Pacific Northwest
NATIONAL LABORATORY

PNNL-32816

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September 2022

D Maddox
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U.S. DEPARTMENT OF ENERGY

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

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Richland, Washington 99354

# Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for the energy-efficient design and construction of new and renovated buildings, consequently reducing energy use and providing related environmental benefits over the lives of buildings. As required by federal statute (42 U.S.C. 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2019 would achieve greater energy efficiency in buildings compared to the 2016 edition of the standard. In support of DOE's determination, Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2019 (DOE 2021). While Standard 90.1 is the national model energy standard for commercial buildings (42 U.S.C. 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings.

This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2021 IECC would save energy and energy costs as compared to the 2018 IECC. The Commercial Energy Efficiency chapter in the 2021 IECC allows users to either follow the provisions in the IECC or use Standard 90.1-2019 as an alternative compliance path. As such, PNNL also compared the energy performance of the 2021 IECC with the corresponding Standard 90.1-2019 to help states and local jurisdictions make informed decisions regarding model code adoption.

The analysis builds on previous work completed by PNNL that assessed the energy performance of the 2018 IECC compared to the 2015 edition of the IECC (Zhang et al. 2018). For this analysis, PNNL first reviewed all code changes from the 2018 to 2021 IECC and identified those having a quantifiable impact on energy. These changes were then implemented in a suite of 16 prototype building models covering all 16 climate zones in the United States. This results in a total of 512 building models – 256 models each for the 2018 and 2021 editions of the IECC. Prototype models for the 2021 IECC were developed by implementing code changes to the 2018 IECC models. The 16 prototype building models represent approximately 75% of the total floor area of new commercial construction in the United States, including multi-family buildings more than three stories tall.

Whole-building energy simulations were conducted using DOE's *EnergyPlus Version 9.0.1* (DOE 2018) building simulation software. The resulting energy use from the complete suite of 512 simulation runs was converted to site energy use intensity (EUI, or energy use per unit floor area), source EUI, energy cost index (ECI), and carbon emissions for each simulation. For each prototype, the resulting EUIs and ECIs in each climate zone were weighted to calculate the aggregate national level site EUI, source EUI, ECI, and carbon emissions. Weighting factors were developed using commercial construction data and are based on new construction floor area of the different building types in each climate zone. Finally, the energy indexes were aggregated across building types to the national level using the same weighting data.

Overall, the 2021 edition of the IECC results in site energy savings of 12.1% at the aggregate national level compared to the 2018 IECC edition. In addition, on a national weighted average basis, the 2021 IECC is 6.5% *more* efficient for site energy use than Standard 90.1-2019 (see Appendix B in this report for the full comparison of the 2021 IECC and Standard 90.1-2019).

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

Savings from the 2018 to 2021 IECC vary significantly by prototype and climate. This is expected because code requirements differ by building type and climate.

A few high-impact changes resulting in significant energy savings are listed below:

- Envelope:
  - Air leakage testing (C402.5)
  - Operable openings interlocking with HVAC systems (C402.5.11)
- HVAC:
  - Demand controlled ventilation (C403.7.1)
  - Data center mechanical load components (C403.1.2)
  - Heating and cooling equipment efficiencies (C403.3.2)
- Lighting and receptacle loads:
  - Lighting power allowance reduction (C405.3.2)
  - Automatic control of receptacle loads (C405.11)
  - Secondary sidelit area daylighting control (C405.2.4)
- Additional efficiency requirements:
  - Lighting power reduction (C406.3)
  - Heating and cooling efficiencies (C406.2)
  - Heat pump water heaters (C406.7.4)
  - Infiltration reduction (C406.9).

Table ES.1 provides a high-level summary of differences between the 2018 IECC and the 2021 IECC, in terms of EUI, ECI and emissions. The analysis shows an estimated site energy savings of 12.1% and energy cost savings of 10.6% on a national aggregated basis. Figure ES.1 illustrates the national weighted savings between the 2018 IECC and the 2021 IECC for all metric types and for each prototype.

Table ES.1. Energy and Emission Savings between the 2018 and 2021 IECC

| | Site EUI kBtu/ft$^2$-yr | Source EUI kBtu/ft$^2$-yr | Site ECI \$/ft$^2$-yr | Emissions ton/ksf-yr |
|---|---|---|---|---|
| 2018 IECC National Weighted | 51.1 | 118.7 | 1.32 | 8.24 |
| 2021 IECC National Weighted | 44.9 | 106.1 | 1.18 | 7.40 |
| National Weighted Savings | 12.1% | 10.6% | 10.6% | 10.2% |
| Minimum Building Type Savings | 2.9% | 1.8% | 1.6% | 1.6% |
| Maximum Building Type Savings | 28.7% | 21.4% | 21.3% | 20.3% |

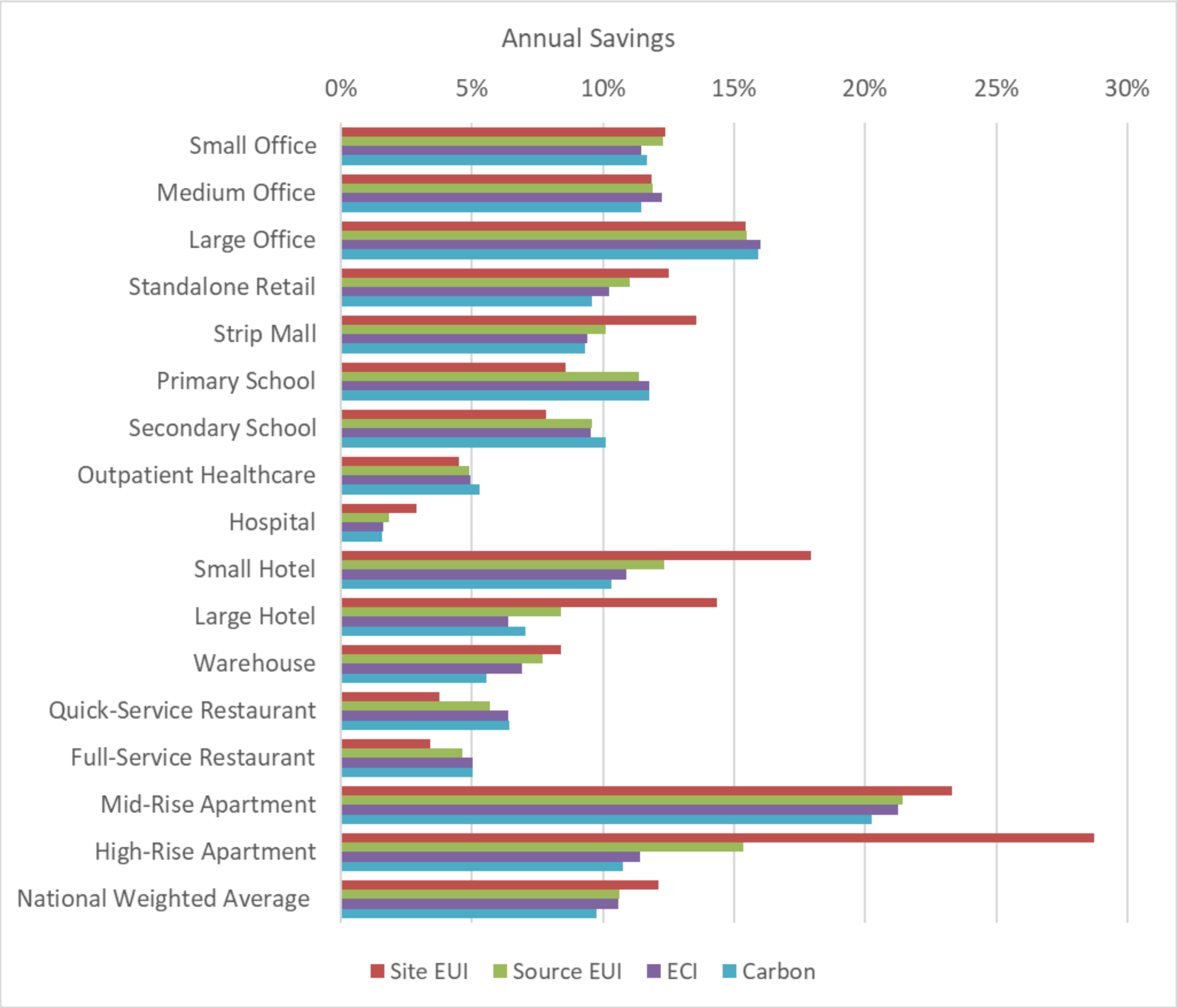


Figure ES.1. National Average Energy, Cost and Emissions Savings for all IECC Prototypes

# Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank Jeremiah Williams at DOE for providing oversight. The authors would also like to thank the numerous PNNL contributors to the Commercial Prototype Building Models, who built a technical foundation for this analysis project.

The authors sincerely thank their PNNL colleagues Reid Hart and Marye Hefty, as well as Jerica Stacey and Kristopher Stenger of the International Code Council, who provided insightful review comments on an earlier draft of this report.

## Acronyms and Abbreviations

| | |
|---|---|
| AEO | Annual Energy Outlook |
| ANSI | American National Standards Institute |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| BECP | Building Energy Codes Program |
| Btu/h | British thermal unit(s) per hour |
| CBECS | Commercial Building Energy Consumption Survey |
| CFM | cubic feet per minute |
| CFR | Code of Federal Regulations |
| $CO_2$ | carbon dioxide |
| DCV | demand control ventilation |
| DOE | U.S. Department of Energy |
| ECI | energy cost index |
| ECPA | Energy Conservation and Production Act |
| EIA | Energy Information Administration |
| EMS | energy management system |
| EPA | U.S. Environmental Protection Agency |
| ERE | energy recovery effectiveness |
| ERR | energy recovery ratio |
| ERV | energy recovery ventilator |
| EUI | energy use intensity |
| $ft^2$ | square feet |
| hp | horsepower |
| HPWH | heat pump water heater |
| HSPF | Heating Seasonal Performance Factor |
| HVAC | heating, ventilation, and air-conditioning |
| ICC | International Code Council |
| IECC | International Energy Conservation Code |
| IEER | Integrated Energy Efficiency Ratio |
| IES | Illuminating Engineering Society |
| INOCT | installed nominal operating cell temperature |
| in wc | inches of water column differential pressure |
| ITE | information technology equipment |
| $kBtu/ft^2$-yr | thousand British thermal unit(s) per square foot per year |
| kBtu/h | thousand British thermal unit(s) per hour |
| ksf | thousand square feet |

| | |
|---|---|
| kWh | kilowatt hour(s) |
| LPD | lighting power density |
| MLC | mechanical load component |
| PNNL | Pacific Northwest National Laboratory |
| OA | outside air |
| SEER | Seasonal Energy Efficiency Ratio |
| SHGC | solar heat gain coefficient |
| supp | supplemental heater |
| SWH | service water heating |
| Tmains | temperature of unheated service water entering the building |
| USC | United States Code |
| VAV | variable air volume |
| WWR | window-to-wall ratio |

# Contents

# Figures



# Tables

# 1.0 Introduction

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, consequently reducing energy use and providing related environmental impacts for the lives of buildings.

As required by federal statute (42 U.S.C. 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2019 would achieve greater energy efficiency in buildings subject to the code compared to the 2016 edition of the standard.[2] Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2019 in support of the determination (DOE 2021). While Standard 90.1 is the national model energy standard for commercial buildings (42 U.S.C. 6833), many states adopt the full suite of International Codes, and thus also adopt the International Energy Conservation Code (IECC), which includes energy conservation requirements for both residential and commercial buildings. Of the 42 states with statewide commercial building energy codes currently, 33 use a version of the IECC (BECP 2022). The Commercial Energy Efficiency chapter of the 2021 IECC (International Code Council, ICC 2021) allows users to either follow the provisions in the IECC or use Standard 90.1-2019 as an alternative compliance path. This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2021 IECC would save energy and energy costs compared to the 2018 IECC (ICC 2018). Because PNNL used the same methodology for both the 2021 IECC analysis and the previous Standard 90.1-2019 analysis, comparisons between the estimated energy performance of the 2021 IECC and that of its referenced Standard 90.1-2019 are presented in Appendix B of this report. The goal of this comparison is to help states and local jurisdictions make informed decisions regarding model code adoption.

This report documents the approach and results for PNNL's analysis for energy and energy cost savings of the 2021 IECC for commercial buildings. PNNL first reviewed all code changes from the 2018 to 2021 IECC and identified those having a quantifiable impact. PNNL then compared two suites of building prototypes, each suite complying with one edition of the IECC. Each suite consists of 256 building prototypes; a combination of 16 building prototypes in all 16 U.S. climate zones. The 2018 IECC prototypes were taken from PNNL's previous analysis of the energy performance of the 2018 IECC compared to its previous edition, which was documented in *Energy and Energy Cost Savings Analysis of the* 2018 *IECC for Commercial Buildings* (Zhang et al. 2018), referred to here as *Analysis of the* 2018 *IECC*.

The remainder of this report is organized in three sections. Section 2.0 summarizes the general development and methodology related to the building prototypes and simulation for energy use and cost. The same methodology was applied in the previous *Analysis of the* 2018 *IECC* and the Standard 90.1-2019 determination (DOE 2021). Section 3.0 describes how PNNL developed the 2021 IECC prototypes using the 2018 IECC prototypes as the basis. Finally, Section 4.0 summarizes the results of the comparison of the two editions of the IECC. Appendix A summarizes the identified code changes between the 2018 and 2021 IECC (with quantified

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

[2] For more information on the DOE Determination of energy savings, see http://www.energycodes.gov/development/determinations.

energy impacts) and identifies which building prototypes are impacted by each change. Appendix B provides energy and energy cost comparisons between Standard 90.1-2019 and the 2021 IECC.

# 2.0 Methodology

To support the development and implementation of building energy codes, PNNL researchers have developed building prototypes that comply with various editions of model energy codes including both Standard 90.1 and the IECC. These building prototypes represent the majority of new commercial building stock and were developed using DOE's *EnergyPlus Version 9.0.1* building energy simulation software (DOE 2018). The results allow comparison of the national weighted average savings of one code to its earlier edition and the relative performance differences between the codes. This section summarizes the general methodology used for this 2021 IECC analysis, which is consistent with that used for the *Analysis of the* 2018 *IECC*.

## 2.1 Building Prototypes

For this analysis, PNNL used a suite of building prototypes (DOE and PNNL 2022) representing the first seven principal building activities in the Commercial Buildings Energy Consumption Survey (CBECS; EIA 2003). These seven principal building activities represent 76% of the energy usage of all commercial buildings. In addition, two multifamily prototypes (Mid-Rise and High-Rise Apartments), which are not included in CBECS, were added into the suite of prototypes because they are also regulated by the commercial provisions of the IECC. Table 2.1 shows the seven principal activities as defined in CBECS and the added apartment activity. These building activities were further divided into 16 building prototypes, which are listed in Table 2.1 along with their floor area. Together, these prototypes represent 75% of new construction floor area in the United States (Lei et al. 2020). Detailed descriptions of the prototypes and enhancements are documented in Thornton et al. (2011) and Goel et al. (2014).

Table 2.1. Commercial Prototype Building Models

| Building Type | Prototype Building | Floor Area ($ft^2$) | Floor Area (%) |
|---|---|---|---|
| Office | Small Office | 5,502 | 3.8% |
| | Medium Office | 53,628 | 5.0% |
| | Large Office | 498,588 | 3.9% |
| Retail | Stand-Alone Retail | 24,692 | 10.9% |
| | Strip Mall | 22,500 | 3.7% |
| Education | Primary School | 73,959 | 4.8% |
| | Secondary School | 210,887 | 10.9% |
| Healthcare | Outpatient Health Care | 40,946 | 3.4% |
| | Hospital | 241,501 | 4.5% |
| Lodging | Small Hotel | 43,202 | 1.6% |
| | Large Hotel | 122,120 | 4.2% |
| Warehouse | Non-Refrigerated Warehouse | 52,045 | 18.6% |
| Food Service | Quick-Service Restaurant | 2,501 | 0.3% |
| | Full-Service Restaurant | 5,502 | 1.0% |
| Apartment | Mid-Rise Apartment | 33,741 | 13.7% |
| | High-Rise Apartment | 84,360 | 9.6% |
| Total | | | 100% |

## 2.2 Climate Zones

The 2021 IECC includes nine climate zones (0 through 8) and three moisture regimes (marine, dry, and humid). Each combination of climate zone and moisture regime defines a climate subzone, resulting in 16 climate subzones in the United States, which are the same as those defined in ASHRAE Standard 169-2013, *Climatic Data for Building Design Standards* (ASHRAE 2013), which assigns U.S. counties to climate zones, as shown in Figure 2.1. There are currently no counties in the U.S. assigned to Climate Zones 0A, 0B, or 1B.

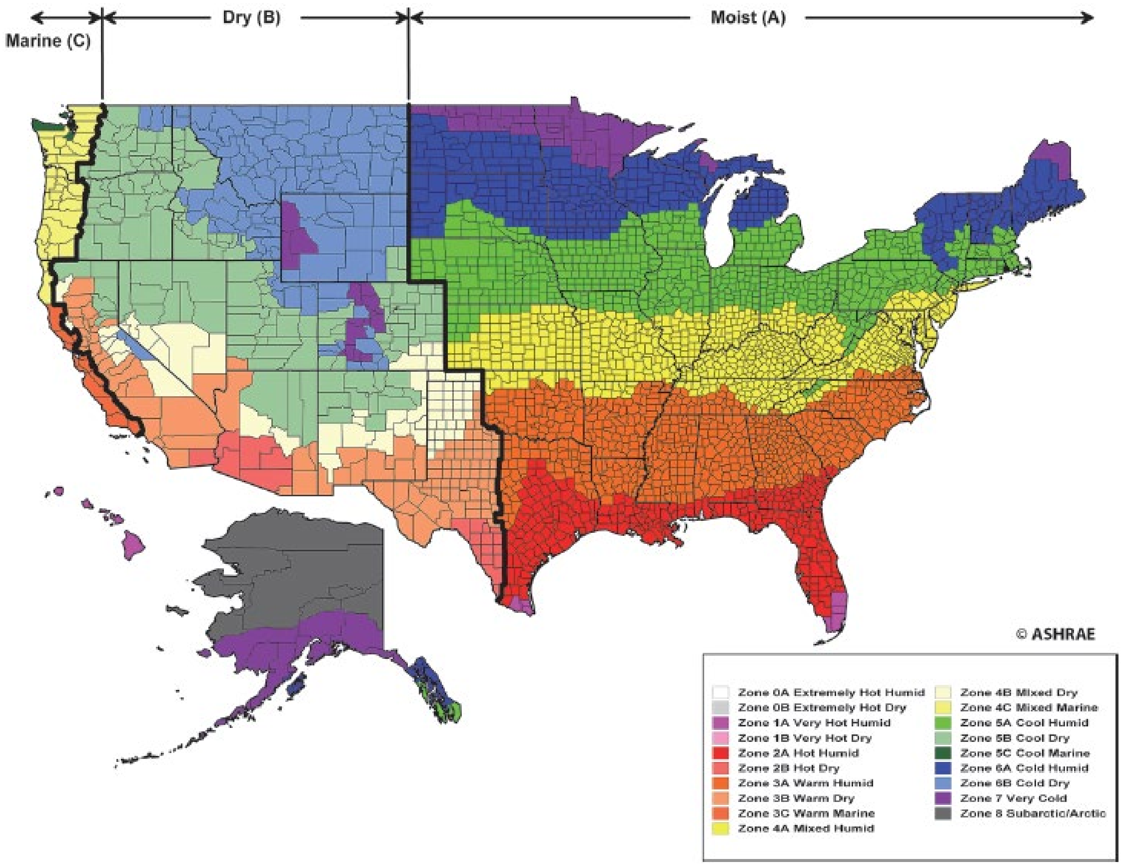


Figure 2.1. United States Climate Zone Map (ASHRAE 2013)

For this analysis, a specific climate location (city) was selected as a representative of each of the 16 climate/moisture zones found in the United States. These are consistent with representative cities approved by the ASHRA E 90.1 Standing Standard Project Committee (SSPC) for setting the criteria for Standard 90.1-2019. One change from the 2018 IECC analysis is that climate zone 1A is now represented by Miami, Florida instead of Honolulu, Hawaii.

The 16 cities used in the current analysis are:

- 1A: Miami, Florida (very hot, humid)
- 2A: Tampa, Florida (hot, humid)
- 2B: Tucson, Arizona (hot, dry)
- 3A: Atlanta, Georgia (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Diego, California (warm, marine)
- 4A: New York, New York (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Seattle, Washington (mixed, marine)
- 5A: Buffalo, New York (cool, humid)
- 5B: Denver, Colorado (cool, dry)
- 5C: Port Angeles, Washington (cool, marine)
- 6A: Rochester, Minnesota (cold, humid)
- 6B: Great Falls, Montana (cold, dry)
- 7: International Falls, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

## 2.3 Comparison Metrics and Construction Weights

Annual electricity and natural gas energy use in each building prototype were simulated across 256 buildings, a combination of 16 prototypes in all 16 U.S. climate zones. The simulated site energy use is utility electricity and natural gas delivered to and used at the building site. The site energy use was converted to site energy use intensity (site EUI, or energy use per unit floor area). Results are also presented in terms of source energy consumption at the level of the power generation facility, site energy cost, and carbon emission reductions. Conversion factors are described in the following paragraphs.

The electric energy source conversion factor of 9,707 Btu/kWh was calculated using Table 2[1] from EIA's Annual Energy Outlook (AEO) 2022 (EIA 2022) as follows:

- Delivered commercial electricity, 2021: 4.50 quads
- Commercial electricity related losses, 2021: 8.30 quads
- Total commercial electric energy use, 2021: 12.80 quads
- Commercial electric source ratio, U.S. 2021: 2.84
- Source electric energy factor[2] (3,413 Btu/kWh site): 9,707 Btu/kWh

Natural gas EUIs in the prototype buildings were converted to source energy using a factor of 1.094 Btu of source energy per Btu of site natural gas use, based on the 2021 national energy use estimate shown in Table 2 of the AEO 2022 as follows:

- Delivered total natural gas, 2021: 28.41 quads
- Natural gas used in well, field, and pipeline: 2.66 quads
- Total gross natural gas use, 2021: 31.06 quads
- Total natural gas source ratio, U.S. 2021: 1.094 Btu source/Btu site
- Source natural gas energy factor (100,000 Btu/therm site): 109,400 Btu/therm

To calculate the energy cost, PNNL relied on national average commercial building energy prices based on EIA statistics for 2021 in Table 3, "Energy Prices by Sector and Source," of the AEO 2022 for commercial sector natural gas and electricity of:

- $0.1132/kWh of electricity
- $8.74 per 1000 cubic feet ($0.843/therm) of natural gas.

PNNL recognizes that actual energy costs will vary somewhat by building type within a region, and even more between regions. However, the use of national average figures sufficiently illustrates energy cost savings and the effect on energy efficiency in commercial buildings. The same methodology was used for the DOE determination for Standard 90.1-2019 (DOE 2021).

Carbon emissions in the quantitative analysis are based on the source energy consumption on a national scale. Carbon emission metrics are provided by the U.S. Environmental Protection

[1] Available at https://www.eia.gov/outlooks/aeo/.

[2] The final conversion value is calculated using the full seven-digit values available in Table 2 of AEO 2022. Other values shown in the text are rounded.

Agency (EPA) Greenhouse Gas Equivalencies Calculator.[1] The EPA greenhouse calculator reports the national marginal carbon emission conversion factor for electricity at 7.07 x $10^{-4}$ metric tons carbon dioxide ($CO_2$)/kWh. For natural gas, the carbon emission conversion factor is 0.0053 metric tons $CO_2$/therm. Table 4.2 summarizes the carbon emission factors. For a detailed discussion of the estimates of the monetized benefits of carbon emission reductions due to implementation of commercial model energy codes see Tyler et al. (2021).

Weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level were developed from construction data purchased from McGraw Hill. Details of the development are further discussed in a PNNL report (Lei et al. 2020). New construction weights were determined for each building type in each climate zone based on the county-climate zone mapping from ASHRAE Standard 169-2013. Table 2.2 lists the weighting factors assigned to each prototype in all 16 U.S. climate zones.

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

Table 2.2. Relative Construction Volume Weights for 16 Prototype Buildings by Climate Zone (percent)

| Building Type | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 | Weights by Bldg Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Large Office | 0.11 | 0.54 | 0.07 | 0.54 | 0.26 | 0.23 | 1.13 | 0.00 | 0.24 | 0.48 | 0.15 | 0.00 | 0.09 | 0.00 | 0.01 | 0.00 | 3.86 |
| Medium Office | 0.14 | 0.78 | 0.19 | 0.73 | 0.45 | 0.16 | 0.95 | 0.03 | 0.17 | 0.88 | 0.31 | 0.00 | 0.17 | 0.03 | 0.02 | 0.00 | 5.01 |
| Small Office | 0.11 | 0.77 | 0.15 | 0.70 | 0.27 | 0.05 | 0.58 | 0.03 | 0.09 | 0.67 | 0.21 | 0.00 | 0.13 | 0.02 | 0.02 | 0.00 | 3.80 |
| Stand-Alone Retail | 0.29 | 1.79 | 0.31 | 1.78 | 0.85 | 0.12 | 1.92 | 0.08 | 0.26 | 2.37 | 0.54 | 0.01 | 0.49 | 0.06 | 0.06 | 0.01 | 10.94 |
| Strip Mall | 0.16 | 0.63 | 0.14 | 0.70 | 0.42 | 0.09 | 0.66 | 0.02 | 0.09 | 0.61 | 0.12 | 0.00 | 0.06 | 0.01 | 0.01 | 0.00 | 3.71 |
| Primary School | 0.13 | 0.98 | 0.12 | 0.94 | 0.36 | 0.04 | 0.88 | 0.03 | 0.12 | 0.77 | 0.23 | 0.00 | 0.16 | 0.05 | 0.02 | 0.00 | 4.83 |
| Secondary School | 0.26 | 1.86 | 0.19 | 2.16 | 0.77 | 0.14 | 1.98 | 0.07 | 0.27 | 2.18 | 0.51 | 0.01 | 0.37 | 0.09 | 0.06 | 0.01 | 10.92 |
| Hospital | 0.09 | 0.75 | 0.11 | 0.63 | 0.32 | 0.10 | 0.92 | 0.03 | 0.13 | 0.95 | 0.23 | 0.01 | 0.20 | 0.03 | 0.03 | 0.00 | 4.52 |
| Outpatient Health Care | 0.05 | 0.54 | 0.09 | 0.53 | 0.17 | 0.04 | 0.62 | 0.02 | 0.10 | 0.80 | 0.20 | 0.00 | 0.18 | 0.03 | 0.03 | 0.00 | 3.42 |
| Full-Service Restaurant | 0.03 | 0.18 | 0.03 | 0.17 | 0.08 | 0.01 | 0.16 | 0.01 | 0.02 | 0.19 | 0.04 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.97 |
| Quick-Service Restaurant | 0.01 | 0.07 | 0.01 | 0.06 | 0.02 | 0.00 | 0.06 | 0.00 | 0.00 | 0.07 | 0.02 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.33 |
| Large Hotel | 0.18 | 0.71 | 0.10 | 0.56 | 0.55 | 0.09 | 0.82 | 0.02 | 0.13 | 0.65 | 0.19 | 0.00 | 0.14 | 0.04 | 0.02 | 0.00 | 4.22 |
| Small Hotel | 0.03 | 0.30 | 0.02 | 0.27 | 0.11 | 0.02 | 0.30 | 0.01 | 0.03 | 0.27 | 0.10 | 0.00 | 0.08 | 0.03 | 0.02 | 0.00 | 1.59 |
| Non-Refrigerated Warehouse | 0.53 | 3.53 | 0.63 | 2.77 | 2.23 | 0.18 | 3.69 | 0.05 | 0.54 | 3.14 | 0.82 | 0.00 | 0.37 | 0.03 | 0.04 | 0.00 | 18.56 |
| High-Rise Apartment | 1.44 | 1.19 | 0.08 | 0.57 | 0.63 | 0.29 | 3.26 | 0.00 | 0.49 | 1.36 | 0.19 | 0.00 | 0.11 | 0.01 | 0.00 | 0.00 | 9.64 |
| Mid-Rise Apartment | 0.36 | 2.24 | 0.27 | 1.78 | 1.18 | 0.49 | 3.02 | 0.03 | 0.71 | 2.22 | 0.73 | 0.01 | 0.57 | 0.05 | 0.04 | 0.00 | 13.69 |
| Weights by Zone | 3.94 | 16.85 | 2.52 | 14.89 | 8.67 | 2.06 | 20.94 | 0.43 | 3.39 | 17.60 | 4.59 | 0.05 | 3.17 | 0.49 | 0.38 | 0.03 | 100.00 |

# 3.0 2021 IECC Building Prototype Development

The starting point for the 2021 prototypes was the 2018 prototypes that were developed for the *Analysis of the 2018 IECC* (Zhang et al. 2018). PNNL reviewed all code changes from the 2018 to 2021 IECC. In this section, PNNL compares code changes in commercial energy efficiency provisions between the 2018 and 2021 IECC and documents how they were implemented in the 2021 IECC prototypes and modeled in *EnergyPlus*.

## 3.1 Review of Code Changes

Chapter 4 Commercial Energy Efficiency of the IECC provides three alternative paths for a new building to demonstrate compliance: (1) the prescriptive requirements in the IECC, (2) the total building performance requirements in the IECC, or (3) the requirements in the referenced Standard 90.1. This analysis looks only at the prescriptive compliance path (1), comparing the energy performance of the mandatory and prescriptive requirements in the 2018 IECC relative to those in the 2021 IECC, which is consistent with how DOE has traditionally evaluated model code updates when issuing its statutorily-directed *Determinations of Energy Savings.*[1]

PNNL classified the changes to the prescriptive compliance path into three categories: 1) changes that provide clarifications, are administrative, or update references to other documents, and thusdo not directly impact energy use; 2) changes that result in energy efficiency impacts but are not quantified using the building prototypes; and 3) changes that result in energy efficiency impacts that can be quantified. Only those in the third category were incorporated into the 2021 IECC prototypes. Changes in the second category were not quantified when they met one of the following criteria:

1. The changes impact features not found in typical building designs. The prototype models include the most common design features found in each building type in the United States. Therefore, there are many less common features that are not represented in the prototypes, such as enclosed parking garages and large diameter ceiling fans. Changes affecting these features of buildings were not captured via the prototypes in order to preserve representation of the typical building stock.
2. The changes apply only to building retrofits or alterations instead of newly constructed buildings.
3. The changes cannot be modeled with currently available tools and data. One example of this is the increased Integrated Energy Efficiency Ratio (IEER) requirements for packaged direct expansion cooling systems. There is currently no performance data available to characterize the impact of IEER changes on part load energy performance.

Table 3.1 lists the changes that have been quantified through the prototype analysis, and Appendix A identifies both the location of each change in the IECC and the list of prototypes that are impacted. The following sections describe these changes in more detail, as well as their modeling strategies in the prototypes.

[1]The latest DOE determinations are available at https://www.energycodes.gov/development/determinations.

Table 3.1. Changes Between the 2018 and 2021 IECC with Quantified Energy

| 2021 IECC Section | Description of Code Changes |
|---|---|
| C402.1.4 Assembly U-factor, C-factor, or F-factor | Imposes more stringent requirement on the insulation requirements for opaque constructions. |
| C402.4 Fenestration | Imposes more stringent requirement on the window thermal properties. |
| C402.4.5 Doors | Increases allowable U-factor requirements for opaque non-swinging doors. Also decreases U-factors for swinging doors in some climates. |
| C402.5 Air leakage - thermal envelope | Adds requirement for air barrier testing, which sets specific limits on air leakage for specific climates. |
| C402.5.11 Operable openings interlocking | Requires that operable openings be interlocked with HVAC setpoints. |
| C403.1.2 Data centers | Adds requirement that data center systems comply with Sections 6 and 8 of ASHRAE 90.4-2016 (ASHRAE 2016), with IECC-specific values for mechanical load component (MLC). |
| C403.3.2 HVAC equipment performance requirements | Increases required HVAC efficiency values for several equipment categories. |
| C403.4.2.3 Automatic start and stop | Adds automatic stop for near the end of occupied periods, where thermostat is set back by 2°F. |
| C403.6.5 Supply air temperature reset | Adds exceptions to supply air temperature reset for some hot climates based on design outside air flow. |
| C403.7.1 Demand control ventilation | Expands the applicability of demand control ventilation (DCV) to all single-zone systems that also require economizer and reduces occupant density threshold. |
| C403.7.4 Energy recovery systems | Adds new requirements for energy recovery ventilator (ERV) in non-transient dwelling units. |
| C403.8.5 Low-capacity ventilation fans | Adds efficacy requirements for low-capacity fans. |
| C403.11.1 Commercial refrigerators and freezers | Decreases maximum daily energy consumption for commercial refrigerators and freezers. |
| C403.11.2 Walk-in coolers and walk-in freezers | Decreases maximum daily energy consumption for walk-in coolers and freezers. |
| Future | Adds new federal requirements for clean water pump efficiency.[1] |
| C405.2.1 Occupant sensor controls | Extends lighting occupancy sensor requirement to corridor spaces. |
| C405.2.4.2 Sidelit daylight zone | Adds requirement for secondary sidelit daylight zone. |
| C405.2.7.3 Exterior lighting setback | Increases exterior lighting control setback amounts to 50% and adds occupancy-based control to outdoor parking areas. |
| C405.3.2 Interior lighting power allowance | Decreases lighting power allowance for most space types. |
| C405.11 Automatic receptacle control | Adds requirement for automatic control of receptacle loads in selected space types. |
| C406 Additional Efficiency Requirements | Establish energy efficiency credit requirements with more optional efficiency requirements with new point values. |

[1] Clean water pump requirements in the CFR section 431.465 have been in effect since January 27, 2020.

Sections 3.2 through 3.4 of this report summarize new prescriptive code requirements in the 2021 IECC. Section 3.5 describes updates to the Additional Efficiency section of the IECC and how that section was applied to the prototypes for the 2021 IECC.

## 3.2 Building Envelope

### 3.2.1 Opaque Envelope

**Code Change Description**. Tables C402.1.3 and C402.1.4 of the 2021 IECC include several significant performance improvements for opaque envelope relative to the 2018 IECC.

**Modeling Strategy**. Key changes that are relevant to the prototypes were made for above grade walls, below grade walls, metal building walls and roofs, and unheated slabs, and all prototypes are affected by the changes. Changes in U-factor requirements of walls, roofs, and floors were implemented in the prototype models by adjusting the insulation R-value to provide the target overall U-factors as needed. Doors are modeled as massless objects in the prototypes, and thus changes to the code requirements were implemented directly as R-value of the doors.

### 3.2.2 Vertical Fenestration U-factor and Solar Heat Gain Coefficient (SHGC)

**Code Change Description**. The 2021 IECC decreases the maximum U-factor and SHGC requirements of vertical fenestration in Table C402.4 for several climate zones. In addition, the window type categories for specification of SHGC were changed from an orientation basis to be based on fixed versus operable window types.

**Modeling Strategy**. All the prototypes have vertical fenestration; therefore, this code change has energy impacts on all prototypes. To capture the window type categories of fixed and operable, weighting factors were developed as shown in Table 3.2 based on recent market data from Ducker[1] to calculate weighted U-factor and SHGC values for each prototype. The previous analysis for the 2018 IECC neglected the alternative SHGC values for the north orientation because the prototypes are oriented true east, south, west, and north, and the impact of relaxed SHGC for a true north-facing facade is negligible.

[1] Detailed market data from https://www.ducker.com/ were processed by the ASHRAE SSPC90.1 Envelope Subcommittee.

Table 3.2. Weighting Factors for Fixed and Operable Windows

| Building Prototype | Vertical fenestration categories | |
|---|---|---|
| | Fixed | Operable |
| Small Office | 96.9% | 3.1% |
| Medium Office | 96.9% | 3.1% |
| Large Office | 96.9% | 3.1% |
| Stand-Alone Retail | 97.8% | 2.2% |
| Strip Mall | 97.8% | 2.2% |
| Primary School | 89.8% | 10.2% |
| Secondary School | 89.8% | 10.2% |
| Outpatient Healthcare | 95.9% | 4.1% |
| Hospital | 95.9% | 4.1% |
| Small Hotel | 92.0% | 8.0% |
| Large Hotel | 92.0% | 8.0% |
| Non-Refrigerated Warehouse | 97.4% | 2.6% |
| Quick-Service Restaurant | 97.8% | 2.2% |
| Full-Service Restaurant | 97.8% | 2.2% |
| Mid-Rise Apartment | 75.4% | 24.6% |
| High-Rise Apartment | 75.4% | 24.6% |

### 3.2.3 Skylight U-factor and Solar Heat Gain Coefficient (SHGC)

**Code Change Description**. The 2021 IECC decreases the maximum U-factor requirements for skylights in Table C402.4 for climate zones 0, 1, 7, and 8. In addition, skylight SHGC values are decreased for climate zones 0 through 3.

**Modeling Strategy**. Skylights are included in the Stand-Alone Retail, Primary School, Secondary School, and Warehouse prototypes. The changes were implemented as new skylight property values for these prototype models in the affected climate zones.

### 3.2.4 Infiltration

**Code Change Description**. Under the requirements of Section C402.5 of the 2021 IECC, air leakage testing is no longer optional for specified building types, building sizes, and climate zones. In the 2018 IECC, the air leakage testing was not required if specified design and construction practices were followed.

**Modeling Strategy**. Table 3.3 lists the new 2021 IECC requirements for air leakage testing as applied to the prototypes. For the 2018 IECC, the infiltration values were set at 1.0 cfm/ft$^2$ at 0.3 inches of water column differential pressure (in wc) for all climate zones except 2B, which was at 1.8 cfm/ft$^2$ at 0.3 in wc. These values are based on recommendations made by the ASHRAE Envelope Subcommittee, where 1.8 cfm/ft$^2$ represents a building without advanced air barriers, and 1.0 cfm/ft$^2$ represents a building with advanced air barriers, but without air leakage testing (Thornton et al., 2011). It should be noted that the infiltration rate specified in 2021 IECC for dwelling and sleeping units of 0.3 cfm/ft$^2$ at 0.2 in wc is equivalent to 0.4 cfm/ft$^2$ at the higher pressure difference of 0.3 in wc, as reported in Table 3.3.

The test condition values from Table 3.3 were converted to natural conditions for the model using the methods described by Gowri et al. (2009). The infiltration rates were further reduced for some prototypes to satisfy the additional efficiency requirements as described in Section 3.5 of this report.

Table 3.3. New IECC 2021 Estimated Infiltration Rates for Prototypes based on Climate, cfm/ft$^2$ at 0.3 in wc

| Group | Prototypes | 0A | 0B | 1A | 1B | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A to 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group R and I | High-Rise Apartment, Mid-Rise Apartment, Hospital, Large Hotel, Small Hotel Outpatient Health Care | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 1.8 | 0.4 | 0.4 | 1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 1 | 0.4 |
| < 5,000 ft$^2$ | Fast Food Restaurant | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 1.8 | 0.4 | 1 | 1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 1 | 0.4 |
| 5,000 to <50,000 ft$^2$ | Office Small, Stand-Alone Retail Strip mall Retail, Sit-Down Restaurant | 0.4 | 1 | 1 | 1 | 1 | 1.8 | 0.4 | 1 | 1 | 0.4 | 1 | 1 | 0.4 | 0.4 | 1 | 0.4 |
| >= 50,000 ft$^2$ | Medium Office, Large Office, Primary School, Secondary School, Warehouse | 1 | 1 | 1 | 1 | 1 | 1.8 | 1 | 1 | 1 | 0.4 | 1 | 1 | 0.4 | 1 | 1 | 0.4 |

## 3.3 Building Mechanical Systems

### 3.3.1 Operable Opening Interlock With HVAC

**Code Change Description**. The 2021 IECC adds a new section (C402.5.11) to require the interlock of HVAC thermostat setpoints with the position of operable openings, such as doors and windows. The code makes this requirement mandatory for operable openings with direct access to the outdoors and a larger than 40-ft$^2$ opening area. The interlock requires resetting the space cooling setpoint to 90°F and heating setpoint to 55°F whenever the operable opening is open. Exceptions apply to the zoned areas associated with food preparation, warehouse, and doors in the vestibule area. Prior to this update, there was no requirement to interlock HVAC with operable openings in the 2018 IECC.

**Modeling Strategy**. The doors in the Mid-Rise Apartment, High-Rise Apartment, Large Hotel, and Small Hotel are impacted by this code change, since they have a larger than 40-$ft^2$ opening area, which meets the requirements in Section 402.5.11. Capturing this technology in the prototypes first requires the use of operable doors for natural ventilation in response to favorable weather. This was first implemented for ASHRAE 90.1-2013 as described by Halverson et al. (2014). Where applicable, sliding doors are opened in the model when outdoor temperatures are between 60°F and 80°F, and the doors remain open as long as indoor temperatures are between 66°F and 78°F. There is an additional probability factor of 33% applied to account for the likelihood that the doors will be opened when conditions are favorable.

An energy management system (EMS) is utilized by the EnergyPlus models to simulate the interlock control. The EMS detects the natural ventilation air volume flow rate in the zones where doors are located and resets the HVAC cooling setpoint and heating setpoint to 90°F and 55°F, respectively, when natural ventilation air flow in those zones is detected.

### 3.3.2 Data Center HVAC Efficiency

**Code Change Description**. The 2021 IECC has added a requirement in C403.1.2 for data center systems to comply with Sections 6 and 8 of ASHRAE Standard 90.4-2016 (ASHRAE 2016), with modified values for design and annual mechanical load component (MLC) tables. The MLC methodology is a performance-based approach that sets limits on both peak and annual energy use with respect to the information technology equipment (ITE) load. A new definition is added to IECC-2021 for a data center, which specifies a zone that has ITE power density exceeding 20 W/$ft^2$ and total design ITE equipment load greater than 10 kW. In the 2018 IECC, data center HVAC systems were regulated by prescriptive requirements for component efficiencies and controls.

**Modeling Strategy**. The only zone in the prototypes that has ITE power exceeding both of the criteria in the 2021 IECC to trigger the MLC requirement is the large basement data center in the large office prototype, as shown in Table 3.4.

Table 3.4. Loads for ITE Zones in Large Office Prototype

| Zone | Area Per Zone | Peak ITE Load Per Zone, kW | W/$ft^2$ |
|---|---|---|---|
| Large Data Center | 8,435 | 379.6 | 45.0 |
| Small IT Closets | 390 | 7.8 | 20.0 |

In order to better understand the implications of the new MLC requirements, several simulations were run with the large office prototype with measures such as an economizer, water cooled chiller, variable air volume (VAV) air handlers, and removal of humidification. The full set of measures surpassed code requirements for some climate zones but failed to meet them for hot and humid climates. Possibly the hot climates could have been satisfied with further exploration of high-efficiency chiller options.

Due to the complexity of exactly meeting the code requirements in different climates with different combinations of HVAC measures, a more simplistic modeling approach was established wherein the MLC concept was implemented into the large office prototype by two changes. The first was to add a dummy electrical equipment load into the zone equal to the product of the peak ITE load and the required maximum annualized MLC. A submeter was assigned to this load to indicate that it represents the HVAC energy associated with the zone, and the load schedule was set to be the same as the ITE load schedule. The second change was to convert the HVAC system to an Ideal Loads system in EnergyPlus, which does not directly consume electric or gas energy. Since the annualized MLC is always lower than the design MLC, this approach will satisfy both MLC requirements.

### 3.3.3 HVAC Equipment Efficiency Updates

**Code Change Description**. The 2021 IECC includes improvements to HVAC equipment efficiencies from the 2018 IECC as summarized in Table 3.5. One code change that was not incorporated into the 2021 IECC update is the increase in IEER values for larger unitary air conditioners and heat pumps. These were deferred to a future update because performance curves are not currently available to characterize the annual energy impacts of changes to IEER in EnergyPlus. The PNNL team has an ongoing research project to develop these curves, and the IEER improvements will be incorporated when those are available.

Table 3.5. Summary of HVAC Efficiency Changes for IECC-2021

| Equipment Category | IECC-2021 Table | Description of Change |
|---|---|---|
| Air-cooled split air conditioners, < 65 kBtu/h | C403.3.2(1) | Change from SEER rating values to SEER2. Equivalent SEER value increases from 13 to 14. Only affects Mid-Rise Apartment. |
| Air-cooled unitary air conditioners and heat pumps, cooling mode, < 65 kBtu/h | C403.3.2(1) & C403.3.2(2) | Change from SEER and HSPF rating values to SEER2 and HSPF2. Actual performance requirement does not change. |
| Air-cooled unitary air conditioners and heat pumps, cooling mode, >= 65 kBtu/h | C403.3.2(1) & C403.3.2(2) | EER is unchanged from IECC-2018. IEER decreases for most categories and sizes. Not modeled due to unavailability of performance curves. |
| Air-cooled unitary heat pumps, heating mode, >= 65 kBtu/h | C403.3.2(2) | Increase heating COP. |
| Warm-air furnace, gas fired, >= 225 kBtu/h | C403.3.2(5) | Increase thermal efficiency.[1] |
| Water-cooled computer room air conditioner, downflow, < 80 kBtu/h | C403.3.2(16) | Increase efficiency |
| Reach-in refrigerator/freezer | C403.11.1 | Decrease maximum daily energy consumption. Prototypes use self-contained units, vertical closed solid. |
| Walk-in cooler and freezer | C403.11.2.1 | Decrease maximum daily energy consumption. |

A key change in the definitions used by the standards is the shift from Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF) to SEER2 and HSPF2 for unitary systems with capacity less than 65,000 Btu/h. The new metrics are

[1] Note that the 2021 IECC has a typographical error in Table C403.3.1(5) for warm air furnace, where the size category is erroneously listed as "< 225,000 Btu/h". This can be verified by reviewing section 431.77 of the CFR.

determined using higher indoor fan static during the lab tests to better represent actual typical installed conditions. The relationship between the new rating metrics and the original metrics is illustrated by the values in Table 3.6.

Table 3.6. Mapping of SEER and HSPF to SEER2 and HSPF2 based on Federal Register Vol. 82

| Product Class | SEER | SEER2 | HSPF | HSPF2 |
|---|---|---|---|---|
| Split system air conditioners | 14.0 | 13.4 | NA | NA |
| Packaged air conditioners | 14.0 | 13.4 | NA | NA |
| Packaged heat pumps | 14.0 | 13.4 | 8.0 | 6.8 |

**Modeling Strategy**. Efficiency values were converted to model rated conditions following the same methods as were used for the 2018 IECC prototypes. Where efficiency is dependent on system capacity, sizing simulations were conducted, and the results of those simulations were used to select the appropriate efficiency values. HVAC equipment efficiencies were further increased for some prototypes to satisfy the additional efficiency requirements as described in Section 3.5 of this report.

### 3.3.4 Automatic Stop

**Code Change Description**. Section C403.4.2.3 of the 2021 IECC requires an HVAC system to have automatic start and stop controls, whereas the 2018 IECC only required automatic start control. The new language states that the automatic stop controls shall be configured to reduce the HVAC system's heating temperature setpoint and increase the cooling temperature setpoint by not less than 2°F before the scheduled unoccupied period.

**Modeling Strategy**. The automatic stop requires the HVAC systems to reset the temperature setpoint based on thermal lag and acceptable drift in space temperature. Thus, it is important to understand how much time is required for a thermal zone to stabilize the indoor thermal condition after the setpoint change. A small set of simulations on the Small Office prototype model was conducted to investigate the control strategy. Figure 3.1 and Figure 3.2 show the indoor air temperature behaviors when the heating or cooling setpoint changed an hour before the unoccupied hour. Both cases show that the space temperature responds quickly to the change in thermostat setpoint (< 10 min). Based on these test results, the optimum stop schedule has been implemented in the prototypes to set back the space temperature setpoint by 2°F 1 hour before the unoccupied period.

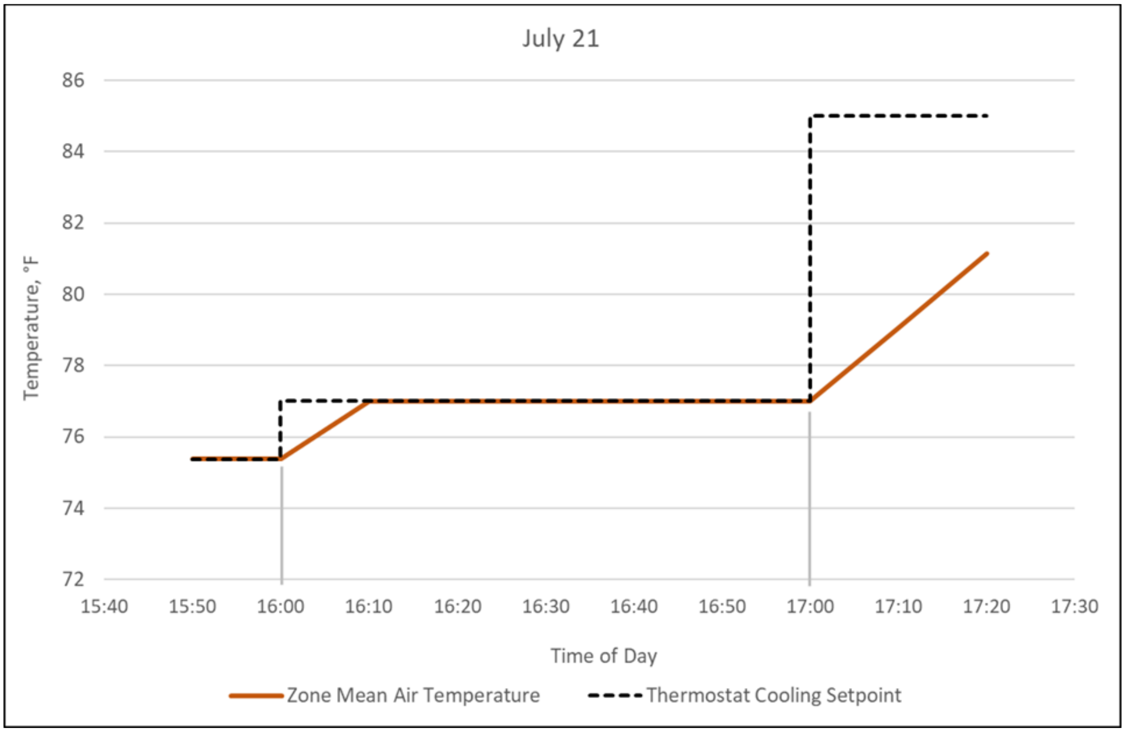


Figure 3.1. Indoor Air Temperature Response to the Cooling Setpoint Change in the Afternoon on July 21

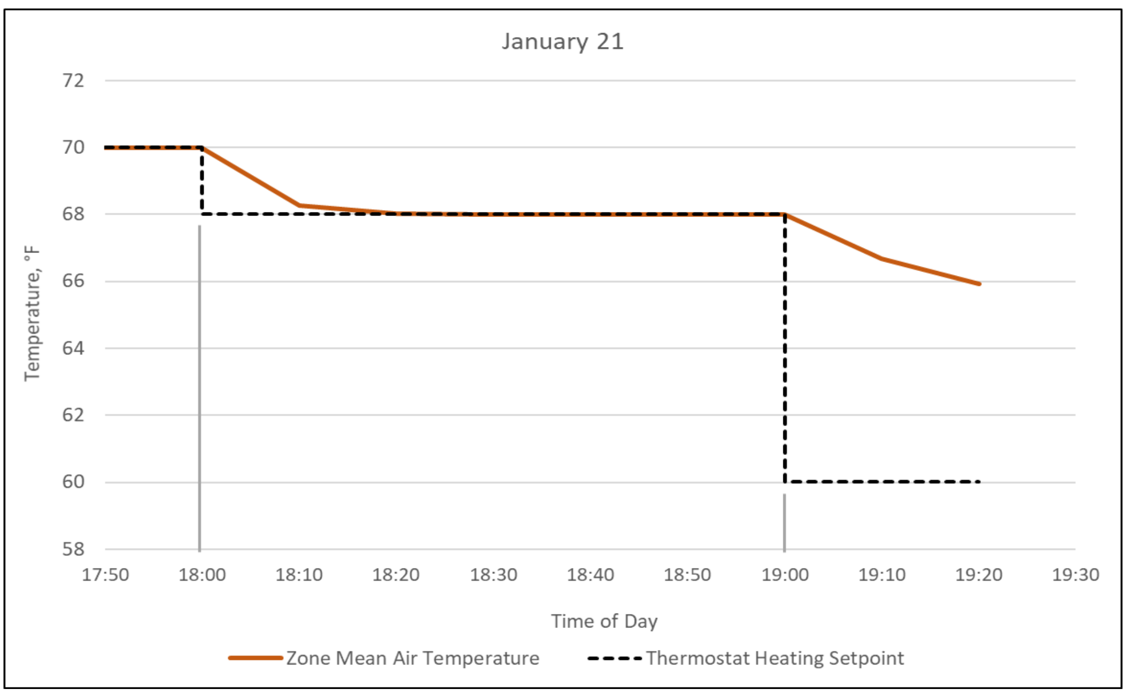


Figure 3.2. Indoor Air Temperature Response to the Heating Setpoint Change in the Afternoon on January 21

### 3.3.5 Supply Air Temperature Reset

**Code Change Description**. Section 403.6.5 of IECC 2021 has added new exceptions to the requirement for supply air temperature reset for hot climates based on system outside air requirements. These exceptions align with the existing requirements of ASHRAE 90.1-2019.

**Modeling Strategy**. The applicability of the exceptions to supply air temperature reset for the prototypes is shown in Table 3.7. For these prototypes and climates, a constant supply air temperature is modeled.

Table 3.7. Supply Air Temperature Reset Exceptions for Prototypes

| Outside Air (OA) Requirement | Climate Zone Exceptions | Applicable Prototypes |
|---|---|---|
| Design OA < 3,000 cfm | 0A, 1A, 2A, 3A | Medium Office |
| Design OA < 10,000 cfm | 2A | Large Office, Outpatient Health Care, Primary and Secondary Schools: non-classroom systems |
| Design OA at least 80% and employing ERV | 0A, 1A, 2A, 3A | Primary and Secondary Schools: classroom pods |

### 3.3.6 Demand Control Ventilation (DCV)

**Code Change Description**. Section C403.7.1 of the 2021 IECC introduces a new category of DCV compliance that requires single-zone systems with economizers to have DCV installed. Other single-zone and multi-zone systems follow a similar compliance path as in the 2018 IECC, but with more stringent requirements. For those systems, the average occupant load threshold is reduced from greater than 25 people per 1,000 $ft^2$ to equal or greater than 15 people per 1000 $ft^2$. In addition, the outdoor airflow threshold for multi-zone systems was reduced from 1,200 cfm in the 2018 IECC to 750 cfm in the 2021 IECC.

Section C403.7.1 also modifies the equation for calculating the makeup air exception. In the 2018 IECC, the exception only applied if the supply airflow rate minus makeup airflow rate is smaller than 1,200 cfm. In the 2021 IECC the updated equation triggers the exception when the makeup airflow rate is over 75% of the supply airflow rate. Another exception was updated in the 2021 IECC regarding spaces with ventilation provided for process load. This exception was modified to exempt spaces that match specific occupancy classifications as defined in Table 403.3.1.1 of the International Mechanical Code.

**Modeling Strategy**. The code changes in the 2021 IECC affect almost all the prototype buildings except Hospital, Restaurant Fast Food, Restaurant Sit Down, and Medium Office. Retail Stand-Alone, Retail Strip Mall, and Small Hotel have the most significant impact among the affected prototypes due to the newly added DCV requirements on single-zone HVAC systems with economizers. With the existing ERV framework, the modeling approach for those zones is to turn on the demand control ventilation option under the mechanical ventilation controller of a HVAC system in the EnergyPlus model. Since the presence of economizers in single-zone systems depends on capacity, the decision regarding DCV for these systems was made after the sizing run and economizer determination were complete for each simulation.

### 3.3.7 Energy Recovery in Non-Transient Dwelling Units

**Code Change Description**. The 2021 IECC Section C403.7.4.1 includes new ERV requirements for non-transient dwelling units (e.g., apartments). There is a complete exemption from this requirement in climate zone 3C. In other climate zones, the ERV selection is based on heating-only in climate zones 4 through 8 and cooling-only in climate zones 0 through 2, while climate zone 3A and 3B have both heating and cooling requirements. In addition, dwelling units smaller than 500 $ft^2$ are exempted from the ERV requirements in climate zone 0 through 3 and 4C and 5C. In the 2018 IECC, there was no specific ERV requirement for residential HVAC systems, and the general ERV requirements were not normally triggered by the design ventilation and supply air flow quantities needed for residential systems.

**Modeling Strategy**. All apartment units modeled in the Mid-Rise and High-Rise Apartments are qualified as non-transient dwelling units larger than 500$ft^2$. Following the same modeling strategy performed in the prototypes for ASHRAE 90.1 2019 (DOE 2021), ERVs are added to all dwelling units except for climate zone 3C. Based on the market product review conducted during the ASHRAE implementation, energy recovery ratio (ERR) requirements are converted to the energy recovery effectiveness (ERE), as summarized in Table 3.8.

Table 3.8. Heat Recovery Effectiveness Based on Required Design ERR for Mid-Rise and High-Rise Apartment Prototypes

| Climate Zone | 0, 1, 2A, 3A | 2B | 3B | 4 thru 8 |
|---|---|---|---|---|
| ERR at local design condition | Cooling 50% | Cooling 50% | Cooling 50% | Heating 60% |
| Sensible Effectiveness at 100% Heating Air Flow | 0.666 | 0.632 | 0.620 | 0.600 |
| Latent Effectiveness at 100% Heating Air Flow | 0.364 | 0.294 | 0.270 | 0.0 |
| Sensible Effectiveness at 75% Heating Air Flow | 0.700 | 0.668 | 0.657 | 0.623 |
| Latent Effectiveness at 75% Heating Air Flow | 0.401 | 0.330 | 0.305 | 0.0 |
| Sensible Effectiveness at 100% Cooling Air Flow | 0.661 | 0.621 | 0.607 | 0.596 |
| Latent Effectiveness at 100% Cooling Air Flow | 0.407 | 0.334 | 0.309 | 0.0 |
| Sensible Effectiveness at 75% Cooling Air Flow | 0.695 | 0.657 | 0.643 | 0.618 |
| Latent Effectiveness at 75% Cooling Air Flow | 0.454 | 0.381 | 0.354 | 0.0 |

### 3.3.8 Low-Capacity Ventilation Fans

**Code Change Description**. The low-capacity ventilation fan efficacy (Section C403.8.5) is a new requirement in the 2021 IECC. It sets efficacy requirements for mechanical ventilation system fans with motors less than 1/12 hp (0.062 kW) in capacity.

**Modeling Strategy**. ERV and bathroom exhaust fans in the Mid-Rise Apartments and High-Rise Apartments are affected by this newly introduced section in the 2021 IECC. The minimum efficacy (cfm/W) is 1.2 cfm/W for ERV fans with no airflow constraints and 2.8 cfm/W for bathroom fans when airflow is within 10 to 90 CFM. The fan power used in the prototypes prior to the new requirements was based on a survey of data for products available in the marketplace. The fan static in the models was established at 0.25 in wc, and the fan power was selected from the manufacturer data corresponding to that pressure. The fan power values specified in Section C403.8.5 are required to be determined at a rated static pressure of at least

0.2 in wc for ERV fans and 0.1 in wc for bathroom exhaust fans. To convert these rated values to the installed pressure of 0.25 in wc, additional manufacturer data at varying installed pressure conditions were evaluated to determine the pressure-power relationship as shown in Table 3.9. The ratios calculated for the product data columns in Table 3.9 were applied to the 2021 IECC columns to determine the typical installed efficacy for the prototype models.

Table 3.9. Conversion of Low-Capacity Ventilation Fan Power from Code Spec Condition to Typical Installed Condition

| Condition | Bathroom Fans | | | ERV Fans | | |
|---|---|---|---|---|---|---|
| | Static in wc | Product data cfm/W | IECC 2021 cfm/W | Static in wc | Product data cfm/W | IECC 2021 cfm/W |
| Code Specification | 0.1 | 1.4 | 2.8 | 0.2 | 1.14 | 1.20 |
| Typical Installed | 0.25 | 1.24 | 2.48 | 0.25 | 1.07 | 1.13 |
| | Ratio | 88.6% | 88.6% | Ratio | 93.9% | 93.9% |

### 3.3.9 Clean Water Pump Efficiency

**Code Change Description**. The DOE 10 CFR has a requirement for clean water pump system efficiency that is not included in the 2021 IECC. Since the new requirement is applicable to all general HVAC pumps in the marketplace, it has been incorporated into the prototype models for the 2021 IECC.

**Modeling Strategy**. The new DOE clean water pump requirements were included in ASHRAE 90.1-2019, and thus have previously been implemented in the prototype models (Zhang et al. 2021). The implementation for the 2021 IECC follows the same methodology, by increasing the modeled pump motor efficiency by 1% relative to the 2018 IECC efficiency values.

## 3.4 Electrical Power and Lighting Systems

### 3.4.1 Automatic Receptacle Control

**Code Change Description**. Section C405.11 has been introduced in the 2021 IECC for automatic receptacle control, which needs to be applied to (1) at least 50% of all 125V, 15- and 20-amp receptacles installed in enclosed offices, conference rooms, rooms used primarily for copy or print functions, breakrooms, classrooms, and individual workstations; and (2) at least 25% of branch circuit feeders installed for modular furniture not shown on the construction documents. The receptacles need to be controlled either by a schedule-based shut-off or an occupancy-based controller to turn off receptacles within 20 minutes after the space is unoccupied. The 2018 IECC did not have any receptacle control requirements.

**Modeling Strategy**. All prototypes and national analysis locations are affected. In Thornton et al. (2011), it was explained how to determine (1) the area percentage of affected space types based on typical building design data; (2) the total fraction of the receptacle load power that can be controlled; and (3) savings percentage from occupancy sensors during occupied hours for each space type. Occupancy sensor control is selected because it is already required for the lighting controls in the relevant space types. Based on (1)-(3), the power density reduction factors for each prototype were calculated, which were multiplied to the prototypes' receptacle load schedules. Halverson et al. (2014) followed the same approach to calculate the power density reduction factors for more space types, including the ones required by the IECC-2021 code change, in each prototype. Therefore, the same modeling strategy has been followed, and the reduction factors in the 2nd and 3rd columns from Halverson et al. (2014) Table 5.19 have been applied.

### 3.4.2 Occupancy Sensor Lighting Control

**Code Change Description**. In Section C405.2.1, corridors have been added to the space types where occupant sensor controls are required in the 2021 IECC. The occupant sensor controls shall uniformly reduce lighting power to not more than 50% of full power within 20 minutes after all occupants have left the space.

**Modeling Strategy**. All the prototypes, except for Retail Strip Mall and Retail Stand-Alone, and all the national analysis locations are affected by this code change. To implement the new occupancy sensor control, PNNL applied a 25% reduction to the 2018 IECC lighting schedule fractions for corridor zones. For zones that represent a composite of corridor and other space types, the 2018 IECC lighting schedule was reduced based on a 25% reduction applied only to the portion of lighting associated with the corridor space type.

### 3.4.3 Interior Lighting Power

**Code Change Description**. The lighting power density (LPD) allowances for all building area types and space types in Tables C405.3.2(1) and C405.3.2(2) are modified by this code change. Most of them have been reduced to decrease the energy use of lighting systems from 2018 to 2021 IECC, while a few building area types and space types related to medical use, kitchen, fire station and exercise have increased LPD allowances for safety considerations.

**Modeling Strategy**. The change affects all prototypes as an adjustment to the installed lighting power of individual zones. Each thermal zone in the prototypes is either mapped to a single space-by-space category or is assumed to be a mix of two or more space types. The lighting power densities were further reduced for some prototypes to satisfy the additional efficiency requirements as described in Section 3.5 of this report.

### 3.4.4 Secondary Sidelit Daylighting Control

**Code Change Description**. In the 2021 IECC, daylight-responsive control requirements are in Section C405.2.4. Compared to the 2018 IECC, new definitions for primary and secondary sidelit daylight zones are introduced consistent with ASHRAE Standard 90.1. Daylight-responsive controls are required when the total lighting power (1) in the primary sidelit area is larger than 150 W, and (2) in the secondary sidelit area is larger than 300 W. The lights in these two types of sidelit zones should be controlled independently. When occupant sensor controls are present, it is explicitly mentioned that daylight responsive controls should continue to adjust electric light levels further even to levels that are below the unoccupied setpoints. Also, continuous dimming from full light output to 15% light output shall be applied to all space types in daylight zones, and Section C405.2.4.4 further clarifies on how to identify daylight zones when multistory atriums are present.

**Modeling Strategy**. The code change is applicable to all prototypes except for Mid-rise Apartment, High-rise Apartment and Retail Strip Mall where daylight-responsive controls are not applicable. All the national analysis locations are affected. Primary and secondary sidelit daylight zones and the minimum wattage of lighting power limits are consistent with the current requirements in ASHRAE Standard 90.1, the modeling strategy of which is documented in Halverson et al. (2014). The fractions of lighting power controlled by primary/secondary sidelit zone daylighting sensors in each prototype, illuminance setpoints, and the sensors' location coordinates can be found in Table 5.20 and Table 5.21 of Halverson et al. (2014). Since the occupant sensor controls are modeled by the factors multiplied by the lighting schedule fractions, the daylight-responsive controls modeled are able to continue adjusting electric light levels even when occupant sensor controls are active.

### 3.4.5 Exterior Lighting Setback Control

**Code Change Description**. Setback control for exterior lighting systems other than façade and landscape lighting have been updated in Section C405.2.7.3 of the 2021 IECC. The setback requirement has changed from a reduction of 30% in the 2018 IECC to 50% in the 2021 IECC. The general requirement is to use a timeclock-based setback control between midnight and 6 a.m. Outdoor parking areas have an additional requirement to setback to 50% whenever activity has not been detected for 15 minutes or more. Thus, the applicability for parking areas is extended beyond the midnight to 6 a.m. time window.

**Modeling Strategy**. Changes to exterior lighting control for the 2021 IECC are summarized in Table 3.10. These changes are applicable to all prototypes that include building entrances and uncovered parking areas, except those with 24/7 operation. The prototypes that are included are the three office building types, the retail buildings, and the restaurants. For implementation, the lighting objects in the prototype models were reconfigured so that building entrances and uncovered parking could be controlled separately. Due to the use of occupancy-based control for parking areas, the reduction schedule for that lighting load is extended to the period from 7 p.m. to 6 a.m.

Table 3.10. Change in Exterior Lighting Control Between the 2018 and 2021 IECC

| Lighting Category | 2018 IECC | 2021 IECC |
|---|---|---|
| Building Entrance | 30% reduction midnight to 6 a.m. | 50% reduction midnight to 6 a.m. |
| Uncovered Parking Area | 30% reduction midnight to 6 a.m. | 50% reduction 7 p.m. to 6 a.m. |

## 3.5 Additional Efficiency Requirements

### 3.5.1 Credit Selections

**Code Change Description**. Section C406 of the 2018 IECC includes a list of eight additional efficiency measures in excess of those required by the prescriptive sections of the code, from which one must be selected for inclusion in each building. The 2021 IECC has been updated with new tables of credit values and some additional credit categories. Each category is assigned credit points based on savings specific to each building group and climate, and the building must select one or more categories as needed to achieve a total of at least 10 points. While the points were designed to make selections more relatively equivalent for energy savings, any combination of measures can be used to achieve the required savings. Measure choices leading to 10 points generally result in much more savings than the options in the 2018 IECC.

**Modeling Strategy**. For each prototype and climate location a number of possible measure combinations are available to achieve 10 points. In order to make selections of energy credit categories for the prototype models in this analysis, PNNL used the following general rules as guidelines for prioritizing selection of measures.

1. Highest priority -- Categories with relative low construction costs, for example:
    a. C406.1(2) Reduced lighting power in accordance with Section C406.3
    b. C406.1(8) Reduced air infiltration in accordance with Section C406.9
2. Medium priority -- Heat pump water heaters (HPWHs) in Group R & I buildings based on their high service water heating loads:
   C406.1(6) High-efficiency service water heating/HPWH in accordance with C406.7.4
3. Medium priority -- Cooling and heating efficiency improvements:
   C406.1(1) More efficient HVAC performance in accordance with C406.2
    a. Heating efficiency improvements are not practical for rooftop gas furnace equipment, which serves most smaller commercial buildings in the north, due to condensate freezing issues.
    b. Cooling efficiency and heat pump efficiency improvements are generally available
    c. One improvement in the 2021 IECC was to separate heating and cooling efficiency credits so that cooling efficiency could be pursued separately from heating efficiency
4. Lower priority -- Onsite renewable, since roof space is sometimes not available or is shaded:
   C406.1(4) Onsite supply of renewable energy in accordance with Section C406.5
5. Avoid categories that do not have quantifiable impacts through energy modeling of the prototypes:
    a. C406.1(3) Enhanced lighting controls in accordance with Section C406.4
    b. C406.1(9) Energy monitoring system in accordance with Section C406.10
    c. C406.1(10) Fault detection and diagnostics in accordance with C406.11
6. Avoid C406.1(5) Dedicated outdoor air system because of modeling complexity and a cascade of other impacts due to changes in HVAC system type
7. Avoid categories where lower cost-effectiveness is anticipated:
    a. C406.1(7) Enhanced envelope performance in accordance with C406.8.

Final selections for each building type and climate zone are listed in Table 3.11 through Table 3.17. For most cases, the combination of selections achieves a total in the range of 10 to 13 points, For the retail prototypes, the range is higher, due to the logical selection of the single reduced lighting power category. For 4 of the 112 building/climate zone combinations, the limitations of the strategy for measure selection results in total credits 1 or 2 points below the target of 10.

Table 3.11. Energy Credit Selections for Group B: Large Office, Medium Office, and Small Office

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.2: 5% cooling efficiency improvement | | | | | | | 3 | | | | 2 | 1 | | | | |
| C406.2.4: 10% cooling efficiency improvement | | | | | | | | | | 4 | | | 4 | 3 | 3 | |
| C406.3.1: Reduced lighting power by 10% | 9 | 9 | 9 | 9 | 9 | 10 | 8 | 9 | 9 | 7 | 8 | 8 | 6 | 7 | 7 | 6 |
| C406.9: Reduced air infiltration | 2 | 1 | 2 | 4 | 1 | | | 2 | 3 | | | 1 | | | | 6 |
| Total points from selections | 11 | 10 | 11 | 13 | 10 | 10 | 11 | 11 | 12 | 11 | 10 | 10 | 10 | 10 | 10 | 12 |

Table 3.12. Energy Credit Selections for Group R & I: Apartments, Hotels, Hospital

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.1: 5% heating efficiency improvement | | | | | | | | | | | | 1 | | | | |
| C406.2.2: 5% cooling efficiency improvement | | | | | | 1 | | | | 1 | | | | | | |
| C406.2.4: 10% cooling efficiency improvement | | | 3 | | | | | | | | | 1 | | | | |
| C406.3.1: Reduced lighting power by 10% | | 2 | 2 | | 2 | 2 | | 2 | 2 | | | 2 | | | 2 | 2 |
| C406.7.4: Heat pump water heater | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | 5 | 5 | | 5 | | 5 |
| C406.9: Reduced air infiltration | 6 | 3 | | 6 | 4 | | 7 | 3 | 3 | 9 | 5 | 1 | 13 | 6 | 8 | 3 |
| Total points from selections | 12 | 10 | 10 | 11 | 11 | 8 | 12 | 10 | 10 | 10 | 10 | 10 | 13 | 11 | 10 | 10 |

Table 3.13. Energy Credit Selections for Group R & I: Outpatient Health Care

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.2: 5% cooling efficiency improvement | 3 | | | | | | 1 | | | | | | | 1 | | |
| C406.2.4: 10% cooling efficiency improvement | | 4 | | 2 | 3 | | | | | | | | | | | |
| C406.3.1: Reduced lighting power by 10% | 2 | 2 | | 2 | 2 | 2 | 2 | | | 2 | | 2 | | 2 | 2 | |
| C406.5: Onsite renewable energy | | | | | | 8 | | 7 | 7 | | 7 | 7 | | 7 | | 7 |
| C406.9: Reduced air infiltration | 6 | 3 | 11 | 6 | 4 | | 7 | 3 | 3 | 9 | 5 | 1 | 13 | | 8 | 3 |
| Total points from selections | 11 | 9 | 11 | 10 | 9 | 10 | 10 | 10 | 10 | 11 | 12 | 10 | 13 | 10 | 10 | 10 |

Table 3.14. Energy Credit Selections for Group E: Schools

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.2: 5% cooling efficiency improvement | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | | 1 | | | | | |
| C406.2.4: 10% cooling efficiency improvement | | | | | | | | | | 2 | | 1 | | 2 | | |
| C406.3.1: Reduced lighting power by 10% | 8 | 8 | 9 | 8 | 9 | 9 | 8 | 9 | 9 | 8 | 9 | 8 | 7 | 8 | 7 | 7 |
| C406.9: Reduced air infiltration | | | | | | | | | | | | | 4 | | 4 | 3 |
| Total points from selections | 12 | 11 | 12 | 10 | 11 | 11 | 10 | 10 | 10 | 10 | 10 | 9 | 11 | 10 | 11 | 10 |

Table 3.15. Energy Credit Selections for Group M: Retail

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.3.1: Reduced lighting power by 10% | 13 | 15 | 14 | 16 | 14 | 17 | 15 | 15 | 14 | 12 | 14 | 14 | 16 | 16 | 14 | 12 |
| Total points from selections | 13 | 15 | 14 | 16 | 14 | 17 | 15 | 15 | 14 | 12 | 14 | 14 | 16 | 16 | 14 | 12 |

Table 3.16. Energy Credit Selections for Group Other: Restaurant

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.2: 5% cooling efficiency improvement | | | | | | | 2 | | | | | | | | | |
| C406.2.4: 10% cooling efficiency improvement | | | | | | | | | | | | 2 | 2 | 2 | 2 | |
| C406.3.1: Reduced lighting power by 10% | 8 | 9 | 9 | 9 | 9 | 10 | 8 | 9 | 9 | 7 | 8 | 8 | 8 | 8 | 8 | 7 |
| C406.9: Reduced air infiltration | 3 | 2 | 4 | 4 | 2 | | | 2 | 2 | 6 | 4 | | | | | 4 |
| Total points from selections | 11 | 11 | 13 | 13 | 11 | 10 | 10 | 11 | 11 | 13 | 12 | 10 | 10 | 10 | 10 | 11 |

Table 3.17. Energy Credit Selections for Group Other: Warehouse

| SECTION | 1A | 2A | 2B | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 5C | 6A | 6B | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C406.2.2: 5% cooling efficiency improvement | | | | | | | 2 | 2 | 1 | | 2 | | | | | |
| C406.2.4: 10% cooling efficiency improvement | | | | | | | | | | | | 2 | 2 | 2 | 2 | |
| C406.3.1: Reduced lighting power by 10% | 8 | 9 | 9 | 9 | 9 | 10 | 8 | 9 | 9 | 7 | 8 | 8 | 8 | 8 | 8 | 7 |
| C406.9: Reduced air infiltration | 3 | 2 | 4 | 4 | 2 | | | | | 6 | | | | | | 4 |
| Total points from selections | 11 | 11 | 13 | 13 | 11 | 10 | 10 | 11 | 10 | 13 | 10 | 10 | 10 | 10 | 10 | 11 |

### 3.5.2 Heating and Cooling Efficiency Improvement

**Code Change Description**. Section C406.2 lists efficiency improvement options of 5% and 10% better than minimum code requirements for both heating and cooling equipment.

**Modeling Strategy**. The heating and cooling efficiency measures were implemented by applying a multiplier of 1.05 or 1.10 to the prescriptive efficiency values used in the prototype models.

### 3.5.3 Reduced Lighting Power

**Code Change Description**. Section C406.3.1 indicates a requirement for a reduction in lighting power of at least 10% compared to the lighting power allowance calculated in accordance with Section C405.3.2.

**Modeling Strategy**. This credit was applied to all prototypes and in most climate zones. The implementation of the credit in the prototype models was accomplished by applying a multiplier of 90% to the LPD of all affected spaces.

### 3.5.4 Reduced Infiltration

**Code Change Description**. Section C406.9 specifies an air leakage rate of no more than 0.25 cfm/ft$^2$ at a pressure differential of 0.3 in wc, as verified by pressurization testing. No exceptions to the required rate are included in the code based on building size or climate zone. The baseline leakage rates that would be required if this credit were not taken were shown previously in Table 3.3.

**Modeling Strategy**. The test condition value of 0.25 cfm/ft$^2$ at 0.3 in wc was converted to natural conditions for the model using the methods described by Gowri et al. (2009).

### 3.5.5 Heat Pump Water Heater (HPWH)

**Code Change Description**. The HPWH energy credit indicates that all service water heater (SWH) requirements shall be met using heat pump technology with a combined input-capacity weighted average energy factor of 3.0. In addition, there is a requirement that the HPWHs not draw conditioned air from within the building.

**Modeling Strategy**. Based on the relatively simplistic requirements for the measure, a number of assumptions were needed to characterize and model the heat pump water heaters in the prototypes. For implementation of the HPWH into the prototypes, large central storage systems were assumed. Following are key elements of the system configurations and controls that were assumed for the model.

#### 3.5.5.1 Sizing

When sizing a HPWH system, the tank is generally larger than for a gas system so the relatively expensive heat pump unit can be sized smaller. For simulation, it is important that the heat pump units are not significantly oversized because that would underestimate the time during which supplemental electric resistance heat is required. For the apartment prototypes, sizing of the HPWH systems was accomplished using the internet-based Ecosizer tool (Ecosizer, 2022). The results of this exercise are listed in Table 3.18.

Table 3.18. Ecosizer Results for Apartment Prototypes

| Prototype | People | Apt Units | Gal/ day/ per | Design Tmains, °F | Supply T, °F | Storage T, °F | Primary tank | | Secondary tank | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | gal | kBtu/h | gal | kBtu/h |
| Apartment Mid-Rise | 79 | 31 | 25 | 50 | 125 | 140 | 465 | 85 | 80 | 19 |
| Apartment High-Rise | 197 | 79 | 25 | 50 | 125 | 140 | 1,175 | 215 | 120 | 48 |

Table 3.19 summarizes the sizing of both the tank and the heat pump unit for all systems where HPWHs were implemented in the prototypes. The Ecosizer unit system sizing values for the apartment prototypes are assumed to follow common practice. For reference the ratio of the

tank size for the heat pump system to the corresponding tank size for a gas system is listed in the table. The usual high-rise apartment prototype gas water heater volume of 600 gallons is on the low side of the volume-versus-recovery capacity trade-off chart in the ASHRAE HVAC Applications Handbook (ASHRAE 2019). A more middle of the road volume is 948 gallons, denoted by the row labeled "Highrise Apartment ASHRAE" in Table 3.19. The "Midrise Apartment ASHRAE" case was sized by the same middle of the road approach. In both cases, the ratio of Ecosizer HPWH tank volume to the middle-of-road sized gas system tank volume is approximately 1.25. Thus, this same ratio was used for the other general use water heaters to size the HPWH tank relative to the prototype gas system tank volume.

For the laundry water heaters, it was found that the prototype gas units were sufficiently oversized such that it was not reasonable to increase tank volume for the HPWH versions, so the HPWH tanks were set to have the same volume as the gas system tanks.

Once the tank sizes were established for each of the general HPWH systems, the sizing charts from the ASHRAE HVAC Applications Handbook (ASHRAE, 2019) were used to determine the required heat pump capacity. For the laundry systems, the heat pump capacity was set based on the original gas water heater capacity prorated to the target intermediate setpoint of 125°F for the heat pump unit. The supplemental electric resistance heater for the laundries was sized to raise the water temperature from 125°F to 180°F.

Table 3.19. Sizing for Gas and Heat Pump Water Heaters

| Heater Description | Gas System Sizing | | Heat Pump System Sizing | | | | |
|---|---|---|---|---|---|---|---|
| | Tank volume gal | Burner output, kBtu/h | Tank volume gal | tank vol ratio: gas/ HPWH | Heat pump output, kBtu/h | Minimum supp capacity kBtu/h | Maximum supp capacity kBtu/h |
| High-Rise Apartment | 600 | 600 | 1,175 | 1.96 | 215 | 47 | 262 |
| High-Rise Apartment ASHRAE | 948 | 279 | 1,175 | 1.24 | 215 | 47 | 262 |
| Mid-Rise Apartment ASHRAE | 372 | 161 | 465 | 1.25 | 87 | 19 | 106 |
| Hospital General | 600 | 600 | 750 | 1.25 | 140 | 460 | 600 |
| Hospital Laundry | 300 | 300 | 300 | 1.00 | 113 | 187 | 300 |
| Small Hotel General | 300 | 300 | 375 | 1.25 | 128 | 28 | 156 |
| Small Hotel Laundry | 200 | 200 | 200 | 1.00 | 83 | 117 | 200 |
| Large Hotel General | 600 | 600 | 750 | 1.25 | 262 | 58 | 320 |
| Large Hotel Laundry | 300 | 557 | 300 | 1.00 | 332 | 225 | 557 |

#### 3.5.5.2 System Configuration

All of the HPWH systems included in the prototypes were modeled based on the assumption of a single pass primary HPWH and a multi-pass secondary water heater to handle pipe loss. Supplemental heat is used in cold weather as needed when heat pump capacity is diminished. The fuel for supplemental heat was selected to match the base case water heater fuel: electric resistance for mid-rise apartment, natural gas for all others.

The primary heat pump system for laundry water heating is sized to heat the water to 125°F on a peak summer day. Supplemental heating is used to bring the temperature up to the laundry setpoint of 180°F.

For all models, it was assumed that partial stratification occurs such that heat pump inlet water temperature is one third of the temperature distance from the mains temperature to the tank outlet temperature. This was modeled in EnergyPlus using an EMS control with hourly adjustment of entering temperature calculated from the mains temperature.

#### 3.5.5.3 Heat Pump Efficiency

As there currently are no federal minimum standards specifically for commercial HPWHs, the efficiency of the commercial HPWH units was determined based on a market survey. Data were collected for 17 products from three manufacturers for capacities ranging from 45 to 605 kBtu/h. The results are shown in Figure 3.3, with lines showing the average and one standard deviation below the average values. For the prototype models, the unit efficiency was set to 3.1 COP, based on the average of the manufacturer data minus one standard deviation.

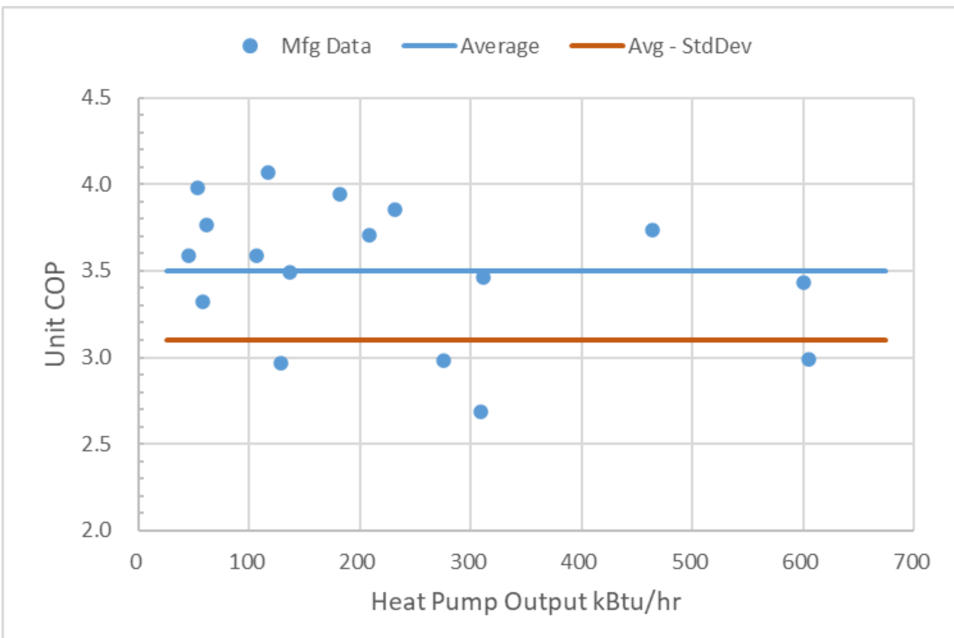


Figure 3.3. Heat Pump Water Heater Market Data for Unit Coefficient of Performance at Rating Conditions of 72.4°F Entering Air Wet Bulb and 130°F Entering Water Temperature

#### 3.5.5.4 HPWH System Location

For all HPWH models, it was assumed that the heat pump units and the storage tanks are located in an unconditioned parking garage. The temperature in the garage was adjusted monthly based on data collected by Heller and Oram (2015) for garage temperature versus daily average outdoor temperature for two buildings in Seattle, WA, which led to the following relationship:

$$GarageT = OA\_T * 0.62 + 10.13$$, where values are given in °C.

The EnergyPlus weather files were processed to obtain average daily outdoor temperature and humidity for each climate, and those were then applied to the garage temperature curve to calculate monthly garage dry bulb temperature for each climate. It was assumed that the garage humidity ratio would be the same as the average outdoor humidity ratio for each month, due to the low latent load in a garage relative to its ventilation rate. These calculated garage temperature and humidity values were then used as the ambient conditions for both the storage tanks and the heat pump evaporator coils.

### 3.5.6 Onsite Renewable Energy

**Code Change Description**. The basic renewable credit is described in C406.5.1 as using an installed renewable capacity of at least 0.25 W/ft$^2$ of conditioned floor area.

**Modeling Strategy**. The measure was applied only to the outpatient health care prototype, which has a conditioned floor area of 40,946 ft$^2$, and thus an installed capacity of 10,236 W. The measure was implemented as a photovoltaic system in the prototype model, and the PVWatts feature was used to model the system performance in EnergyPlus. The following additional design parameters assumed for the simulation are based on requirements in Addendum ck to ASHRAE 90.1-2019 (ASHRAE 2020):

- Module Type: Crystalline Silicon Panel with a glass cover, 19.1%nominal efficiency and temperature coefficient of -0.47%/°C. Performance shall be based on a reference temperature of 77°F (25°C) and irradiance of 317 Btu/ft2-hr (1,000 W/m2)
- Array Type: Rack mounted array with installed nominal operating cell temperature (INOCT) of  03°F (45°C).
- Total System losses (DC output to AC output): 11.3%
- Tilt: 0-degrees (mounted horizontally)
- Azimuth:180 degrees.

# 4.0 Site Energy and Energy Cost Savings Results

This section summarizes the estimated energy, emissions, and energy cost savings for the 2021 IECC compared to the 2018 IECC. The site energy and source energy savings results of the analysis are summarized in Table 4.1. This table groups the building prototypes by their principal activity and shows the construction weighting factors by building prototype. The table provides a side-by-side comparison of the site Energy Use Index (EUI) and Energy Cost Index (ECI) for the 2018 and 2021 editions of the IECC. Site energy is utility electricity and natural gas delivered and used at the building site. When the renewable energy credit is used by a prototype, the generated electricity is used by the building without storage or feeding electricity back to the grid. The EUI and ECI are the net of site energy consumption and renewable production. The EUI and ECI shown in Table 4.1 for each prototype are national weighted averages across climate zones in the United States. The percent savings (reduction) in EUI and ECI are presented as well. A negative percentage reflects increases in EUI or ECI. The last row of Table 4.1 shows the national weighted average results from all 16 prototypes and 16 climate zones using the construction weighting factors (see Table 2.2 in this report). As shown in Table 4.1, on a weighted national basis, the 2021 IECC results in 12.1% site energy savings and 10.6% energy cost savings over the 2018 IECC. These savings include federally mandated efficiency improvements of appliances and equipment that have taken effect since (but independent of) the publication of the 2018 IECC. Table 4.2 shows similar results for energy cost and emissions savings for the 2021 IECC compared to the 2018 IECC.

Table 4.1. Site and Source Energy Savings between the 2018 and 2021 IECC

| Building Activity | Building Prototype | Floor Area Weight (%) | Site EUI (kBtu/ft$^2$-yr) | | Site EUI Savings (%) | Source EUI (kBtu/ft$^2$-yr) | | Source EUI Savings (%) |
|---|---|---|---|---|---|---|---|---|
| | | | 2018 IECC | 2021 IECC | | 2018 IECC | 2021 IECC | |
| Office | Small Office | 3.8% | 29.9 | 26.2 | 12.4% | 83.0 | 72.8 | 12.3% |
| | Medium Office | 5.0% | 32.0 | 28.2 | 11.9% | 85.0 | 74.9 | 11.9% |
| | Large Office | 3.9% | 56.3 | 47.6 | 15.5% | 155.7 | 131.6 | 15.5% |
| Retail | Stand-Alone Retail | 10.9% | 47.1 | 41.2 | 12.5% | 106.3 | 94.6 | 11.0% |
| | Strip Mall | 3.7% | 50.1 | 43.3 | 13.6% | 122.7 | 110.3 | 10.1% |
| Education | Primary School | 4.8% | 48.9 | 44.7 | 8.6% | 120.6 | 106.9 | 11.4% |
| | Secondary School | 10.9% | 44.6 | 41.1 | 7.8% | 111.5 | 100.8 | 9.6% |
| Healthcare | Outpatient Healthcare | 3.4% | 112.8 | 107.7 | 4.5% | 270.0 | 256.8 | 4.9% |
| | Hospital | 4.5% | 123.9 | 120.3 | 2.9% | 279.3 | 274.2 | 1.8% |
| Lodging | Small Hotel | 1.6% | 70.3 | 57.7 | 17.9% | 145.1 | 127.2 | 12.3% |
| | Large Hotel | 4.2% | 93.4 | 80.0 | 14.3% | 190.8 | 174.8 | 8.4% |
| Warehouse | Warehouse | 18.6% | 13.1 | 12.0 | 8.4% | 27.2 | 25.1 | 7.7% |
| Food Service | Quick-Service Restaurant | 0.3% | 525.6 | 505.8 | 3.8% | 912.6 | 860.6 | 5.7% |
| | Full-Service Restaurant | 1.0% | 349.7 | 337.8 | 3.4% | 665.9 | 634.9 | 4.7% |
| Apartment | Mid-Rise Apartment | 13.7% | 41.2 | 31.6 | 23.3% | 110.1 | 86.5 | 21.4% |
| | High-Rise Apartment | 9.6% | 43.5 | 31.0 | 28.7% | 95.7 | 81.0 | 15.4% |
| National Weighted Average | | 100% | 51.1 | 44.9 | 12.1% | 118.7 | 106.1 | 10.6% |

Table 4.2. Energy Cost and Emissions Savings between the 2018 and 2021 IECC

| Building Activity | Building Prototype | Floor Area Weight (%) | ECI ($/ft²-yr) | | ECI Savings (%) | Emissions (ton/kft²-yr) | | Emission Reduction (%) |
|---|---|---|---|---|---|---|---|---|
| | | | 2018 IECC | 2021 IECC | | 2018 IECC | 2021 IECC | |
| Office | Small Office | 3.8% | $0.96 | $0.85 | 11.5% | 6.0 | 5.3 | 12.3% |
| | Medium Office | 5.0% | $0.98 | $0.86 | 12.2% | 6.1 | 5.4 | 11.8% |
| | Large Office | 3.9% | $1.81 | $1.52 | 16.0% | 11.3 | 9.5 | 15.5% |
| Retail | Stand-Alone Retail | 10.9% | $1.17 | $1.05 | 10.3% | 7.3 | 6.6 | 10.5% |
| | Strip Mall | 3.7% | $1.38 | $1.25 | 9.4% | 8.6 | 7.8 | 9.3% |
| Education | Primary School | 4.8% | $1.36 | $1.20 | 11.8% | 8.5 | 7.5 | 12.1% |
| | Secondary School | 10.9% | $1.26 | $1.14 | 9.5% | 7.9 | 7.1 | 10.1% |
| Healthcare | Outpatient Healthcare | 3.4% | $3.02 | $2.87 | 5.0% | 18.9 | 18.0 | 5.0% |
| | Hospital | 4.5% | $3.08 | $3.03 | 1.6% | 19.2 | 18.9 | 1.6% |
| Lodging | Small Hotel | 1.6% | $1.56 | $1.39 | 10.9% | 9.7 | 8.7 | 10.6% |
| | Large Hotel | 4.2% | $2.04 | $1.91 | 6.4% | 12.8 | 11.9 | 6.5% |
| Warehouse | Warehouse | 18.6% | $0.29 | $0.27 | 6.9% | 1.8 | 1.7 | 7.1% |
| Food Service | Quick-Service Restaurant | 0.3% | $9.20 | $8.61 | 6.4% | 57.6 | 53.9 | 6.5% |
| | Full-Service Restaurant | 1.0% | $6.95 | $6.60 | 5.0% | 43.5 | 41.3 | 5.1% |
| Apartment | Mid-Rise Apartment | 13.7% | $1.27 | $1.00 | 21.3% | 7.9 | 6.3 | 21.0% |
| | High-Rise Apartment | 9.6% | $1.05 | $0.93 | 11.4% | 6.6 | 5.8 | 11.6% |
| National Weighted Average | | 100% | $1.32 | $1.18 | 10.6% | 8.2 | 7.4 | 10.2% |

As can be seen from Table 4.1, the savings vary significantly by prototype. This is expected as code requirements are different by building type and by climate. PNNL did not explicitly quantify the national impacts of individual code changes. Although this approach does not allow the ranking of all code changes based on their energy savings impacts, a few high-impact changes resulting in significant energy savings were identified by examining individual prototype implementation results and are listed below (categorized by end use).

- Envelope:
  - Air leakage testing (Section 3.2.4)
  - Operable opening interlock with HVAC (Section 3.3.1)
- HVAC:
  - Demand controlled ventilation (Section 3.3.6)
  - Data center MLC requirement (Section 3.3.2)
  - Heating and cooling efficiencies (Sections 3.3.4)
- Lighting and receptacle loads:
  - Lighting power reduction (Sections 3.4.3)
  - Automatic control of receptacle loads (Section 3.4.1)
  - Secondary sidelit daylighting control (Section 3.4.4)

- Additional efficiency requirements:
  - Lighting power reduction (Sections 3.5.3)
  - Heating and cooling efficiencies (Sections 3.5.2)
  - Heat pump water heater (Section 3.5.5)
  - Infiltration reduction (Section 3.5.4)

Figure 4.1 illustrates the weighted percent change in the national weighted values for EUI, ECI, and emissions due to the change from the 2018 IECC to the 2021 IECC.

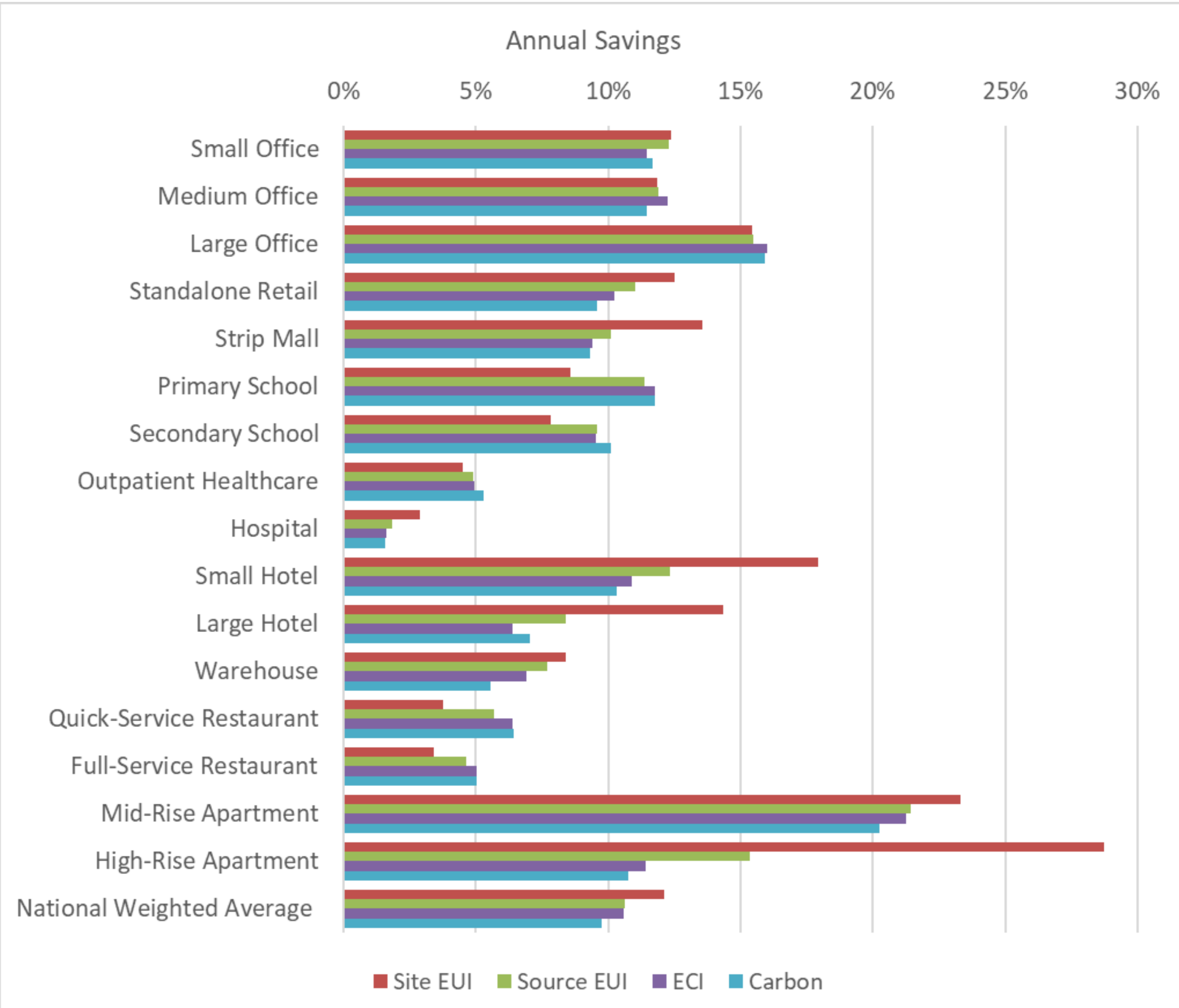


Figure 4.1. National Average Energy, Cost and Carbon Intensity for all IECC Prototypes

Table 4.3 presents the 2021 IECC savings for all prototype buildings aggregated by climate zone. The energy and energy cost savings vary by climate zone. The site energy savings in most climate zones are greater than 9% and the savings in the coldest two climate zones (i.e., 7 and 8) are 5.8 and 7.3%, respectively. The energy cost savings in all climate zones are over 8% except for climate zones 7 and 8. For most climate zones, the percentages of energy cost savings are somewhat lower than the site energy savings. The savings variance is attributed to the applicability of the code changes to different climate zones and the construction weights of the building types within the climate zones.

Table 4.3. Site Energy and Energy Cost Savings between the 2018 and 2021 IECC by Climate Zone

| Climate Zones | Site EUI (kBtu/ft²-yr) | | Site EUI Savings (%) | Source EUI (kBtu/ft²-yr) | | Source EUI Savings (%) | ECI ($/ft²-yr) | | ECI Savings (%) | Emissions (ton/kft²-yr) | | Emission Savings (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 IECC | 2021 IECC | | 2018 IECC | 2021 IECC | | 2018 IECC | 2021 IECC | | 2018 IECC | 2021 IECC | |
| 1A | 49.5 | 41.8 | 15.6% | 125.5 | 110.9 | 11.6% | 1.43 | 1.27 | 11.2% | 8.91 | 7.95 | 10.8% |
| 2A | 49.6 | 44.0 | 11.3% | 124.8 | 111.7 | 10.5% | 1.41 | 1.27 | 9.9% | 8.84 | 7.93 | 10.3% |
| 2B | 44.9 | 40.3 | 10.2% | 113.5 | 102.3 | 9.9% | 1.29 | 1.16 | 10.1% | 8.05 | 7.26 | 9.8% |
| 3A | 49.4 | 44.0 | 10.9% | 118.3 | 106.5 | 10.0% | 1.33 | 1.19 | 10.5% | 8.28 | 7.47 | 9.8% |
| 3B | 42.6 | 37.1 | 12.9% | 104.4 | 92.9 | 11.0% | 1.18 | 1.05 | 11.0% | 7.35 | 6.58 | 10.5% |
| 3C | 43.4 | 36.3 | 16.4% | 108.5 | 92.7 | 14.6% | 1.23 | 1.05 | 14.6% | 7.67 | 6.59 | 14.1% |
| 4A | 50.6 | 42.7 | 15.6% | 114.8 | 100.5 | 12.5% | 1.27 | 1.12 | 11.8% | 7.92 | 7.00 | 11.6% |
| 4B | 53.7 | 48.5 | 9.7% | 125.4 | 114.2 | 8.9% | 1.39 | 1.27 | 8.6% | 8.71 | 7.95 | 8.7% |
| 4C | 44.1 | 36.6 | 17.0% | 102.2 | 88.5 | 13.4% | 1.13 | 0.99 | 12.4% | 7.09 | 6.20 | 12.6% |
| 5A | 57.8 | 52.6 | 9.0% | 122.8 | 112.5 | 8.4% | 1.33 | 1.22 | 8.3% | 8.31 | 7.63 | 8.2% |
| 5B | 52.3 | 45.8 | 12.4% | 118.4 | 105.2 | 11.1% | 1.31 | 1.17 | 10.7% | 8.16 | 7.28 | 10.8% |
| 5C | 58.1 | 51.9 | 10.7% | 130.0 | 117.4 | 9.7% | 1.43 | 1.29 | 9.8% | 8.93 | 8.09 | 9.4% |
| 6A | 68.1 | 61.8 | 9.3% | 140.9 | 129.5 | 8.1% | 1.51 | 1.39 | 7.9% | 9.45 | 8.72 | 7.7% |
| 6B | 64.2 | 57.1 | 11.1% | 137.2 | 123.8 | 9.8% | 1.49 | 1.35 | 9.4% | 9.30 | 8.43 | 9.4% |
| 7 | 73.7 | 69.4 | 5.8% | 151.1 | 141.3 | 6.5% | 1.62 | 1.51 | 6.8% | 10.12 | 9.43 | 6.8% |
| 8 | 91.7 | 85.0 | 7.3% | 170.2 | 158.1 | 7.1% | 1.76 | 1.64 | 6.8% | 11.02 | 10.24 | 7.1% |
| National Weighted Average | 51.1 | 44.9 | 12.1% | 118.7 | 106.1 | 10.6% | 1.32 | 1.18 | 10.6% | 8.24 | 7.40 | 10.2% |

# 5.0 References


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.

82 FR 1615. 2017. Federal Register Volume 82, Number 4 (January 6, 2017), p. 1615. U.S. Government Publishing Office, Washington, D.C. Available at: https://www.govinfo.gov/app/details/FR-2017-01-06.

83 FR 8463. 2018. Federal Register Volume 83, Number 39 (February 27, 2018). Page 8463 – 8465. U.S. Government Publishing Office, Washington, D.C. Available at https://www.regulations.gov/document?D=EERE-2017-BT-DET-0046-0008.

ASHRAE. 2013. ANSI/ASHRAE Standard 169-2013. *Climatic Data for Building Design Standards.* ASHRAE, Atlanta, Georgia.

ASHRAE. 2016. ANSI/ASHRAE 90.4-2016, *Energy Standard for Data Center*. ASHRAE, Atlanta, GA

ASHRAE. 2019. ANSI/ASHRAE/IES 90.1-2019, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE, Atlanta, GA.

ASHRAE. 2019. *HVAC Applications Handbook, Chapter 51, Service Water Heating*. ASHRAE, Atlanta, Georgia.

ASHRAE. 2020. *ANSI/ASHRAE/IES Addendum by to ANSI/ASHRAE/IES Standard 90.1-2019*. ASHRAE, Atlanta, GA.

BECP – U.S. Department of Energy, Building Energy Codes Program. 2022. *Status of State Energy Code Adoption*. Accessed March 30, 2022 at http://www.energycodes.gov/status/commercial.

DOE. 2018. *EnergyPlus Energy Simulation Software, Version 9.0.1*. U.S. Department of Energy, Washington, D.C. Accessed August 29, 2019 at http://apps1.eere.energy.gov/buildings/EnergyPlus/.

DOE. 2021. *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019*. U.S. Department of Energy, Washington, D.C. Accessed April 12, 2022 at https://www.energycodes.gov/sites/default/files/2021-07/Standard_90.1-2019_Final_Determination_TSD.pdf.

DOE and PNNL. 2022. *Commercial Prototype Building Models*, Richland, WA, Pacific Northwest National Laboratory. Available at https://www.energycodes.gov/development/commercial/prototype_models.

*Ecosizer tool for sizing centralized heat pump water heater systems*, Accessed January 19, 2022 at https://ecosizer.ecotope.com/sizer/.

ECPA. *Energy Conservation and Production Act of 1976*. Public Law 94-385. Accessed April 29, 2015 at http://www.gpo.gov/fdsys/pkg/STATUTE-90/pdf/STATUTE-90-Pg1125.pdf.

EIA. 2003. *Commercial Buildings Energy Consumption Survey 2003*. Energy Information Administration of U.S. Department of Energy, Washington, D.C. Accessed August 29, 2018 at http://www.eia.doe.gov/emeu/cbecs/contents.html.

EIA – U.S. Energy Information Administration. 2022. *Annual Energy Outlook 2022*. Energy Information Administration of U.S. Department of Energy, Washington, D.C. Available at https://www.eia.gov/outlooks/aeo/.

Goel S, R. A. Athalye, W. Wang, J. Zhang, M. I. Rosenberg, Y. L. Xie, P. R. Hart, and V. V. Mendon. 2014. *Enhancements to ASHRAE Standard 90.1 Prototype Building Models*. PNNL-23269, Pacific Northwest National Laboratory, Richland, WA. Accessed April 29, 2015 at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23269.pdf.

Gowri, K., D.W. Winiarski, and R.E. Jarnagin. 2009. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis*. PNNL-18898, Pacific Northwest National Laboratory, Richland, Washington.

Halverson M. A., R. A. Athalye, M. I. Rosenberg, Y. L. Xie, W. Wang, P. R. Hart, J. Zhang, S. Goel, and V. V. Mendon. 2014. *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis*. PNNL-23479, Pacific Northwest National Laboratory, Richland, WA. Assessed April 29, 2015 at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23479.pdf.

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

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

Lei, X, JB Butzbaugh, Y Chen, J Zhang, and MI Rosenberg. 2020. *Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018)*. PNNL-29787. Pacific Northwest National Laboratory, Richland, WA. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-29787.pdf.

Thornton, B. A., W. Wang, H. Cho, Y. Xie, V. V. Mendon., E. E. Richman, J. Zhang, R. A. Athalye, M. I. Rosenberg, and B. Liu. 2011. *Achieving 30% Goal: Energy and Cost Saving Analysis of ASHRAE/IES Standard 90.1-2010*. PNNL-20405. Pacific Northwest National Laboratory, Richland, Washington. Accessed April 29, 2015 at https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20405.pdf.

Tyler, M., D. Winiarski, M. Rosenberg, and B. Liu. 2021. *Impacts of Model Building Energy Codes – Interim Update.* PNNL-31437. Pacific Northwest National Laboratory, Richland, Washington.

Zhang, J., Y. Chen, Y. Xie, M. Rosenberg, R. Hart. *Energy and Energy Cost Savings Analysis of the 2018 IECC for Commercial Buildings*. 2018. PNNL-28125. Richland, WA: Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28125.pdf.

Zhang J., M.I. Rosenberg, J. Lerond, Y. Xie, C. Chandrasekharan Nambiar, Y. Chen, and R. Hart, et al. 2021. *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019*. PNNL-31488. Richland, WA: Pacific Northwest National Laboratory. https://www.energycodes.gov/sites/default/files/2021-07/20210407_Standard_90.1-2019_Determination_TSD.pdf.

# Appendix A – Code Changes from the 2018 to 2021 IECC Included in Analysis and their Impact on Building Prototypes

The following table lists the code changes to the 2018 IECC that result in energy savings that were quantified in the analysis, as well as the relevant section of the IECC and which prototypes were affected.

Table A.1. Changes Between the 2018 and 2021 IECC with Quantified Energy Impacts and Impacted Prototypes

| Section Number in the 2021 IECC | Description of Code Changes | Small Office | Medium Office | Large Office | Stand-Alone Retail | Strip Mall | Primary School | Secondary School | Outpatient Health Care | Hospital | Small Hotel | Large Hotel | Non-Refrigerated Warehouse | Quick-Service Restaurant | Full-Service Restaurant | Mid-Rise Apartment | High-Rise Apartment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C402.1.4 Assembly U-factor, C-factor or F-factor-based method | Imposes more stringent requirement on the insulation requirements for opaque constructions. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| C402.4 Fenestration | Imposes more stringent requirement on the window thermal properties. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| C402.4.5 Doors | Increases allowable U-factor requirements for opaque non-swinging doors. Also decreases U-factors for swinging doors in some climates. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | |
| C402.5 Air leakage - thermal envelope | Adds requirement for air barrier testing, which sets specific limits on air leakage for specific climates. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| C402.5.11 Operable openings interlocking | Requires that operable openings be interlocked with HVAC setpoints. | | | | | | | | | | X | X | | | | X | X |
| C403.1.2 Data centers | Adds requirement that data center systems comply with Sections 6 and 8 of ASHRAE 90.4-2016, with IECC-specific values for MLC. | | | X | | | | | | | | | | | | | |

| Section Number in the 2021 IECC | Description of Code Changes | Small Office | Medium Office | Large Office | Stand-Alone Retail | Strip Mall | Primary School | Secondary School | Outpatient Health Care | Hospital | Small Hotel | Large Hotel | Non-Refrigerated Warehouse | Quick-Service Restaurant | Full-Service Restaurant | Mid-Rise Apartment | High-Rise Apartment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C403.3.2 HVAC equipment performance requirements | Increases required HVAC efficiency values for several equipment categories. | | | | X | | X | X | | | | | X | X | X | X | |
| C403.4.2.3 Automatic start and stop | Adds automatic stop for near the end of occupied periods, where thermostat is set back by 2°F. | X | X | X | X | X | X | X | X | | | | X | X | X | X | X |
| C403.6.5 Supply air temperature reset | Adds exceptions to supply air temperature reset for some hot climates based on design outside air flow. | | X | X | | | X | X | X | | | | | | | | |
| C403.7.1 Demand control ventilation | Expands the applicability of DCV to all single zone systems that also require economizer and reduces occupant density threshold. | | | | X | X | | | | | X | | X | | | | |
| C403.7.4 Energy recovery systems | Adds new requirements for ERV in non-transient dwelling units. | | | | | | | | | | | | | | | X | X |
| C403.8.5 Low-capacity ventilation fans | Adds efficacy requirements for low-capacity fans. | | | | | | | | | | | | | | | X | X |
| C403.11.1 Commercial refrigerators and refrigerator-freezers | Decreases maximum daily energy consumption for commercial refrigerators and freezers. | | | | | | X | X | | X | | X | | X | X | | |
| C403.11.2 Walk-in coolers and walk-in freezers | Decreases maximum daily energy consumption for walk-in coolers and freezers. | | | | | | X | X | | X | | X | | X | X | | |
| Future | Adds new federal requirements for clean water pump efficiency. | | | X | | | X | X | X | X | | X | | | | | X |
| C405.2.1 Occupant sensor controls | Extends requirement to corridor spaces. | X | X | X | | | X | X | X | X | X | X | X | X | X | X | X |
| C405.2.4.2 Sidelit daylight zone | Adds requirement for secondary sidelit daylight zone. | X | X | X | X | | X | X | X | X | X | X | X | X | X | | |

| Section Number in the 2021 IECC | Description of Code Changes | Small Office | Medium Office | Large Office | Stand-Alone Retail | Strip Mall | Primary School | Secondary School | Outpatient Health Care | Hospital | Small Hotel | Large Hotel | Non-Refrigerated Warehouse | Quick-Service Restaurant | Full-Service Restaurant | Mid-Rise Apartment | High-Rise Apartment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C405.2.7.3 Exterior lighting setback | Increase setback amount to 50% and add occupancy-based control to outdoor parking areas. | X | X | X | X | X | X | X | X | | | | X | X | X | | |
| C405.3.2 Interior lighting power allowance | Decrease lighting power density for most space types. | X | X | X | X | X | X | X | X | X | X | X | X | | | X | X |
| C405.11 Automatic receptacle control | Adds requirement for automatic control of receptacle loads in selected space types. | X | X | X | | | X | X | X | X | X | | X | | | X | X |
| C406 Additional Efficiency Requirements | Adds new categories for efficiency credits and new point values. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

# Appendix B – Energy and Energy Cost Savings for the 2021 IECC and Corresponding Standard 90.1-2019

Section 304(b) of the ECPA (Energy Conservation and Production Act), as amended, requires the Secretary of Energy to make a determination each time a revised edition of Standard 90.1 is published with respect to whether the revised standard would improve energy efficiency in commercial buildings. When DOE issues an affirmative determination on Standard 90.1, states are statutorily required to certify within 2 years that they have reviewed and updated the commercial provisions of their building energy code, with respect to energy efficiency, to meet or exceed the revised standard (42 U.S.C. 6833).

In support of DOE's determination, PNNL conducted an energy savings analysis for Standard 90.1-2019 compared to Standard 90.1-2016 (DOE 2021). Based on that analysis, DOE issued a determination that Standard 90.1-2019 would achieve greater energy efficiency in buildings compared to the 2016 edition of the standard.

As many states have historically adopted the IECC for both residential and commercial buildings, PNNL has also compared energy performance of Standard 90.1-2019 with the 2021 IECC to help states and local jurisdictions make informed decisions regarding model code adoption. Of the 42 states with statewide commercial building energy codes currently, 33 use a version of the IECC (BECP 2022).

Table B.1 shows side-by-side comparisons of the site EUI and ECI for Standard 90.1-2019 and the 2021 IECC for each of 16 prototype buildings along with the percent difference between the two. The national weighted average of all prototypes combined is also shown. Negative percentage differences indicate higher energy usage or energy costs for buildings designed to the 2021 IECC compared to those designed to Standard 90.1-2019. Figure B.1 shows the same results graphically. For some prototypes, EUIs or ECIs were lower using Standard 90.1-2019 but the 2021 IECC resulted in both lower energy use and lower energy costs in the national weighted average.

## Table B.1. Site Energy and Energy Cost Savings between Standard 90.1-2019 and the 2021 IECC

| Building Prototype | Site EUI (kBtu/ft²-yr) | | | Source EUI (kBtu/ft²-yr) | | | ECI ($/ft²-yr) | | | Emissions (ton/ft²-yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) |
| Small Office | 26.8 | 26.2 | 2.2% | 74.7 | 72.8 | 2.5% | $0.87 | $0.85 | 2.3% | 5.4 | 5.3 | 2.4% |
| Medium Office | 30.3 | 28.2 | 6.9% | 78.7 | 74.9 | 4.8% | $0.90 | $0.86 | 4.4% | 5.6 | 5.4 | 4.3% |
| Large Office | 53.3 | 47.6 | 10.7% | 146.8 | 131.6 | 10.4% | $1.70 | $1.52 | 10.6% | 10.6 | 9.5 | 10.3% |
| Stand-Alone Retail | 46.2 | 41.2 | 10.8% | 102.9 | 94.6 | 8.1% | $1.13 | $1.05 | 7.1% | 7.1 | 6.6 | 7.2% |
| Strip Mall | 49.2 | 43.3 | 12.0% | 120.1 | 110.3 | 8.2% | $1.35 | $1.25 | 7.4% | 8.4 | 7.8 | 7.1% |
| Primary School | 43.2 | 44.7 | -3.5% | 101.5 | 106.9 | -5.3% | $1.13 | $1.20 | -6.2% | 7.1 | 7.5 | -5.7% |
| Secondary School | 38.8 | 41.1 | -5.9% | 93.5 | 100.8 | -7.8% | $1.05 | $1.14 | -8.6% | 6.6 | 7.1 | -8.2% |
| Outpatient Healthcare | 108.4 | 107.7 | 0.6% | 259.6 | 256.8 | 1.1% | $2.91 | $2.87 | | 18.2 | 18.0 | 1.2% |
| Hospital | 106.4 | 120.3 | -13.1% | 254.4 | 274.2 | -7.8% | $2.85 | $3.03 | -6.3% | 17.8 | 18.9 | -6.4% |
| Small Hotel[1] | 63.5 | 57.7 | 9.1% | 125.7 | 127.2 | -1.2% | $1.33 | $1.39 | -4.5% | 8.3 | 8.7 | -4.6% |
| Large Hotel | 86.9 | 80.0 | 7.9% | 173.2 | 174.8 | -0.9% | $1.84 | $1.91 | -3.8% | 11.5 | 11.9 | -3.7% |
| Warehouse | 13.6 | 12.0 | 11.8% | 26.7 | 25.1 | 6.0% | $0.28 | $0.27 | 3.6% | 1.8 | 1.7 | 4.0% |
| Quick-Service Restaurant | 499.2 | 505.8 | -1.3% | 854.8 | 860.6 | -0.7% | $8.57 | $8.61 | -0.5% | 53.6 | 53.9 | -0.4% |
| Full-Service Restaurant | 337.9 | 337.8 | 0.0% | 636.9 | 634.9 | 0.3% | $6.63 | $6.60 | 0.5% | 41.5 | 41.3 | 0.4% |
| Mid-Rise Apartment | 39.3 | 31.6 | 19.6% | 106.5 | 86.5 | 18.8% | $1.23 | $1.00 | 18.7% | 7.7 | 6.3 | 18.6% |
| High-Rise Apartment | 43.2 | 31.0 | 28.2% | 91.9 | 81.0 | 11.9% | $1.00 | $0.93 | 7.0% | 6.2 | 5.8 | 6.9% |
| National Weighted Average | 48.0 | 44.9 | 6.5% | 110.4 | 106.1 | 3.9% | $1.22 | $1.18 | 3.3% | 7.6 | 7.4 | 3.1% |

[1] The hotel prototypes show positive savings for site EUI and negative savings for the other metrics due to the switch of a portion of service water heating energy from gas to electric heat pump.

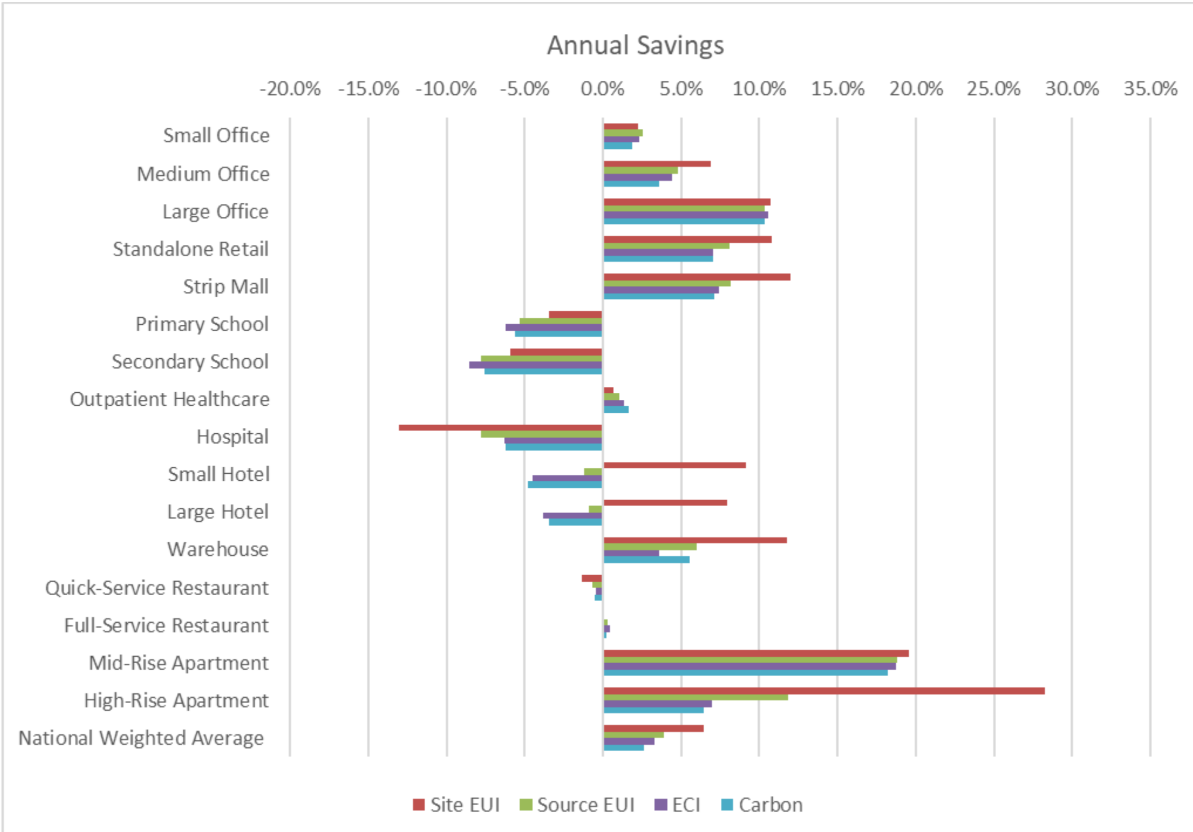


Figure B.1. National Average Site Energy Use Intensity for Standard 90.1 and IECC Prototypes

The comparisons show the combined energy impacts of differences between the 2021 IECC and Standard 90.1-2019. Although the current analysis does not compare or rank the individual differences based on their energy savings, a few high-impact differences by category can be identified as follows:

- Envelope
  - Prescriptive window-to-wall ratio (WWR) limit: the 2021 IECC allows a WWR up to 30% unless a significant portion of the building is equipped with daylight-responsive controls, in which case up to 40% is allowed. Standard 90.1-2019 requires WWR less than 40%.
  - Semi-heated space envelope requirements: the 2021 IECC does not have separate envelope requirements for semi-heated spaces. Semi-heated spaces are required to follow conditioned space requirements. Standard 90.1-2019 has less stringent insulation requirements for semi-heated spaces.
  - Vestibule exceptions: the 2021 IECC exempts building entrance doors that open up to a space less than 3,000 $ft^2$; Standard 90.1-2019 does not. The 2021 IECC also includes an exception from vestibule requirements if an air curtain is installed instead; Standard 90.1-2019 does not have such an exception.
  - Fenestration orientation: the 2021 IECC does not limit the distribution of fenestration area. Standard 90.1-2019 limits the proportion of fenestration area on the east and west façades.

  - Skylights: the 2021 IECC has an exception for spaces with daylighting control that allow higher U-factor and SHGC for skylights. This exception does not exist for Standard 90.1-2019.
  - Infiltration: Testing for infiltration is no longer optional for the 2021 IECC in certain cases, so air leakage limits are now set at 0.4 cfm/$ft^2$ for some prototypes in some climate zones. This is significantly lower than the value of 1.0 cfm/$ft^2$ used for Standard 90.1-2019.
- Building mechanical systems
  - Transfer air: the 2021 IECC requires the use of transfer air to kitchen exhaust systems. Standard 90.1-2019 expands the requirement to more exhaust systems, including restroom and laundry exhaust.
  - Pipe sizing: Standard 90.1-2019 includes requirements for pipe sizing to reduce pump power. IECC 2021 does not have similar requirements, and thus pump pressure loss is higher.
  - Occupied-standby controls: Standard 90.1-2019 includes a thermostat/VAV box control requirement that is connected to automatic lighting controls. IECC 2021 does not have a similar requirement.
  - Chilled water flow: Standard 90.1-2019 has a requirement for sizing chilled water coils based on a 15°F temperature difference. The 2021 IECC prototypes used 12°F temperature difference for air cooled chillers and 10°F temperature difference for water cooled chillers.
  - Minimum damper position for VAV terminals: Standard 90.1-2019 sets the minimum air flow setting based on the Simplified Procedure of ASHRAE Standard 62.1, whereas IECC-2021 sets the minimum based on the larger of 20% and the ventilation requirements.
  - One pump per chiller: Standard 90.1-2019 has a provision that requires each chiller to have its own primary chilled water pump, but the 2021 IECC does not have this requirement. Thus, in the 2021 IECC prototypes, a single larger pump is run, even if only one chiller operates.
  - Chilled and hot water reset control: The 2021 IECC prototypes are modeled with both chilled and hot water reset control, and the Standard 90.1-2019 models do not include this control.
  - Optimal stop control: The 2021 IECC has a requirement for optimal stop control which is not shared by Standard 90.1-2019. This amounts to a partial thermostat set back that occurs one hour before the end of the occupied period.
  - Demand controlled ventilation: The 2021 IECC has new language that requires demand controlled ventilation for all single zone HVAC systems that include economizer controls and that do not require energy recovery ventilation. This blanket requirement is not included in Standard 90.1-2019, so the 2021 IECC has greater use of the technology.
  - Heat recovery chiller: Heat recovery chillers are included in the Standard 90.1-2019 hospital prototype, but are not required for the 2021 IECC.

- Lighting
  - Dwelling unit (apartment) lighting power: the 2021 IECC requires 90% of all permanently installed luminaires in dwelling units to be high efficacy. Standard 90.1-2019 requires only 75%.
  - Egress lighting control: Standard 90.1-2019 requires lighting connected to emergency circuits to be turned off in spaces that comply with the automatic full off or scheduled off requirements when there are no occupants. It provides an exception to the automatic full off and scheduled off requirements for egress lighting by allowing 0.02 W/ft$^2$ or less lighting power to remain on during the unoccupied period. The 2021 IECC does not have such a requirement.
  - Daylighting minimum ratio: Where daylighting controls are required, IECC 2021 specifies a minimum light output of 15%, whereas Standard 90.1-2019 specifies a minimum output of 20%.
  - Building façade lighting: Standard 90.1-2019 has lower allowances for building façade lighting than the IECC 2021.
- Additional efficiency package options: Additional efficiency package requirements are in the 2021 IECC, but not in Standard 90.1-2019.
  - Interior lighting power: The lighting power allowances specified in the 2021 IECC are almost the same as the corresponding requirements in Standard 90.1-2019. The lighting efficiency package was selected for all prototypes and in most climate zones. Consequently, the lighting power for the 2021 IECC prototypes is typically 10% lower than Standard 90.1-2019.
  - Cooling efficiency: The cooling efficiency package was selected for most climates for the school prototypes, and for a few climates in all other prototypes except retail. The prescriptive requirements for cooling efficiency in the 2021 IECC are nearly identical to 90.1-2019, so the cooling efficiency improvements of 5% to 10% are primarily due to the efficiency package.
  - Heating efficiency: The heating efficiency 5% improvement package was applied only for the apartments, hotels, and hospital, and only in climate zone 5C. The prescriptive requirements for heating efficiency in the 2021 IECC for these prototypes are identical to those of Standard 90.1-2019. The heating efficiency 10% improvement package was not used.
  - Infiltration: The infiltration energy credit was selected for all prototypes except retail, and in several climate zones. To achieve the infiltration credit, the 2021 IECC prototype air leakage rates are based on 0.25 cfm/ft$^2$, as compared with 1.0 cfm/ft$^2$ for 90.1-2019.
  - Heat pump water heater: The HPWH credit was selected for the apartments, the hotels, and the hospital. The corresponding water heating systems in the 90.1-2019 prototypes were electric storage for the mid-rise apartment and gas storage for all the others.
  - Onsite renewable energy: The credit for onsite renewable energy was selected only for the outpatient health care prototype, and only is seven climates. The corresponding 90.1-2019 prototypes did not include onsite renewable energy.

Table B.2 shows the comparison of the analysis results for Standard 90.1-2019 and the 2021 IECC by climate zone. The EUI, ECI, and emissions factor shown in the table for each climate zone are weighted averages across the 16 prototypes within that climate zone in the United States. For all climate zones, the table shows buildings designed to the 2021 IECC have lower energy consumption and costs than those designed to Standard 90.1-2019 based on a weighted average. On a national average basis for all prototypes combined, the 2021 IECC is 6.5% more efficient for site energy use and 3.3% more for energy costs than Standard 90.1-2019.

Table B.2. Site Energy and Energy Cost Savings between Standard 90.1-2019 and the 2021 IECC by Climate Zone

| Climate Zones | Site EUI (kBtu/ft²-yr) | | | Source EUI (kBtu/ft²-yr) | | | ECI ($/ft²-yr) | | | Emissions (ton/kft²-yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) | Standard 90.1-2019 | 2021 IECC | Difference (%) |
| 1A | 47.1 | 41.8 | 11.3% | 117.6 | 110.9 | 5.7% | 1.33 | 1.27 | 4.5% | 8.32 | 7.95 | 4.4% |
| 2A | 46.0 | 44.0 | 4.3% | 115.5 | 111.7 | 3.3% | 1.31 | 1.27 | 3.1% | 8.18 | 7.93 | 3.1% |
| 2B | 41.7 | 40.3 | 3.4% | 105.3 | 102.3 | 2.8% | 1.19 | 1.16 | 2.5% | 7.46 | 7.26 | 2.7% |
| 3A | 46.1 | 44.0 | 4.6% | 109.5 | 106.5 | 2.7% | 1.22 | 1.19 | 2.5% | 7.64 | 7.47 | 2.2% |
| 3B | 39.9 | 37.1 | 7.0% | 97.1 | 92.9 | 4.3% | 1.09 | 1.05 | 3.7% | 6.83 | 6.58 | 3.7% |
| 3C | 40.4 | 36.3 | 10.1% | 100.8 | 92.7 | 8.0% | 1.14 | 1.05 | 7.9% | 7.13 | 6.59 | 7.6% |
| 4A | 48.0 | 42.7 | 11.0% | 107.3 | 100.5 | 6.3% | 1.18 | 1.12 | 5.1% | 7.38 | 7.00 | 5.1% |
| 4B | 49.7 | 48.5 | 2.4% | 114.8 | 114.2 | 0.5% | 1.27 | 1.27 | 0.0% | 7.96 | 7.95 | 0.1% |
| 4C | 41.2 | 36.6 | 11.2% | 95.6 | 88.5 | 7.4% | 1.06 | 0.99 | 6.6% | 6.63 | 6.20 | 6.5% |
| 5A | 54.7 | 52.6 | 3.8% | 114.5 | 112.5 | 1.7% | 1.23 | 1.22 | 0.8% | 7.71 | 7.63 | 1.0% |
| 5B | 48.8 | 45.8 | 6.1% | 109.4 | 105.2 | 3.8% | 1.20 | 1.17 | 2.5% | 7.52 | 7.28 | 3.2% |
| 5C | 54.9 | 51.9 | 5.5% | 121.5 | 117.4 | 3.4% | 1.33 | 1.29 | 3.0% | 8.32 | 8.09 | 2.8% |
| 6A | 64.3 | 61.8 | 3.9% | 131.5 | 129.5 | 1.5% | 1.41 | 1.39 | 1.4% | 8.79 | 8.72 | 0.8% |
| 6B | 60.2 | 57.1 | 5.1% | 125.7 | 123.8 | 1.5% | 1.35 | 1.35 | 0.0% | 8.46 | 8.43 | 0.4% |
| 7 | 69.9 | 69.4 | 0.7% | 140.8 | 141.3 | -0.4% | 1.50 | 1.51 | -0.7% | 9.37 | 9.43 | -0.6% |
| 8 | 85.9 | 85.0 | 1.0% | 157.3 | 158.1 | -0.5% | 1.62 | 1.64 | -1.2% | 10.13 | 10.24 | -1.1% |
| National Weighted Average | 48.0 | 44.9 | 6.5% | 110.4 | 106.1 | 3.9% | 1.22 | 1.18 | 3.3% | 7.64 | 7.40 | 3.1% |

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