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PNNL-31018

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April 2021

V. Robert Salcido
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Executive Summary

Section 304(a) of the Energy Conservation and Production Act (ECPA), as amended, directs the U.S. Secretary of Energy to review the International Energy Conservation Code (IECC)[1] and make a *determination* as to whether updated editions would improve energy efficiency in residential buildings. The IECC is developed by the International Code Council (ICC) through an established industry review and consensus process with updated editions typically published every 3 years. The U.S. Department of Energy (DOE) reviews the energy saving impacts of updated code editions and publishes its findings in the *Federal Register*. The DOE determination and accompanying technical analysis serve as useful guidance to state and local governments as they review and update their building codes.

The most recent edition, the 2021 IECC, was published on January 29, 2021, triggering the DOE review and determination process[2]. DOE and Pacific Northwest National Laboratory (PNNL) conducted a technical analysis to determine energy savings for the 2021 IECC residential provisions relative to the previous edition, the 2018 IECC (ICC 2017). This report documents the methodology used to conduct the analysis and summarizes the results.

Methodology

The determination analysis is based on an established DOE Methodology (Taylor et al. 2015) and is consistent with the previously published determination (DOE 2019). The analysis entails a combination of *qualitative* and *quantitative* components to identify changes that have a direct impact on residential energy efficiency, and which can be reasonably quantified in estimating overall national average saving impacts. This process can be summarized as follows:

- **Qualitative Assessment**: A compilation of all code changes approved by the ICC for inclusion in the IECC. Individual changes are characterized to identify those expected to have a direct impact on energy efficiency in a significant portion of typical residential buildings.
- **Quantitative Assessment**: Code changes are filtered to retain those that could be reasonably quantified through energy modeling and analysis. The resulting collection is then further analyzed to estimate combined effects, with the results aggregated and weighted across the range of climates, building types, and foundation types to quantify the national average savings impacts of the updated code.

Results

A total of 114 approved code change proposals were identified and analyzed for the 2021 IECC. Analyses of those changes indicate the following:

- 35 changes with a direct impact on energy use in residential buildings—29 of these are expected to reduce energy use while 6 are expected to increase energy use
- 79 additional changes—changes in this category are administrative, impact non-energy portions of the code, or are otherwise not expected to have a direct impact on energy savings under the applied methodology

[1] ECPA originally recognized the 1992 Council of American Building Officials (CABO) Model Energy Code and its successor editions. The IECC is the contemporary successor to the CABO Model Energy Code.
[2] The publication of the 2021 IECC was delayed several months due to appeals.

Of the 35 code changes characterized as having a direct impact on energy efficiency, 11 are expected to impact a sufficient fraction of new homes to warrant further quantitative analysis to assess the overall magnitude of the 2021 IECC's impact. Those 11 changes are analyzed as part of the quantitative analysis, the results of which indicate that residential buildings meeting the 2021 IECC incur the following savings on a weighted national average basis:

- 9.38 percent of annual site energy use intensity (EUI)
- 8.79 percent of annual source EUI
- 8.66 percent of annual energy cost
- 8.66 percent of carbon emissions and social cost of carbon (SC-CO_2)

Table ES.1 shows energy and carbon savings results, tabulated by climate zone. Relative savings in terms of annual energy costs vary modestly across climate zones, ranging from 4.56 percent in climate zone 6 to 10.38 percent in climate zone 8.

Table ES.2 and Table ES.3 summarize the estimated EUIs for the 2018 and 2021 IECC, respectively. Table ES.4,

Table ES.5, and Table ES.6 show the results aggregated by building type.

Table ES.1. Relative Energy, Carbon and Social Cost of Carbon Savings of the 2021 IECC compared to the 2018 IECC by Climate Zone (percent)

Climate Zone	Weight (%)	Site EUI (%)	Source EUI (%)	Energy Costs (%)	CO_2 Emissions & Social Cost of Carbon (%)
1	4.30	10.80	9.73	9.51	9.53
2	22.43	10.00	9.13	8.93	8.95
3	29.04	10.48	9.75	9.57	9.59
4	19.49	10.05	9.45	9.32	9.32
5	19.51	8.50	7.63	7.44	7.42
6	4.68	4.28	4.43	4.56	4.52
7	0.53	12.65	10.72	10.13	10.17
8	0.02	12.48	10.93	10.38	10.44
National	100.00	9.38	8.79	8.66	8.66

Table ES.2. Energy Use and Carbon Emissions of the 2018 IECC by Climate Zone

Climate Zone	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
1	4.30	28.8	79.1	2,046	11.0	561
2	22.43	31.2	80.7	2,088	11.2	572
3	29.04	31.5	78.4	2,024	10.9	557
4	19.49	37.1	83.5	2,139	11.5	587
5	19.51	45.4	86.6	2,252	12.1	618
6	4.68	50.9	96.5	2,613	14.0	715
7	0.53	58.1	110.8	2,936	15.8	807
8	0.02	78.0	147.1	3,845	20.8	1,063
National	100.00	36.4	82.7	2,139	11.5	587

Table ES.3. Energy Use and Carbon Emissions of the 2021 IECC by Climate Zone

Climate Zone	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
1	4.30	25.7	71.4	1,851	9.9	506
2	22.43	28.1	73.3	1,902	10.2	521
3	29.04	28.2	70.8	1,830	9.8	501
4	19.49	33.3	75.6	1,940	10.4	531
5	19.51	41.5	80.0	2,084	11.2	572
6	4.68	48.7	92.2	2,494	13.4	684
7	0.53	50.7	98.9	2,638	14.2	725
8	0.02	68.3	131.1	3,445	18.6	950
National	100.00	33.0	75.4	1,954	10.5	536

Table ES.4. Relative Energy, Carbon and Social Cost of Carbon Savings of the 2021 IECC compared to the 2018 IECC by Building Type (percent)

Building Type	Weight (%)	Site EUI (%)	Source EUI (%)	Energy Costs (%)	CO_2 Emissions & Social Cost of Carbon (%)
Single-family	66.04	12.56	11.21	10.91	10.91
Multifamily Unit	33.96	8.51	8.12	8.03	8.04
National	100.00	9.38	8.79	8.66	8.66

Table ES.5. Energy Use and Carbon Emissions of the 2018 IECC by Building Type

Building Type	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
Single-family	66.04	38.5	87.9	1,372	7.4	378
Multifamily Unit	33.96	35.9	81.4	2,533	13.6	695
National	100.00	36.4	82.7	2,139	11.5	587

Table ES.6. Energy Use and Carbon Emissions of the 2021 IECC by Building Type

Building Type	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
Single-family	66.04	33.6	78.0	1,222	6.6	337
Multifamily Unit	33.96	32.8	74.8	2,330	12.5	639
National	100.00	33.0	75.4	1,954	10.5	536

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 per hour at 50 pascals
AEO	Annual Energy Outlook
AFUE	annual fuel utilization efficiencies
AHRI	Air Conditioning, Heating, and refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu	British thermal unit(s)
CABO	Council of American Building Officials
CF	cubic foot (feet)
CFL	compact fluorescent lamp
CFM	cubic feet per minute
DOE	U.S. Department of Energy
ECPA	Energy Conservation and Production Act
EER	energy efficiency ratio
EF	energy factor
EIA	U.S. Energy Information Administration
ERI	Energy Rating Index
EPA	U.S. Environmental Protection Agency
ERV	energy recovery ventilator
EUI	energy use intensity
°F	degree(s) Fahrenheit
ft^2	square foot(feet)
hr	hour(s)
HRV	heat recovery ventilator
HSPF	heating season performance factors
HVAC	heating, ventilating, and air conditioning
HWDS	hot water distribution system
IAM	integrated assessment model
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)
LED	light emitting diode
LF	linear fluorescent

MEC	Model Energy Code
PNNL	Pacific Northwest National Laboratory
REC	Renewable Energy Certificate
RECS	Residential Energy Consumption Survey
SC-CO_2	Social cost of carbon
SEER	seasonal energy efficiency rating
SHGC	solar heat gain coefficient
SWH	service water heating
TDE	thermal distribution efficiency
W	watt
yr	year(s)

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1.0 Introduction

The International Energy Conservation Code (IECC) is recognized by the U.S. Congress as the national model energy code for residential buildings under the Energy Conservation and Production Act, as amended (ECPA) (42 USC 6833). Section 304(a) of the ECPA provides that whenever the 1992 Council of American Building Officials (CABO) Model Energy Code (MEC) or any successor to that code is revised, the U.S. Secretary of Energy must make a *determination*, not later than 12 months after such revision, whether the revised code would improve energy efficiency in residential buildings and must publish notice of such determination in the *Federal Register* (42 U.S.C. 6833(a)(5)(A)). The IECC is the contemporary successor to the 1992 CABO MEC specified in the ECPA.

On December 10, 2019, the U.S. Department of Energy (DOE) issued an affirmative determination of energy savings for the 2018 IECC, the relevant successor to the 1992 MEC at the time, that concluded that the 2018 IECC would achieve greater energy efficiency in residential buildings than the 2015 IECC (84 FR 67435). Through this determination, the 2018 IECC became the national model energy code for residential buildings. Consequently, and consistent with previous determinations, the 2018 IECC also became the baseline to which future changes are compared, including the current review of the 2021 IECC.

To support DOE in fulfilling its statutory directive, Pacific Northwest National Laboratory (PNNL) conducted an analysis to determine energy savings for the 2021 IECC residential provisions compared to those of the 2018 IECC. This report documents the methodology used to conduct the analysis and provides a summary of results and findings.

Section 2.0 of this report provides an overview of the analysis, which is based on a combination of both qualitative and quantitative components. Section 3.0 provides the qualitative and quantitative analysis results. A comprehensive list of all code change proposals approved for inclusion in the 2021 IECC is included in Appendix A. Additionally, Appendix B and Appendix C detail weighting factors and updates to the energy savings calculation methodology related to *EnergyPlus* software updates. Appendix D details the modeling strategies used in the quantitative analysis.

2.0 Methodology

2.1 Overview

The current analysis is based on an established DOE Methodology (Taylor et al. 2015) and is consistent with previously published determinations (DOE 2019). The analysis is based on a combination of *qualitative* and *quantitative* components to identify changes that have a direct impact on residential energy efficiency that can be reasonably quantified in estimating overall savings impacts. This process can be summarized as follows:

- **Qualitative Assessment**: A compilation of all code changes approved by the ICC for inclusion in the IECC. Individual changes are characterized to identify those expected to have a direct impact on energy efficiency in a significant portion of typical residential buildings.
- **Quantitative Assessment**: Code changes are filtered to retain those that could be reasonably quantified through energy modeling and analysis. The resulting collection is then further analyzed to estimate combined effects, with the results aggregated and weighted across the range of climates and building types to quantify the national average impacts of the 2021 IECC.

The proceeding sections provide additional detail on the analysis methodology. Several individual changes warrant additional consideration and are discussed in Section 3.1.1. Findings resulting from the analysis are covered in Section 3.0.

2.2 Qualitative Assessment

The first step of the analysis is a qualitative assessment by which all approved code change proposals are categorized according to their effect on homes, with particular attention to their expected impact on energy use. Changes expected to have an impact on residential energy efficiency are characterized as follows:

1. *Decreases Energy Use*: The change is expected to have a beneficial efficiency impact on some or all homes complying with the code (increased energy efficiency and savings)
2. *Increases Energy Use*: The change is expected to have a detrimental efficiency impact on some or all homes complying with the code (decreased energy efficiency and savings).

Many changes do not have a direct impact on energy efficiency and therefore are not designated as falling into one of the above categories. Examples of such changes often include:

- Changes affecting only procedural aspects of complying with the code, such as those providing guidance on inspection protocols or modeling rulesets
- Changes where impacts are captured under a complementary code requirement, such as the relationship between air tightness testing, associated thresholds (e.g., 5 ACH50), and component air sealing requirements—this serves to avoid double-counting in the quantitative analysis
- Changes targeting non-energy aspects of the IECC, such as envelope efficiency requirements for performance compliance
- Administrative changes, including editorial corrections, new definitions, reordering or numbering of code sections, clarifications, and reference updates.

Code changes characterized as increasing or decreasing energy use are further evaluated as to whether they can be reasonably quantified through quantitative energy analysis. Appendix A contains a full list of all code changes included in the 2021 IECC and their categorizations.

2.3 Quantitative Assessment

The current analysis is based on an established DOE Methodology (Taylor et al. 2015) and builds on previous work by PNNL (DOE 2019). DOE has historically focused its review of model codes on changes that affect the *mandatory* and *prescriptive* requirements of the code because such changes are considered to have the most direct and quantifiable impact on energy efficiency in buildings and also historically have been viewed as the predominant compliance option employed by users of the IECC. While all changes are reviewed individually and assessed as to their anticipated impact during the qualitative analysis, only those changes with a direct and reasonably measurable energy impact are included in the quantitative assessment and therefore the final savings estimates.

Further, the 2021 IECC includes two performance-based compliance options (Performance and Energy Rating Index (ERI)). These are intended to provide increased flexibility while ensuring that the resulting building is designed to use less (or equal) energy compared to the standard reference baseline. Performance-based alternatives have received increased attention and emphasis in recent code updates. However, these are generally considered optional alternatives to the more traditional prescriptive requirements and in all cases remain subject to the mandatory code requirements.

Changes in the performance-based options can be difficult to reasonably quantify via commonly accepted methods or are speculative in terms of their expected uptake in practice (i.e., have not been widely implemented in the field to date). For this reason, performance-based changes are generally excluded from the quantitative assessment, in which case DOE often defers to the qualitative assessment of the individual change.

The following sections describe the analysis procedures and simulation models relied upon in the quantitative assessment.

2.3.1 Building Types and Model Prototypes

DOE's established methodology uses a suite of representative residential prototype buildings, including a single-family and a low-rise multifamily residential building, each with four different foundation types (i.e., slab-on-grade, vented crawlspace, heated basement, unheated basement) and four heating system types (i.e., gas furnace, electric resistance, heat pump, fuel oil furnace). The entire set of configurations is designed to represent the majority of the new residential building construction stock in the United States and 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).

Thus, a total of 32 prototype buildings and configurations are represented (i.e., 2 building types, 4 foundation types, and 4 fuel/equipment types) resulting in 576 individual energy simulation models. Detailed descriptions of the prototype building models and their representative operational assumptions are documented by Mendon et al. (2013, 2015) and Mendon and Taylor (2014).

2.3.2 Climate Zones

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 1.

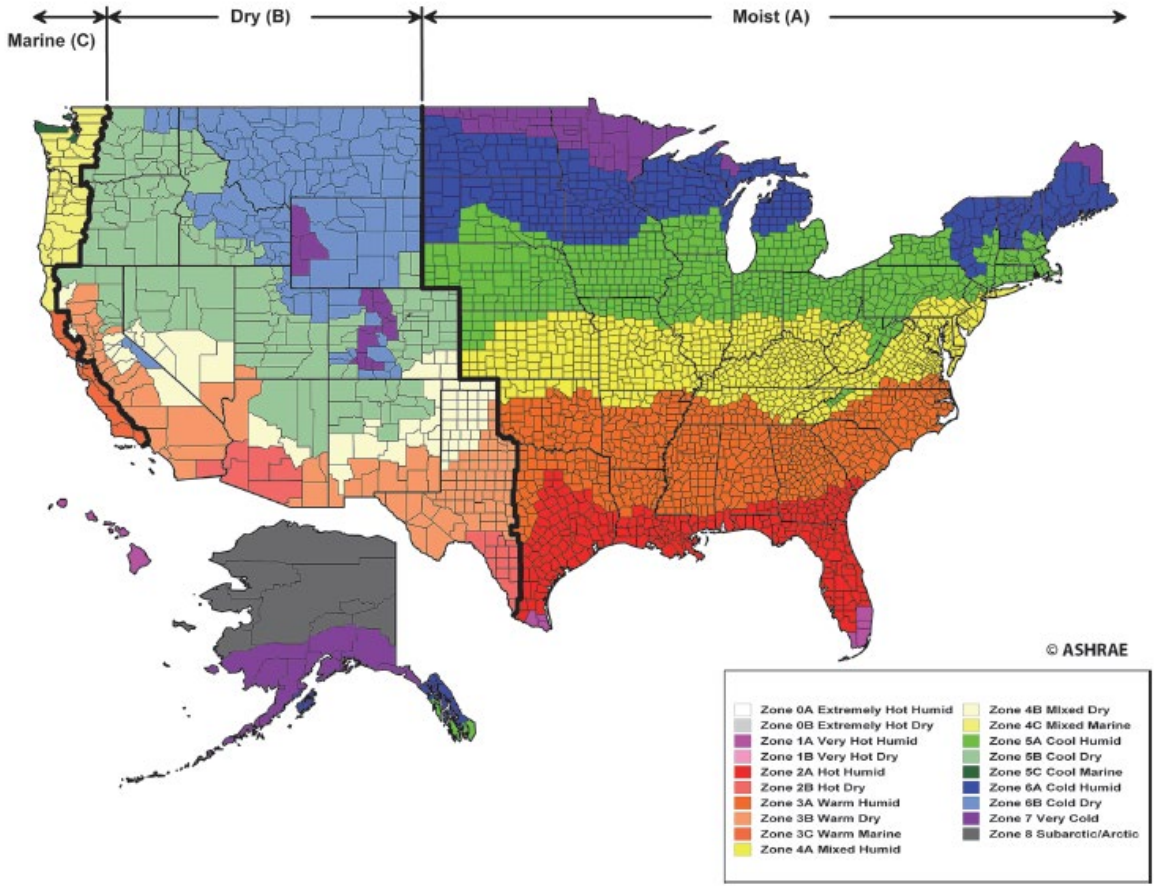

Figure 1. U.S. Climate Zone Map

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.

2.3.3 Weighting Factors

Weighting factors for each of the prototype buildings were developed for all U.S. climate zones using 2019 new residential construction starts[1] and residential construction details from the U.S. Census (Census 2010), the Residential Energy Consumption Survey (RECS 2013) 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. Table 1 through Table 4 summarize the weights aggregated to building type, foundation type, heating system, and climate zone levels. The detailed weighting factors for each prototype building are included in Appendix B.

[1] See the U.S. Census Bureau webpage at https://www.census.gov/construction/bps/stateannual.html.

Table 1. Weighting Factors by Building Type

Building Type	Weight (%)
Single-Family	66.04
Multifamily	33.96
Total	100.00

Table 2. Weighting Factors by Foundation Type

Foundation Type	Weight (%)
Crawlspace	27.44
Slab-on-Grade	50.86
Heated Basement	11.77
Unheated Basement	9.93
Total	100.00

Table 3. Weighting Factors by Heating System

Heating System Type	Weight (%)
Gas-Fired Furnace	49.15
Electric Furnace	5.64
Oil-fired Furnace	1.28
Heat Pump	43.93
Total	100.00

Table 4. 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
Total	100.00

2.4 Conversion of Energy Units

The determination analysis is based on three metrics of energy consumption and one for carbon emissions:

1. *Site Energy*: The energy consumed at the end of the generation cycle within the building site, sometimes references as “behind the meter” or as shown on the building’s utility bill

2. *Source Energy*: The energy required to power a building including generation and distribution
3. *Energy Cost*: The total cost of energy required for building functions
4. *Carbon Emissions*: The weight of carbon released to the atmosphere from source energy consumption.
5. *Social Cost of Carbon (SC-CO_2)*: the monetary value of the net harm to society associated with adding a small amount of that CO_2 to the atmosphere in a given year[1].

The annual site energy results for total building energy use were converted to annual site EUIs based on the conditioned floor area of the residential prototype models. This conversion includes considering heating, cooling, fans, domestic water heating, lighting, appliances, plug loads, and ventilation from the simulation analysis of the residential prototype models that minimally comply with the prescriptive and mandatory requirements of the 2018 and 2021 IECC. The site energy use was converted to source energy (or primary energy), which accounts for the inefficiencies of generation and losses involved in delivering energy to the site.

The source-site conversion ratios for electricity and natural gas were calculated from the 2020 values reported in Table 2 of the 2021 Annual Energy Outlook produced by the U.S. Energy Information Administration (EIA 2021a). Table 5 and Table 6 summarize the source-site conversion factor calculations for electricity and natural gas, respectively. The EIA does not report similar losses associated with fuel oil. In absence of these data, a source-site conversion ratio of 1.1 is used for fuel oil based on the 2021 IECC.

Table 5. Calculation of the Source-Site Ratio for Electricity

Electricity (quadrillion Btu)	Electricity- Related Losses (quadrillion Btu)	Source-Site Ratio[(a)]
4.99	9.71	2.95

(a) Source-Site ratio= (4.99+9.71)/4.99=2.95

Table 6. Calculation of the Source-Site Ratio for Natural Gas

Sum of Natural Gas Use, Pipeline, Lease and Plant Fuel (quadrillion Btu)	Delivered to Consumers (quadrillion Btu)	Source-Site Ratio[(a)]
30.41	27.79	1.09

(a) Source-Site ratio= 30.41/27.79= 1.09

Finally, the annual energy results from the simulation analysis were converted to annual energy costs using the 2020 national average fuel prices from the EIA. 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 for natural gas 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

[1] https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

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 (EIA 2021b), resulting in a national average price of $18.19/million Btu for fuel oil.

Carbon emissions in the quantitative analysis are based on the source energy consumption on a national scale. Carbon emission metrics are provided by the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Equivalencies Calculator[1]. The Greenhouse calculator reports the national marginal carbon emission conversion factor for electricity at 7.07 x 10^{-4} metric tons CO_2/kWh. For natural gas, the carbon emission conversion factor is 0.0053 metric tons CO_2/therm. For oil, the carbon emission conversion factor is 10.243 x 10-3 metric tons CO_2/gallon. Table 7 summarizes the carbon emission factors.

Table 7. Carbon Emission Factors by Fuel Type

Fuel Source	Carbon Emission Factor
Electricity	7.07 x 10^{-4} metric tons CO_2/kWh
Natural Gas	0.0053 metric tons CO_2/therm
Fuel Oil	10.243 x 10^{-3} metric tons CO_2/gallon

On January 20, 2021, President Biden issued E.O. 13990[2], which noted that it is essential that agencies capture the full costs of greenhouse gas emissions as accurately as possible, including by taking global damages into account and that doing so facilitates sound decision-making, recognizes the breadth of climate impacts, and supports the international leadership of the United States on climate issues. To that end, DOE is including estimates of the absolute cost and relative costs savings of greenhouse gas emissions associated with the building energy use examined in this analysis.

The principal greenhouse gas emission associated with residential building energy use as examined in this analysis is carbon dioxide (CO_2). We estimate the global social benefits of first year CO_2 emission reductions expected from implementation of the 2021 using the SC-CO_2 estimates presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* (IWG 2021). These SC-CO_2 estimates are interim values developed under Executive Order (E.O.) 13990 for use in benefit-cost analyses until an improved estimate of the impacts of climate change can be developed based on the best available science and economics. These SC-CO_2 estimates are the same as those used in the *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (IWG 2016), but are updated to 2020$. An unrounded value of $51.086 (2020$/Metric Ton CO_2) is used in this analysis reflecting a SC-CO_2 present value per metric ton of carbon dioxide emissions avoided in 2020 based on a 3% discount rate and the average global damage estimate from three integrated assessment models (IAMs).

[1] See the EPA webpage at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

[2] Exec. Order No. 13990, 86 Fed. Reg. 7037 (January 20, 2021) <https://www.federalregister.gov/documents/2021/01/25/2021-01765/protecting-public-health-and-the-environment-and-restoring-science-to-tackle-the-climate-crisis>

3.0 Results

3.1 Qualitative Assessment

The approved code changes incorporated into the 2021 IECC that have a direct effect on energy use are listed in Table 7. The following information is shown for each change:

1. **Proposal Number**: Change proposal designation assigned by the ICC
2. **Code Section(s)**: Section numbers in the 2018 IECC that are affected by the code change[1]
3. **Description of Change(s)**: Descriptive summary of the change
4. **Impact on Energy Efficiency:** Qualitative characterization of those changes expected to increase or decrease energy use
5. **Included in Energy Analysis:** Indication whether the change can be reasonably assessed through further quantitative analysis
6. **Discussion:** A brief discussion expanding on the description providing additional rationale if appropriate.

[1] Because sections are often added or deleted, section numbers will often differ in the 2021 IECC.

Table 7. 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	Included in Energy Analysis	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	Yes	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	Yes	
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	Yes	
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	Yes	
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 2-4 and adds new requirement for minimum fenestration U-factor in climate zones 3-8.	Reduces energy use	Yes	
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	Yes	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	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	Yes	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	Yes	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	Yes	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	Yes	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 R407 (New), R407.1 (New), R407.2 (New), R407.2.1 (New), R407.2.2 (New), R407.2.3 (New), R407.2.4 (New), R407.2.5 (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	Yes	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.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE27	Table R402.1.2 (IRC N1102.1.2)	Adds alternative wood frame wall options in all climates.	Reduces energy use	No	Adds cavity-only options for 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)	Eliminate footnote gas option for floor cavity insulation.	Reduces energy use	No	Footnote g allowed merely filling the cavity (but at least R19) 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 solar heat gain coefficient (SHGC) of 0.4 in climate zone 5 and marine 4.	Reduces energy use	No	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	No	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	No	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	No	Makes weatherstripping mandatory, leaves insulation requirement prescriptive. Total insulation and air leakage requirements remain unchanged and thus not part of the quantitative analysis.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	Prescriptive wall insulation requirements remain unchanged and not factored in the quantitative analysis.
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	No	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	No	Lowers the allowable area-weighted maximum U-factor for climate zones 4-8 and 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	No	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.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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.
RE149	R404.2 (IRC N1104.2) (New)	Adds 4 new automated control requirements for exterior lighting if installed lighting power is greater than 30 watts.	Reduces energy use	No	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 (HWDS) compactness factor to the calculation of the proposed design hot water use (gallons/day) in Table R405.5.2(1).	Reduces energy use	No	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	No	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 (SWH) efficiency compared to envelope efficiency. Both proposed and baseline buildings have the same reduced water usage.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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 trade-offs are used.
RE192	TABLE R406.4 (IRC N1106.4)	Reduces ERI compliance targets for all climate zones to the 2015 IECC levels.	Reduces energy use	No	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	No	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	No	Sets ERI thresholds for "zero energy." The ERI is 0 for analysis that includes on-site power production and varies from 43 to 47 for analysis that does not include on-site power production. Only reduces energy use if Appendix RB is adopted.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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	No	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.
RE53	R402.2.8 (IRC N1102.2.8)	Expands on language of floor insulation installation for clarification	Increases energy use	No	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 at 50 pascals (ACH50).	Increases energy use	No	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.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE130	R403.6.2 (IRC N1103.6.2) (New)	Adds testing requirements for mechanical ventilation systems.	Increases energy use	No	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	No	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.

3.1.1 Summary of Individual Changes

Error! Reference source not found. summarizes the changes to the 2021 IECC by category. Among a total of 114 changes, 35 were characterized as impacting energy use in residential buildings, 29 of which are expected to reduce energy use while 6 are expected to increase energy use. Eleven of the energy-impacting changes were included in further quantitative analysis to assess the national average energy savings impact that can be expected with the 2021 IECC. Among the other remaining changes approved for inclusion in the 2021 IECC, 79 were identified as administrative in nature.

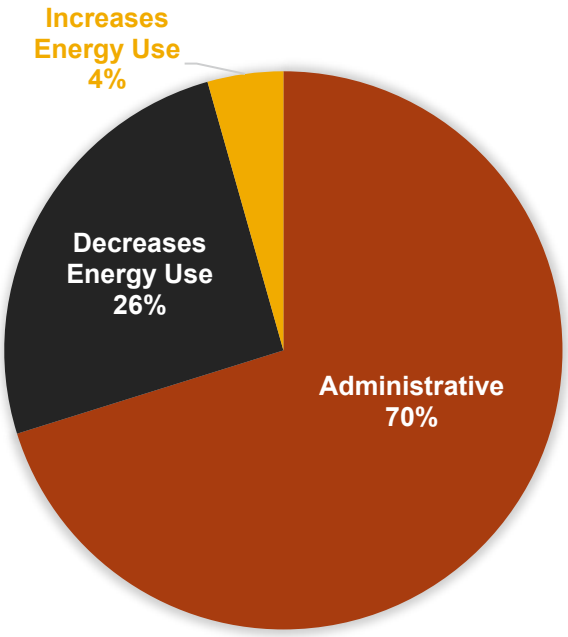

Figure 2. Categorization of Approved Code Changes

3.1.2 Additional Discussion of Significant Changes

All section numbers listed in the discussion are from the 2018 IECC and may not align with section numbers from the 2021 IECC.

3.1.2.1 Renewable Energy Definitions and Operation (CE31 Part II)

This code change updates the definition for “On-Site Renewable Energy” and adds a new definition for “Renewable Energy Resources.” There has been a definition for “On-Site Renewable Energy” in the commercial IECC since 2012 and the phrase was used in the 2018 IECC residential portion but not defined. The definition for “Renewable Energy Resources” adjusts the renewable sources to distinguish between systems that extract hot fluid or steam from the earth (which are considered renewable resources) and ground source heat pumps (which are not). The language used for the new definitions will bring consistency between IECC (residential and commercial) and ASHRAE 90.1 while simplifying compliance for on-site renewable energy systems.

3.1.2.2 Updates Climate Zones to Correlate with ASHRAE Standard 169 (CE36 Part II)

As discussed in Section 2.3.2, the 2021 IECC incorporates several administrative changes introduced by the 2013 edition of ASHRAE Standard 169, Climatic Data for Building Design Standards (ASHRAE 2013a). 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 was added. Approximately 400 U.S. counties out of more than 3,000 were reassigned, most to warmer climate zones[1]. Those jurisdictions that shifted to warmer climate zones will in some cases have less stringent insulation requirements independent of any other changes to the code. The administrative shifting of climate zones is not a focus of the current analysis, so the impacts on prescriptive requirements are not captured here. However, new construction weights were developed for each climate zone based on the new county-climate zone updates. Those construction weights were applied to both the IECC 2018 and IECC 2021 results. The addition of climate zone 0 has no impact, since it does not occur in the U.S.

3.1.2.3 Envelope Backstop for ERI with and without Renewables (RE182 & RE150)

RE182 sets the building thermal envelope backstop to the 2018 IECC for a home complying via the Energy Rating Index (ERI) where the building utilizes on-site renewable energy. RE152 stipulates where the ERI does not utilize on-site renewable energy, the design building thermal envelope total heat loss coefficient (UA value) shall be less than or equal to the building thermal envelope utilizing the prescriptive U-factors from the 2021 IECC multiplied by 1.15. In essence, the design building thermal envelope can be 85 percent as efficient as the 2021 IECC prescriptive envelope.

Homes employing on-site renewable energy systems can achieve significant reduction in ERI points and can use that credit to trade-off envelope efficiency to meet the target ERI requirements. There is concern in the industry that allowing envelope efficiency measures with a lifetime of 60 years to be equally traded with photovoltaic systems that have a much shorter lifetime will result in a failure to capture the code's energy conservation intent over the long-term. It could be problematic to allow ERI-based compliance of a home that contains substantial on-site renewable energy and a sub-standard thermal envelope.

3.1.2.4 Renewable Energy Limit for ERI to 5 Percent of Total Energy (RE184)

RE184 adds language that limits the amount of credit from on-site renewable energy to 5 percent of total home energy use when showing residential IECC compliance with the ERI. The ERI is an asset rating of a home based on the 2006 IECC as the standard reference home. It is defined as a numerical rating where 100 is equivalent to the 2006 IECC and 0 is equivalent to a zero-energy home. The lower the ERI score, the more energy efficient a home will perform.

This change aligns the limits on renewables in Section R-406.3 with the simulated performance in Section C403.3 and ASHRAE 90.1's Energy Cost Budget and Appendix G methodologies. Both commercial codes limit the credit from on-site renewable energy to 5 percent of the total energy cost or calculated energy cost budget.

RE184 does not limit the amount of on-site renewable energy that can be installed or penalize a home for added renewable energy sources; it merely disallows taking credit for more than 5

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

percent in the calculation of the ERI. Like RE182, the intent of RE184 is to enforce high-efficiency envelope construction and reward the reduction of energy over the on-site production of energy.

3.1.2.5 Reduced ERI Compliance Targets to 2015 IECC Levels (RE192)

RE192 sets the 2021 IECC ERI targets for compliance back to the 2015 IECC levels (51–54 based on climate zone) to establish lower (more efficient) ERI target scores.

The ERI compliance path was added to the 2015 IECC for residential buildings, with the ERI scores methodology based on RESNET Standard 301-2014 (RESNET 2014). The 2015 ERI target scores were set based on analyses of one- and two-story homes built to the 2012 IECC combined with cost-effective, high-efficiency and service water heating equipment. The homes were modeled for optimized orientation and architecture and included an additional 10 percent reduction in energy use to account for higher efficiency equipment in the future.

The 2018 IECC made a few changes to the ERI compliance path. First, ERI targets were increased to make them easier to meet (57–62 based on climate zone). Second, language was added to reduce the mechanical ventilation of the ERI Reference Home (RESNET 2014). Finally, the 2018 IECC clarified that on-site power production was allowed in the calculation of the ERI. The result made the ERI compliance path easier to meet but increased energy use. The ventilation adjustment in the ERI Reference Home had the unintended consequence of increasing the ERI scores of all homes.

Given the increased stringency of the 2021 IECC ERI target scores with the ventilation change in the ERI Reference Home still in place, the ERI compliance path may require the most stringency to show compliance even with all its design flexibility and trade-off allowances.

3.1.2.6 RECs Definition and Requirement for ERI Credit (RE204)

RE204 adds two changes: sets a new definition for “Renewable Energy Certificate (REC)” and requires the homeowner be in ownership of the RECs for the home that utilizes on-site renewable energy towards credit for ERI compliance. Requiring the homeowner to own the RECs applies the environmental attributes of the renewable energy system to be counted only for the home in question while preventing another entity from selling the RECs to another party.

When a REC is sold to more than one party, there is a double counting of the energy generated as well as the environmental benefits of the on-site renewable energy system. The benefits of the RECs could be used for ERI compliance for one home while showing the same environmental benefit for another entity such as an electric power provider. For a specific home that has an on-site renewable energy system where the homeowner does not own the RECs, the power produced by the on-site power system would be unqualified as renewable energy.

3.1.2.7 Appendix RB for Zero Energy Residential Building Provisions (RE223)

RE 223 adds a new appendix to the 2021 IECC for zero energy residential buildings. Appendix RB: Zero Energy Residential Buildings outlines the ERI requirements to label the design home as a net zero energy building. This section is not required for compliance with the 2021 IECC unless the jurisdiction specifically adopts Appendix RB to define the requirements for a net zero energy home.

To meet the provisions of Appendix RB, a home must meet or exceed two ERI targets. The first ERI target (43–47, depending on climate zone) must be achieved without accounting for any on-site power production; the second ERI target (zero by definition) must be achieved taking account of on-site power production. Both ERIs are to be calculated in accordance with RESNET 301 (RESNET 2014). In addition, the thermal envelope must meet the prescriptive efficiency levels of the 2015 IECC. Requiring that ERI scores without on-site power generation be in the 40s ensures a well-designed and energy efficient home as well as on-site power production.

3.2 Quantitative Assessment

Table 8 and Table 9 show the results in terms of relative energy savings (percent) of the 2021 IECC compared to the 2018 IECC by climate zone and by building type. These results are based on changes identified as impacting energy efficiency through the qualitative component of the analysis, and that could also be reasonably measured via the established energy modeling and simulation methodology. The 2021 IECC includes the following 11 changes which fit this classification:

- RE7 and RE145 – High-Efficacy Lighting
- RE29 – Increase Wall Insulation
- RE32 – Increase Slab Insulation
- RE33 & RE36 – Increase Ceiling Insulation
- RE35 – Improve Fenestration U-Factor
- RE133 – Improve Mechanical Ventilation Fan Efficacy
- RE139 – Heat Recovery Ventilation
- RE148 – Exterior Lighting Allowances
- RE209 – Additional Efficiency Package.

Results are shown in terms of four metrics—site EUI, source EUI, energy cost, carbon emissions and SC-CO_2. The energy cost metric is used by DOE in reporting its determinations of the energy savings of new code revisions; the other metrics are shown here for reference. The energy cost savings are lower at 8.66 percent relative to the site energy savings reflecting the greater impact of reduced heating loads when conversion costs of electricity are considered. Relative carbon emissions and SC-CO2 savings are equal to energy cost savings at 8.66 percent nationally.

Relative savings in terms of annual energy costs vary from 4.56 percent in climate zone 6 to 10.38 percent in climate zone 8. The variations by climate zone reflect differences in the relative magnitudes of heating and cooling loads as well as nuances in the relative prevalence of building types, foundation types, and system types.

Table 10 through Table 13 show the raw energy savings values from which the percentages in Table 8 and Table 9 were calculated. The tables show the sum of all regulated energy end uses as calculated from the whole-building energy simulations.

Table 8. Relative Energy, Carbon and Social Cost of Carbon Savings of the 2021 IECC compared to the 2018 IECC by Climate Zone (percent)

Climate Zone	Weight (%)	Site EUI (%)	Source EUI (%)	Energy Costs (%)	CO_2 Emissions & Social Cost of Carbon (%)
1	4.30	10.80	9.73	9.51	9.53
2	22.43	10.00	9.13	8.93	8.95
3	29.04	10.48	9.75	9.57	9.59
4	19.49	10.05	9.45	9.32	9.32
5	19.51	8.50	7.63	7.44	7.42
6	4.68	4.28	4.43	4.56	4.52
7	0.53	12.65	10.72	10.13	10.17
8	0.02	12.48	10.93	10.38	10.44
National	100.00	9.38	8.79	8.66	8.66

Table 9. Relative Energy, Carbon and Social Cost of Carbon Savings of the 2021 IECC compared to the 2018 IECC by Climate Zone (percent)

Building Type	Weight (%)	Site EUI (%)	Source EUI (%)	Energy Costs (%)	CO_2 Emissions & Social Cost of Carbon (%)
Single-family	66.04	12.56	11.21	10.91	10.91
Multifamily Unit	33.96	8.51	8.12	8.03	8.04
National	100.00	9.38	8.79	8.66	8.66

Table 10. Energy Use and Carbon Emissions of the 2018 IECC by Climate Zone

Climate Zone	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
1	4.30	28.8	79.1	2,046	11.0	561
2	22.43	31.2	80.7	2,088	11.2	572
3	29.04	31.5	78.4	2,024	10.9	557
4	19.49	37.1	83.5	2,139	11.5	587
5	19.51	45.4	86.6	2,252	12.1	618
6	4.68	50.9	96.5	2,613	14.0	715
7	0.53	58.1	110.8	2,936	15.8	807
8	0.02	78.0	147.1	3,845	20.8	1,063
National	100.00	36.4	82.7	2,139	11.5	587

Table 11. Energy Use and Carbon Emissions of the 2018 IECC by Building Type

Building Type	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
Single-family	66.04	38.5	87.9	1,372	7.4	378
Multifamily Unit	33.96	35.9	81.4	2,533	13.6	695
National	100.00	36.4	82.7	2,139	11.5	587

Table 12. Energy Use and Carbon Emissions of the 2021 IECC by Climate Zone

Climate Zone	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
1	4.30	25.7	71.4	1,851	9.9	506
2	22.43	28.1	73.3	1,902	10.2	521
3	29.04	28.2	70.8	1,830	9.8	501
4	19.49	33.3	75.6	1,940	10.4	531
5	19.51	41.5	80.0	2,084	11.2	572
6	4.68	48.7	92.2	2,494	13.4	684
7	0.53	50.7	98.9	2,638	14.2	725
8	0.02	68.3	131.1	3,445	18.6	950
National	100.00	33.0	75.4	1,954	10.5	536

Table 13. Energy Use and Carbon Emissions of the 2021 IECC by Building Type

Building Type	Weight (%)	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	Energy Costs ($/residence-yr)	CO_2 Emission (tons/residence-yr)	Social Cost of Carbon ($/residence-yr)
Single-family	66.04	33.6	78.0	1,222	6.6	337
Multifamily Unit	33.96	32.8	74.8	2,330	12.5	639
National	100.00	33.0	75.4	1,954	10.5	536

3.3 Conclusion

A total of 114 approved code change proposals were analyzed for the 2021 IECC. The qualitative component of the analyses identified 35 changes with a direct impact on energy use in residential buildings—29 of which are expected to reduce energy use and 6 increase energy use. Further assessment of the 11 code changes included in the quantitative analysis:

- RE7 and RE145 – High-Efficacy Lighting
- RE29 – Increase Wall Insulation
- RE32 – Increase Slab Insulation
- RE33 & RE36 – Increase Ceiling Insulation
- RE35 – Improve Fenestration U-Factor
- RE133 – Improve Mechanical Ventilation Fan Efficacy
- RE139 – Heat Recovery Ventilation
- RE148 – Exterior Lighting Allowances
- RE209 – Additional Efficiency Package.

Suggest national average savings of approximately:

- 9.38 percent of annual site energy use intensity (EUI)
- 8.79 percent of annual source EUI
- 8.66 percent of annual energy cost
- 8.66 percent of carbon emissions and social cost of carbon (SC-CO_2)

Based on these results, the 2021 IECC is expected to improve energy efficiency in residential buildings by almost 10 percent.

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Appendix A – Comprehensive List of Code Change Proposals Approved for Inclusion in the 2021 IECC

There were 114 formal code change proposals resulting in 35 classifiable changes to the IECC, as shown in Table A.1. Of the 35 changes impacting energy use (29 decreasing, 6 increasing), 11 were further analyzed by energy simulation to quantify their impact.

Table A.1. Summary of Approved Code Changes in the 2021 IECC

Category of Change	Number
Decreases Energy Use	29
Increases Energy Use	6
Administrative	79
Total	114

Table A.2 lists all the successful code change proposals incorporated into the 2021 IECC. For each proposal, the following six columns of information are shown:

1. **Proposal Number**: the change proposal designation assigned by the ICC
2. **Code Section(s)**: a list of the section numbers in the 2018 IECC that are affected by the code change. Because sections are often added or deleted, section numbers will often differ in the 2021 IECC
3. **Description of Change(s)**: a brief summary of the changes made by the proposal
4. **Category of Change**: the qualitative categorization of the nature of the change
5. **Included in Energy Analysis**: an indication whether the change was subjected to an additional energy analysis in the subsequent quantitative analysis
6. **Discussion**: a brief discussion expanding on the change categorization and providing additional rationale, for changes that impact energy use, explaining whether the change is to be included in the subsequent quantitative analysis.

Table A.2. Qualitative Analysis of All 2021 IECC Code Changes

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	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	Yes	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 4-5.	Reduces energy use	Yes	
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	Yes	
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	Yes	
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 2-4 and adds new requirement for minimum fenestration U-factor in climate zones 3-8.	Reduces energy use	Yes	
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 se	Yes	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	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	Yes	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	Yes	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	Yes	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	Yes	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 R407 (New) R407.1 (New) R407.2 (New) R407.2.1 (New) R407.2.2 (New) R407.2.3 (New) R407.2.4 (New) R407.2.5 (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	Yes	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	Included in Energy Analysis	Discussion
RE27	Table R402.1.2 (IRC N1102.1.2)	Adds alternative wood frame wall options in all climates.	Reduces energy use	No	Adds cavity-only options for 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)	Eliminate footnote gas option for floor cavity insulation.	Reduces energy use	No	Footnote g allowed merely filling the cavity (but at least R19) 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	No	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	No	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	No	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	No	Makes weatherstripping mandatory, leaves insulation requirement prescriptive. Total insulation and air leakage requirements remain unchanged and thus not part of the quantitative analysis.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	Prescriptive wall insulation requirements remain unchanged and not factored in the quantitative analysis.
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	No	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	No	Lowers the allowable area-weighted maximum U-factor for climate zones 4-8 and 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	No	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.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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.
RE149	R404.2 (IRC N1104.2) (New)	Adds 4 new automated control requirements for exterior lighting if installed lighting power is greater than 30 watts.	Reduces energy use	No	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 (HWDS) compactness factor to the calculation of the proposed design hot water use (gallons/day) in Table R405.5.2(1).	Reduces energy use	No	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	No	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 (SWH) efficiency compared to envelope efficiency. Both proposed and baseline buildings have the same reduced water usage.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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 trade-offs are used.
RE192	TABLE R406.4 (IRC N1106.4)	Reduces ERI compliance targets for all climate zones to the 2015 IECC levels.	Reduces energy use	No	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	No	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	No	Sets ERI thresholds for "zero energy." The ERI is 0 for analysis that includes on-site power production and varies from 43 to 47 for analysis that does not include on-site power production. Only reduces energy use if Appendix RB is adopted.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
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	No	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	No	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.
RE53	R402.2.8 (IRC N1102.2.8)	Expands on language of floor insulation installation for clarification.	Increases energy use	No	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 ACH50.	Increases energy use	No	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.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE130	R403.6.2 (IRC N1103.6.2) (New)	Adds testing requirements for mechanical ventilation systems.	Increases Energy use	No	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	No	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.
ADM31 P III	R106 R105.7 R105.7.1	Reworks Notice of Approval and Revocation sections.	Administrative	No	
ADM40 P IV	R109 R109.1 R109.2 R109.3 R109.4	Reworks Board of Appeals section.	Administrative	No	
ADM41 P IV	R108 R108.1 R108.2 R108.3 R108.4	Reworks Stop Work Order section.	Administrative	No	
ADM46 P IV	R103.1	Allows use of digital submissions where approved by building official.	Administrative	No	
CE10 P II	R102.1	Adds requirement that "alternative methods or design must be approved" in General section.	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
CE12 P II	R102.1.1 (N1101.4)	Adds requirements for buildings meeting above code programs to meet mandatory requirements and the thermal envelope "backstop." Backstops are the 2009 IECC.	Administrative	No	
CE13 P II	R103.2 (IRC N1101.5)	Adds "energy compliance path" to list of items to be on construction documents.	Administrative	No	Allows plans examiner to target specific requirements based on compliance path.
CE19 P II	R202 (IRC N1101.6)	Adds new definition of "air-impermeable insulation" to code.	Administrative	No	Modifies current definition to include specific definition of "impermeable," including reference to ASTM E2178 or E283.
CE22 P II	R202 (IRC N1101.6)	Revises definition of "demand recirculation water system" to match IPC definition.	Administrative	No	
CE29 P II	R202 (IRC N1101.6 R303.3 (IRC N1101.12) R403.5.1 (IRC N1103.5.1) R403.10.1 (IRC N1103.10.1)	Removes definition of "accessible" and "readily accessible," adds definitions of "ready access (to)" and "access (to)," and makes corresponding changes where deleted terms are used in text.	Administrative	No	
CE31 P II	R202 (IRC N1101.6)	Updates definition for "on-site renewable energy" and adds new definition for "renewable energy resources."	Administrative	No	Adds and aligns definition for "on-site renewable energy" with the commercial IECC. Definition for "renewable energy resources" distinguishes between geothermal energy sources and ground source heat pumps.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
CE36 P II	Figure R301.1 (IRC N1101.7) Table R301.1 (IRC N1101.7) R301.3 (IRC N1101.7.2) Table R301.3(1) [IRC N1101.7.2(1)] Table R301.3(2) [IRC N1101.7.2(2)]	Updates climate zones to correlate with ASHRAE Standard 169.	Administrative	No	The impact of shifting climate zones is not captured in analysis but the impacts of the climate zone weightings have been captured. Jurisdictions that shifted to warmer climate zones have less stringent requirements.
CE40 P II	R303.1.2 (IRC N1101.10.2)	Adds new requirement that for materials with an observable manufacturer's R-value mark, that an insulation certificate be left in a conspicuous location in the building.	Administrative	No	
CE42 P II	All Mandatory Requirements Sections	Clarifies which residential sections are mandatory and which prescriptive.	Administrative	No	Proposal eliminates the "mandatory" and "prescriptive" labels in favor of specific tables defining "requirements" (formerly mandatory requirements) associated with each performance path (old performance path and new ERI). This is intended to simply be a restructuring. Sections that were formerly labeled "mandatory" must now be defined as such in two different places, opening the possibility of their getting out of sync.
CE60 P II	R202 (IRC N1101.6) R402.1.3 (IRC N1102.1.3)	Adds definition of "cavity insulation" and specifies use of cavity insulation in R-value computation.	Administrative	No	Proposal is effectively clarification of how to sum R-values for cavity and continuous insulation.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
CE151 P II	R202 (IRC N1101.6) R403.3.1 (IRC N1103.3.1)	Adds new definition of "thermal distribution efficiency (TDE)" and adds new requirements for underground ducts.	Administrative	No	Proposal also adds listing and labeling of ducts that use the TDE method. Savings may occur from using properly listed and labeled ducts in underground installations.
CE159 P II	R403.5.1.1 (IRC N1103.5.1.1) R403.5.2 (IRC N1103.5.2)	Relocates requirement that demand recirculating water systems have controls to limit temperature of water entering cold water piping.	Administrative	No	Move requirement for controls that limit water entering the cold-water piping to 104F from demand recirculating systems to all recirculating systems.
RE4	R202 (IRC N1101.6) (New)	Adds new definition of "" cavity insulation."	Administrative	No	
RE6	R202 (IRC N1101.6) (New)	Amends definition of "fenestration" to include skylights, tubular daylighting devices, and glazing materials in solariums, sunrooms, roofs, and sloped walls.	Administrative	No	Clarifies what constitutes as a "skylight."
RE9 P I	R202 (IRC N1101.6)	Editorial change to definition of "roof recover."	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE15	R401.2 (IRC N1101.13) R401.2.1 (IRC N1101.13.1) R401.2.1 (IRC N1101.13.1) (New) R401.2.2 (IRC N1101.13.2) (New) R401.2.3 (IRC N1101.13.3) (New) R401.2.4 (IRC N1101.13.4) (New) R407 (IRC N1107) (New) R407.1 (IRC N1107.1) (New)	Clarifies compliance requirements in Chapter 4.	Administrative	No	Splits compliance pathway requirements into separate sections for clarity.
RE18	R401.3 (IRC N1101.14)	Amends compliance certificate requirements to include on-site renewable systems when installed.	Administrative	No	Requires the specifications of on-site renewable systems on the compliance certificate for homebuyers, inspectors, and appraisal addendums.
RE20	R401.3 (IRC N1101.14)	Amends compliance certificate requirements to add name of builder, code year complied with, and compliance path used.	Administrative	No	
RE21	R401.3 (IRC N1101.14)	Amends compliance certificate requirements by adding ERI if applicable.	Administrative	No	Adding to ERI compliance path, the ERI must be shown with and without renewable energy generation for compliance purposes and future homeowners.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE23	Table R402.1.2 (IRC N1102.1.2)	Adds alternative basement wall and crawlspace wall options for cold climates.	Administrative	No	Moves detail from footnotes to table and adds text clarifying which R-values are cavity vs continuous.
RE28	TABLE R402.1.2 (IRC N1102.1.2	Clarifies wood frame wall, basement wall, and crawlspace wall insulation requirements in CZ 3-8.	Administrative	No	
RE38	R402.1.2 (IRC N1102.1.2) TABLE R402.1.2 (IRC N1102.1.2) R402.1.3 (IRC N1102.1.3) (New) TABLE R402.1.4 (IRC N1102.1.4) R402.1.3 (IRC N1102.1.3) R402.1.4 (IRC N1102.1.4) R402.1.5 (IRC N1102.1.5)	Renders the U-factor compliance the default for prescriptive compliance. R-values are the alternative.	Administrative	No	No real change in the requirements.
RE42	R402.2.1 (IRC N1102.2.1) R402.2.2 (IRC N1102.2.2)	Editorial changes to requirements for ceilings with and without attic spaces.	Administrative	No	
RE49	R402.2.4 (IRC N1102.2.4)	Editorial changes to the access hatch door requirements.	Administrative	No	
RE50	R202 (IRC N1101.6) R402.2.5 (IRC N1102.2.5)	Adds mass timber as a type of mass wall and adds definition of mass timber.	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE51	Table 402.2.5 (IRC N1102.2.6)	Adds additional equivalents to Table R402.2.6 Steel-Frame Ceiling, Wall, and Floor Insulation R-values.	Administrative	No	
RE55	R402.2.9 (IRC N1102.2.9)	Expands language of basement wall insulation installation requirements for walls associated with unconditioned basements.	Administrative	No	The exceptions outline the characteristics that must be present in an unconditioned basement to "willfully and knowingly" remove the basement from consideration as an extension of conditioned space.
RE58	Table R402.4.1.1 (IRC N1102.4.1.1)	Removes redundant language from air barrier table.	Administrative	No	
RE59	R402.2.9 (IRC N1102.2.9) (New) R402.2.9 (IRC N1102.2.9)	Establishes separate design and installation requirements for basement wall insulation, with the installation being mandatory.	Administrative	No	
RE60	R402.2.10 R402.2.10.1 (IRC N1102.2.10.1) (New)	Establishes separate design and installation requirements for slab-on-grade insulation, with the installation being mandatory.	Administrative	No	Makes only the installation requirements mandatory without affecting the R-value/depth requirements.
RE62	R402.2.11 (IRC N1102.2.11) (New) R402.2.11 (IRC N1102.2.11)	Establishes separate design and installation requirements for crawl space wall insulation, with the installation being mandatory.	Administrative	No	Clarifies the scope of the section and makes the installation requirements mandatory.
RE68	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (plumbing and wiring).	Administrative	No	
RE70	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (recessed lighting).	Administrative	No	
RE71	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (garage separation).	Administrative	No	
RE72	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (narrow cavities).	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE73	Table R402.4.1.1 (IRC N1102.4.1.1)	Clarification of requirements for sealing and insulating around penetrations	Administrative	No	
RE74	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (crawl space walls, basement walls, and slabs).	Administrative	No	
RE82	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (rim joists).	Administrative	No	
RE86	Table R402.4.1.1 (IRC N1102.4.1.1)	Editorial changes to air sealing table (shafts and penetrations).	Administrative	No	
RE88	R202 (IRC N1101.6) R402.4.1.2 (IRC N1102.4.1.2) R403.6 (IRC N1103.6)	Adds definition for Dwelling Unit Enclosure Area and allows 0.30 cfm25/ft^2 of Dwelling Unit Enclosure Area as an exception to 3 or 5 ACH50 for air leakage.	Administrative	No	Only allowed for attached dwelling units and buildings or dwelling units under 1,500 ft^2. The cfm25/ft^2 of dwelling unit enclosure area removes the bias of large volume homes.
RE98	R402.4.1.2 (IRC N1102.4.1.2) TABLE R405.5.2(1) [IRC N1105.5.2(1)]	Adds additional digit to the air leakage rate of the Standard Reference Design in Table R405.5.2(1) to eliminate roundoff error.	Administrative	No	This clarification supports code official compliance determination.
RE103	R402.4.2 (New) R402.4.6 (New)	Adds explicit requirement for use of air-sealed electrical and communication outlet boxes.	Administrative	No	Explicitly requires that outlet boxes be tested using NEMA OS.4 and sets a maximum air leakage rate. Savings not captured in quantitative analysis because maximum ACH50 is unchanged.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE106	R403.1.1 (IRC N1103.1.1)	Clarifies programmable thermostat requirements and requires weekday/weekend operation for thermostats.	Administrative	No	Requires weekday/weekend functionality in thermostats, which may lead to potential savings for those buildings that did not use thermostats with this capability before.
RE108	R403.2 (IRC N1103.2)	Expands options for hot water boiler temperature reset.	Administrative	No	
RE109	R403.3 (IRC N1103.3) R403.3.1 (IRC N1103.3.1) R403.3.7 (IRC N1103.3.7)	Clarifies duct insulation requirements based on location.	Administrative	No	Requirements are unchanged. Added is a list of conditions that must be met for ducts to be considered "in conditioned space." Brings this section into closer coordination with the buried duct provisions.
RE111	R403.3.1 (IRC N1103.3.1) R403.3.1.1 (IRC N1103.3.1.1) (New) R403.3.1.2 (IRC N1103.3.1.2) (New) R405.2 (IRC N1105.2) R406.2 (IRC N1106.2)	Revises and consolidates the duct insulation requirements into one section.	Administrative	No	
RE114	R403.3.3 (IRC N1103.3.3) Chapter 6RE (IRC Chapter 44) (New)	Requires RESNET/ICC 380 or ASTM E1554 for duct testing.	Administrative	No	Introduces new reference standard for duct testing protocols.
RE118	R403.3.3 (IRC N1103.3.3)	Editorial change to duct leakage requirements.	Administrative	No	
RE122	R403.3.6.1 (IRC N1103.3.6.1)	Makes effective R-value of insulation of deeply buried ducts mandatory.	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE123	R403.4.1 (IRC N1103.4.1)	Makes protection of piping insulation mandatory.	Administrative	No	
RE125	R403.5.2 (IRC N1103.5.2)	Makes hot water demand recirculation system control requirements mandatory.	Administrative	No	Provides clarification that the requirement only applies if these systems are installed.
RE127	R403.5.3 (IRC N1103.5.3)	Clarifies hot water pipe insulation requirements.	Administrative	No	
RE129	R403.5.4 (IRC N1103.5.4)	Makes drain water heat recovery unit testing and operating requirements mandatory.	Administrative	No	While making drain water heat recovery unit testing mandatory, it does not require drain water heat recovery be installed in homes.
RE132 P I	R403.6 (IRC N1103.6)	Editorial change to mechanical ventilation requirements.	Administrative	No	Changes "buildings" to "buildings and dwelling units" and "ventilation" to "mechanical ventilation."
RE132 P II	R303.4	Requires dwelling units complying with Section N1102.4.1 to have whole-house mechanical ventilation in accordance with Section M1505.4.	Administrative	No	Ensures that homes meeting the air leakage requirements of N1102.4 are provided with mechanical ventilation according to M1505.4. This provides assurance in the future that air-tight dwelling units will be provided with mechanical ventilation.
RE136	TABLE R403.6.1 (IRC N1103.6.1)	Adds test specifications (static pressure) for various ventilation system types.	Administrative	No	
RE137	TABLE R403.6.1 (IRC N1103.6.1)	Editorial changes to Table R403.6.1 whole-house mechanical ventilation system fan efficacy requirements.	Administrative	No	Clarification and restructuring of requirements table while adding specific system type such as "balanced fans without HRV or ERV." Attempts to match up with ventilation types in code compliance software.
RE144	R403.12 (IRC N1103.12)	Makes pool and spa requirements mandatory.	Administrative	No	

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE150	R406.2 (IRC N1106.2)	Adjusts the UA backstop for the ERI compliance pathway to be Proposed UA <= Standard UA (2021 IECC) x 1.15.	Administrative	No	
RE151	R405.2 (IRC N1105.2) ICC Chapter 6 (IRC Chapter 44)	Sets minimum envelope and SHGC efficiency requirements to meet 2009 IECC for the performance path.	Administrative	No	New envelope insulative backstop for performance compliance but minimal energy impact since the same overall level of efficiency to comply is unchanged.
RE157	R405.4.2 (IRC N1105.4.2)	Removes allowance for batch sampling for multi-family units.	Administrative	No	There is no process or criteria defined within the IECC for "batch sampling." Could threaten compliance/enforcement as not all dwelling units will be inspected.
RE158	R405.4.2 (IRC N1105.4.2) R405.4.2.1 (IRC N1105.4.2.1) R405.4.2.2 (IRC N1105.4.2.2) R405.4.3 (IRC N1105.4.3)	Re-write of Section R405.4.2 related to performance path compliance reporting.	Administrative	No	Rewrites sections on reports detailing the information to be supplied for permit applications and certificate of occupancy.
RE159	R405.4.2.1	Adds a statement that simulated performance path is being used to the compliance report requirements.	Administrative	No	
RE172	R405.5.2.(1) [IRC N1105.5.2(1)]	Specifies that the duct location in both the Proposed and Standard Designs for performance compliance will be set to the Proposed Design duct location.	Administrative	No	
RE173	TABLE R405.5.2(1) [IRC N1105.5.2(1)]	Adds a new section for dehumidistats.	Administrative	No	Adds a new section on dehumidistats and requires the proposed design and reference design to be the same.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE178	TABLE R405.5.2(1) [IRC N1105.5.2(1)] TABLE R403.6.1 (IRC N1103.6.1)	Specifies the mechanical ventilation type of the Standard Design shall be the same type as in the Proposed Design and efficacy is based on the ventilation type.	Administrative	No	
RE182	R406.2 (IRC N1106.2) TABLE R406.4 (IRC N1106.4)	Changes building thermal envelope efficiency backstop for ERI compliance with renewable energy to the 2018 IECC.	Administrative	No	Since the 2018 is only slightly more efficient than the 2015, this will amount to a 1.7% improvement requirement in envelope efficiency based on the 2018 IECC Determination but overall ERI compliance targets remain unchanged.
RE199	R406.5 (IRC N1106.5	Expands on the requirements for the approved third-party person/entity that will verify the ERI compliance requirements have been met.	Administrative	No	This divides compliance verification between an approved third party for R406.4 and R406.6 (the base ERI and documentation thereof) and the authority having jurisdiction or approved third party inspection agency per Section R105.4 for R406.2 (mandatory requirements).
RE202	R406.6.2	Adds statement requiring the Energy Rating Index on title page of ERI compliance report.	Administrative	No	
RE204	R202 (IRC N1101.6) R406.6.3 (IRC N1106.6.3) (New)	Adds definition for Renewable Energy Certificate (REC) and requiring documentation of the RECs for renewable energy credit in the ERI compliance path.	Administrative	No	Requires that a home with PV/renewable energy systems provide legal documentation that nobody else owns credit for the renewable energy capacity.
RE205	R406.6.2 (IRC N1106.6.2) R406.6.2.1 (IRC N1106.6.2.1) (New) R406.6.2.2 (IRC N1106.6.2.2) (New)	Re-write of Section R406.6.2 related to ERI compliance path reporting.	Administrative	No	Makes extensive changes to the ERI report requirements for permit application or certificate of occupancy. Adds new language "proposed" to the rated design as well as "confirmed built dwelling" that both must meet the ERI score requirements.

Proposal Number[a]	Code Section(s)[b]	Description of Change(s)	Impact on Energy Efficiency	Included in Energy Analysis	Discussion
RE215	R503.1 (IRC N1109.1)	Removes redundant language related to Alterations.	Administrative	No	
RE221	R505.1 (IRC N1107.1) R505.2 (IRC N1111.2)	Clarifies application section for spaces undergoing change in occupancy and spaces converted to dwelling units.	Administrative	No	
RE222	RA103.1 (IRC AT103.1) RA103.5 (IRC AT103.5) (New) RA103.6 (IRC AT103.6) (New)	Adds clarification related to shading.	Administrative	No	Brings the IECC's solar-ready appendix into agreement with the IRC's, which was updated last cycle.

(a) Proposal numbers are as assigned by the ICC (http://media.iccsafe.org/codes/2015-2017/GroupB/CAH/IECC-R.pdf).
(b) Code sections refer to the 2018 IECC. Sections may be renumbered by the ICC in the 2021 IECC.

Appendix B – Detailed Weighting Factors for Each Residential Prototype

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

Appendix C – Updates to the Energy Savings Calculation Methodology

Although the present analysis of the 2021 IECC builds on the previous 2018 IECC energy savings analysis, the methodology differs in a few ways:

1. Used a newer version of DOE's *EnergyPlus* building energy simulation software; this was done to accommodate the software update process and to incorporate software improvements and new data
2. Updated modeling strategy for air leakage, duct leakage, and ventilation
3. Updated weights
4. Updated fuel costs
5. Representative weather file changes resulting from climate zone changes
6. Bug fixes and other improvement were made to the prototype models.

These changes are important because they impact the 2018 IECC models which are the baseline for this analysis. To ensure that the current analysis was both up-to-date and the comparison between the 2018 and 2021 IECC versions was valid, all 2018 models were re-run incorporating these changes.

C.1 EnergyPlus Version Upgrade

DOE regularly updates the *EnergyPlus* software program twice a year. The 2018 determination of energy savings was accomplished using *EnergyPlus* V8.6. The determination of energy savings for the 2021 IECC was conducted using an adaptation of *EnergyPlus* version 9.4 where the source code was modified to allow additional zonal equipment while simultaneously simulating the detailed effects of duct leakage via the *EnergyPlus* Airflow network. The modified source code will be available in the *EnergyPlus* version 9.5 release.

C.2 Updated Modeling Strategy for Air Leakage, Duct Leakage and Ventilation

The energy impact of duct insulation and air leakage was calculated using the *EnergyPlus Airflow* network model which allows the creation of a detailed air-distribution system and the placement of ducts in various thermal zones. Prior to the Airflow network model enhancement, due to compatibility issues between the Airflow network objects and the other *EnergyPlus* objects, the duct and air leakage impact was calculated in isolation and incorporated through post-processing without the Airflow network model (Mendon et al. 2015). The single-family building prototypes now directly incorporate the Airflow network model while the multifamily prototype buildings still use the post-processing method due to the compatibility issue.

C.3 Updated Weights and Fuel Costs

Weighting factor and fuel cost changes have been updated to reflect current building permits and economic conditions. Weighting factors and fuel cost adjustments were summarized in Sections 2.3 and 2.4 in the report.

C.4 Representative weather file changes resulting from climate zone changes

As discussed in Section 2.3.2, the 2021 IECC has aligned the climate zone map with that from ASHRAE 169-2013. 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. Approximately 300 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones. A new county-to-climate zone map was built to match the climate zones to every county to assist in developing new residential weights. A new weather location for the new climate zone 5C (Port Angeles, Washington) was included in the quantitative analysis in addition to adjusting weather files to match the updated climate zones as discussed in Section 2.3.2.

C.5 Bug Fixes

During the 2021 IECC determination analysis, various bugs were fixed such as water heater tank size settings, calculation of envelope leakage area, and window area calculations for prototype models with basements. The water heating tank size issue resulted in the tank size being too small for oil furnace home. The calculations to set window area for homes with basements were incorrect, which set the window area to be lower than expected. Those corrections had a minor impact on total energy consumption.

Appendix D – Modeling of Individual Code Changes

This section describes the modeling strategies used for modeling the 11 code changes in the quantitative analysis.

D.1 RE7 & RE145: High-Efficacy Lighting Requirements

RE145 reduces the lighting energy consumption in homes by increasing the requirement of high-efficacy lighting from 90 percent of permanently installed lighting fixtures 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.

Lighting energy in the DOE prototypes is calculated based on the Building America House Simulation Protocols as detailed by Mendon et al. (2013) and divided into hardwired, plug-in, exterior, and garage lighting. The Building America protocols establish a set of equations that can be used to calculate annual lighting energy consumption depending on the fraction of incandescent lamps, compact fluorescent lamps (CFLs), light emitting diodes (LEDs), and linear fluorescents (LFs) present in the home (Wilson et al. 2014). Because RE7 & RE145 apply only to permanently installed (hardwired) fixtures, the impact of this code change is calculated using Building America's smart lamp replacement approach using Equations 3.1 and 3.2 and the fractions specified in Table D.1. With LEDs gaining popularity in the residential market, this analysis assumes that low-efficacy lighting is replaced with 80 percent LEDs and 20 percent CFLs—this yields a conservative estimate of energy savings from this measure.

$$\textit{Baseline Interior Hardwired Lighting Energy (kWh/yr)} = 0.8 \times (\textit{Conditioned Floor Area} \times 0.542 + 334) \quad (3.1)$$

$$\textit{Interior Hardwired lighting energy (kWh/yr)} = L_{HW} \times \{[(F_{inc,\,HW} + 0.34) + (F_{CFL,\,HW} - 0.21) \times 0.27 + F_{LED,\,HW} \times 0.30 + (F_{LF,\,HW} - 0.13) \times 0.17] \times SAF \times 0.9 + 0.1 \quad (3.2)$$

where
- L_{HW} = Baseline annual interior hardwired lighting energy from equation 3.1
- $F_{inc,\,HW}$ = Fraction of hardwired lamps that are incandescent
- $F_{CFL,\,HW}$ = Fraction of hardwired lamps that are CFLs
- $F_{LF,\,HW}$ = Fraction of hardwired lamps that are LFs
- $F_{LED,\,HW}$ = Fraction of hardwired lamps that are LEDs
- SAF = Smart replacement algorithm factor: $1.1 \times F_{inc}^{4} - 1.9 \times F_{inc}^{3} + 1.5 \times F_{inc}^{2} - 0.7 \times Fi_{nc} + 1$

Table D.1. Lighting Type Fractions for the 2015 and 2018 IECC

	2018 IECC	2021 IECC
Fraction Incandescent (F_{inc})	0.10	0.00
Fraction CFL (F_{CFL})	0.77	0.20
Fraction Linear Fluorescent (F_{LF})	0.13	0.00
Fraction LED (F_{LED})	0.00	0.80

Table D.2 summarizes the resulting annual hardwired interior lighting energy consumption for the 2018 and 2021 IECC for the single-family building prototype and the multifamily prototype building unit. This value is converted to a lighting power density input for the models using the annual hours of use based on the lighting schedule. In addition to the direct reduction in lighting

energy use, the energy simulation also accounts for the interactive effects between the reduced internal gains from the high-efficacy lighting and the corresponding increase in heating energy and reduction in cooling energy. The IECC regulates only hardwired interior lighting but the residential prototypes incorporate unregulated plug-in lighting of the same magnitude across all code years.

Table D.2. Calculated Annual Interior Hardwired Lighting Energy for the 2018 and 2021 IECC by Building Type

Building Type	2018 IECC	2021 IECC
Single-family	783 kWh	713 kWh
Multifamily Unit	475 kWh	433 kWh

D.2 RE29: Increased Wood Frame Wall Insulation

RE29 increases wood frame wall insulation by adding an additional R-5 continuous insulation for climate zones 4 and 5. Table D.3 shows the changes between the wall insulation values between 2018 IECC and 2021 IECC. The exterior walls for the prototype models were simulated with R-20 cavity insulation with R-0 for sheathing insulation for the 2018 IECC. For the 2021 IECC, the sheathing insulation was increased to R-5.

Table D.3. Wall Insulation R-Values for Climate Zones 4-5 for the 2018 and 2021 IECC

Climate Zone	2018 IECC	2021 IECC
4 & 5	20	20+5ci

D.3 RE32: Increased Slab Floor Insulation

RE32 adds slab insulation for slab-on-grade homes in climate zone 3 to R-10 at 2 ft of depth. Table D.4 illustrates the changes in the slab insulation between 2018 and 2021 IECC. 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.

Table D.4. Slab Insulation R-Values for Climate Zones 3-5 for the 2018 and 2021 IECC

Climate Zone	2018 IECC	2021 IECC
3	NR	R-10, 2 ft
4 & 5	R-10, 2 ft	R-10, 4 ft

D.4 RE33 & RE36: Increased Ceiling Insulation

R33 and R36 increase the ceiling insulation levels depending on climate zone. R33 increases the ceiling insulation in climate zones 2 and 3 from R-38 to R-49 for the 2021 IECC. R36 increases the ceiling insulation in climates zones 4 through 8 from R-49 to R-60. The ceiling insulation for the prototype models for the 2021 IECC were adjusted as shown in Table D.5 while the 2018 IECC prototypes remained at R-38 and R-49 respectively.

Table D.5. Ceiling Insulation R-Values for Climate Zones 2-8 for the 2018 and 2021 IECC

Climate Zone	2018 IECC	2021 IECC
2 - 3	R-38	R-49
4 - 8	R-49	R-60

D.5 RE35: Increased Stringency of Fenestration U-Factors

RE35 improves fenestration U-factors in climate zones 3 and 4 from 0.32 to 0.30. All prototype window U-factors in climate zones 3, 4A, and 4B were reduced to 0.30. Table D.6 shows the fenestration U-factors in 2018 and 2021 IECC.

Table D.6. Ceiling insulation R-Values for Climate Zones 2-8 for the 2018 and 2021 IECC

Climate Zone	2018 IECC	2021 IECC
3, 4A & 4B	0.32	0.30

D.6 RE133: Increase Mechanical Ventilation Fan Efficacy

RE133 adds new efficacy requirements for whole-house mechanical ventilation fans based on fan location. The residential prototypes utilize a simple bathroom exhaust fan running continuously. For the 2018 IECC, the fan efficacy was 1.4 cfm/watt. For 2021 IECC, the fan efficacy was increase to 2.8 cfm/watt. Table D.7 shows the fan efficacies used in the quantitative analysis.

Table D.7. Mechanical Fan Efficacies for the 2018 and 2021 IECC

Climate Zone	2018 IECC	2021 IECC
1-6	1.4 cfm/watt	2.8 cfm/watt

D.7 RE139: Requiring Heat Recovery Ventilators in Climate Zones 7-8

RE139 adds new language in the 2021 IECC requiring dwelling units in climate zones 7 and 8 be provided with a heat recovery or energy recovery ventilator. The ventilation system is to be balanced with a sensible heat recovery efficiency not less than 65 percent.

For the quantitative analysis, a heat recovery ventilator replaced the exhaust fan in both single family and multifamily prototypes as a balanced air system (one supply fan and one exhaust fan) within the airflow network. The HRV provides 45 cfm of continuous ventilation for the multifamily dwelling units and 60 cfm of continuous ventilation for the single-family home. The recovery efficiency was set to 65 percent and fan efficacy for both the supply and exhaust fans were each set to 2.4 cfm/watt so that the HRV system efficacy meets the required 1.2 cfm/watt. Table D.8 highlights the ventilation fan efficacies for the heat recovery ventilator

Table D.8. Heat Recovery Ventilation Fan Efficacy for the 2018 and 2021 IECC

Exhaust System	2018 IECC	2021 IECC
HRV Fan Efficacy	NA	1.2 cfm/watt
HRV Recovery Efficiency	NA	65%

D.8 RE148: Exterior Lighting Allowances

RE148 adds new language to the 2021 IECC that requires R-2, R-3, and R-4 buildings to comply with Section C405.5 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 the quantitative analysis.

The exterior lighting configuration of the residential multifamily prototypes were aligned with the multifamily prototypes used in the commercial (ASHRAE 90.1) determination. Lighting allowances were selected from Exterior Lighting Zone 2, which consists of residential zoning. Three areas of exterior lighting were considered for the residential multifamily buildings: the base wattage allowance plus parking and façade lighting. Table D.9 highlights the exterior lighting allowances for each area.

Table D.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

Residential editions of the IECC prior to the 2021 IECC did not regulate exterior lighting. As a result, any amount of connected power would be acceptable in both single family and multifamily buildings. However, past DOE analyses have assumed a modest level of exterior lighting in the residential prototypes. To implement the new requirements for the 2021 IECC only while maintaining the original exterior lighting power assumptions for the 2018 IECC and earlier codes would show an unrealistic increase in energy consumption. The unregulated exterior lighting power simulated for earlier energy codes was much lower than the lighting allowances in Section C405.5. Because of this, the decision was made to model the exterior lighting equally for the 2018 IECC and 2021 IECC according to Section C405.5. The result is zero lighting savings from exterior lighting. If the exterior lighting allowances are changed in future editions of the IECC, the energy savings (or losses) can be captured in the associated determination studies.

D.9 RE209: Additional Energy Efficiency Packages

RE209 adds Section R408 to the 2021 IECC to establish five efficiency packages with the goal of adding an additional 5 percent of energy efficiency by various means. For the prescriptive compliance path, one of the five additional efficiency packages must be utilized in the design home. The five efficiency packages are as follows:

- Enhanced Envelope Option: Proposed Design UA <= 0.95 x Standard Design UA
- More Efficient HVAC Equipment Performance Option:

  - Furnace >= 95 AFUE and Air Conditioner >= 16 SEER
  - Heat Pump >= 10 HSPF / 16 SEER
- Reduced Energy Use in Service Water Heating Option:
  - Fossil Fuel Water Heating System >= 0.82 EF
  - Electric Water Heating System >= 2.0 EF
  - Solar Water Heating System >= 0.4 Solar Fraction
- More Efficient Duct Thermal Distribution System Option:
  - 100 percent of ducts located entirely within the building thermal envelope
  - 100 percent systems ductless or hydronic system located within building thermal envelope
- Improved Air Sealing and Efficient Ventilation System Option:
  - Measured air leakage <= 3.0 ACH50
  - Heat/Energy Recovery Ventilator.

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-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 proposal. 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 D.10 shows the water heating systems set up for the 2021 IECC to represent reduced energy use in service water heating as compared to the 2018 IECC.

Table D.10. 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 reduced energy use in service water heating option allows an oil water heating system (tankless or storage) to be used in oil-heated homes. However, according to the Air Conditioning, Heating, and Refrigeration Institute (AHRI) directory,[1] the highest listed energy factor for oil water heaters is 0.68. Oil water heaters with an energy factor of 0.82 do not exist.

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

Research indicated that electric resistance water heaters are more common than oil-fired water heaters in new buildings heated by oil. Propane furnaces are more common currently in the northeast than oil furnaces. To represent new construction with oil furnaces, the decision was made to utilize a heat pump water heater to obtain the reduced energy for water heating. There was resistance to utilizing a gas water heater as having three fuel types in a single home is likely rare.

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