renewables are present vs. not present [R406.3]
- Requires evidence that the Renewable Energy Certificate (REC) for the on-site renewables are owned by the homeowner [R406.7.3]
- Requires that the ERI value be at least 5% less than the ERI target in Table R406.5 [R401.2.5]

Tropical Climate Region Compliance Path [R407]

- Moves requirements from Section R401.2.1 to a new section.

Additional Efficiency Requirements [R408]

- Requires adding additional energy efficient features to the building for all compliance paths. [R408.1]
- Adds enhanced envelope performance option [R408.2.1]
- Adds more efficient HVAC option [R408.2.2]
- Adds reduced energy use in service water heating option [R408.2.3]
- Adds more efficient duct thermal distribution system option [R408.2.4]
- Adds improved air sealing and efficient ventilation system option [R408.2.5]

Comparison of Key (not all) 2009-2021 IECC Residential Prescriptive Requirements in OH Climate Zones

Requirements		2009 IECC -R	2012 IECC -R	2015 IECC -R	2018 IECC -R	2021 IECC -R (CZ map changed)
Fenestration U-factor (#)	CZ 4	0.35	0.35	0.35	0.32	0.30
	CZ 5	0.35	0.32	0.32	0.30	0.30
Skylight U-factor (#)	CZ 4	0.60	0.55	0.55	0.55	0.55
	CZ 5	0.60	0.55	0.55	0.55	0.55
Fenestration SHGC (#)	CZ 4	NR	0.40	0.40	0.40	0.40
	CZ 5	NR	NR	NR	NR	0.40
Ceiling R-value (#)	CZ 4	38	49	49	49	60
	CZ 5	38	49	49	49	60
Wood Frame Wall R-value (#)	CZ 4	13	20 or 13+5	20 or 13+5	20 or 13+5	20+5 or 13+10ci or 0+15
	CZ 5	20 or 13+5	20 or 13+5	20 or 13+5	20 or 13+5	20+5 or 13+10ci or 0+15
Mass Wall R-value (#)	CZ 4	5/10	8/13	8/13	8/13	8/13
	CZ 5	13/17	13/17	13/17	13/17	13/17
Floor R-value (#)	CZ 4	19	19	19	19	19
	CZ 5	30	30	30	30	30
Basement wall R-value (#)	CZ 4	10/13	10/13	10/13	10/13	10ci or 13
	CZ 5	10/13	15/19	15/19	15/19	15ci or 19 or 13+5ci
Slab R-value & depth (#)	CZ 4	10, 2 ft	10, 2 ft	10, 2 ft	10, 2 ft	10ci, 4 ft
	CZ 5	10, 2 ft	10, 2 ft	10, 2 ft	10, 2 ft	10ci, 4 ft
Crawl space wall R-value (#)	CZ 4	10/13	10/13	10/13	10/13	10ci or 13
	CZ 5	10/13	15/19	15/19	15/19	15ci or 19 or 13+5ci
Thermal envelope testing (*)		Visual inspection or Tested to ≤ 7ACH50	Tested to ≤ 3ACH50	Tested to ≤ 3ACH50	Tested to ≤ 3ACH50	Tested to ≤ 3 ACH50
Duct testing (*)		Post-construction: Total leakage: 12 cfm/100 sq. ft. Leakage to outdoors: 8 cfm/100 sq. ft. Rough-in: Total leakage: 6 cfm/100 sq. ft.	Post construction: Total leakage: 4 cfm/100 sq. ft. Rough-in: Total leakage: 4 cfm/100 sq. ft.	Post construction: Total leakage: 4 cfm/100 sq. ft. Rough-in: Total leakage: 4 cfm/100 sq. ft.	Post construction: Total leakage: 4 cfm/100 sq. ft. Rough-in: Total leakage: 4 cfm/100 sq. ft.	Post construction: Total leakage: 4 cfm/100 sq. ft. Rough-in: Total leakage: 4 cfm/100 sq. ft. Ducts within thermal envelope: Total leakage: 8 cfm/100 sq. ft.

Log homes	-	**References ICC 400 as an added requirement**	References ICC 400 as an added requirement	References ICC 400 as an alternative method	Exempt from IECC envelope reqts if complies w ICC 400
Room required for outside combustion air duct openings serving open combustion appliances (*)	-	-	Yes	Yes	Yes
Thermal envelope sealing (*)	Yes	Yes	Yes	Yes	Yes
Eave baffle (#)	-	**Yes**	Yes	Yes	Yes
Duct insulation (#)	Supply in attic: R-8 Other ducts: R-6 Unless inside building thermal envelope	Supply in attic: R-8 Other ducts: R-6 Unless inside building thermal envelope	Supply/return in attic: R-8 (≥3") or R-6 (<3") Other supply/return: R-6 (≥3") or R-4.2 (<3") Unless inside building thermal envelope	Supply/return in attic: R-8 (≥3") or R-6 (<3") Other supply/return: R-6 (≥3") or R-4.2 (<3") Unless inside building thermal envelope	Supply/return outside conditioned space: R-8 (≥3") or R-6 (<3")
Ducts buried within ceiling insulation	-	-	-	Allows and adds new requirements	Allows and includes requirements
Whole house mechanical ventilation (*)	-	Yes, when tested at ≤5 ACH50	Yes, when tested at ≤5 ACH50	Yes, when tested at ≤5 ACH50	Yes
Mechanical ventilation system testing	-	-	-	-	Yes
Framing cavities permitted to be used as ducts or plenums (*)	No, for supply Yes, for return	No	No	No	No
Mechanical piping insulation (*)	R-3	R-3	R-3	R-3	R-3
Hot water pipe insulation (#)	R-2 (if circulating)	R-3 (in several situations)	R-3 (in several situations)	R-3 (in several situations)	R-3 (in several situations)
High-Efficacy Lighting Equipment (*)	50%	75%	75%	90%	All
Lighting controls	-	-	-	-	Dimmer or occupancy sensors reqd for interior (except bathrooms, hallways, safety)
Additional Energy Efficiency	-	-	-	-	Per R401.2.5, one of the optional efficiency packages in R408 is required in addition to compliance with the base requirements of the prescriptive compliance path

Simulated Performance Alternative		Includes HVAC & service water heating	Includes HVAC & service water heating	Includes HVAC & service water heating	Includes HVAC, mech ventilation, & service water heating	Requires compliance with R405 + additional energy efficiency package or proposed design annual energy cost ≤.95(standard reference design annual energy cost)
Energy Rating Index (ERI) Compliance Alternative		-	-	Added new compliance path	Requires RESNET/ICC 301 software to set the ERI score	Requires compliance with R406 + 5% less than max ERI found in Table R406.5
Maximum ERI	CZ 4	-	-	54	62	54
	CZ 5	-	-	55	61	55

- Prescriptive requirements are noted with a (#)
- Mandatory requirements are noted with a (*)

PNNL-31617

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July 2021

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Pacific Northwest National Laboratory
Richland, Washington 99354

Highlights

The 2021 IECC provides cost-effective levels of energy efficiency and performance for residential buildings in Ohio

Moving to the 2021 International Energy Conservation Code (IECC) is cost-effective for both single-family and low-rise multifamily residential buildings in Ohio. The 2021 IECC will provide statewide energy savings of 12% across all climate zones compared to the current state energy code. This equates to $ 253 of annual utility bill savings for the average Ohio household. It will reduce statewide CO_2 emissions over 30 years by 11,770,000 metric tons, equivalent to the annual CO_2 emissions of 2,559,000 cars on the road (1 MMT CO_2 = 217,480 cars driven/year). Updating the state energy code based on the 2021 IECC will also stimulate the creation of high-quality jobs across the state. Adopting the 2021 IECC in Ohio is expected to result in homes that are energy efficient, more affordable to own and operate, and based on current industry standards for health, comfort and resilience.

The average expected statewide economic impact (per dwelling unit) of upgrading to the 2021 IECC is shown in the tables below based on cost-effectiveness and carbon metrics established by the U.S. Department of Energy.[1]

Consumer Impact

Metric	Compared to the 2015 IECC with amendments
Life-cycle cost savings of the 2021 IECC	$3,143
Net annual consumer cash flow in year 1 of the 2021 IECC[2]	$66
Annual (first year) energy cost savings of the 2021 IECC ($)[3]	$253
Annual (first year) energy cost savings of the 2021 IECC (%)[4]	12%

[1] A weighted average is calculated across building configurations and climate zones.
[2] The annual cash flow is defined as the net difference between annual energy savings and annual cash outlays (mortgage payments, etc.), including all tax effects but excluding up-front costs (mortgage down payment, loan fees, etc.). First-year net cash flow is reported; subsequent years' cash flow will differ due to the effects of inflation and fuel price escalation, changing income tax effects as the mortgage interest payments decline, etc.
[3] Annual energy savings is reported at time zero, before any inflation or price escalations are considered.
[4] Annual energy savings is reported as a percentage of end uses regulated by the IECC (HVAC, water heating, and interior lighting).

Statewide Impact - Emissions

Statewide Impact	First Year	30 Years Cumulative
Energy cost savings, $	4,626,000	1,519,000,000
CO_2 emission reduction, Metric tons	25,630	11,770,000
CH_4 emissions reductions, Metric tons	2.06	948
N_2O emissions reductions, Metric tons	0.288	132
NOx emissions reductions, Metric tons	15.30	7,023
SOx emissions reductions, Metric tons	13.00	5,970

Statewide Impact – Jobs Created

Statewide Impact	First Year	30 Years Cumulative
Jobs Created -- Reduction in Utility Bills	253	6,557
Jobs Created -- Construction Related Activities	428	11,100

Acronyms and Abbreviations

AVERT	U.S. EPA Avoided Emissions and GeneRation Tool
BC3	Building Component Cost Community
BECP	Building Energy Codes Program
CH_4	Methane
CO_2	Carbon Dioxide
CPI	consumer price index
DOE	U.S. Department of Energy
E.O.	Executive Order
eGRID	EPA Emissions & Generation Resource Integrated Database dataset
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ERI	Energy Rating Index
GHG	greenhouse gas
IAM	Integrated assessment models
ICC	International Code Council
IECC	International Energy Conservation Code
LCC	Life-Cycle Cost
NAHB	National Association of Home Builders
N_2O	Nitrous Oxide
NO_X	Nitrogen Oxides
PNNL	Pacific Northwest National Laboratory
SO_X	Sulfur Oxides

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1.0 Cost-Effectiveness Results for the 2021 IECC for Ohio

This section summarizes the cost-effectiveness analysis in terms of three primary economic metrics applicable to the homeowner:

- Life-Cycle Cost (LCC): Full accounting over a 30-year period of the cost savings, considering energy savings, the initial investment financed through increased mortgage costs, tax impacts, and residual values of energy efficiency measures
- Consumer Cash Flow: Net annual cost outlay (i.e., difference between annual energy cost savings and increased annual costs for mortgage payments, etc.)
- Simple Payback Period: Number of years required for energy cost savings to exceed the incremental first costs of a new code, ignoring inflation and fuel price escalation rates

LCC savings is the primary metric established by the U.S. Department of Energy (DOE) to assess the economic impact of residential building energy codes. Simple payback period and the Consumer Cash Flow analysis are reported to provide additional information to stakeholders, including states which have established a range of alternative economic metrics. Both the LCC savings and the year-by-year cash flow values from which it is calculated assume that initial costs are mortgaged, that homeowners take advantage of mortgage interest tax deductions, that individual efficiency measures are replaced with like measures at the end of their useful lifetimes, and that efficiency measures may retain a prorated residual value at the end of the 30-year analysis period.

Societal benefits such as benefits from energy codes as well as reduction of carbon emissions and jobs generated from moving to the 2021 IECC are discussed in Section 5.0.

A complete description of the DOE methodology for assessing the cost-effectiveness of building energy codes is available on energycodes.gov[1].

1.1 Life-Cycle Cost

The Life-Cycle Cost (LCC) analysis computes overall cost savings per dwelling unit resulting from implementing the efficiency improvements of a new energy code. LCC savings is based on the net change in overall cash flows (energy savings minus additional costs) resulting from implementing a new energy code, and balances incremental costs of construction against longer-term energy savings, including consideration for costs of operations and replacements, as needed. LCC savings is a sum over an analysis period of 30 years. Future cash flows, which vary from year to year, are discounted to present values using a discount rate that accounts for the changing value of money over time. LCC savings is the primary economic metric established by DOE for assessing the cost-effectiveness of building energy codes.

Table 1 shows the LCC savings (discounted present value) over the 30-year analysis period for the 2021 IECC compared to the 2015 IECC with amendments.

[1] https://www.energycodes.gov/sites/default/files/documents/residential_methodology_2015.pdf

Table 1. Life-Cycle Cost Savings of the 2021 IECC compared to the 2018 IECC with amendments

Climate Zone	Life-Cycle Cost Savings ($)
4A	2,960
5A	3,229
State Average	**3,143**

Note: Warm-humid climate zones are labeled "WH"

1.2 Consumer Cash Flow

The Consumer Cash Flow results are derived from the year-by-year calculations that underlie the Life-Cycle Cost savings values shown above. The specific cash flow values shown here allow an assessment of how annual cost outlays are compensated by annual energy savings and the time required for cumulative energy savings to exceed cumulative costs, including both increased mortgage payments and the down payment and other up-front costs.

Table 2 shows the per-dwelling-unit impact of the improvements in the 2021 IECC on Consumer Cash Flow compared to the 2018 IECC with amendments.

Table 2. Consumer Cash Flow from Compliance with the 2021 IECC Compared to the 2018 IECC with amendments

	Cost/Benefit	4A	5A	State Average
A	Incremental down payment and other first costs	$372	$446	$422
B	Annual energy savings (year one)	$242	$270	$261
C	Annual mortgage increase	$129	$154	$146
D	Net annual cost of mortgage interest deductions, mortgage insurance, and property taxes (year one)	$44	$52	$49
E = [B-(C+D)]	Net annual cash flow savings (year one)	$70	$63	$66
F = [A/E]	Years to positive savings, including up-front cost impacts	5	6	6

Note: Item D includes mortgage interest deductions, mortgage insurance, and property taxes for the first year. Deductions can partially or completely offset insurance and tax costs. As such, the "net" result appears relatively small or is sometimes even negative.

1.3 Simple Payback Period

The simple payback period is a straightforward metric including only the costs and benefits directly related to the implementation of energy-saving measures associated with a code change. It represents the number of years required for the energy savings to pay for the cost of the measures, without regard for inflation, changes in fuel prices, tax effects, measure replacements, resale values, etc. The simple payback period is useful for its ease of calculation and understandability. Because it focuses on the two primary characterizations of a code change—cost and energy performance—it allows an assessment of cost effectiveness that is easy to compare with other investment options and requires a minimum of input data. DOE reports the simple payback period because it is a familiar metric used in many contexts, and because some states have expressed the desire for this metric. However, because it ignores many of the longer-term factors in the economic performance of an energy-efficiency investment, DOE does not use the payback period as a primary indicator of cost effectiveness for its own decision-making purposes.

Table 3 shows the simple payback period for the 2021 IECC. The simple payback period is calculated by dividing the incremental construction cost by the annual energy cost savings assuming time-zero fuel prices. It estimates the number of years required for the energy cost savings to pay back the incremental cost investment without consideration of financing of the initial costs through a mortgage, the favored tax treatment of mortgages, the useful lifetimes of individual efficiency measures, or future escalation of fuel prices.

Table 3. Simple Payback Period for the 2021 IECC Compared to the 2018 IECC with amendments

Climate Zone	Payback Period (Years)
4A	12.3
5A	13.2
State Average	**12.9**

2.0 Overview of the Cost-Effectiveness Analysis 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 the 2021 edition of the IECC, relative to the 2018 IECC with amendments. The analysis covers one- and two-family dwelling units, townhouses, and low-rise multifamily residential buildings covered by the residential provisions of the IECC. The analysis is based on the prescriptive requirements of the IECC. The IECC's simulated performance path (Section 405) and Energy Rating Index (ERI) path (Section 406) are not in the scope of this analysis, as they are generally based on the core prescriptive requirements of the IECC, and due to the unlimited range of building configurations that are allowed. Buildings complying via these paths 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 or homeowner.

The current analysis is based on the methodology by DOE for assessing energy savings and cost-effectiveness of residential building energy codes (Taylor et al. 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.

2.1 Estimation of Energy Usage and Savings

In order to estimate the energy impact of residential code changes, PNNL developed a single-family prototype building and a low-rise multifamily prototype building to represent typical new residential building construction (BECP 2012, Mendon et al. 2014, and Mendon et al. 2015). The key characteristics of these prototypes are:

- **Single-Family Prototype:** A two-story home with a roughly 30-ft by 40-ft rectangular shape, 2,376 ft^2 of conditioned floor area excluding the conditioned basement (if any), and window area equal to 15% of the conditioned floor area equally distributed toward the four cardinal directions.
- **Multifamily Prototype:** A three-story building with 18 dwelling units (6 units per floor), each unit having conditioned floor area of 1,200 ft^2 and window area equal to approximately 23% of the exterior wall area (not including breezeway walls) equally distributed toward the four cardinal directions.

These two building prototypes are further expanded to cover four common heating systems (natural gas furnace, heat pump, electric resistance, oil-fired furnace) and four common foundation types (slab-on-grade, heated basement, unheated basement, crawlspace), leading to an expanded set of 32 residential prototype building models. This set is used to simulate the energy usage for typical homes built to comply with the requirements of the 2021 IECC and those built to comply with the requirements of the for one location in each climate zone[1] in the state using DOE's *EnergyPlus*™ software, version 9.5 (DOE 2021). Energy savings of the 2021 IECC relative to the 2015 IECC with amendments, including space heating, space cooling, water heating, lighting and plug loads are extracted from the simulation results.

2.2 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.

[1] One location is simulated for each combination of climate zone, moisture regime (Moist, Dry, Marine) and humidity designation (Warm-Humid, Not Warm-Humid) that exists in the state.

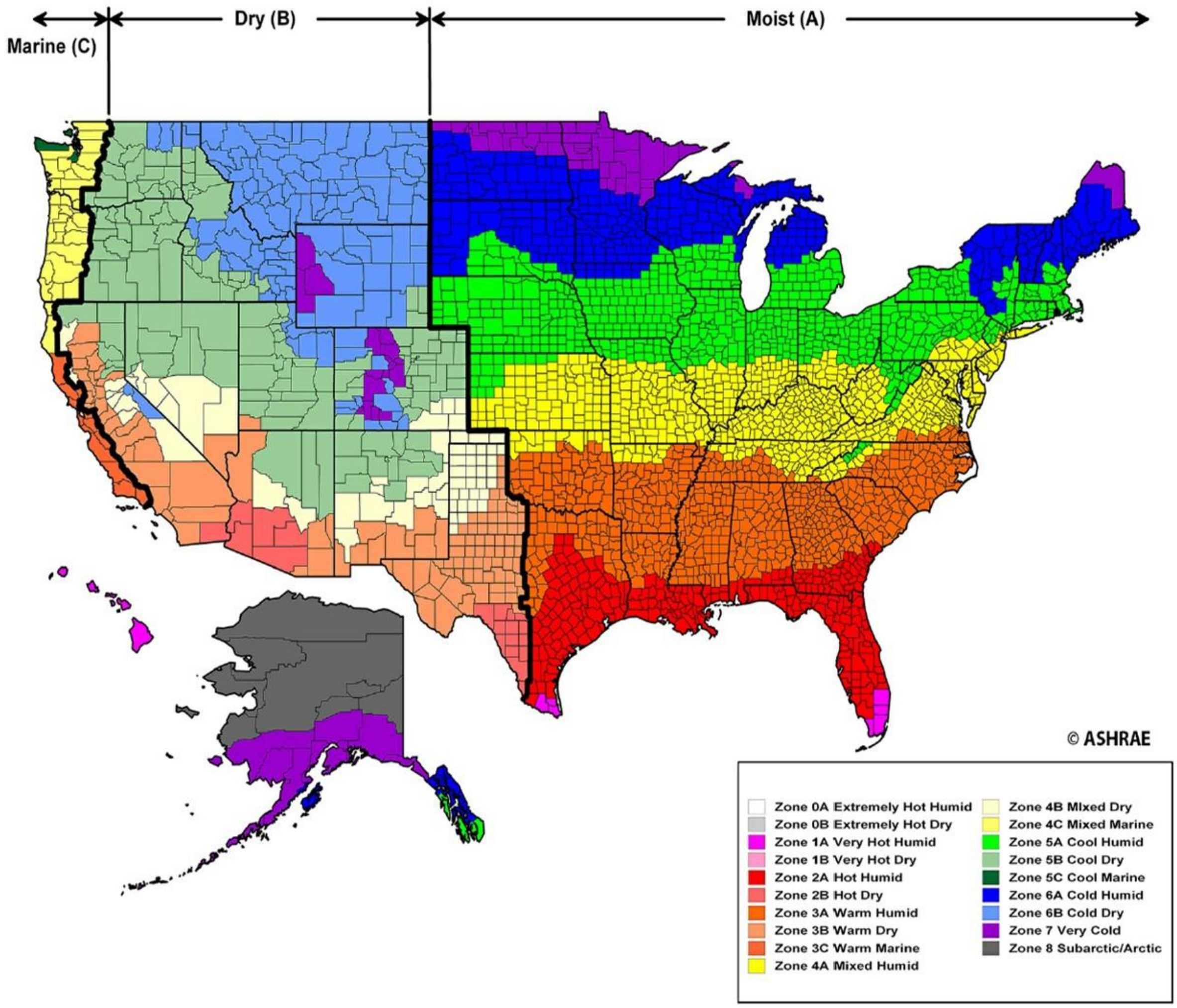

Figure 1. National Climate Zones

2.3 Fuel Prices

The energy savings from the simulation analysis are converted to energy cost savings using the most recent state-specific residential fuel prices from DOE's Energy Information Administration (EIA 2020a, EIA 2020b, EIA 2020c). The fuel prices used in the analysis are shown in Table 4.

Table 4. Fuel Prices used in the Analysis

Electricity ($/kWh)	Gas ($/Therm)	Oil ($/MBtu)
0.121	0.735	2.279

2.4 Financial and Economic Parameters

The financial and economic parameters used in calculating the LCC and annual consumer cash flow are based on the latest DOE cost-effectiveness methodology (Taylor et al. 2015) to represent the current economic scenario. The parameters are summarized in Table 5 for reference.

Table 5. Economic Parameters Used in the Analysis

Parameter	Value
Mortgage interest rate (fixed rate)	3%
Loan fees	1% of mortgage amount
Loan term	30 years
Down payment	12% of home value
Nominal discount rate (equal to mortgage rate)	3%
Inflation rate	1.4%
Marginal federal income tax	12%
Marginal state income tax	3.33%
Property tax	1.36%

2.5 Aggregation Scheme

Energy results, weighted by foundation and heating system type, are provided at the state level and separately for each climate zone within the state. The distribution of heating systems for Ohio is derived from data collected by the National Association of Home Builders data (NAHB 2009) and is summarized in Table 6. The distribution of foundation types is derived from the Residential Energy Consumption Survey data (RECS 2013) and is summarized in Table 7. The single-family and multifamily results are combined for each climate zone in the state and the climate zone results are combined to calculate a weighted average for the state using 2019 new residential construction starts from the 2010 U.S. Census data (Census 2010). The distribution of single- and multifamily building starts is summarized in Table 8.

Table 6. Heating Equipment Shares

Heating System	Share of New Homes (percent)	
	Single-Family	Multifamily
Natural Gas	79.7	79.7
Heat Pump	19.2	19.2
Electric Resistance	0.6	0.6
Oil	0.4	0.4

Table 7. Foundation Type Shares

Foundation Type	Slab-on-grade	Heated Basement	Unheated Basement	Crawlspace
Share of New Homes (percent)	25.7	28.4	23	23

Table 8. Construction Shares by Climate Zone

Climate Zone	Share of New Homes (percent)	
	Single-Family	Multifamily
4A	69.2	30.8
5A	69.2	30.8

3.0 Incremental Construction Costs

In order to evaluate the cost-effectiveness of the changes introduced by the 2021 IECC over the 2015 IECC, PNNL estimated the incremental construction costs associated with these changes. For this analysis, cost data sources consulted by PNNL include:

- Building Component Cost Community (BC3) data repository (DOE 2012)
- Construction cost data collected by Faithful+Gould under contract with PNNL (Faithful + Gould 2012)
- RS Means Residential Cost Data (RSMeans 2020)
- National Residential Efficiency Measures Database (NREL 2014)
- Price data from nationally recognized home supply stores

The consumer price index (CPI) is used to adjust cost data from earlier years to the study year (U.S. Inflation Calculator 2021).

The estimated costs of implementing the prescriptive provisions of the 2021 IECC over the 2018 IECC with amendments are taken from earlier PNNL studies that evaluated the cost-effectiveness (Lucas et al. 2012), (Mendon et.al. 2015) and (Taylor et al. 2019). The national scope costs from those studies are adjusted to reflect local construction costs in using location factors provided by RSMeans (2020). The incremental costs of implementing the provisions of the 2021 IECC over the 2018 IECC are described in National Cost Effectiveness of the Residential Provisions of the 2021 IECC (Salcido et al. 2021).

Table 9 and Table 10 show the incremental construction costs associated with the 2021 IECC compared to the 2018 IECC with amendments for an individual dwelling unit. Table 9 shows results for a house and Table 10 shows results for an apartment or condominium. These have been adjusted using a construction cost multiplier, 0.9671, to reflect local construction costs based on location factors provided by RSMeans (2020).

Table 9. Total Single-Family Construction Cost Increase for the 2021 IECC Compared to the 2018 IECC with amendments ($)

Single-family Prototype House				
Climate Zone	**Crawlspace**	**Heated Basement**	**Slab**	**Unheated Basement**
4A	$3,442	$3,442	$3,939	$3,442
5A	$3,980	$4,635	$4,477	$3,980

Table 10. Total Multifamily Construction Cost Increase for the 2021 IECC Compared to the 2018 IECC with amendments ($)[1]

Multifamily Prototype Apartment/Condo				
Climate Zone	**Crawlspace**	**Heated Basement**	**Slab**	**Unheated Basement**
4A	$1,337	$1,337	$1,411	$1,337
5A	$1,535	$1,631	$1,608	$1,535

[1] In the multifamily prototype model, the heated basement is added to the building, and not to the individual apartments. The incremental cost associated with heated basements is divided among all apartments equally.

4.0 Energy Cost Savings

Table 11 and Table 12 show the estimated the annual per-dwelling unit energy costs of end uses regulated by the IECC as well as miscellaneous end use loads, which comprise heating, cooling, water heating, lighting, fans, mechanical ventilation and plug loads that result from meeting the requirements of the 2021 IECC and the 2018 IECC with amendments

Table 11. Annual (First Year) Energy Costs for the 2018 IECC with amendments

Climate Zone	2018 IECC with amendments						
	Heating	**Cooling**	**Water Heating**	**Lighting**	**Fans**	**Vents**	**Total**
4A	$508	$176	$173	$162	$89	$42	$2,011
5A	$618	$183	$177	$162	$119	$42	$2,161
State Average	**$583**	**$180**	**$176**	**$162**	**$110**	**$42**	**$2,113**

Table 12. Annual (First Year) Energy Costs for the 2021 IECC

Climate Zone	2021 IECC						
	Heating	**Cooling**	**Water Heating**	**Lighting**	**Fans**	**Vents**	**Total**
4A	$423	$155	$85	$152	$79	$21	$1,776
5A	$512	$161	$88	$152	$106	$21	$1,899
State Average	**$483**	**$159**	**$87**	**$152**	**$97**	**$21**	**$1,860**

Table 13 shows the first-year energy cost savings as both a net dollar savings and as a percentage of the total regulated end use energy costs. Results are weighted by single- and multifamily housing starts, foundation type, and heating system type.

Table 13. Total Energy Cost Savings (First Year) for the 2021 IECC Compared to the 2018 IECC with amendments

Climate Zone	First Year Energy Cost Savings	First Year Energy Cost Savings (percent)
4A	$235	11.7%
5A	$262	12.1%
State Average	**$253**	**12.0%**

5.0 Societal Benefits

5.1 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.

5.2 Greenhouse Gas Emissions

The urban built environment is responsible for 75% of annual global greenhouse gas (GHG) emissions while buildings alone account for 39%.[1] 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.

While carbon dioxide emissions represent the largest share of greenhouse gas emissions, building electricity use and fossil fuel consumption on site also contribute to the release of other emissions, two of which, methane (CH_4) and nitrous oxide (N_2O) are significant greenhouse gases in their own right.

For natural gas and for fuel oil 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

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[1] Architecture 2030

[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>

[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 14 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.

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 & 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 14 summarizes the marginal carbon emission factors available from AVERT, eGRID and the EPA Greenhouse Gas Equivalencies Calculator.

Table 14. Greenhouse Gas Emission Factors for Ohio by Fuel Type

GHG	Electricity lb/MWh	Natural Gas (lb/mmcf)	Fuel Oil (lb/1000 gal)
CO_2	1,567	120,000	23,000
SO_2	1.194	0.6	12
NO_X	0.771	96	19
N_2O	0.032	0.23	0.45
CH_4	0.183	2.3	0.7

Table 15 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 15. Societal Benefits of the 2021 IECC

Statewide Impact	First Year	30 Years Cumulative
Energy cost savings, $	4,626,000	1,519,000,000
CO_2 emission reduction, Metric tons	25,630	11,770,000
CH_4 emissions reductions, Metric tons	2.06	948
N_2O emissions reductions, Metric tons	0.288	132
NOx emissions reductions, Metric tons	15.30	7,023
SOx emissions reductions, Metric tons	13.00	5,970

5.3 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 home or building is built to a more stringent energy code, there is the long-term benefit of the home or building owner 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 which can be spent on other goods and services in the economy, just like any other income, generating economic benefits in turn creating additional employment opportunities.

Table 16 also shows the number of jobs created because of efficiency gains in the 2021 IECC. Results are weighted by single- and multifamily housing starts, foundation type, and heating system type.

Table 16. Jobs Created from the 2021 IECC

Statewide Impact	First Year	30 Years Cumulative
Jobs Created -- Reduction in Utility Bills	253	6,557
Jobs Created -- Construction Related Activities	428	11,100

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PNNL-31019

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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 (BECP) supports the development and implementation of model building energy codes and standards for new residential and commercial construction. These codes set the minimum requirements for energy-efficient building design and construction and impact energy use over the life of the buildings. Building energy codes are developed through consensus-based public processes. DOE participates in the code development process by recommending technologically feasible and economically justified energy efficiency measures for inclusion in the latest model codes. Assuring the cost effectiveness of model code changes also encourages their adoption and implementation at the state and local levels. Pacific Northwest National Laboratory (PNNL) conducted this analysis to support DOE in evaluating the energy and economic impacts associated with updated codes in residential buildings.

This analysis focuses on single-family and low-rise multifamily residential buildings based on the International Energy Conservation Code (IECC). The IECC is developed by the International Code Council (ICC) on a 3-year cycle through a public development and public hearing process. While proponents of code changes often include the energy and cost-effectiveness criteria for their respective code change, the IECC process does not include an energy or cost-effectiveness analysis of the entire edition of the code.

PNNL evaluated the cost effectiveness of the changes in the prescriptive and mandatory residential provisions of the 2021 edition of the IECC, hereafter referred as the 2021 IECC, compared to those in the prior edition, the 2018 IECC. The simulated performance path and the Energy Rating Index (ERI) path (introduced in the 2015 IECC) are not considered in this analysis due to the wide variation in building construction characteristics that are allowed.

The process of examining the cost effectiveness of the code changes has four main parts:

- Identification of the building components affected by the updates to the prescriptive and mandatory residential provisions of the IECC that directly affect energy use
- Assessment of construction costs associated with these updates
- Analysis of energy and cost impacts associated with these updates
- Cost-effectiveness analysis of the updates that combines the incremental costs of these updates with the associated energy impact.

The current analysis builds on the PNNL technical report titled *Energy Savings Analysis: 2021 IECC for Residential Buildings* (Salcido et al. 2021), which identified the prescriptive and mandatory changes introduced by the 2021 IECC compared to the 2018 IECC and determined their energy savings impact.

DOE has an established methodology for determining the energy savings and cost effectiveness of residential building energy codes (Taylor et al. 2015). [1] This methodology forms the basis of the analysis and defines three cost-effectiveness metrics to be calculated in assessing cost effectiveness of code changes:

- Life-Cycle Cost (LCC) – This is reported as the savings (reduction) in LCC.

[1] See DOE Residential Energy and Cost Analysis Methodology at: http://www.energycodes.gov/development/residential/methodology

- Simple Payback – A simple metric that estimates the number of years required for energy cost savings to make up for increased construction costs, assuming no escalation in prices or discounting of future cash flows.
- Cash Flow – A small suite of metrics summarizing the net cash flows (outlays versus savings) in the early years of the analysis period.

Table ES.1 summarizes the weighted LCC savings per dwelling unit for the 2021 IECC compared to the 2018 IECC for each climate zone, aggregated over all residential prototype buildings. Table ES.2 and Table ES.3 summarize the associated simple payback periods and impacts on consumer cash flows. The results show that construction based on the 2021 IECC is cost effective when compared to construction based on the 2018 IECC across all climate zones. Simple payback by climate zone ranges from 4.8 to 16.7 years, with a national average of 10.5 years. Homeowners see net positive cash flows ranging from 1 to 10 years, with a national average of 4 years.

Table ES.1. Life-Cycle Cost Savings for the 2021 IECC

Climate Zone	Compared to the 2018 IECC ($/dwelling unit)
1	3,536
2	2,854
3	2,829
4	2,243
5	1,034
6	970
7	3,783
8	6,782
National Average	2,320

Table ES.2. Simple Payback Period for the 2021 IECC

Climate Zone	Compared to the 2018 IECC (Years)
1	4.8
2	7.6
3	8.6
4	12.4
5	16.7
6	11.2
7	9.6
8	7.3
National Average	10.5

Table ES.3. Impacts on Consumers' Cash Flow from Compliance with the 2021 IECC

	Compared to the 2018 IECC	
Climate Zone	Net Annual Cash Flow Savings ($ for Year 1)	Years to Cumulative Positive Cash Flow
1	145	1
2	108	2
3	101	3
4	59	5
5	7	10
6	44	4
7	138	3
8	239	2
National Average	76	4

The prescriptive and mandatory provisions of the 2021 IECC are shown to generate an average life-cycle cost savings of $2,320, an average payback of 10.5 years, and the years to cumulative positive cashflow averaging 4 years for all climate zones. Between the relatively modest energy savings and high first costs for R-5 sheathing in climate zones 4 and 5, the cumulative cash flow turns positive in years 5 and 10 respectively. The results illustrate that homeowners can benefit financially from the investment in energy efficiency of the 2021 IECC. The results also show that the higher efficiency levels of the 2021 IECC require increased investment and higher payback times while remaining cost effective.

Acknowledgments

This report was prepared for the DOE Office of Energy Efficiency and Renewable Energy (EERE) Building Technologies Office (BTO). The authors would like to thank Jeremy Williams at DOE for providing programmatic direction and oversight.

Acronyms and Abbreviations

ACH50	air changes at 50-pascal pressure differential
AEO	Annual Energy Outlook
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BC3	Building Component Cost Community
BECP	Building Energy Codes Program
Btu	British thermal unit(s)
CF	cubic foot (feet)
CFM	cubic feet per minute
CPI	Consumer Price Index
DOE	U.S. Department of Energy
DX	direct expansion
ECPA	Energy Conservation and Production Act
EIA	U.S. Energy Information Administration
EF	energy factor
ERI	Energy Rating Index
ERV	energy recovery ventilator
EUI	Energy Use Intensity
°F	degree(s) Fahrenheit
ft^2	square foot(feet)
hr	hour(s)
HPWH	heat pump water heater
HRV	heat recovery ventilator
HVAC	heating, ventilating, and air conditioning
HWDS	hot water distribution system
ICC	International Code Council
IECC	International Energy Conservation Code
IgCC	International Green Construction Code
IPC	International Plumbing Code
IRC	International Residential Code
kWh	kilowatt-hour(s)
LCC	life-cycle cost
LED	light-emitting diode
million Btu	million British thermal units
NREL	National Renewable Energy Laboratory
PID	proportional, integral, derivative
PNNL	Pacific Northwest National Laboratory

SHGC	solar heat gain coefficient
yr	year(s)

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1.0 Introduction

The U.S. Department of Energy (DOE) supports the development and adoption of energy-efficient building energy codes. Title III of the Energy Conservation and Production Act (ECPA), as amended, requires DOE to participate in the development of model building energy codes and assist states in the adoption and implementation of these codes (42 U.S.C. 6831 et seq.). ECPA also mandates DOE to conduct a determination analysis to evaluate whether the new edition of the code saves energy compared to its immediate predecessor, within 1 year of a new code being published (42 U.S.C. 6833(a)(5)(A)).

Building energy codes set the minimum requirements for energy-efficient building design and construction for new buildings as well as impact energy consumed by the building over its life. These are developed through consensus-based public processes that DOE participates in by proposing changes that are technologically feasible and economically justified. Pacific Northwest National Laboratory (PNNL) provides technical analysis and support to DOE during the code development processes.

This analysis focuses on single-family and low-rise multifamily residential buildings. The basis of the energy codes for these buildings is the International Energy Conservation Code (IECC). The IECC is updated on a 3-year cycle (i.e., a new edition of the code is published every 3 years, by the International Code Council [ICC]). The 2021 edition of the IECC, hereafter referred as the 2021 IECC, was published on January 29, 2021 (ICC 2021). Subsequently, DOE published a notice of preliminary determination of the 2021 IECC on March 16, 2021. DOE's 2021 IECC determination analyses indicate an increase in energy efficiency in single-family and low-rise multifamily residential buildings that are subject to the 2021 IECC compared to the 2018 IECC.

1.1 Purpose

The IECC is developed through a public process administered by the ICC.[1] While proponents of code changes often include the energy and cost-effectiveness criteria associated with their respective code change proposals, the IECC process does not include an energy or cost-effectiveness analysis of the entire edition of the code. Ensuring the cost effectiveness of model code changes encourages their adoption and implementation at the state and local levels. In support of this goal, DOE conducts cost-effectiveness analyses of the latest edition of the code compared to its predecessor, following the publication of an updated edition of the IECC. These analyses are conducted at the national and state level by accounting for regional construction and fuel costs.

DOE provides technical assistance, such as the present cost-effectiveness analysis, to states to ensure informed decision-making during their consideration of adopting, implementing, and enforcing the latest model building energy codes. DOE has commissioned prior cost-effectiveness analyses of the 2009 and 2012 IECC (Mendon et al. 2013), the 2015 IECC (Mendon et al. 2015), and the 2018 IECC (DOE 2019). Figure 1 shows the status of the adoption of residential building energy codes as of February 2021 (BECP 2021). The state adoption map shows the functional equivalent of the adopted code plus amendments.

[1] https://www.iccsafe.org/codes-tech-support/codes/code-development/

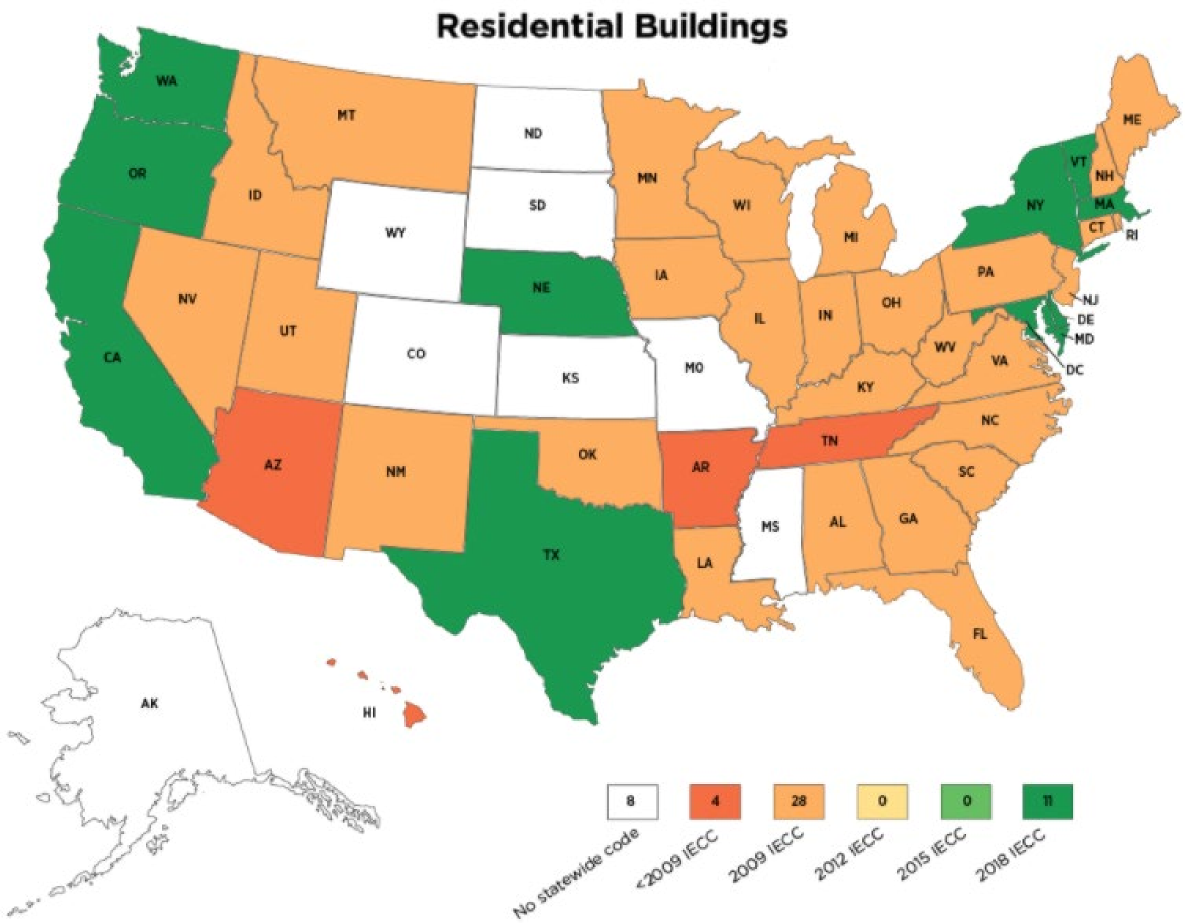

Figure 1. Current Residential Building Energy Code Adoption Status in the United States (BECP 2021)

1.2 Overview

This analysis examines the cost effectiveness of the prescriptive and mandatory residential provisions of the 2021 IECC. The simulated performance path and the Energy Rating Index (ERI) path (introduced in the 2015 IECC) are not considered in this analysis due to the wide variation in building construction characteristics that are allowed. While some states choose to adopt amended versions of the IECC, this analysis focuses on the unamended provisions of the 2021 and 2018 IECC. The methodology established by DOE for determining the energy savings and cost effectiveness of residential building energy codes (Taylor et al. 2015) forms the basis of this cost-effectiveness analysis.

1.2.1 Building Prototypes

The DOE methodology proposes a suite of 32 residential prototype building models to represent the U.S. new residential building construction stock. This suite, summarized in Table 1, was created based on construction data from the U.S. Census (Census 2010), the Residential Energy Consumption Survey (RECS 2013) and the National Association of Home Builders

(NAHB 2009). Detailed descriptions of the 32 prototype building models and operational assumptions are documented in previous reports by Mendon et al. (2013 and 2014).

Table 1. Residential Prototype Buildings

No.	Building Type	Foundation Type	Heating System Type
1	Single-family	Vented Crawlspace	Gas-Fired Furnace
2	Single-family	Vented Crawlspace	Electric Furnace
3	Single-family	Vented Crawlspace	Oil-Fired Furnace
4	Single-family	Vented Crawlspace	Heat Pump
5	Single-family	Slab-On-Grade	Gas-Fired Furnace
6	Single-family	Slab-On-Grade	Electric Furnace
7	Single-family	Slab-On-Grade	Oil-Fired Furnace
8	Single-family	Slab-On-Grade	Heat Pump
9	Single-family	Heated Basement	Gas-Fired Furnace
10	Single-family	Heated Basement	Electric Furnace
11	Single-family	Heated Basement	Oil-Fired Furnace
12	Single-family	Heated Basement	Heat Pump
13	Single-family	Unheated Basement	Gas-Fired Furnace
14	Single-family	Unheated Basement	Electric Furnace
15	Single-family	Unheated Basement	Oil-Fired Furnace
16	Single-family	Unheated Basement	Heat Pump
17	Multifamily	Vented Crawlspace	Gas-Fired Furnace
18	Multifamily	Vented Crawlspace	Electric Furnace
19	Multifamily	Vented Crawlspace	Oil-Fired Furnace
20	Multifamily	Vented Crawlspace	Heat Pump
21	Multifamily	Slab-On-Grade	Gas-Fired Furnace
22	Multifamily	Slab-On-Grade	Electric Furnace
23	Multifamily	Slab-On-Grade	Oil-Fired Furnace
24	Multifamily	Slab-On-Grade	Heat Pump
25	Multifamily	Heated Basement	Gas-Fired Furnace
26	Multifamily	Heated Basement	Electric Furnace
27	Multifamily	Heated Basement	Oil-Fired Furnace
28	Multifamily	Heated Basement	Heat Pump
29	Multifamily	Unheated Basement	Gas-Fired Furnace
30	Multifamily	Unheated Basement	Electric Furnace
31	Multifamily	Unheated Basement	Oil-Fired Furnace
32	Multifamily	Unheated Basement	Heat Pump

Energy models created for the determination analysis of the 2021 IECC as well as earlier state and national cost-effectiveness analyses of the 2015 IECC (Mendon et al. 2015 and 2013) are leveraged in the present analysis.

1.2.2 Climate Locations

The 2021 IECC incorporates several changes introduced by the 2013 edition of ASHRAE Standard 169, Climatic Data for Building Design Standards (ASHRAE 2013). ASHRAE 169-2013 redefined climate zones and moisture regimes based on a more recent period of weather data. As a result, a number of U.S. counties were reassigned to different zones/regimes, and a new, extremely hot climate zone 0, which does not occur in the United States, was added. Approximately 400 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones[1]. The 2021 IECC now aligns the climate zone map with that of ASHRAE 90.1, ASHRAE 90.2, and the International Green Construction Code (IgCC). Standard 169-2013 includes nine thermal zones and three moisture regimes.

The U.S. climate zones and moisture regimes are shown in Figure 2.

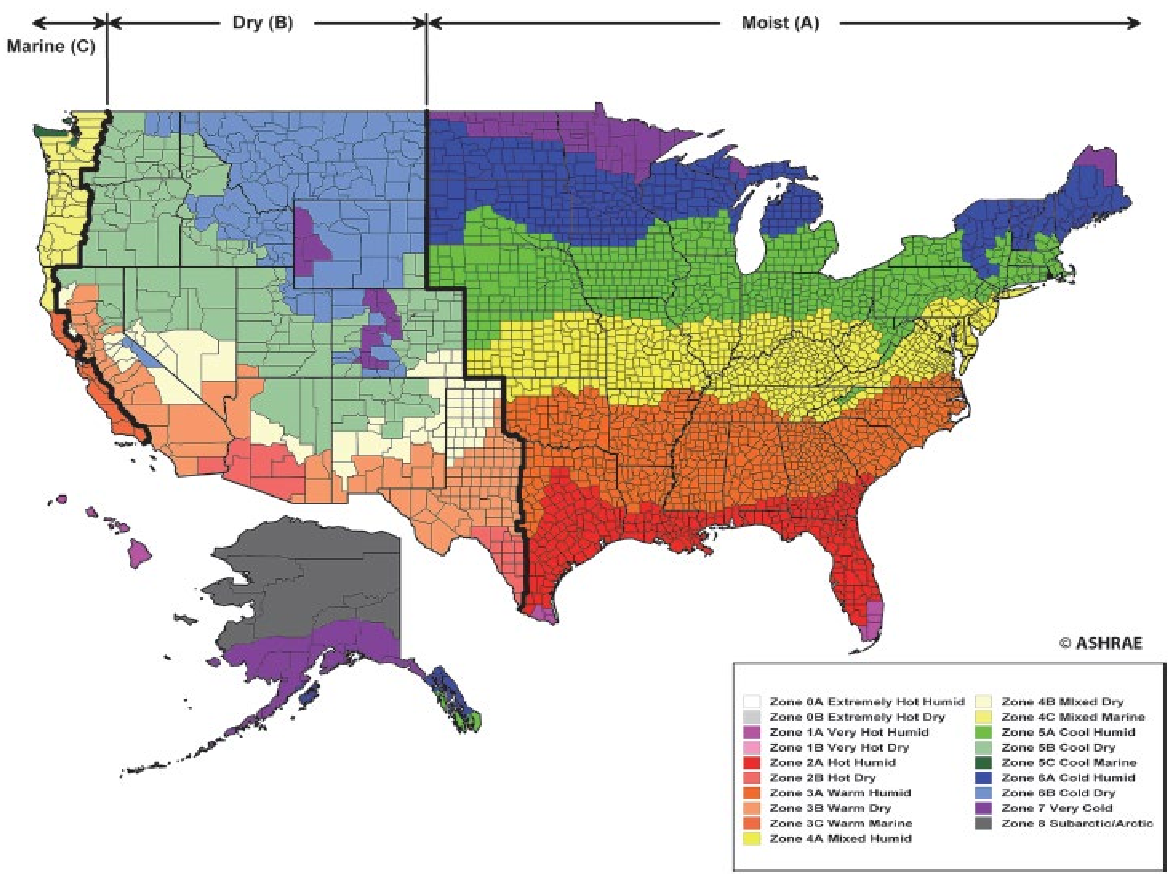

Figure 2. U.S. Climate Zone Map

Climate zones are divided into moist (A), dry (B), and marine (C) regions. However, not all the moisture regimes apply to all climate zones in the United States, and some zones have no moisture designations at all (zones 7 and 8 in the United States); thus, only 19 thermal-moisture zones exist in ASHRAE 169-2013, of which 16 are represented in the United States. In addition, the residential IECC includes a tropical climate designation with an alternative prescriptive compliance path for semi-conditioned buildings meeting certain criteria. Because the national

[1] https://ibpsa-usa.org/index.php/ibpusa/article/view/389.

analysis for DOE determinations looks only at the primary prescriptive compliance path, the alternative for tropical semi-conditioned buildings is not considered in this analysis. All homes in the tropical zone are modeled as complying with the prescriptive path. The appropriate state level analyses will include the parameters of the tropical semi-conditioned prescriptive requirements.

The IECC further defines a warm-humid region in the southeastern United States. This region is defined by humidity levels, whereas the moist (A) regime is more closely associated with rainfall. The warm-humid distinction affects only whether basement insulation is required in climate zone 3. This brings the total number of representative cities analyzed to 18.

For the quantitative analysis, a specific climate location (i.e., city) was selected as representative of each of the 18 climate/moisture zones found in the United States:

- 1A: Honolulu, Hawaii (tropical)
- 1A: Miami, Florida
- 2A: Tampa, Florida
- 2B: Tucson, Arizona
- 3A: Atlanta, Georgia
- 3A: Montgomery, Alabama (warm-humid)
- 3B: El Paso, Texas
- 3C: San Diego, California
- 4A: New York, New York
- 4B: Albuquerque, New Mexico
- 4C: Seattle, Washington
- 5A: Buffalo, New York
- 5B: Denver, Colorado
- 5C: Port Angeles, Washington
- 6A: Rochester, Minnesota
- 6B: Great Falls, Montana
- 7: International Falls, Minnesota
- 8: Fairbanks, Alaska

For the determination analysis, one set of prototype models was configured to represent construction practices as dictated by the 2018 IECC, another set was configured to represent the 2021 IECC, and then both sets were simulated in all the climate zones and moisture regimes defined in the IECC. Annual energy simulations were carried out for each of the 576 models using *EnergyPlus* version 9.4 (DOE 2020). The resulting energy use data were converted to energy costs using national average fuel prices, and the energy and energy cost results were weighted to the national level using weighting factors based on housing starts.

1.2.3 Weighting Factors

Weighting factors for each of the 32 residential prototype buildings were developed for each of the climate zones using 2019 state new residential construction starts[1] and residential construction details from the U.S. Census (Census 2010) and the National Association of Home Builders (NAHB 2009). The weights were fine-tuned by the revised county-to-climate zone map based on ASHRAE 169 climate zone changes. These weighting factors are used to aggregate energy and costs across all building types for each climate zone. Table 2 through Table 5 summarize the weights aggregated to building type, foundation type, heating system, and climate zone levels. Table 6 shows the detailed weighting factors for all 32 residential prototype buildings.

[1] https://www.census.gov/construction/bps/stateannual.html

Table 2. Weighting Factors by Building Type

Bldg. Type	Weight (%)
Single-Family	66.04
Multifamily	33.96

Table 3. Weighting Factors by Foundation Type

Foundation Type	Weight (%)
Crawlspace	27.44
Slab-On-Grade	50.86
Heated Basement	11.77
Unheated Basement	9.93

Table 4. Weighting Factors by Heating System

Heating System Type	Weight (%)
Gas-Fired Furnace	49.15
Electric Furnace	5.63
Oil-Fired Furnace	1.29
Heat Pump	43.93

Table 5. Weighting Factors by Climate Zone

Climate Zone	Weight (%)
1	4.30
2	22.43
3	29.04
4	19.49
5	19.51
6	4.68
7	0.53
8	0.02

Table 6. Weighting Factors for the Residential Prototype Building Models by Climate Zone (CZ)

Building Type	Foundations	Heating Systems	CZ1 (%)	CZ2 (%)	CZ3 (%)	CZ4 (%)	CZ5 (%)	CZ6 (%)	CZ7 (%)	CZ8 (%)	Weights by Prototype
Single-Family	Crawlspace	Gas-Fired Furnace	0.17	0.93	2.66	1.74	2.20	0.39	0.06	0.01	8.15
Single-Family	Crawlspace	Electric Furnace	0.03	0.39	0.35	0.11	0.06	0.01	0.00	0.00	0.95
Single-Family	Crawlspace	Oil-Fired Furnace	0.00	0.00	0.01	0.02	0.05	0.02	0.00	0.00	0.10
Single-Family	Crawlspace	Heat Pump	0.29	1.30	4.73	1.96	0.65	0.14	0.03	0.00	9.09
Single-Family	Slab-On-Grade	Gas-Fired Furnace	0.59	5.23	4.62	1.95	2.46	0.42	0.06	0.00	15.35
Single-Family	Slab-On-Grade	Electric Furnace	0.12	1.48	0.78	0.15	0.06	0.02	0.00	0.00	2.62
Single-Family	Slab-On-Grade	Oil-Fired Furnace	0.00	0.01	0.01	0.03	0.07	0.03	0.00	0.00	0.15
Single-Family	Slab-On-Grade	Heat Pump	1.67	6.25	5.48	1.94	0.72	0.16	0.03	0.00	16.23
Single-Family	Heated Basement	Gas-Fired Furnace	0.01	0.01	0.13	1.05	2.62	0.75	0.07	0.00	4.65
Single-Family	Heated Basement	Electric Furnace	0.00	0.00	0.01	0.05	0.06	0.03	0.00	0.00	0.15
Single-Family	Heated Basement	Oil-Fired Furnace	0.00	0.00	0.00	0.02	0.09	0.04	0.00	0.00	0.15
Single-Family	Heated Basement	Heat Pump	0.01	0.04	0.32	1.03	0.73	0.30	0.03	0.00	2.46
Single-Family	Unheated Basement	Gas-Fired Furnace	0.00	0.02	0.33	0.86	1.77	0.42	0.03	0.00	3.43
Single-Family	Unheated Basement	Electric Furnace	0.00	0.00	0.02	0.04	0.04	0.01	0.00	0.00	0.11
Single-Family	Unheated Basement	Oil-Fired Furnace	0.00	0.00	0.00	0.03	0.19	0.06	0.00	0.00	0.29
Single-Family	Unheated Basement	Heat Pump	0.00	0.06	0.69	0.78	0.49	0.13	0.01	0.00	2.15

Building Type	Foundations	Heating Systems	CZ1 (%)	CZ2 (%)	CZ3 (%)	CZ4 (%)	CZ5 (%)	CZ6 (%)	CZ7 (%)	CZ8 (%)	Weights by Prototype
Multifamily	Crawlspace	Gas-Fired Furnace	0.10	0.40	1.42	1.24	1.25	0.21	0.03	0.00	4.66
Multifamily	Crawlspace	Electric Furnace	0.02	0.17	0.13	0.06	0.03	0.01	0.00	0.00	0.43
Multifamily	Crawlspace	Oil-Fired Furnace	0.00	0.00	0.00	0.02	0.05	0.01	0.00	0.00	0.09
Multifamily	Crawlspace	Heat Pump	0.14	0.55	1.69	1.10	0.39	0.09	0.01	0.00	3.97
Multifamily	Slab-On-Grade	Gas-Fired Furnace	0.30	2.10	2.49	1.28	1.36	0.25	0.03	0.00	7.80
Multifamily	Slab-On-Grade	Electric Furnace	0.06	0.69	0.33	0.08	0.04	0.01	0.00	0.00	1.21
Multifamily	Slab-On-Grade	Oil-Fired Furnace	0.00	0.00	0.01	0.03	0.07	0.01	0.00	0.00	0.12
Multifamily	Slab-On-Grade	Heat Pump	0.78	2.77	2.19	1.10	0.42	0.11	0.01	0.00	7.38
Multifamily	Heated Basement	Gas-Fired Furnace	0.01	0.00	0.06	0.75	1.43	0.45	0.05	0.00	2.74
Multifamily	Heated Basement	Electric Furnace	0.00	0.00	0.00	0.03	0.03	0.02	0.00	0.00	0.09
Multifamily	Heated Basement	Oil-Fired Furnace	0.00	0.00	0.00	0.03	0.08	0.02	0.00	0.00	0.13
Multifamily	Heated Basement	Heat Pump	0.00	0.01	0.12	0.62	0.41	0.21	0.03	0.00	1.39
Multifamily	Unheated Basement	Gas-Fired Furnace	0.00	0.00	0.19	0.77	1.15	0.24	0.02	0.00	2.36
Multifamily	Unheated Basement	Electric Furnace	0.00	0.00	0.01	0.03	0.03	0.01	0.00	0.00	0.08
Multifamily	Unheated Basement	Oil-Fired Furnace	0.00	0.00	0.00	0.04	0.18	0.03	0.00	0.00	0.26
Multifamily	Unheated Basement	Heat Pump	0.00	0.02	0.25	0.54	0.33	0.09	0.01	0.00	1.24
Totals by Climate Zone			4.30	22.43	29.04	19.49	19.51	4.68	0.53	0.02	100.00

1.3 Report Contents and Organization

This report documents the methodology and results of the cost-effectiveness analysis of the prescriptive and mandatory provisions of the 2021 IECC compared to those of the 2018 IECC. The present analysis builds on work conducted by PNNL during the determination analysis of the 2021 IECC (Salcido et al. 2021).

Building energy models were developed to evaluate the energy performance of the 2021 and 2018 IECC editions as applied to DOE's established residential prototypes. Incremental cost estimates for the provisions of the 2021 IECC compared to the 2018 IECC are combined with the energy performance results to calculate the cost effectiveness of the 2021 IECC.

This report is divided into three parts. Section 2.0 provides a summary of residential code changes in the 2021 IECC compared to the 2018 IECC and the details of the code changes considered in the present cost-effectiveness analysis. Section 3.0 details the methodology and incremental cost for the code changes considered in this analysis. Section 4.0 provides an overview of the economic analyses and summarizes the aggregated results of the cost-effectiveness analysis at the climate zone level.

The approved code changes incorporated into the 2021 IECC that have a direct effect on energy use are listed in Appendix A. Additional details about the building energy models created for simulating the energy use of buildings built to meet the provisions of the various editions of the IECC are provided in Appendix B.

2.0 Changes Introduced in the 2021 IECC

Following the publication of the 2021 IECC, DOE conducted both a qualitative and a quantitative energy savings analysis of that code compared to its immediate predecessor, the 2018 IECC. All the changes introduced in the 2021 IECC were identified, and their impact on energy efficiency was qualified. A total of 114 formal code change proposals were accepted into the 2021 IECC as shown in Table A.1. Of the 114 changes, 35 were identified as impacting energy use (29 decreasing, six increasing), and 11 were identified as requiring further analysis by energy simulation to quantify their impact using whole-building energy simulations of the 32 PNNL residential prototype buildings across the IECC climate zones.

Table 7 summarizes the characterization of the 11 approved code changes with quantifiable energy impacts considered in the present cost-effectiveness analysis.

Table 7. Summary of Analyzed Changes to the 2021 IECC

Proposal Number[(a)]	Code Section(s)[(b)]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE7	R202 (IRC N1101.6), R404.1 (IRC N1104.1)	Changes definition of high-efficacy lamps to high-efficacy light sources. Increases efficacy to 65 lumens per watt for lamps and 45 lumens per watt for luminaires. Also requires ALL permanently installed lighting fixtures be high-efficacy lighting sources.	Reduces energy use	Requires increased efficacy for light sources and provides separate thresholds for lamps vs luminaires.
RE29	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency of wood frame wall R-value requirements in climate zones 4 and 5.	Reduces energy use	
RE32	Table R402.1.2 (IRC N1102.1.2)	Increases slab insulation R-value requirements and depth in climate zones 3-5.	Reduces energy use	
RE33	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency for ceiling insulation in climate zones 2-3.	Reduces energy use	
RE35	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency of fenestration U-factors in climate zones 3-4 and adds new requirement for minimum fenestration U-factor in climate zones 3-8.	Reduces energy use	
RE36	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4), R402.2.1 (IRC N1102.2.1)	Increases stringency of ceiling insulation requirements in climate zones 4-8 and adds new exception for what to do when there is not room for R-60 insulation in ceiling.	Reduces energy use	

Proposal Number[(a)]	Code Section(s)[(b)]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE133	Table R403.6.1 (IRC N1103.6.1)	Increases whole-house mechanical ventilation system fan efficacy requirements for inline fans and bathroom/utility rooms.	Reduces energy use	Raises fan efficacy requirements to match current Energy Star 4.0 requirements.
RE139	R403.6.1 (IRC N1103.6.1) (New)	Requires ventilation systems to be heat or energy recovery for climate zones 7-8.	Reduces energy use	Stipulates HRV or ERV requirements of 65% heat recovery efficiency at 32°F at a flow greater than or equal to the design airflow.
RE145	R202, R404.1, R404.2 (New)	Increases efficacy in the definition of high-efficacy lamps to 70 lumens/watt. All permanently installed lighting must contain only high-efficacy lamps. Adds definitions of "dimmer" and "occupant sensor control" and requires automatic lighting controls in specific spaces. There is overlap with RE7 for high-efficacy lighting.	Reduces energy use	Adds a new requirement for residential lighting controls in the IECC. Savings expected through higher efficacy lighting and the use of automatic lighting controls to reduce lighting energy use.
RE148	R404.1.1 (IRC N1104.1.1) (New)	Requires exterior lighting for Group R-2, R-3, or R-4 buildings to comply with Section C405.4 of the IECC.	Reduces energy use	Requires exterior lighting power meets the commercial lighting power provisions for R-2, R-3, and R-4 buildings except for solar powered lamps and fixtures with motion sensors.
RE209	R401.2, R401.2.1 (New), Section R408 (New), R408.1 (New), R408.2 (New), R408.2.1 (New), R408.2.2 (New), R408.2.3 (New), R408.2.4 (New), R408.2.5 (New)	Adds new section for additional efficiency package options to reduce energy use. Package options chosen based on compliance pathway that targets an energy use reduction of 5%.	Reduces energy use	Efficiency Package Options include: Enhanced Envelope Performance, Efficient HVAC, Efficient Hot Water Heating, Efficient Thermal Distribution, and Improved Air Sealing with Efficient Ventilation. For prescriptive compliance, one option is required for an estimated 5% reduction in energy use. Performance and ERI compliance must demonstrate a 5% reduction in energy cost or ERI score.

(a) Proposal numbers are as assigned by the ICC (http://media.iccsafe.org/code-development/group-b/2019-Group-B-CAH-compressed.pdf)
(b) Code sections refer to the 2018 IECC. Sections may be renumbered by the ICC in the 2021 IECC.

3.0 Construction Cost Estimates

This section describes the methodology used for calculating the incremental costs of construction of the 2021 IECC compared to the 2018 IECC. Detailed incremental cost estimates for the new provisions of the 2021 IECC considered in this analysis are provided along with a summary of total incremental costs by building type and climate zone.

3.1 Methodology

The present analysis includes only the prescriptive and mandatory provisions of the IECC pertaining to residential buildings. The first step in evaluating the cost effectiveness of these changes introduced by the 2021 IECC is estimating their incremental construction costs. Data sources consulted for these estimates include, but are not limited to, the following:

- Building Component Cost Community (BC3) data repository (DOE 2012)
- Residential construction cost data collected by Faithful+Gould under contract with PNNL (Faithful + Gould 2012)
- RS Means Residential Cost Data (RS Means 2020)
- National Renewable Energy Laboratory (NREL's) National Residential Efficiency Measures Database (NREL 2012)
- Cost data from prominent and commonly recognized home supply stores.

The incremental costs are calculated separately for each code change, and then added together to obtain a total incremental cost by climate zone and building type. The following sections discuss the specific cost estimates identified for the efficiency measures that changed in the 2021 IECC.

3.2 Incremental Cost Estimates for New Provisions of the 2021 IECC

The incremental construction costs associated with the 11 changes in Table 7 are detailed in the following sections. Only costs for the 11 changes with quantifiable energy impacts are considered. Costs due to the administrative changes are not considered.

3.2.1 Increased High-Efficacy Lighting

RE7 defines high-efficacy lighting to a greater level of efficacy in lumens per watt than the 2018 IECC. RE147 increases the fraction of permanently installed lighting fixtures that must be high efficacy from 90 percent to 100 percent. RE7 defines high-efficacy lighting as lamps with an efficacy not less than 65 lumens per watt or luminaires with an efficacy not less than 45 lumens per watt. High-efficacy lighting is defined such that most fluorescent lighting and light-emitting diode (LED) lighting qualifies, while incandescent does not. Because the efficacy of lighting fixtures and lamps is regulated by federal standards that now effectively prohibit incandescent options in most residential applications, the incremental cost estimate for the 90 percent to 100 percent change is defined as zero.

3.2.2 Increased Wall Insulation

RE29 increases wood frame wall insulation requirements by adding an additional R-5 continuous insulation for climate zones 4 and 5.

A review of RS Means 2020 shows that 1-inch of polyisocyanurate or expanded polystyrene (R-5 insulated sheathing) has an installed cost of \$0.98/ft^2 of wall area. This cost agrees with prices at major home improvement stores for 1-inch R-5 insulation board.

3.2.3 Increased Slab Insulation

RE32 adds a new requirement of R-10 at 2 ft of depth for slab insulation for slab-on-grade homes in climate zone 3. For slab-on-grade homes in climate zones 4 and 5, the existing R-10 slab insulation depth was increased from 2 ft to 4 ft.

The BC3 cost database (DOE 2012) includes average/typical costs for various slab insulation levels. All cases of increased slab insulation for the 2021 IECC will require an added 2 ft depth of R-10 insulation; thus, the installed cost will be the same. The cost of 2 inches of R-10 expanded polystyrene foam (XPS) in 2012 was \$3.24 per linear foot of slab. These costs were adjusted from 2012 to 2020 dollars using a consumer price index increase of 10 percent as found on the Inflation Calculator provided by the Bureau of Labor Statistics website,[1] resulting in costs of \$3.69 per linear ft.

3.2.4 Increased Ceiling Insulation

Both R33 and R36 increase the stringency of ceiling insulation in different climate zones. R33 increases the ceiling insulation requirement in climate zones 2 and 3 from R-38 to R-49 for the 2021 IECC. R36 increases the ceiling insulation requirement in climates zones 4 through 8 from R-49 to R-60. To determine first cost of increased ceiling insulation, it was assumed that cellulose insulation would be used as a lower cost alternative to fiberglass.

RS Means 2020 was used to obtain costs for cellulose insulation. RS Means 2020 stated the cost to install R-38 cellulose insulation as \$1.72/ft^2 of ceiling area. The cost to install R-49 cellulose insulation from RS Means 2020 was \$2.24/ft^2 of ceiling area. Thus, the incremental cost to install R-49 insulation for climate zones 2 and 3 is calculated to be \$0.52/ft^2 of ceiling area.

For RE36, RS Means 2020 stated the cost to install R-60 cellulose insulation in the ceiling at \$2.75/ft^2. Thus, the incremental cost to install R-60 insulation for climate zones 4 through 8 is calculated to be \$0.51/ft^2 of ceiling area.

3.2.5 Lower Fenestration U-Factor

The 2021 IECC lowers (makes more efficient) the U-factor required for residential fenestration (windows and doors) in climate zones 3, 4A, and 4B. The U-factor was lowered from 0.32 to 0.30.

The BC3 cost database (DOE 2012) includes residential data giving average/typical costs for various window unit upgrades. A summary of the BC3 data shows the cost difference between

[1] http://www.bls.gov/data/inflation_calculator.htm

window units with U-factors of 0.32 and 0.30 is $0.12/ft^2 of window area. These costs were adjusted from 2012 to 2021 dollars using a consumer price index increase of 10 percent as found on the Inflation Calculator provided by the Bureau of Labor Statistics website, resulting in a cost of $0.14/ft^2 to move from U=0.32 to 0.30.

3.2.6 Increased Mechanical Ventilation Fan Efficacy

The 2021 IECC updates the mechanical ventilation fan efficacy requirements to those from ENERGY STAR Ventilating Fans Specifications v4.0. The new fan efficacy requirements are conservative given that all fans on the market exceed these requirements according to the fans listed in the Home Ventilating Institute's database[1].

All ventilation fans reviewed at Home Depot[2] showed efficacies well above the fan efficacy requirements in the 2021 IECC; costs varied only by flow rate, color, noise, and special features. Given that there is no cost difference between levels of efficiency, the incremental cost for higher efficacy ventilation fans will be zero.

3.2.7 Added Heat Recovery Ventilation

The 2021 IECC adds a requirement that dwelling units in climate zones 7 and 8 must be provided with a heat recovery or energy recovery ventilation system. These balanced ventilation systems must operate with a minimum sensible heat recovery efficiency of 65 percent.

PNNL conducted a cost-benefit analysis of heat recovery ventilators to determine their cost effectiveness.[3] The study found through various sources that the addition of a heat recovery ventilator would incur costs between $1,200 and $1,550. In the final analysis, the primary first cost of $1,500 represented the cost of an HRV in a typical dwelling unit as a best estimate that includes installation.

3.2.8 Additional Efficiency Options

The 2021 IECC adds a new section (R408) that establishes five efficiency packages with the goal of adding an additional 5 percent of energy efficiency. For the prescriptive compliance path, one of the five additional efficiency packages must be utilized in the design home. The five efficiency packages are the following:

- Enhanced Envelope Option
- More Efficiency HVAC Equipment Performance Option
- Reduced Energy Use in Service Water Heating Option
- More Efficient Duct Thermal Distribution System Option
- Improved Air Sealing and Efficient Ventilation System Option.

Based on PNNL discussions with directors of the ENERGY STAR New Homes Program, builders typically utilize high-efficiency water heating systems to meet the efficiency demands of the program. Builders found that installing high-efficiency water heaters were the most cost-

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[1] https://www.hvi.org/

[2] www.homedepot.com. November 2020.

[3] https://www.energycodes.gov/sites/default/files/documents/iecc2018_R-3_analysis_final.pdf

effective way to meet the ERI target requirements for ENERGY STAR certification. Based on these discussions, the Reduced Energy Use in Service Water Heating Option was selected to represent this requirement. Factors considered were initial installation cost and builder choices for additional energy efficiency necessary to certify with the ENERGY STAR New Homes program.

The residential prototype water heaters are storage type water heaters and utilize the same fuel type as that for the space heating. The four space heating system types are gas furnace, oil furnace, electric furnace, and heat pump. Thus, there are two fossil fuel space heating and water heating systems and two electric space heating and water heating systems. Table 8 shows the water heating systems and energy factors (EF) for a gas tankless and a heat pump water heater (HPWH) set up for the 2021 IECC to represent the Reduced Energy Use in Service Water Heating package compared to the original prototypes.

Table 8. Water Heating Systems modeled for 2018 IECC and for the additional efficiency option package for 2021 IECC

Space Heating Type	2018 IECC Water Heating	2021 IECC Water Heating
Gas Furnace	Gas Storage, 0.58 EF, 40 gal	Gas Tankless, 0.82 EF
Oil Furnace	Oil Storage, 0.61 EF, 52 gal	HPWH, 2.0 EF, 50 gal
Electric Furnace	Electric Storage, 0.92 EF, 52 gal	HPWH, 2.0 EF, 50 gal
Heat Pump	Electric Storage, 0.92 EF, 52 gal	HPWH, 2.0 EF, 50 gal

The BC3 cost database (DOE 2012) includes residential data giving average/typical costs for various water heater types. A summary of the BC3 data shows the cost difference of upgrading from a standard 50-gallon gas storage water heater of 0.58 EF to a gas tankless water heater with an energy factor of 0.82 is $727. These costs were adjusted from 2012 to 2021 dollars using a consumer price index increase of 10 percent as found on the Inflation Calculator provided by the Bureau of Labor Statistics website,[1] resulting in a cost of $830.

The same data shows the cost difference of upgrading from a 50-gallon standard electric storage water heater with a 0.92 EF to a 50-gallon HPWH with an EF of 2.0 is $1,370. These costs were adjusted from 2012 to 2021 dollars using a consumer price index increase of 10 percent as found on the Inflation Calculator provided by the Bureau of Labor Statistics website, resulting in a cost of $1,510. Local home improvement stores show the average cost for 50-gallon electric storage water heaters is $400 while the average cost for 50-gallon HPWHs is $1,300, establishing a cost differential of $900. The costs for installation for the electric storage water heater and HPWH are assumed to be the same except for the cost of a condensate pump and associated tubing required for condensate removal from the HPWH. The cost of the condensate pump and tubing is $75 based on local home improvement websites. The total incremental cost for upgrading an electric water heater to a HPHW is $975 utilizing the average costs from home improvement stores. For the purposes of this analysis and age of the previous cost estimates, the incremental cost of $975 is used for upgrading to a HPWH.

[1] http://www.bls.gov/data/inflation_calculator.htm

3.2.9 Exterior Lighting

The 2021 IECC adds a new section that requires R-2, R-3, and R-4 buildings (multifamily) to comply with Section C405.5 of the commercial provisions of the IECC. Section C405.5 governs the exterior lighting power requirements based on the exterior lighting zone of the building. This proposal only applies to the multifamily prototypes in this analysis.

Given these changes, the exterior lighting for the residential multifamily prototypes was aligned with the commercial multifamily prototypes. Lighting allowances were selected from Exterior Lighting Zone 2[1] in the commercial IECC, which consists of residential zoning. There were three areas of lighting considered for the residential multifamily prototypes: base wattage, parking area, and façade lighting. Table 9 highlights the exterior lighting allowances.

Table 9. Exterior Lighting Allowances for 2021 IECC

Lighting Area	Area ft^2	2021 IECC Allowance	Total Wattage
Base Wattage	N/A	400 W	400
Parking Area	19,483	0.04 W/ft^2	794
Façade Lighting	853	0.075 W/ft^2	64

Since prior versions of the IECC had no exterior lighting power requirements, the prototype simulations have assumed a modest exterior lighting power (40 W) based on Building America protocols (Wilson et al. 2014). The 2021 IECC update for exterior lighting power requirements allows much more connected power than has been assumed in the past. However, because past assumptions were not based on any code requirement, assessments of the 2021 IECC will assume the same (new) exterior lighting allowances for all past codes. Table 9 shows these allowances. This results in no changes in exterior lighting and no savings gained, and thus has a first cost change of $0.

3.3 Summary of Incremental Costs

Table 10 summarizes the incremental costs for each new code provision of the 2021 IECC evaluated in the present analysis compared to the 2018 IECC.

Table 10. Construction Cost Increase of the New Provisions of the 2021 IECC

Provision	Specifications	Scope	Associated Cost	Incremental Cost Used in Analysis ($/dwelling unit)
High-efficacy lighting and lighting fraction	Required fraction of high-efficacy lighting (65 lumens/watt) in permanent fixtures up from 90% to 100%	All new dwelling units, both single-family and multifamily	$0.00/ft^2$	$0.00
Wood frame wall insulation	Add R-5 sheathing insulation to wood frame walls in climate zones 4 and 5	All new dwelling units, both single-family and multifamily	$0.98/ft^2$	$374.96 for multifamily and $1,961.96 for single-family

[1] Table C405.5.2(1) in 2021 IECC

Provision	Specifications	Scope	Associated Cost	Incremental Cost Used in Analysis ($/dwelling unit)
Slab floor insulation	Add R-10 perimeter slab insulation at 2 ft depth for climate zone 3 and increase depth of R-10 insulation to 4 ft for climate zones 4 and 5	All new dwelling units, both single-family and multifamily with slab foundation type	$3.69/linear ft	$75.85 for multifamily and $512.91 for single-family slab buildings
Ceiling insulation	Increase ceiling insulation from R-38 to R-49 in climate zones 2 and 3; increase R-49 to R-60 ceiling insulation in climate zones 4-8	All new dwelling units, both single-family and multifamily	$0.52/ft^2 for climate zones 2-3; $0.51/ft^2 for climate zones 4-8	$221.00 to $612.04 based on climate zone and building type
Fenestration U-factor	Improve from 0.32 to 0.30 in climate zones 3, 4A, and 4B	All new dwelling units, both single-family and multifamily	$0.14/ft^2	$16.88 for multifamily and $49.90 for single-family slab buildings
Mechanical ventilation fan efficacy	Improve exhaust fan efficacy from 1.4 cfm/watt to 2.8 cfm/watt	All new dwelling units, both single-family and multifamily	$0.00/ft^2	$0.00
Heat recovery ventilation	Add heat recovery ventilation to climate zones 7 and 8	All new dwelling units, both single-family and multifamily	$1,500	$1,500 for each dwelling unit in climate zones 7 and 8
Exterior lighting	Exterior lighting allowances according to C405.4	Multifamily dwelling units	$0.00/ft^2	$0.00
Efficiency option packages	Applying reduced energy use for service water heating option; natural gas tankless water heater of 0.82 EF or HPWH of 2.0 EF	All new dwelling units, both single-family and multifamily	$830 for tankless water heater; $975 for HPWH	$830 or $975 based on system type

The total incremental costs for the prescriptive and mandatory provisions of the 2021 IECC compared to those of the 2018 IECC are summarized in Table 11.

Table 11. Total Construction Cost Increase for the 2021 IECC Compared to the 2018 IECC

Climate Zone	Single Family 2,376 ft^2	Apartment/Condo 1,200 ft^2
1	$936	$933
2	$1,530	$1,146
3	$1,859	$1,192
4	$3,687	$1,533
5	$3,569	$1,487
6	$1,477	$1,102
7	$2,980	$2,603
8	$2,982	$2,603
National Average	$2,372	$1,316

4.0 Economic Analysis

This section provides an overview of the methodology used in evaluating the cost effectiveness of the prescriptive and mandatory provisions of the 2021 IECC compared to those of the 2018 IECC. Cost-effectiveness results for life-cycle cost (LCC) savings, simple payback, and cash flow are calculated for each building type in each climate zone; the results are weighted using factors detailed in Section 1.2.3 to aggregate results to the climate zone level.

4.1 DOE Residential Cost-Effectiveness Methodology

DOE developed a standardized methodology for determining the cost effectiveness of residential energy code changes through a public Request for Information (76 FR 56413). The established methodology[1] describes the process of assessing energy savings and cost effectiveness and is used by DOE in the evaluation of published codes as well as code changes proposed by DOE for inclusion in the IECC (Taylor et al. 2012). The methodology forms the basis of this cost-effectiveness analysis by

- defining an energy analysis procedure, including definitions of two building prototypes (single-family and multifamily), identification of preferred calculation tools, and selection of climate locations to be analyzed
- establishing preferred construction cost data sources
- defining cost-effectiveness metrics and associated economic parameters
- defining a procedure for aggregating location-specific results to state, climate zone, and national levels.

Per the methodology, DOE calculates three metrics from the perspective of the homeowner—LCC, simple payback, and cash flow. LCC is the primary metric used by DOE for determining the cost effectiveness of an overall code or individual code change. The economic parameters used in the current cost-effectiveness analysis are summarized in Table 12. DOE updated the economic parameters following the established methodology[1] to account for changing economic conditions.

[1] See DOE Residential Energy and Cost Analysis Methodology at: http://www.energycodes.gov/development/residential/methodology

Table 12. Summary of Economic Parameters Used in Cost-Effectiveness Analysis

Parameter	Value
Mortgage Interest Rate	3%
Loan Term	30 years
Down-Payment Rate	12% of home price
Points and Loan Fees	1.0% (non-deductible)
Analysis Period	30 years
Property Tax Rate	1.24% of home price/value
Income Tax Rate	12% federal
Inflation Rate	1.4% annual
Home Price Escalation Rate	Equal to inflation rate

4.2 Fuel Prices and Escalation Rates

Data published by the EIA are used to determine the latest national average fuel prices for the three fuel types considered in this analysis—electricity, natural gas, and fuel oil. To avoid seasonal fluctuations and regional variations in the price of electricity, the analysis used the average annual residential electricity price of 13.23 ¢/kWh (EIA 2020a). The EIA reports a national annual average cost of $9.77/1,000 ft^3 and an average heat content of 1,037 Btu/ft^3 for natural gas delivered to consumers in 2016 (EIA 2020b, 2020c). The resulting national average price of $0.94/therm for natural gas was used in this analysis. In addition, the EIA reports a national annual average cost of $2.519/gallon for No. 2 fuel oil (EIA 2020d). The heat content of No. 2 fuel oil is assumed to be 138,500 Btu/gallon (NCHH 2015), resulting in a national average price of $18.19/million Btu for fuel oil.

Fuel escalation rates are calculated separately for electricity, natural gas, and fuel oil using annual projected fuel prices published in the 2021 Annual Energy Outlook (AEO; EIA 2021). The AEO year-by-year projections are used in the 30-year analysis.

4.3 Energy Cost Savings

The calculation of cost-effectiveness metrics primarily requires annual energy cost savings and the associated incremental costs. Energy estimates from the simulations are converted to energy costs using the latest fuel prices described in Section 4.2. Table 13 summarizes the first year annual energy cost savings per dwelling unit for the 2021 IECC compared to the 2018 IECC, aggregated over all 32 residential prototype building models using weighting factors described in Section 1.2.3. Energy cost savings stated in the 2021 IECC Determination report (Salcido et al. 2021) are time zero dollars which are not escalated due to inflation or fuel price escalation.

Table 13. Average Annual Energy Cost Savings for the 2021 IECC

Climate Zone	Compared to the 2018 IECC ($/dwelling unit yr)
1	200
2	192
3	200
4	205
5	173
6	123
7	306
8	411
National Average	191

4.4 Life-Cycle Cost

LCC is the primary metric used by DOE to determine the cost effectiveness of the code or specific code changes. LCC is the total consumer cost of owning a home for a single homeowner calculated over a 30-year period. The economic analysis assumes that initial costs are mortgaged, that homeowners take advantage of the mortgage interest deductions, that short-lived efficiency measures are replaced at end-of-life, and that all efficiency measures with useful life remaining at the end of the 30-year period of analysis retain a residual value at that point.

Table 14 shows the LCC savings (discounted present value) per home over the 30-year analysis period for the prescriptive and mandatory provisions of the 2021 IECC compared to those of the 2018 IECC. These savings are aggregated over all 32 residential prototype buildings using weights described in Section 1.2.3.

Table 14. Life-Cycle Cost Savings for the 2021 IECC

Climate Zone	Compared to the 2018 IECC ($/dwelling unit)
1	3,536
2	2,854
3	2,829
4	2,243
5	1,034
6	970
7	3,783
8	6,782
National Average	2,320

4.5 Simple Payback

Simple payback is a commonly used measure of cost effectiveness, defined as the number of years required for the sum of the annual returns on an investment to equal the original investment. Simple payback does not take into consideration any financing of the initial costs through a mortgage or favored tax treatment of mortgages. In other words, simple payback is the ratio of the incremental cost of construction and the first-year energy cost savings. The simple payback is reported for information purposes only and is not used as a basis for determining the cost effectiveness of the 2021 IECC.

Table 15 shows the simple payback period of the 2021 IECC when compared to the 2018 IECC aggregated over all 32 residential prototype buildings using weights described in Section 1.2.3. As seen from the table, the simple payback period for the 2021 IECC compared to that of the 2018 IECC ranges from 4.8 to 16.7 years, depending on climate zone.

Table 15. Simple Payback Period for the 2021 IECC

Climate Zone	Compared to the 2018 IECC (Years)
1	4.8
2	7.6
3	8.6
4	12.4
5	16.7
6	11.2
7	9.6
8	7.3
National Average	10.5

4.6 Cash Flow

Most houses are financed[1], and the financial implications of buying a home constructed to meet the provisions of the 2021 IECC compared to the provisions of the 2018 IECC are important to homeowners. Mortgages spread the payment for the cost of a house or an apartment over a long period of time and the cash flow analysis clearly depicts the impact of mortgages. This analysis assumes a 30-year fixed-rate mortgage and that the homebuyers will deduct the interest portion of the payments from their income taxes.

Table 16 shows the impact of the provisions of the 2021 IECC on a typical consumer's cash flow compared to that of the 2018 IECC aggregated over all 32 residential prototype buildings using weights described in Section 1.2.3. In all climate zones, beginning in year 1, there is a net positive cash flow per year to the customer for the 2021 IECC-compliant home when compared to the 2018 IECC-compliant home. Positive cumulative savings, including payment of up-front

[1] https://www.statista.com/statistics/185206/us-house-sales-with-fha-and-va-insured-mortgages-from-2002/

costs, are achieved in years 1 through 10 depending on the climate zone. Between the relatively modest energy savings and high first costs for R-5 sheathing in climate zones 4 and 5, the cumulative cash flow turns positive in year 5 and 10 respectively.

Table 16. Impacts on Consumer Cash Flow from the 2021 IECC

	Compared to the 2018 IECC	
Climate Zone	Net Annual Cash Flow Savings ($ for Year 1)	Years to Cumulative Positive Cash Flow
1	145	1
2	108	2
3	101	3
4	59	5
5	7	10
6	44	4
7	138	3
8	239	2
National Average	76	4

5.0 Conclusions

As seen from the cost-effectiveness results presented in Section 4.0, residential buildings constructed to the prescriptive and mandatory requirements of the 2021 IECC save homeowners money over the life of their homes compared to those built to the prescriptive and mandatory requirements of the 2018 IECC.

The prescriptive and mandatory provisions of the 2021 IECC are shown to generate an average life-cycle cost savings of $2,254, an average payback of 10.09 years, and the years to cumulative positive cashflow averaging 4 years for all climate zones. The results illustrate that homeowners can benefit financially from the investment in energy efficiency of the 2021 IECC. The results also show that the higher efficiency of the 2021 IECC requires increased investment and higher payback times while remaining cost effective.

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Appendix A – Qualitative Analysis of 2021 IECC

Table A.1. Qualitative Analysis of 2021 IECC Code Changes Affecting Energy Use

Proposal Number[(a)]	Code Section(s)[(b)]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE7	R202 (IRC N1101.6), R404.1 (IRC N1104.1)	Changes definition of high-efficacy lamps to high-efficacy light sources. Increases efficacy to 65 lumens per watt for lamps and 45 lumens per watt for luminaires. Also requires ALL permanently installed lighting fixtures be high-efficacy lighting sources.	Reduces energy use	Requires increased efficacy for light sources and provides separate thresholds for lamps vs luminaires.
RE29	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency of wood frame wall R-value requirements in climate zones 4 and 5.	Reduces energy use	
RE32	Table R402.1.2 (IRC N1102.1.2)	Increases slab insulation R-value requirements and depth in climate zones 3-5.	Reduces energy use	
RE33	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency for ceiling insulation in climate zones 2-3.	Reduces energy use	
RE35	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Increases stringency of fenestration U-factors in climate zones 3-4 and adds new requirement for minimum fenestration U-factor in climate zones 3-8.	Reduces energy use	
RE36	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4), R402.2.1 (IRC N1102.2.1)	Increases stringency of ceiling insulation requirements in climate zones 4-8 and adds new exception for what to do when there is not room for R-60 insulation in ceiling.	Reduces energy use	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE133	Table R403.6.1 (IRC N1103.6.1)	Increases whole-house mechanical ventilation system fan efficacy requirements for inline fans and bathroom/utility rooms.	Reduces energy use	Raises fan efficacy requirements to match current Energy Star 4.0 requirements.
RE139	R403.6.1 (IRC N1103.6.1) (New)	Requires ventilation systems to be heat or energy recovery for climate zones 7-8.	Reduces energy use	Stipulates HRV or ERV requirements of 65% heat recovery efficiency at 32°F at a flow greater than or equal to the design airflow.
RE145	R202, R404.1, R404.2 (New)	Increases efficacy in the definition of high-efficacy lamps to 70 lumens/watt. All permanently installed lighting must contain only high-efficacy lamps. Adds definitions of "dimmer" and "occupant sensor control" and requires automatic lighting controls in specific spaces. There is overlap with RE7 for high-efficacy lighting.	Reduces energy use	Adds a new requirement for residential lighting controls in the IECC. Savings expected through higher efficacy lighting and the use of automatic lighting controls to reduce lighting energy use.
RE148	R404.1.1 (IRC N1104.1.1) (New)	Requires exterior lighting for Group R-2, R-3, or R-4 buildings comply with Section C405.4 of the IECC.	Reduces energy use	Requires exterior lighting power meets the commercial lighting power provisions for R-2, R-3, and R-4 buildings except for solar powered lamps and fixtures with motion sensors.
RE209	R401.2, R401.2.1 (New), Section R408 (New), R408.1 (New), R408.2 (New), R408.2.1 (New), R408.2.2 (New), R408.2.3 (New), R408.2.4 (New), R408.2.5 (New)	Adds new section for additional efficiency package options to reduce energy use. Package options chosen based on compliance pathway that targets an energy use reduction of 5%.	Reduces energy use	Efficiency package options include enhanced envelope performance, efficient HVAC, efficient hot water heating, efficient thermal distribution, and improved air sealing with efficient ventilation. For prescriptive compliance, one option is required for an estimated 5% reduction. Performance and ERI compliance must demonstrate a 5% reduction in energy cost or ERI score.

Proposal Number[(a)]	Code Section(s)[(b)]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE27	Table R402.1.2 (IRC N1102.1.2)	Adds alternative wood frame wall options in all climates.	Reduces energy use	Adds cavity-only options for climate zones 7-8 and continuous-only options for all zones. Provides U-factor calculations showing that the new options are equal to or better than the U-factors required in Table R402.1.4. Not included in quantitative analysis since prescriptive wall insulation requirements remain unchanged.
RE34	Table R402.1.2 (IRC N1102.1.2)	Eliminates footnote gas option for floor cavity insulation.	Reduces energy use	Footnote g allowed merely filling the cavity (but at least R-19) if framing left insufficient space for the required insulation R-value. Floors must meet the prescriptive requirement with continuous insulation if cavity insulation will not meet the requirement.
RE37	Table R402.1.2 (IRC N1102.1.2)	Adds new requirement for fenestration SHGC of 0.4 in climate zone 5 and marine 4.	Reduces energy use	Quantitative analysis assumed 0.4 SHGC as standard practice in prototypes for climate zones without SHGC requirements.
RE44	R402.2.3 (IRC N1102.2.3)	Adds more specific requirements details to achieve a continuous eave baffle.	Reduces energy use	Potential for air leakage reduction and improved attic insulation coverage. Total air leakage requirements remain unchanged and thus not part of the quantitative analysis.
RE45	R402.2.3 (IRC N1102.2.3)	Makes eave baffle requirement mandatory.	Reduces energy use	Not included in quantitative analysis as it was already a prescriptive requirement.
RE46	R402.2.4 (IRC N1102.2.4) (New), R402.2.4 (IRC N1102.2.4)	Establishes separate design and installation requirements for attic hatches and doors, with the installation being mandatory.	Reduces energy use	Makes weather stripping mandatory, leaves insulation requirement prescriptive. Total insulation and air leakage requirements remain unchanged and thus not part of the quantitative analysis.
RE52	R402.2.7 (IRC N1102.2.7)	Deletes section on walls with partial structural sheathing that allows a reduction in continuous insulation of up to R-3.	Reduces energy use	Prescriptive wall insulation requirements remain unchanged and not factored in the quantitative analysis.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE100	R402.4.1.2 (IRC N1102.4.1.2), R402.2.13 (IRC N1102.2.13), R402.3.5 (IRC N1102.3.5)	Adds new air leakage and thermal isolation requirements for heated garages.	Reduces energy use	Adds a new requirement for heated garages that applies the same envelope requirements as sunrooms. Could show savings if garages are insulated minimally instead of not being insulated at all. However, prototypes do not include a garage.
RE105	R402.5 (IRC N1102.5)	Lowers the maximum fenestration U-factor and SHGC requirements.	Reduces energy use	Lowers the allowable area weighted SHGC for climate zones 1-3. Savings not captured in quantitative analysis because prototypes use prescriptive window requirements.
RE112	R403.3.3 (IRC N1103.3.3), R403.3.4 (IRC N1103.3.4)	Removes duct testing exception for ducts located within the building thermal envelope and adds a new duct leakage testing requirement for such ducts.	Reduces energy use	Eliminates exception for testing ducts entirely within the building thermal boundary on the basis that these systems need to be tested to ensure long term energy savings and that lack of testing entirely could lead to problems. Sets the total duct leakage rate for ducts within the thermal boundary to twice the leakage rate for systems not entirely in conditioned space. Prototype building duct location is either in the attic, crawlspace, or unconditioned basement.
RE134	R403.6.1 (IRC N1103.6.1), Table R403.6.1 (IRC N1103.6.1)	Adds air-handler integrated ventilation system fan efficacy requirements to Table R403.6.1.	Reduces energy use	Removes exception for air-handler integrated ventilation system to provide whole-house ventilation and added fan efficacy requirements for such systems. Not included in the quantitative analysis because air-handler integrated ventilation systems are not part of typical homes as represented by the prototypes.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE149	R404.2 (IRC N1104.2) (New)	Adds four new automated control requirements for exterior lighting if installed lighting power is greater than 30 watts.	Reduces energy use	The exterior lighting schedules used for the single-family and multifamily prototypes have historically set all exterior lighting to off during daylight hours, meaning the current exterior lighting schedules already comply with the requirements of the 2021 IECC, so no changes to the prototypes were made.
RE162	Table R405.5.2(1) [IRC N1105.5.2(1)]	Adds hot water distribution system compactness factor (HWDS) to the calculation of the proposed design hot water use (gallons/day) in Table R405.5.2(1).	Reduces energy use	Adds a methodology to show better design of hot water systems can reduce energy use.
RE163	Table R405.5.2(1) [IRC N1105.5.2(1)]	Adjusts the calculation for service hot water consumption (gal/day) for the performance path proposed and standard designs, which in effect lowers the overall hot water consumption.	Reduces energy use	Revises formula for estimating hot water usage for performance compliance, which has been unchanged since 1998. The new usage equation gives lower water usage (gal/day), which would decrease the importance of service water heating efficiency compared to envelope efficiency. Both proposed and baseline buildings have the same reduced water usage.
RE184	R406.3 (IRC N1106.3)	Adds new requirement for ERI compliance stipulating any reduction in energy use from renewable energy shall not exceed 5% of total energy use.	Reduces energy use	In theory this limits builders' ability to trade down envelope efficiency in the ERI path. In practice, there is already an envelope backstop at the 2015 prescriptive levels, so this additional backstop may have little impact. A “backstop” is sometimes called a “mandatory minimum” and refers to a minimum efficiency level that cannot be violated even when compliance tradeoffs are used.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE192	Table R406.4 (IRC N1106.4)	Reduces ERI compliance targets for all climate zones to the 2015 IECC levels.	Reduces energy use	Adjusts ERI compliance targets to be more stringent and specifies the ANSI/RESNET/ICC 301 Standard as the basis. Ventilation rates for the 301 ERI Reference Home are based on the International Mechanical Code.
RE218	R503.1.4	Revises exception for new lighting systems in alterations from 10% of luminaires to 50% of luminaires.	Reduces energy use	Exception allows more luminaires to be exempt from lighting requirements in alterations provided they do not increase the installed interior lighting power.
RE223	Appendix RB (IRC Appendix Q) (New)	Adds Appendix RB for zero energy residential building provisions.	Reduces energy use	Sets ERI thresholds for "zero energy." The ERI is 0 for analysis that includes onsite power production and varies from 43 to 47 for analysis that does not include onsite power production. Only reduces energy use if Appendix RB is adopted.
RE41	Table R402.1.2 (IRC N1102.1.2), Table R402.1.4 (IRC N1102.1.4)	Adds footnote j that allows a maximum fenestration U-factor of 0.32 for climate zones marine 4 and 5-8 for high elevations and wind prone areas.	Increases energy use	Increases allowed U-factor requirement from 0.30 to 0.32 for climate zone 4C to 8 for homes above 4,000 ft and wind prone regions. Fenestration at high altitude requires the ability for pressure equalization during transit while windborne protection requires laminated glass for durability. Both these requirements reduce thermal performance.
RE47	R402.2.4 (IRC N1102.2.4)	Adds exception for horizontal pull-down stair-type access hatches and doors.	Increases energy use	While technically a reduction in R-value requirements for drop-down attic hatches, the practical argument that "field crafted detachable apparatuses" are usually used to achieve the current requirement means this change will have minimal impact.

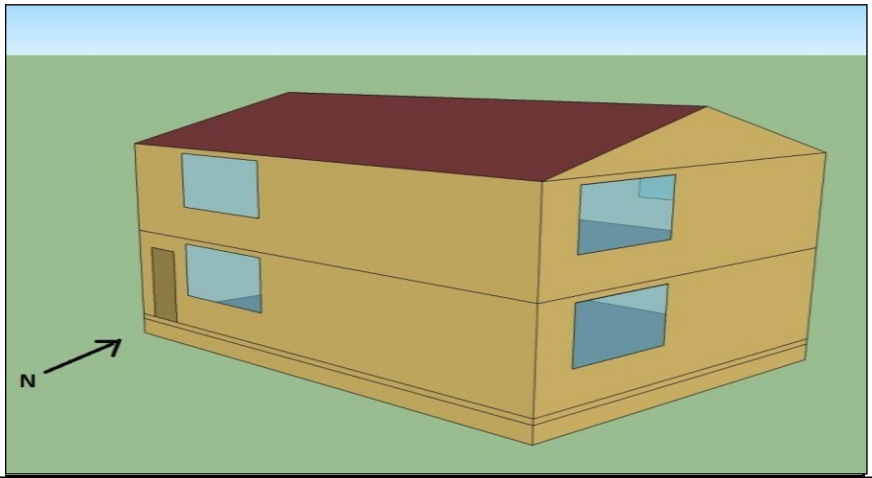
Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Discussion
RE53	R402.2.8 (IRC N1102.2.8)	Expands on language of floor insulation installation for clarification.	Increases energy use	The proposal reduces the floor-R requirements by allowing insulation sufficient to fill the available cavity space as an alternative to the required R-value.
RE96	R402.4 (IRC N1102.4), R402.4.1 (IRC N1102.4.1), R402.4.1.1 (IRC N1102.4.1.1) , R402.4.1.2 (IRC N1102.4.1.2) , R402.4.1.3 (IRC N1102.4.1.3) (New)	Revises air leakage threshold from a mandatory to a prescriptive requirement, while preserving an absolute maximum air leakage rate of 5.0 air changes per hour.	Increases energy use	In effect makes air leakage rates eligible for performance tradeoffs, while leaving the testing requirement mandatory. Preserves 5.0 ACH50 backstop for performance compliance in all climate zones.
RE130	R403.6.2 (IRC N1103.6.2) (New)	Adds testing requirements for mechanical ventilation systems.	Increases energy use	Adds new requirement for testing of mechanical ventilation systems, with exception for specific kitchen range hoods. Potential savings from identifying problems during testing, but potential energy increases due to pushing some systems to ventilate more than they would have.
CE160 P II	R403.10 (IRC N1103.10), R403.10.1 (IRC N1103.10.1), R403.10.3 (IRC N1103.10.3), R403.12 (IRC N1103.12)	Modifies pool and spa requirements to match the pool code.	Increases energy use	Primarily editorial but does include renewable systems that provide only 70% as opposed to 75% of energy. The renewable energy exception for pool and spa covers allows on-site or off-site renewable energy.

(a) Proposal numbers are as assigned by the ICC (http://media.iccsafe.org/code-development/group-b/2019-Group-B-CAH-compressed.pdf)
(b) Code sections refer to the 2018 IECC. Sections may be renumbered by the ICC in the 2021 IECC.

Appendix B – Prototype Building Model Description

B.1 Single-Family Prototype Model

	Item	Description	Data Source
General			
	Vintage	New Construction	
	Locations	See under Section 1.2.2	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Available fuel types	Natural Gas/Electricity/Fuel Oil	
	Building Type (Principal Building Function)	Residential	
	Building Prototype	Single-family detached	
Form			
	Total Floor Area (ft^2)	2,376 (29.8' x 39.8' x 2 stories)	Reference: Methodology for Evaluating Cost Effectiveness of

	Item	Description	Data Source
General			
	Building shape		Residential Energy Code Changes
	Aspect Ratio	1.33	
	Number of Floors	2	
	Window Fraction (Window-to-Floor Ratio)	Average Total: 15.0% divided equally among all facades	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Window Locations	All facades	
	Shading Geometry	None	
	Orientation	Back of the house faces North (see image)	
	Thermal Zoning	The house is divided into three thermal zones: 'living space', 'attic' and 'crawlspace', 'heated basement', 'unheated basement' when applicable	
	Floor to ceiling height	8.5’	

	Item	Description	Data Source
General			
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2x4 16" O.C. or 2x6 24" O.C.) 1" Stucco + Building Paper Felt + Insulating Sheathing (if applicable) + 5/8" Oriented Strand Board + Wall Insulation + 1/2" Drywall	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Walls, above grade, Wood Frame	IECC
	Dimensions	Based on floor area and aspect ratio	
	Tilts and orientations	Vertical	
	Roof		
	Construction	Asphalt Shingles	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Roofs, Insulation entirely above deck	IECC
	Tilts and orientations	Gabled Roof with a Slope of 4/12	
	Window		
	Dimensions	Based on window fraction, location, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	IECC Requirements Residential; Glazing	IECC
	SHGC (all)		
	Operable area	100%	
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		

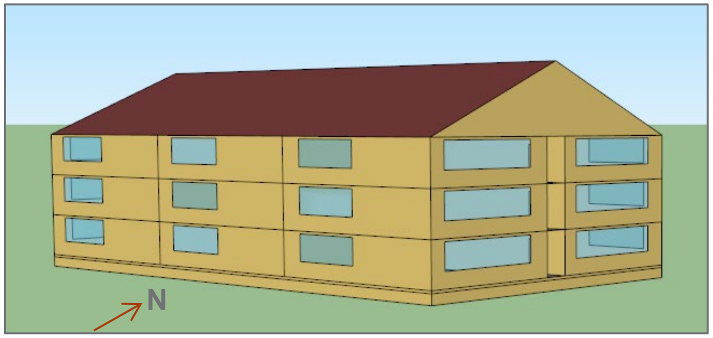
	Item	Description	Data Source
General			
	Visible transmittance		
	Foundation		
	Foundation Type	Four Foundation Types are Modeled- i. Slab-on Grade ii. Vented Crawlspace Depth 2' iii. Heated Basement - Depth 7' iv. Unheated Basement- Depth 7'	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Insulation level	IECC requirements for floors and basement walls	IECC
	Dimensions	Based on floor area and aspect ratio	
	Internal Mass	8 lb/ft^2 of floor area	IECC 2015 Section 404
	Infiltration (ACH)	2006 IECC: 8 Air Changes/Hour at 50 Pa (8 ACH50) 2009 IECC: 7 Air Changes/Hour at 50 Pa (7 ACH50) 2012-2021 IECC: 5 or 3 Air Changes/Hour at 50 Pa (5 or 3 ACH50) depending on climate zone	
HVAC			
	System Type		
	Heating type	Four Heating System Types are Modeled- i. Gas Furnace ii. Oil Furnace iii. Electric Furnace iv. Heat Pump	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes

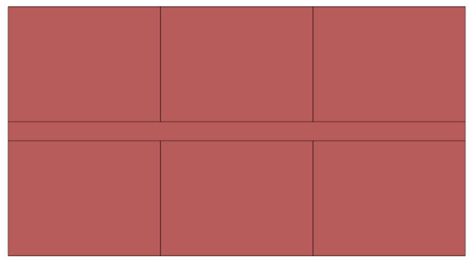
	Item	Description	Data Source
General			
	Cooling type	Central DX Air-Conditioner/Heat Pump	
	HVAC Sizing		
	Cooling	Autosized to design day	
	Heating	Autosized to design day	
	HVAC Efficiency		
	Air Conditioning	SEER 13	Federal minimum efficiency
	Heating	AFUE 78% / HSPF 7.7	Federal minimum efficiency
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/72°F Heating	
	Thermostat Setback	No setback	
	Supply air temperature	Maximum 110 F, Minimum 52 F	
	Ventilation	60 CFM Outdoor Air; Continuous Supply	2015 IRC
	Supply Fan		
	Fan schedules	See Appendix B.3	
	Supply Fan Total Efficiency (%)	Depending on the fan motor size	Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document[1]
	Supply Fan Pressure Drop	Depending on the fan supply air cfm	

[1] Residential Furnaces and Central Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document – Chapter 7 'Energy Use Characterization' http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/hvac_ch_07_energy-use_2011-04-25.pdf

	Item	Description	Data Source
General			
	Domestic Hot Water		
	DHW type	Individual Residential Water Heater with Storage Tank	
	Fuel type	Natural Gas/Electricity/Oil	
	Thermal efficiency (%)	EF = 0.59 for Gas-fired Water Heaters EF = 0.917 for Electric Water Heaters EF = 0.61 for Oil Water Heaters	Federal minimum efficiency
	Tank Volume (gal)	40 for Gas-fired Water Heaters 52 for Electric or Oil Water Heaters	Reference: Building America Research Benchmark
	Water temperature setpoint	120 F	
	Schedules	See Appendix B.2	
Internal Loads and Schedules			
	Lighting		
	Average interior power density (W/ft^2)	Living space: Lighting Power Density is 0.68 W/ft^2 (For interior lighting) Lighting loads for Garage and Exterior Lighting have also been included	Reference: 2014 Building America House Simulation Protocols
	Interior Lighting Schedule	See Appendix B.3	
	Internal Gains		
	Load (Btu/day)	17,900 + 23.8 x CFA + 4104 x Nbr See Appendix B.4 for the detailed calculations	Reference: IECC 2015 and Building America Research Benchmark
	Internal gains Schedule(s)	See Appendix B.3	
	Occupancy		
	Average people	800 ft2/per person for conditional total and 1601 ft2/per person for total	
	Occupancy Schedule	See Appendix B.3	

B.2 Multifamily Prototype Model

	Item	Description	Data Source
General			
	Vintage	New Construction	
	Location	See Section 1.2.2	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Available Fuel Types	Natural Gas/Electricity/Fuel Oil	
	Building Type	Residential	
	Building Prototype	Low-rise Multifamily	
Form			
	Total Floor Area	Whole Building- 23,400 ft^2 Each Dwelling Unit - 1200 ft^2	
	Building Shape		Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Aspect Ratio	Whole Building- 1.85 Each Dwelling Unit - 1.33	
	Number of Floors	3	
	Number of Units per Floor	6	
	Orientation	Back of the house faces North (see image)	
	Dimensions	Whole Building - 120' x 65' x 25'6" Each Dwelling Unit - 40' x 30' x 8'6"	

	Item	Description	Data Source
	Conditioned Floor Area	Each Dwelling Unit- 1200 ft^2	
	Window Area (Window-to- Exterior Wall Ratio)	23% WWR (Does not include breezeway walls)	
	Exterior Door Area	Each Dwelling Unit - 21 ft^2 Whole Building - 378 ft^2	
	Shading Geometry	None	
	Thermal Zoning	Each floor has six dwelling units with a breezeway in the center. Each dwelling unit is modeled as a separate zone. The other thermal zones are: attic, breezeway and foundation (basements and crawlspace only)	
			
	Floor to ceiling height	8.5’	
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2x4 16" O.C. or 2x6 24" O.C.) 1" Stucco + Building Paper Felt + Insulating Sheathing (if applicable) + 5/8" Oriented Strand Board + Wall Insulation + 1/2" Drywall	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Wood-Frame Wall R-value	IECC
	Dimensions	Each Dwelling Unit: 40' x 8'6" and 30' x 8'6"	
	Tilts and orientations	Vertical	

	Item	Description	Data Source
	Roof		
	Construction	Built-up Roof: Asphalt Shingles+ 1/2 in. OSB	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	IECC Requirements Residential; Ceiling R-value	IECC
	Tilts and orientations	Gabled Roof with a Slope of 4/12	
	Window		
	Dimensions	Based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	IECC Requirements Fenestration U-factor and SHGC	
	SHGC (all)		
	Operable area	100%	
	Skylight		
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Four Foundation Types are Modeled- i. Slab-on Grade ii. Vented Crawlspace Depth 2' iii. Heated Basement - Depth 7' iv. Unheated Basement- Depth 7'	Reference: Methodology for Evaluating Cost Effectiveness of Residential Energy Code Changes
	Insulation level	IECC Requirements for floors, slabs, and basement walls	
	Dimensions	Based on floor area and aspect ratio	

	Item	Description	Data Source
	Internal Mass	8 lb/ft^2 of floor area	IECC 2006 Section 404
	Infiltration (ACH)	2006 IECC: 8 Air Changes/Hour at 50 Pa 2009 IECC: 7 Air Changes/Hour at 50 Pa 2012-2021 IECC: 5 or 3 Air Changes/Hour at 50 Pa depending on climate zone	
HVAC			
	System Type		
	Heating type	Four Heating System Types are Modeled- i. Gas Furnace ii. Oil Furnace iii. Electric Furnace iv. Heat Pump	
	Cooling type	Central DX Air-Conditioner/Heat Pump (1 per unit)	
	HVAC Sizing		
	Cooling	Autosized to design day	
	Heating	Autosized to design day	
	HVAC Efficiency		
	Air Conditioning	SEER 13	Federal Minimum Equipment Efficiency for Air Conditioners and Condensing Units
	Heating	AFUE 78% / HSPF 7.7	Federal Minimum Equipment Efficiency
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/72°F Heating	
	Thermostat Setback	No setback	
	Supply air temperature	Maximum 110 F, Minimum 52 F	
	Ventilation	45 CFM Outdoor Air per dwelling unit; Continuous Supply	2015 International Residential Code (IRC)
	Supply Fan		
	Fan schedules	See Appendix B.3	

	Item	Description	Data Source
	Supply Fan Total Efficiency (%)	Fan efficiency 58%; Motor efficiency 65% (PSC motor)	Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document[1]
	Supply Fan Pressure Drop	0.6" w.g.	
	Service Water Heating (SWH)		
	SWH type	Individual Residential Water Heater with Storage Tank	
	Fuel type	Natural Gas / Electricity/Oil	
	Thermal efficiency (%)	EF = 0.59 for Gas-fired Water Heaters EF = 0.917 for Electric Water Heaters EF = 0.61 for Oil Water Heaters	Federal Minimum Equipment Efficiency
	Tank Volume (gal)	40 for Gas-fired Water Heaters 52 for Electric or Oil Water Heaters	
	Water temperature setpoint	120 F	
	Schedules	See Appendix B.3	
Internal Loads and Schedules			
	Lighting		
	Average power density (W/ft^2)	Apartment units: Lighting Power Density is 0.82 W/ft^2 (For interior lighting) Lighting loads for Garage and Exterior Lighting have also been included	2014 Building America House Simulation Protocols
	Interior Lighting Schedule	See Appendix B.3	
	Internal Gains		
	Internal Gains (Btu/day per Dwelling Unit)	$17{,}900 + 23.8 \times CFA + 4104 \times N_{br}$ See Appendix B.4 for the detailed calculations	

[1] Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document: Chapter 7 'Energy Use Characterization.' Residential Furnaces and Centralized Air Conditioners and Heat Pumps Direct Final Rule Technical Support Document

	Item	Description	Data Source
	Internal Gains Schedule(s)	See under Appendix B.3	
	Occupancy		
	Average people	2 people/apartment unit	
	Occupancy Schedule	See Appendix B.3	

B.3 Schedules

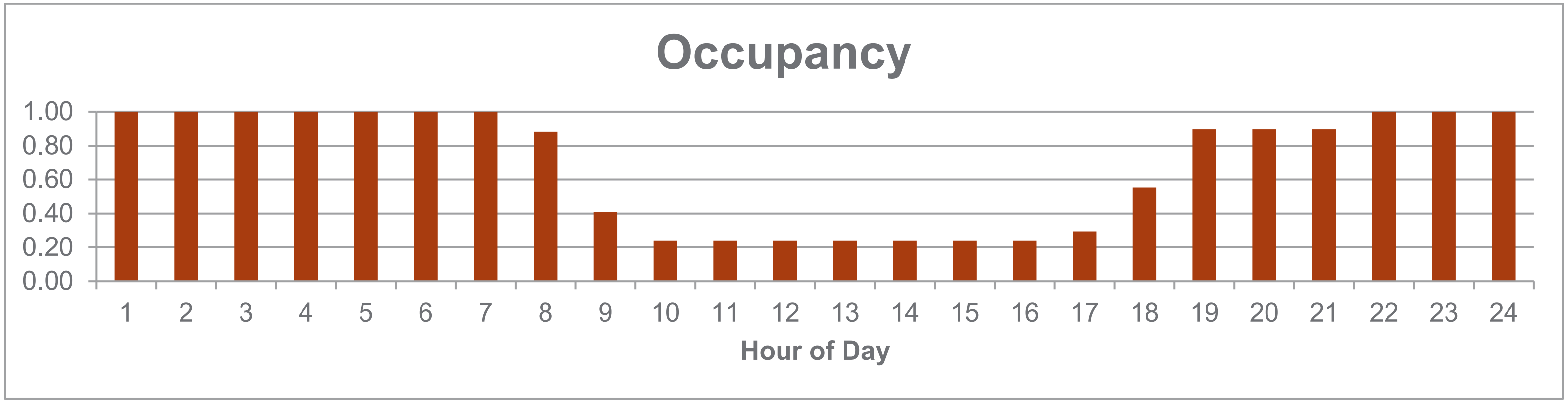


Figure B.1. Occupancy Schedules

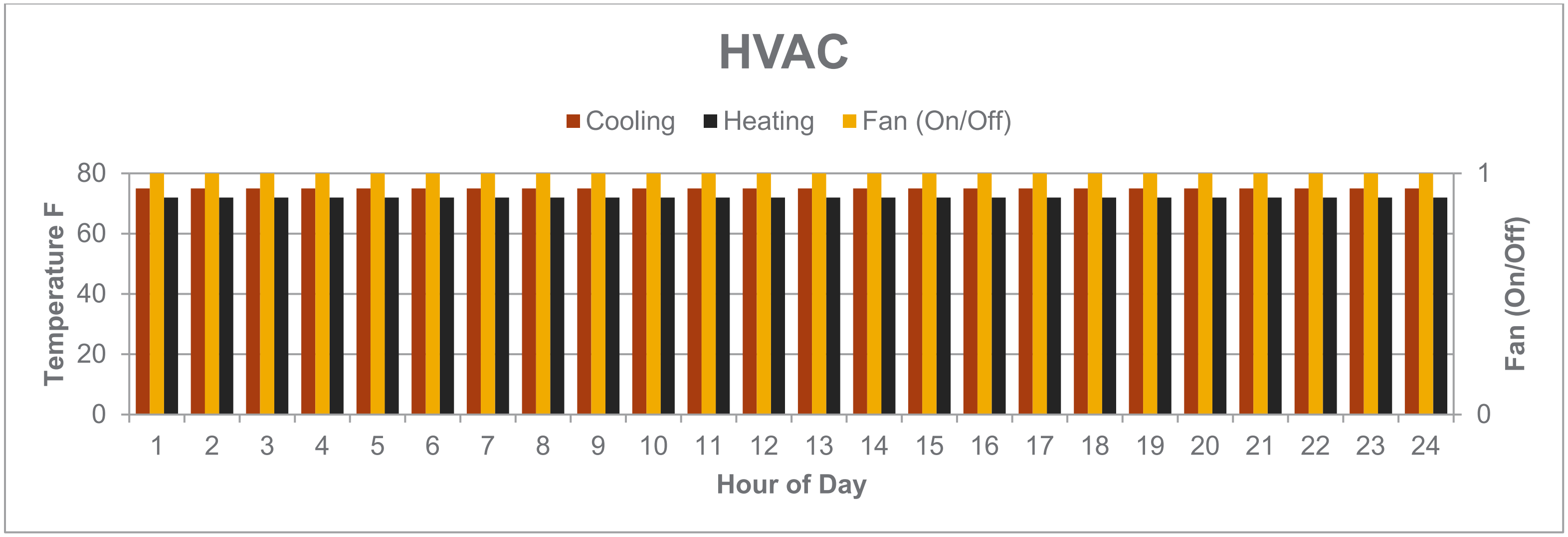


Figure B.2. HVAC Temperature Schedule

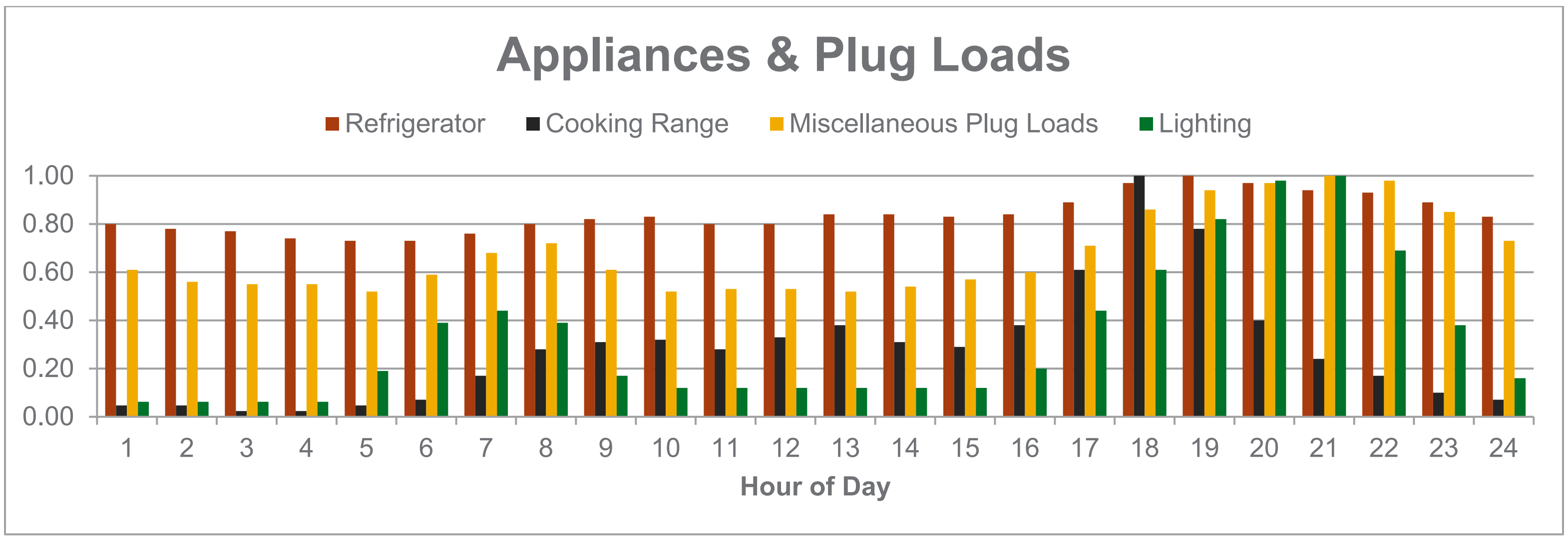


Figure B.3. Lighting and Appliance Schedules

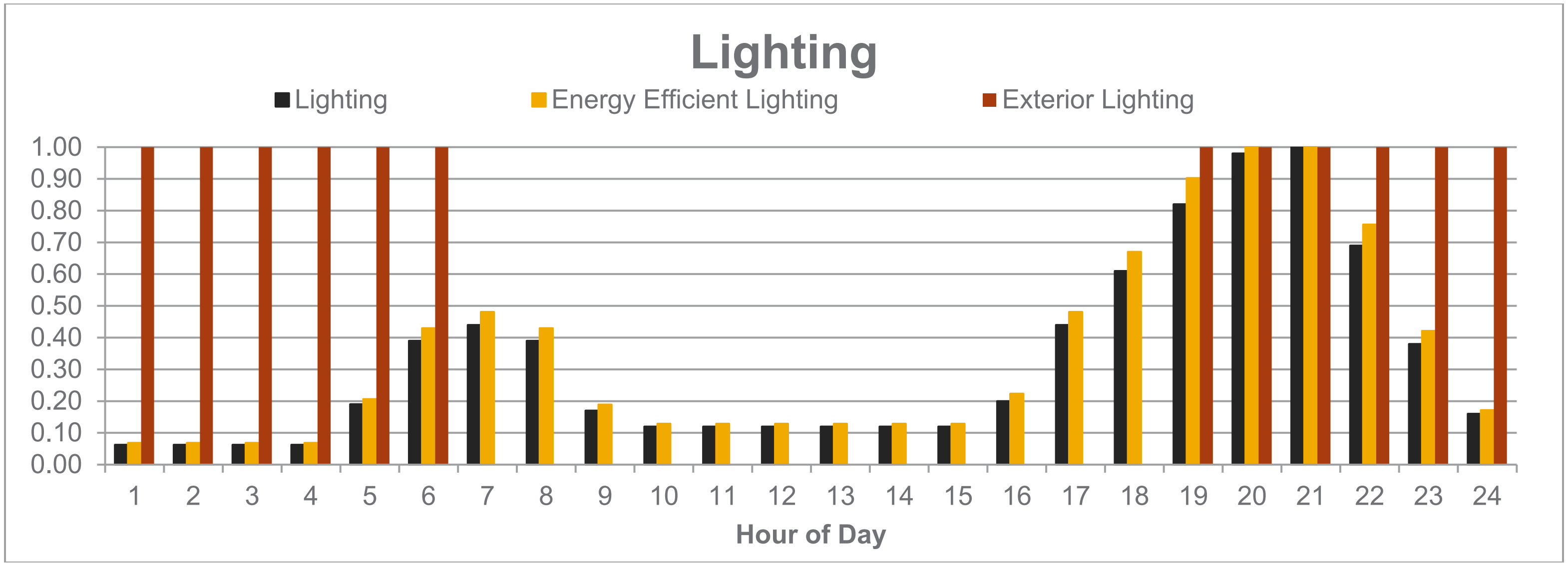


Figure B.4. Interior and Exterior Lighting Schedules

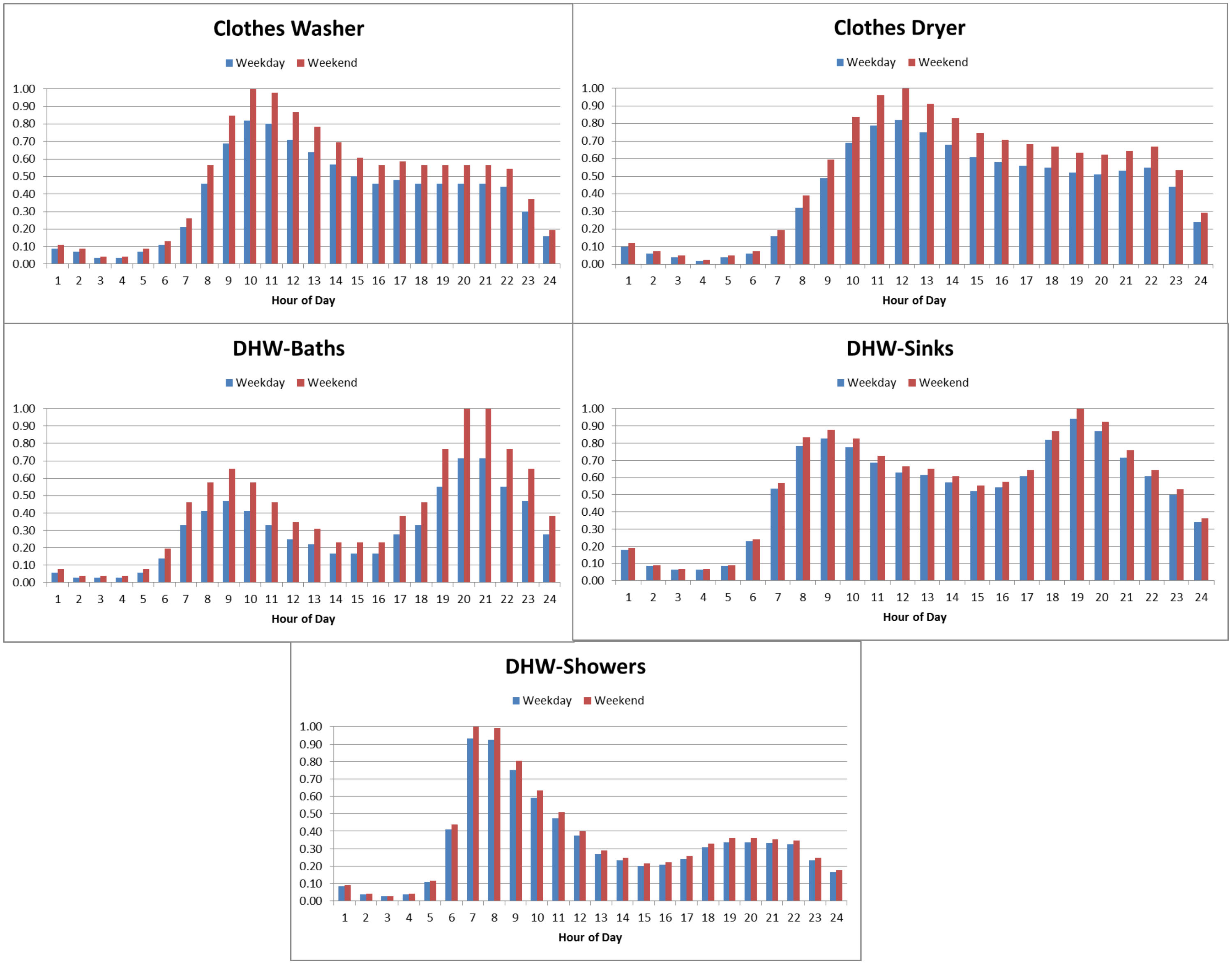


Figure B.5. Service Hot Water Demand Schedules

B.4 Internal Gains Assumptions

Table B.1. Total Internal Gains for the Single-Family Prototype for the 2012 through 2021 IECC

Appliance	Power	Total Electricity (kWh/yr)	Fraction Sensible	Fraction Latent	Fraction of Electricity Use Not Turned into Heat	Internal Heat Gains (kWh/yr)		
						2012 IECC	2015 IECC	2018-2021 IECC
Refrigerator	91.09 W	668.90	1.00	0.00	0.00	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.20	87	87	87
Clothes Dryer	222.11 W	868.15	0.15	0.05	0.80	174	174	174
Dishwasher	68.33 W	214.16	0.60	0.15	0.25	161	161	161
Range	248.97 W	604.90	0.40	0.30	0.30	423	423	423
Misc. Plug Load	0.228 W/ft^2	3238.13	0.69	0.06	0.25	2429	2429	2429
Miscellaneous Electric Loads	182.5 W	1598.00	0.69	0.06	0.25	1199	1199	1199
IECC Adjustment Factor	0.0275 W/ft^2	390.56	0.69	0.06	0.25	293	293	293
Lighting			1.00	0.00	0.00	1345	1164	1164
Occupants	3 Occupants					2123	2123	2123
Total					kWh/yr	8902	8721	8721
					kBtu/yr	30373	29755	29755
					Btu/day	83213	81522	81522

Table B.2. Total Internal Gains for the Multifamily Prototype for the 2012 through 2021 IECC (per dwelling unit)

Appliance	Power	Total Electricity (kWh/yr)	Fraction Sensible	Fraction Latent	Fraction of Electricity Use Not Turned into Heat	Internal Heat Gains (kWh/yr)		
						2012 IECC	2015 IECC	2018-2021 IECC
Refrigerator	91.09 W	668.90	1.00	0.00	0	669	669	669
Clothes Washer	29.6 W	109.16	0.80	0.00	0.2	87	87	87
Clothes Dryer	222.11 W	868.15	0.15	0.05	0.8	174	174	174
Dishwasher	68.33 W	214.16	0.60	0.15	0.25	161	161	161
Range	248.97 W	604.00	0.40	0.30	0.3	423	423	423
Misc. Plug Load	0.228 W/ft^2	1619.00	0.69	0.06	0.25	1214	1214	1214
Miscellaneous Electric Loads	121.88 W	1067.00	0.69	0.06	0.25	800	800	800
IECC Adjustment Factor	0.0275 W/ft^2	195.28	0.69	0.06	0.25	146	146	146
Lighting			1.00	0.00	0	405	351	351
Occupants	2 Occupants					1416	1416	1416
Total					kWh/yr	5495	5440	5440
					kBtu/yr	18748	18562	18562
					Btu/Day	51364	50855	50855

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