PNNL-31019

# National Cost Effectiveness of the Residential Provisions of the 2021 IECC

June 2021

V. Robert Salcido
Yan Chen
YuLong Xie
Z. Todd Taylor

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

PACIFIC NORTHWEST NATIONAL LABORATORY
*operated by*
BATTELLE
*for the*
UNITED STATES DEPARTMENT OF ENERGY
*under Contract DE-AC05-76RL01830*

**Printed in the United States of America**

**Available to DOE and DOE contractors from the**
**Office of Scientific and Technical Information,**
**P.O. Box 62, Oak Ridge, TN 37831-0062;**
**ph: (865) 576-8401**
**fax: (865) 576-5728**
**email: reports@adonis.osti.gov**

**Available to the public from the National Technical Information Service**
**5301 Shawnee Rd., Alexandria, VA 22312**
**ph: (800) 553-NTIS (6847)**
**email: orders@ntis.gov <https://www.ntis.gov/about>**
**Online ordering: http://www.ntis.gov**

PNNL-31019

# National Cost Effectiveness of the Residential Provisions of the 2021 IECC

June 2021

V. Robert Salcido
Yan Chen
YuLong Xie
Z. Todd Taylor

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

Pacific Northwest National Laboratory
Richland, Washington 99354

# Executive Summary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# Acknowledgments

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

# Acronyms and Abbreviations

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

| | |
|---|---|
| SHGC | solar heat gain coefficient |
| yr | year(s) |

# Contents

# Figures



# Tables

# 1.0 Introduction

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

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

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

## 1.1 Purpose

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

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

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

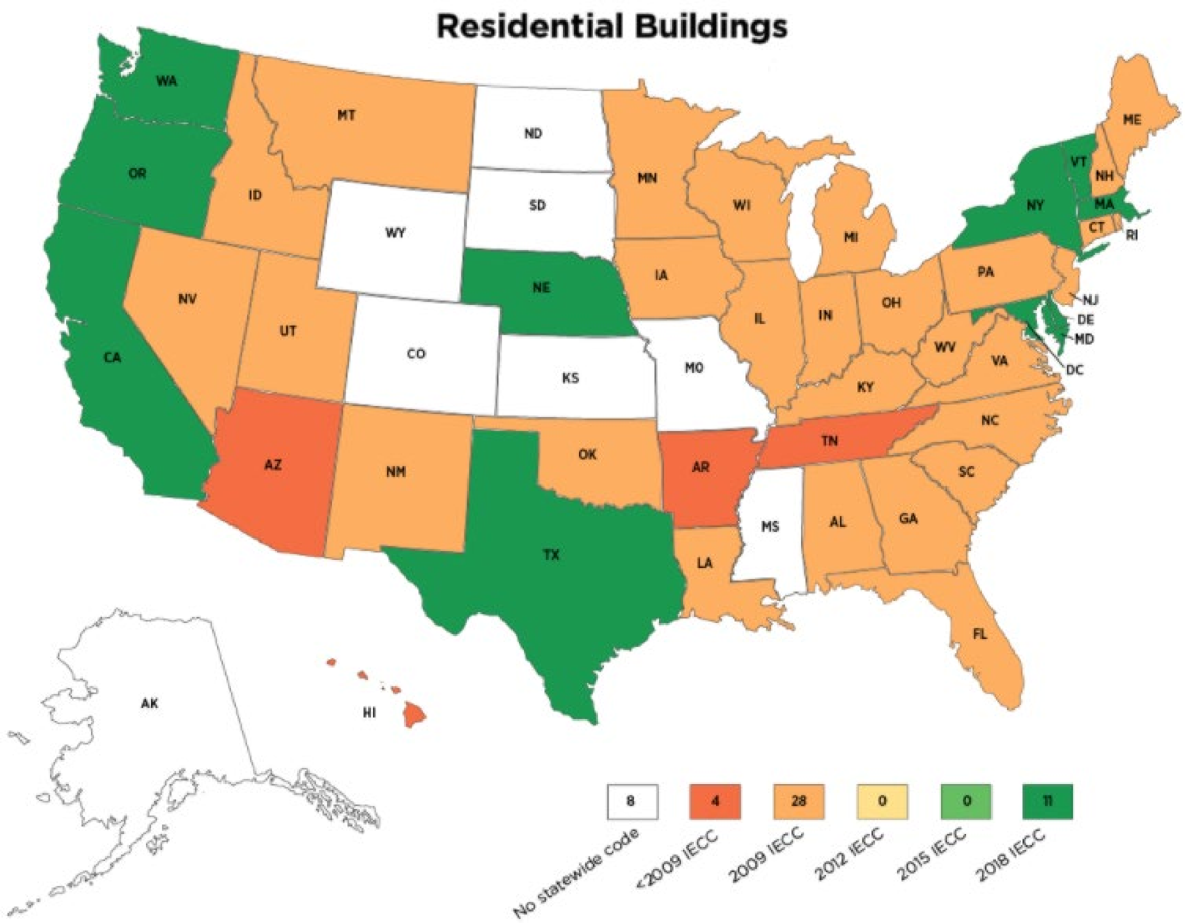



Figure 1. Current Residential Building Energy Code Adoption Status in the United States (BECP 2021)

## 1.2 Overview

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

### 1.2.1 Building Prototypes

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

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

Table 1. Residential Prototype Buildings

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

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

### 1.2.2 Climate Locations

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

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

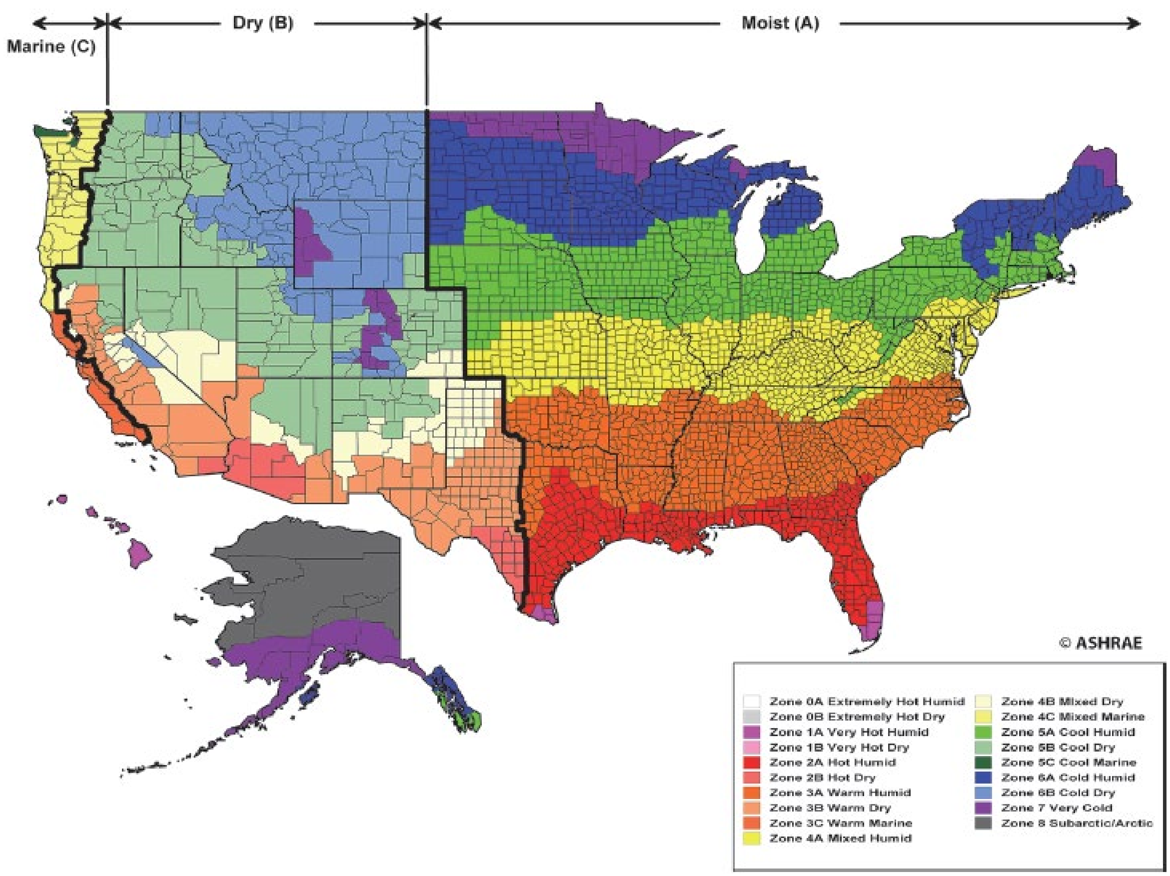



Figure 2. U.S. Climate Zone Map

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

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

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

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

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

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

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

### 1.2.3 Weighting Factors

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

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

Table 2. Weighting Factors by Building Type

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

Table 3. Weighting Factors by Foundation Type

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

Table 4. Weighting Factors by Heating System

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

Table 5. Weighting Factors by Climate Zone

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

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

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

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

## 1.3 Report Contents and Organization

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

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

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

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

# 2.0 Changes Introduced in the 2021 IECC

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

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

Table 7. Summary of Analyzed Changes to the 2021 IECC

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

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

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

# 3.0 Construction Cost Estimates

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

## 3.1 Methodology

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

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

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

## 3.2 Incremental Cost Estimates for New Provisions of the 2021 IECC

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

### 3.2.1 Increased High-Efficacy Lighting

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

### 3.2.2 Increased Wall Insulation

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

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

### 3.2.3 Increased Slab Insulation

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

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

### 3.2.4 Increased Ceiling Insulation

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

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

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

### 3.2.5 Lower Fenestration U-Factor

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

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

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

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

### 3.2.6 Increased Mechanical Ventilation Fan Efficacy

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

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

### 3.2.7 Added Heat Recovery Ventilation

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

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

### 3.2.8 Additional Efficiency Options

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

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

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

---

[1] https://www.hvi.org/
[2] www.homedepot.com. November 2020.
[3] https://www.energycodes.gov/sites/default/files/documents/iecc2018_R-3_analysis_final.pdf

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

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

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

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

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

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

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

### 3.2.9 Exterior Lighting

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

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

Table 9. Exterior Lighting Allowances for 2021 IECC

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

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

## 3.3 Summary of Incremental Costs

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

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

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

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

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

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

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

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

# 4.0 Economic Analysis

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

## 4.1 DOE Residential Cost-Effectiveness Methodology

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

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

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

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

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

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

## 4.2 Fuel Prices and Escalation Rates

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

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

## 4.3 Energy Cost Savings

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

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

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

## 4.4 Life-Cycle Cost

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

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

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

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

## 4.5 Simple Payback

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

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

Table 15. Simple Payback Period for the 2021 IECC

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

## 4.6 Cash Flow

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

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

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

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

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

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

# 5.0 Conclusions

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

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

# 6.0 References


42 U.S.C. 6831 et seq. Chapter 42, U.S. Code, Section 6831. Available at http://www.gpo.gov/fdsys/granule/USCODE-2010-title42/USCODE-2010-title42-chap81-subchapII-sec6831.

42 U.S.C. 6833. Chapter 42, U.S. Code, Section 6833. Available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

76 FR 56413. Request for Information for the DOE Residential Codes Cost-Effectiveness Methodology. Available at http://www.gpo.gov/fdsys/pkg/FR-2011-09-13/pdf/2011-23236.pdf.

ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. *Climatic Data for Building Design Standards*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia.

BECP – Building Energy Codes Program. 2021. Status of State Residential Energy Code Adoption as of December 2020. Available at http://www.energycodes.gov/adoption/states.

Census. 2010. *Characteristics of New Housing*. U.S. Census Bureau, Washington, D.C. Available at http://www.census.gov/construction/chars/completed.html.

DOE – U.S. Department of Energy. 2012. Building Component Cost Community Database. Available at https://bc3.pnnl.gov/.

DOE – U.S. Department of Energy. 2014. *Preliminary Determination Regarding Energy Efficiency Improvements in the 2015 International Energy Conservation Code*. Available at http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-DET-0030-0001.

DOE – U.S. Department of Energy. 2015. *Determination Regarding Energy Efficiency Improvements in the 2015 International Energy Conservation Code*. Available at https://www.regulations.gov/document?D=EERE-2014-BT-DET-0030-0007.

DOE – U.S. Department of Energy. 2019. *National Cost-Effectiveness of the Residential Provisions of the 2018 IECC*. U.S. Department of Energy, Washington, D.C. *Pending Release*.

DOE – U.S. Department of Energy. 2020. *EnergyPlus, Version 9.4*. U.S. Department of Energy. Washington, D.C. Available at https://energyplus.net/downloads.

EIA – U.S. Energy Information Administration. 2020a. *Table 5.3. Average Price of Electricity to Ultimate Customers*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_3.

EIA – U.S. Energy Information Administration. 2020b. *Natural Gas*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm.

EIA – U.S. Energy Information Administration. 2020c. *Natural Gas Heat Content*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/dnav/ng/ng_cons_heat_a_EPG0_VGTH_btucf_a.htm.

EIA – U.S. Energy Information Administration. 2020d. *Petroleum Marketing*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/dnav/pet/PET_PRI_WFR_A_EPD2F_PRS_DPGAL_W.htm.

EIA – U.S. Energy Information Administration. 2021. *Annual Energy Outlook 2021*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=2-AEO2021&cases=ref2021&sourcekey=0.

Faithful+Gould. 2012. *Prototype Estimate and Cost Data.* Available at http://bc3.pnnl.gov/wiki/images/f/fa/Residential_Report.pdf.

ICC – International Code Council. 2011. *2012 International Energy Conservation Code*. Washington, D.C.

ICC – International Code Council. 2014. *2015 International Energy Conservation Code*. Washington, D.C.

ICC – International Code Council. 2017. *2018 International Energy Conservation Code*. Washington, D.C.

ICC – International Code Council. 2021. *2021 International Energy Conservation Code*. Washington, D.C.

Lucas RG, ZT Taylor, VV Mendon, and SG Goel. 2012. *National Energy and Cost Savings for New Single- and Multifamily Homes: A Comparison of the 2006, 2009 and 2012 Editions of the IECC*. Pacific Northwest National Laboratory. Richland, Washington. Available at http://www.energycodes.gov/sites/default/files/documents/NationalResidentialCostEffectiveness.pdf.

Mendon VV, RG Lucas, and SG Goel. 2013. *Cost-effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions – Technical Support Document*. Pacific Northwest National Laboratory. Richland, Washington. Available at http://www.energycodes.gov/sites/default/files/documents/State_CostEffectiveness_TSD_Final.pdf.

Mendon VV and ZT Taylor. 2014. *Development of Residential Prototype Building Models and Analysis System for Large-Scale Energy Efficiency Studies Using EnergyPlus*. 2014 ASHRAE/IBPSA-USA Building Simulation Conference, Atlanta, Georgia.

Mendon VV, ZT Taylor, SU Rao, and YL Xie. 2014. *2015 IECC Determination of Energy Savings: Preliminary Technical Analysis*. Available at http://www.energycodes.gov/sites/default/files/documents/2015_IECC_preliminaryDeterminationAnalysis.pdf.

Mendon VV, A Selvacanabady, M Zhao, and ZT Taylor. 2015. *National Cost-Effectiveness of the Residential Provisions of the 2015 IECC.* Available at https://www.energycodes.gov/sites/default/files/documents/2015IECC_CE_Residential.pdf.

NAHB – National Association of Home Builders. 2009. *Economic Database in Support of ASHRAE 90.2 (Energy Efficient Design of Low-Rise Residential Buildings).* Report 3296_051409. NAHB Research Center, Upper Marlboro, Maryland.

NCHH – National Center for Healthy Housing. 2015. Available at http://www.nchh.org/Portals/0/Contents/Exercise_1_Benchmarking1.pdf.

NREL – National Renewable Energy Laboratory. 2012. *National Residential Efficiency Measures Database*. Available at http://www.nrel.gov/ap/retrofits/.

RECS – Residential Energy Consumption Survey. 2013. *2009 RECS Survey Data*. U.S. Energy Information Administration. Washington D.C. Available at https://www.eia.gov/consumption/residential/data/2009/

RS Means. 2020. *2020 Residential Cost Data.* RS Means Company. Kingston, Massachusetts.

Salcido V. Robert, Y Chen, Y Xie and ZT Taylor. 2021. *Energy Savings Analysis: 2021 IECC for Residential Buildings*. Pacific Northwest National Laboratory, Richland, Washington.

Taylor T, N Fernandez, and R Lucas. 2012. *Methodology for Evaluating Cost-effectiveness of Residential Energy Code Changes.* PNNL-21294. Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, Richland, Washington.

Taylor ZT, VV Mendon, and N Fernandez. 2015. *Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes*. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/sites/default/files/documents/residential_methodology_2015.pdf

Wilson E, C Engebrecht Metzger, S Horowitz, and R Hendron. 2014. *2014 Building America House Simulation Protocols*. National Renewable Energy Laboratory, Golden, Colorado. Available at http://energy.gov/sites/prod/files/2014/03/f13/house_simulation_protocols_2014.pdf.

# Appendix A – Qualitative Analysis of 2021 IECC

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

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

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

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

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

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

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

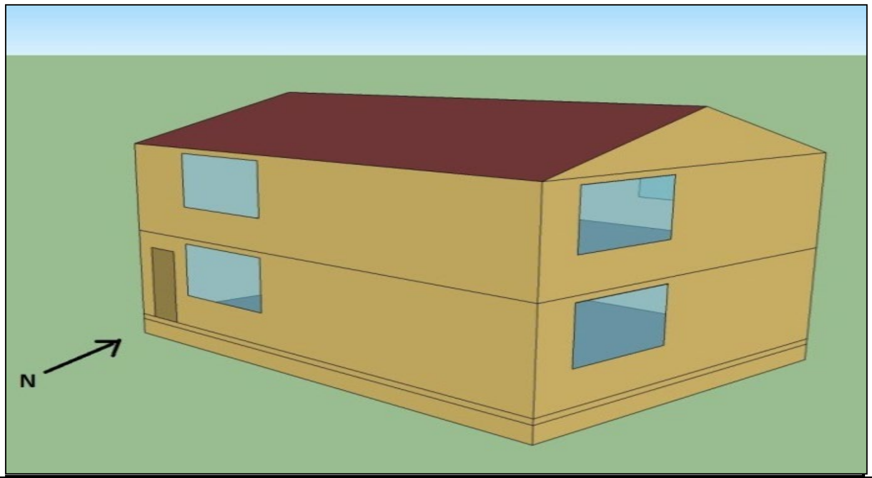
| Proposal Number[a] | Code Section(s)[b] | Description of Change(s) | Impact on Energy Efficiency | Discussion |
|---|---|---|---|---|
| RE53 | R402.2.8 (IRC N1102.2.8) | Expands on language of floor insulation installation for clarification. | Increases energy use | The proposal reduces the floor-R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

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

# Appendix B – Prototype Building Model Description

## B.1 Single-Family Prototype Model

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

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

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

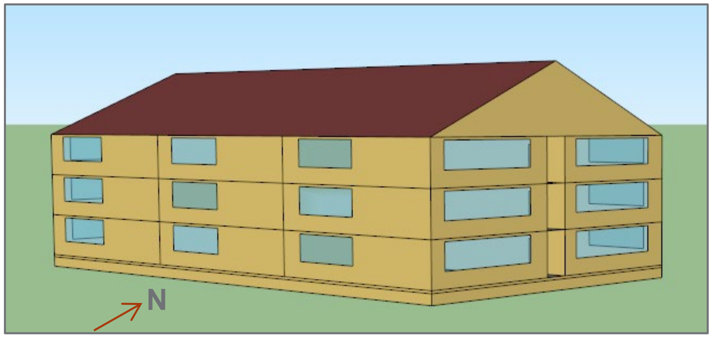
| | Item | Description | Data Source |
|---|---|---|---|
| **General** | | | |
| | Visible transmittance | | |
| | **Foundation** | | |
| | Foundation Type | Four Foundation Types are Modeled-<br>i. Slab-on Grade<br>ii. Vented Crawlspace Depth 2'<br>iii. Heated Basement - Depth 7'<br>iv. Unheated Basement-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

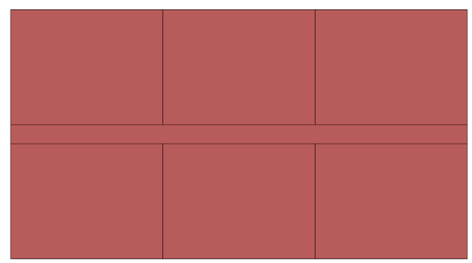
| | Item | Description | Data Source |
|---|---|---|---|
| **General** | | | |
| | Cooling type | Central DX Air-Conditioner/Heat Pump | |
| | **HVAC Sizing** | | |
| | Cooling | Autosized to design day | |
| | Heating | Autosized to design day | |
| | **HVAC Efficiency** | | |
| | Air Conditioning |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

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

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

## B.2 Multifamily Prototype Model

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

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

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

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

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

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

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

## B.3 Schedules

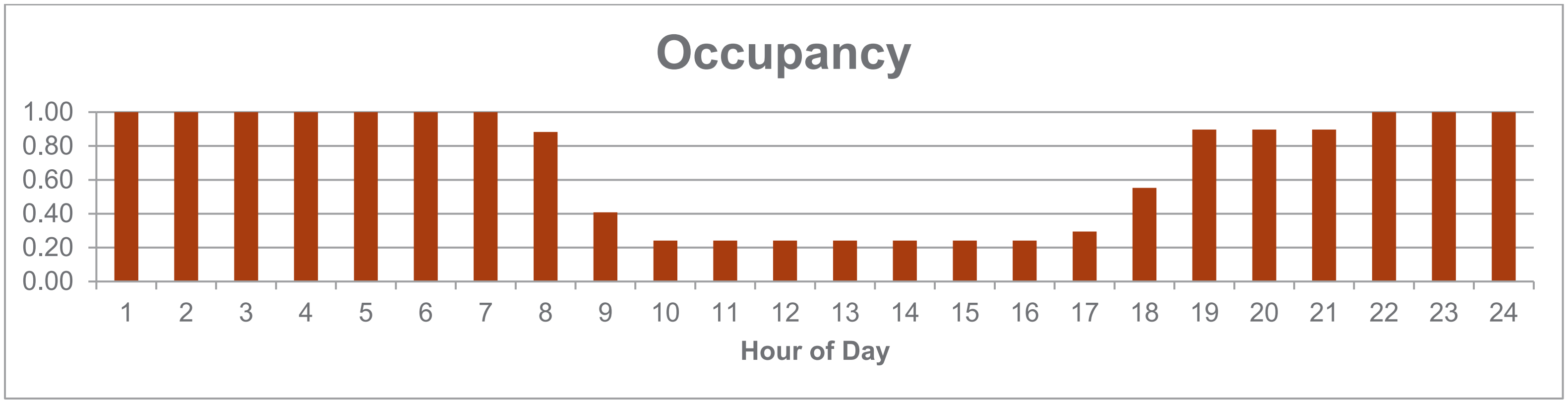



Figure B.1. Occupancy Schedules

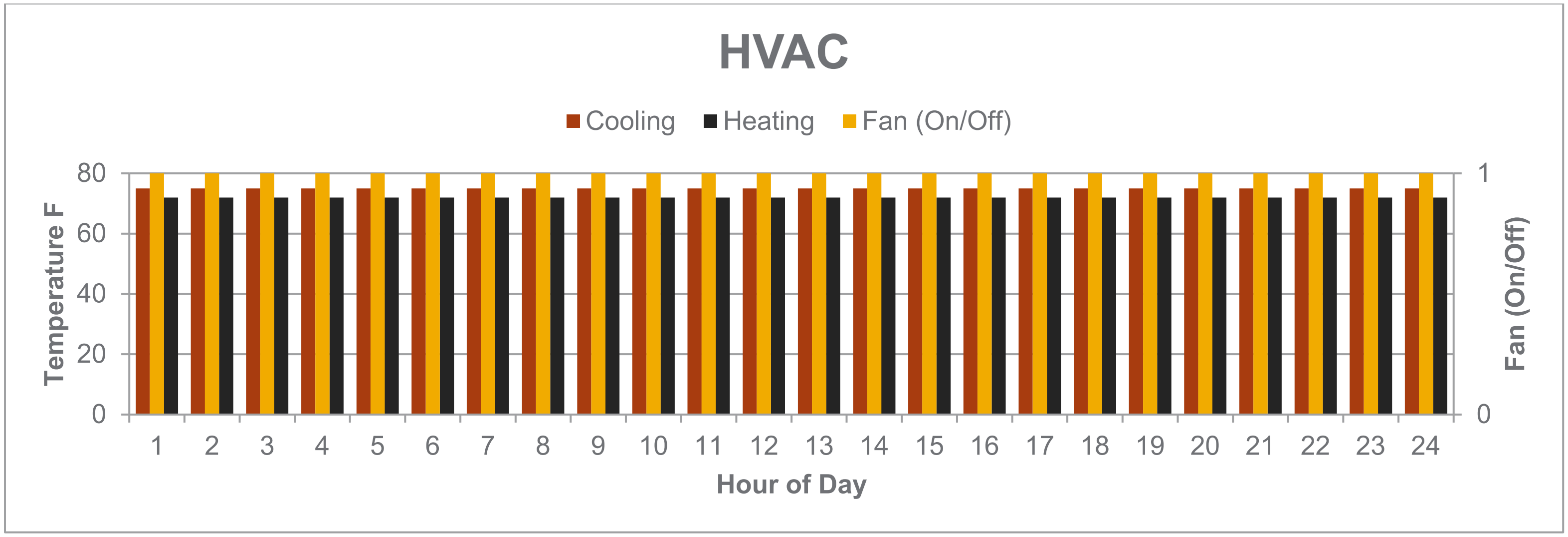



Figure B.2. HVAC Temperature Schedule

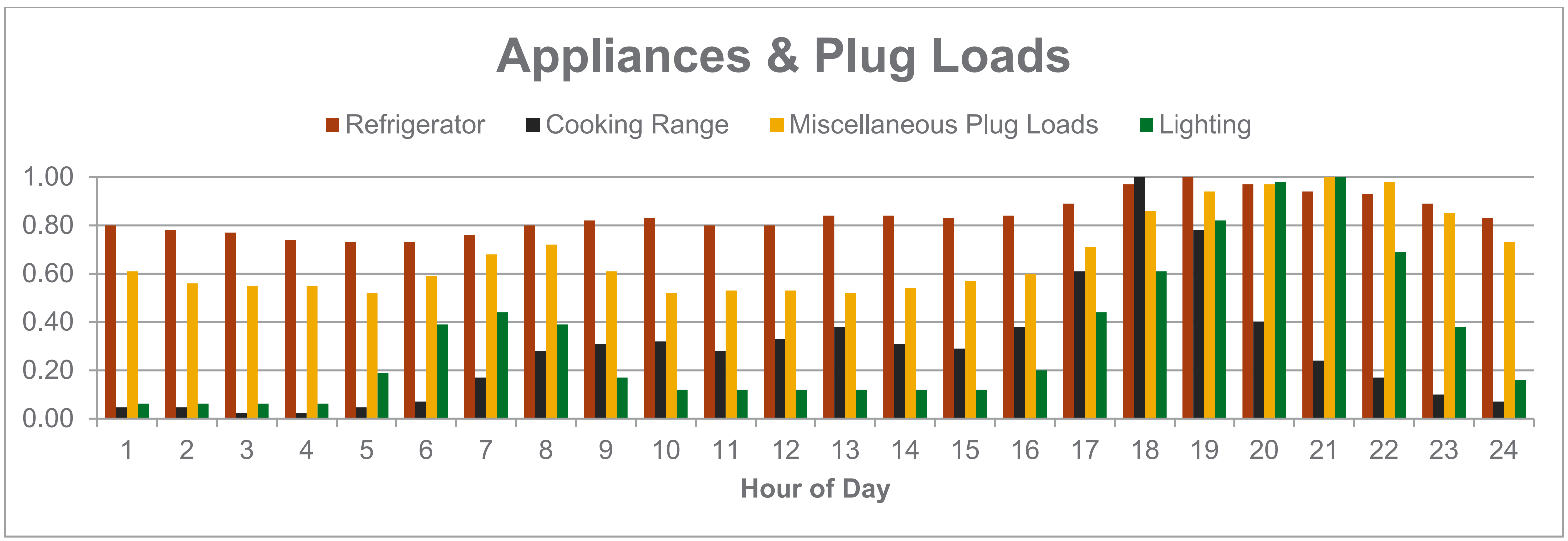



Figure B.3. Lighting and Appliance Schedules

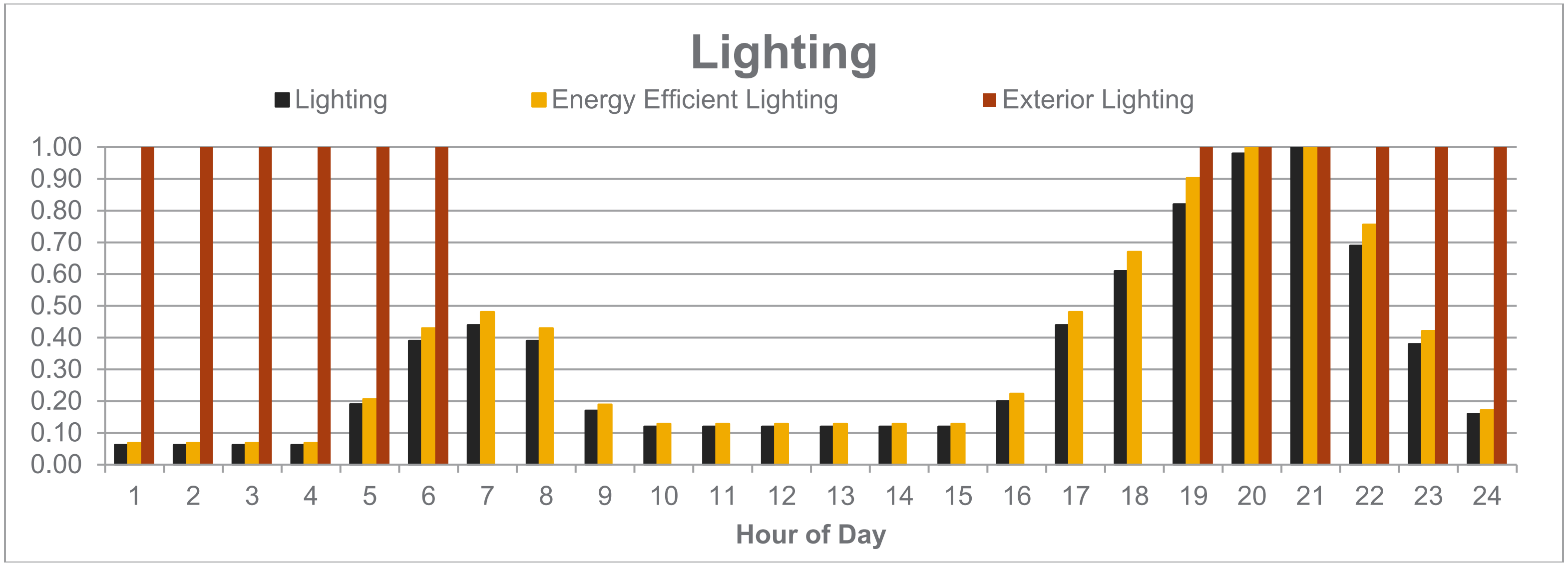



Figure B.4. Interior and Exterior Lighting Schedules

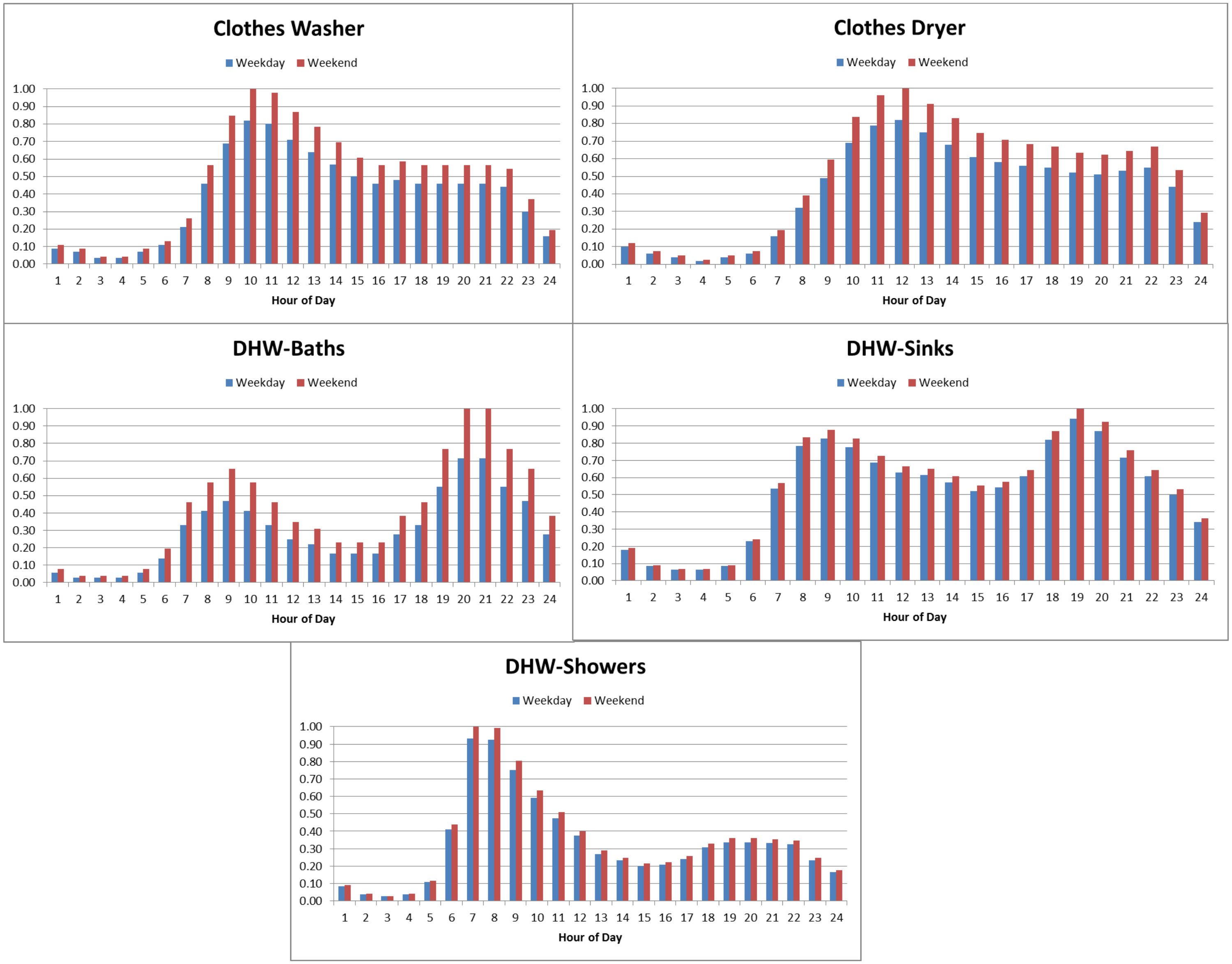



Figure B.5. Service Hot Water Demand Schedules

## B.4 Internal Gains Assumptions

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

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

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

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

**Pacific Northwest National Laboratory**

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

***www.pnnl.gov***