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Energy and Energy Cost Savings Analysis of the 2015 IECC for Commercial Buildings

June 2015

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Y Xie
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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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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and greenhouse gas emissions for the life of buildings. As required by federal statute (42 USC 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2013 would achieve greater energy efficiency in buildings compared to the 2010 edition of the standard. In support of DOE's determination, Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2013 (Halverson et al. 2014). While Standard 90.1 is the national model energy standard for commercial buildings (42 USC 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings.

This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2015 IECC would save energy and energy costs as compared to the 2012 IECC. PNNL also compared the energy performance of the 2015 IECC with the corresponding Standard 90.1-2013. The purpose of this analysis is to help states and local jurisdictions make informed decisions regarding model code adoption.

The analysis builds on previous work done by PNNL that assessed the energy performance of the 2012 IECC compared to the 2006 and 2009 editions of the IECC (Zhang et al. 2013). For this analysis, PNNL first reviewed all code changes from the 2012 to 2015 IECC and identified those having a quantifiable impact on energy. These changes were then implemented in a suite of 16 prototype building models covering all 15 climate zones in the United States. This results in a total of 480 building models, 240 models each for the 2012 and 2015 editions of the IECC. Prototype models for the 2015 IECC were developed by implementing code changes to the 2012 IECC models. The 16 prototype building models represent more than 80% of the national stock of commercial buildings in the United States.

Whole-building energy simulations were conducted using DOE's *EnergyPlus Version 8.0* (DOE 2013) building simulation software. The resulting energy use from the complete suite of 480 simulation runs was converted to site energy use intensity (EUI, or energy use per unit floor area), and energy cost index (ECI) for each simulation. For each prototype, the resulting EUIs and ECIs in each climate zone were weighted to calculate the aggregate national level EUI and ECI. Weighting factors were developed using commercial construction data and are based on construction floor area of the different building types in each climate zone (Jarnagin and Bandyopadhyay 2010). Finally, the EUIs were aggregated across building types to the national level using the same weighting data.

Overall, the 2015 edition of the IECC results in site energy savings of 11.5% at the aggregate national level compared to the 2012 IECC edition; on a national average basis for all prototypes combined, the 2015 IECC and Standard 90.1-2013 are within 1% for both energy use and energy costs (see Appendix B in this report). Savings from the 2012 to 2015 IECC vary significantly by prototype. This is expected

[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

because code requirements are different by building type and by climate. A few high impact changes resulting in significant energy savings are listed below:

- Envelope: Changes to opaque envelope (see Section 3.2.1 in this report) and continuous air barrier (see Section3.2.2).
- HVAC: Equipment efficiency improvements (see Section 3.3.1), ERV (see Section 3.3.3), kitchen exhaust systems (see Section 3.3.4), staged cooling (see Section 3.3.9), fan airflow control (see Section 3.3.10), VAV reheat control (see Section 3.3.14), VAV system for critical area in healthcare facility (see Section 3.3.15), and outdoor air ventilation optimization (see Section 3.3.17).
- Lighting: Daylight responsive control (see Section 3.5.3), exterior lighting control (see Section 3.5.5), interior lighting power (see Section 3.5.6), and exterior lighting power (see Section 3.5.7).

Table ES.1 summarizes the analysis results. The 16 building prototypes are listed along with their construction weighting factors. Side-by-side comparisons of the site EUI and ECI for the 2012 and 2015 IECC are shown in the table along with their percent savings. Positive percentage savings indicate a reduction in energy or energy costs from the 2012 IECC. As shown in Table ES.1, the analysis shows an estimated site energy savings of 11.1% and energy cost savings of 11.5% on a national aggregated basis. The analysis also indicates that all building prototypes, except the Warehouse prototype, use less energy under the 2015 IECC. The Warehouse prototype uses more energy because the requirements in the 2015 IECC resulted in reduced daylit area under control compared to the 2012 IECC. These changes are specific to the Warehouse prototype and are more pronounced because lighting energy is a large portion of the total energy consumption in the Warehouse prototype.

Table ES.1. Site Energy and Energy Cost Savings between the 2012 and 2015 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI (kBtu/ft^2-yr)		Site EUI Savings (%)	ECI ($/ft²-yr)		ECI Savings (%)
			2012 IECC	2015 IECC		2012 IECC	2015 IECC	
Office	Small Office	5.6	31.1	29.6	4.8	0.93	0.88	4.8
	Medium Office	6.0	35.5	34.6	2.5	0.99	0.97	1.9
	Large Office	3.3	76.2	71.7	6.0	2.15	2.04	5.2
Retail	Standalone Retail	15.3	54.1	47.3	12.6	1.44	1.21	16.0
	Strip Mall	5.7	58.3	54.0	7.4	1.54	1.39	9.7
Education	Primary School	5.0	62.3	55.5	10.9	1.52	1.34	11.4
	Secondary School	10.4	51.8	42.8	17.4	1.35	1.12	16.8
Healthcare	Outpatient Healthcare	4.4	137.2	117.6	14.3	3.53	3.07	13.0
	Hospital	3.4	172.2	128.0	25.7	3.72	2.98	20.0
Lodging	Small Hotel	1.7	66.4	60.4	9.2	1.49	1.3	12.6
	Large Hotel	5.0	109.5	87.9	19.8	2.37	1.81	23.9
Warehouse	Warehouse	16.7	15.0	15.5	-3.1	0.34	0.36	-5.2
Food Service	Quick-Service Restaurant	0.6	602.5	582	3.4	9.66	8.83	8.6
	Full-Service Restaurant	0.7	405.6	373.8	7.8	7.22	6.44	10.8
Apartment	Mid-Rise Apartment	7.3	45.0	44.2	1.7	1.23	1.22	1.0
	High-Rise Apartment	9.0	49.1	47.6	3.0	1.14	1.11	3.1
National Weighted Average		**100**	**61.4**	**54.5**	**11.1**	**1.49**	**1.31**	**11.5**

Figures ES.1 and ES.2 illustrate the weighted EUI and ECI for each prototype and the national weighted average results for the 2012 and 2015 editions of the IECC, respectively.

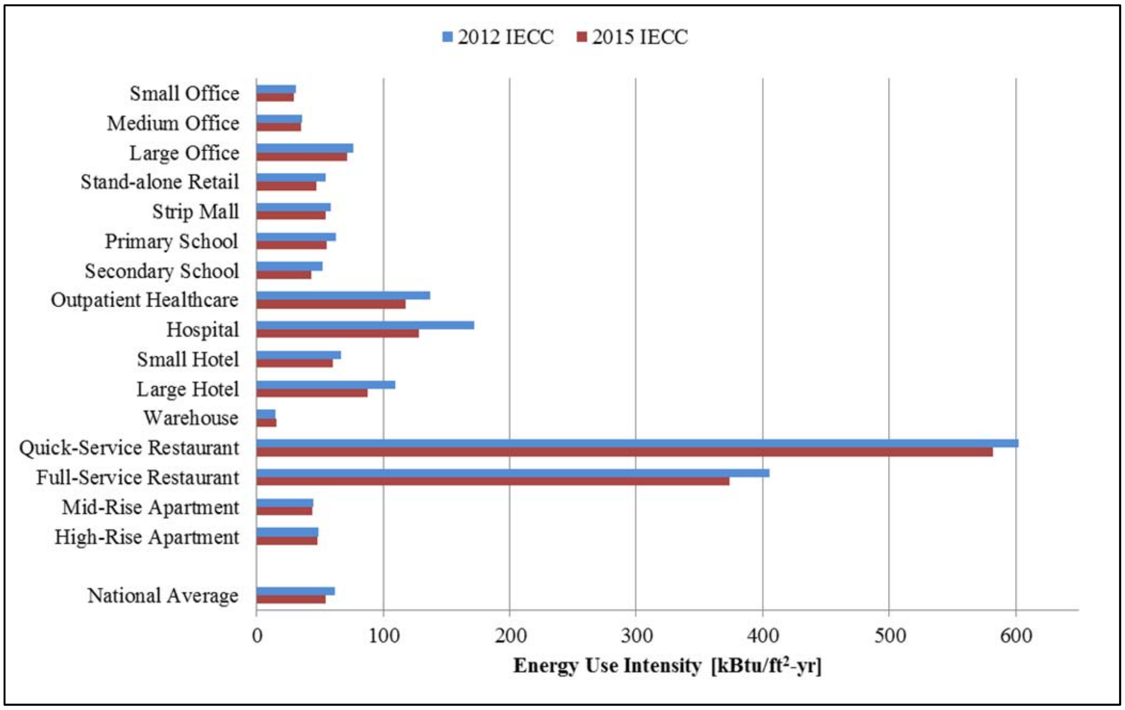

Figure ES.1. National Average Energy Use Intensity for all IECC Prototypes

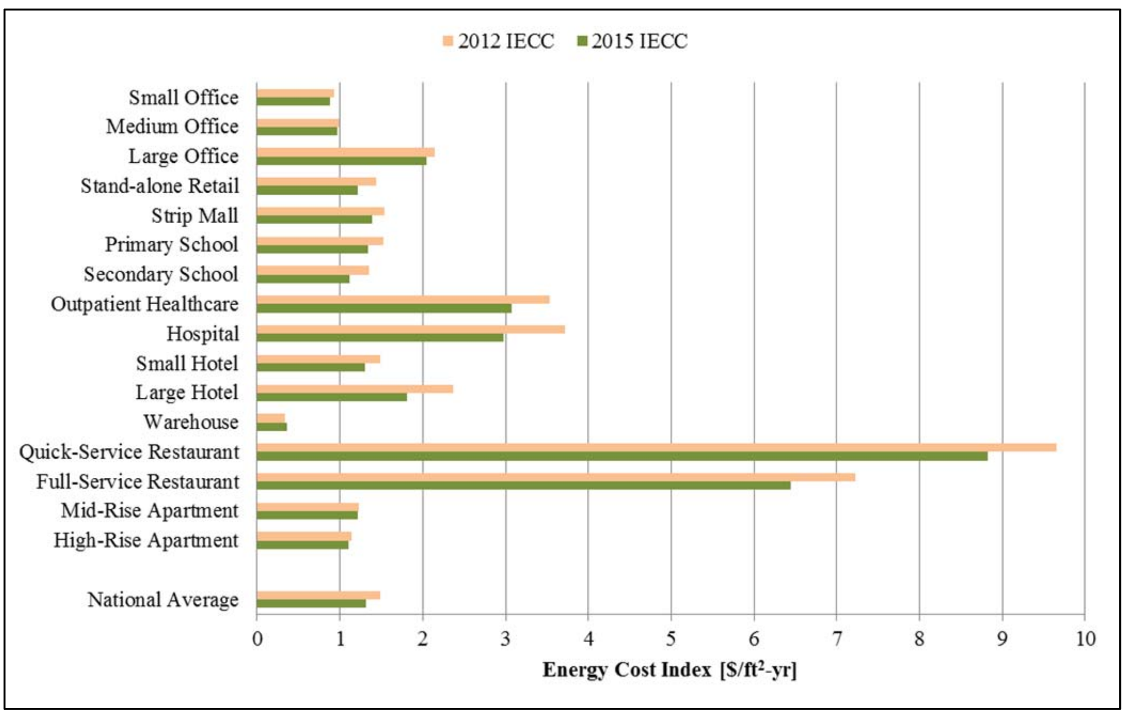

Figure ES. 2. National Average Energy Cost Index for all IECC Prototypes

Acknowledgments

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Jian Zhang, Ph.D.
Pacific Northwest National Laboratory

Acronyms and Abbreviations

AEDG	Advanced Energy Design Guide
AIA	American Institute of Architects
ANSI	American National Standards Institute
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BECP	Building Energy Codes Program
bhp	brake horsepower
Btu/h	British thermal unit(s) per hour
CBECS	Commercial Building Energy Consumption Survey
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DX	direct expansion
EC	electronically commutated
ECI	energy cost index
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EMS	energy management system
EPAct	Energy Policy Act
ERV	energy recovery ventilator
EUI	energy use intensity
ft^2	square feet
hp	horsepower
HVAC	heating, ventilation, and air-conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IMC	International Mechanical Code
$kBtu/ft^2$-yr	thousand British thermal unit(s) per square foot per year
kBtu/h	thousand British thermal unit(s) per hour
kWh	kilowatt hour(s)
LPD	lighting power density
MAT	mixed air temperature
NAECA	National Appliance Energy Conservation Act
PLR	part load ratio

PNNL	Pacific Northwest National Laboratory
SAT	supply air temperature
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SWH	service water heating
TMY	typical meteorological year
VAV	variable air volume
VT	visible transmittance
WSHP	water source heat pump
WWR	window-to-wall ratio
w.c.	water column

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1.0 Introduction

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the development and implementation of building energy codes and standards, which set minimum requirements for energy-efficient design and construction for new and renovated buildings, and impact energy use and greenhouse gas emissions for the life of buildings.

As required by federal statute (42 USC 6833), DOE recently issued a determination that ANSI/ASHRAE/IES[1] Standard 90.1-2013 would achieve greater energy efficiency in buildings subject to the code compared to the 2010 edition of the standard.[2] Pacific Northwest National Laboratory (PNNL) conducted an energy savings analysis for Standard 90.1-2013 in support of the determination (Halverson et al. 2014). While Standard 90.1 is the national model energy standard for commercial buildings (42 USC 6833), many states have historically adopted the International Energy Conservation Code (IECC) for both residential and commercial buildings. Of the 47 states with statewide commercial building energy codes currently, 37 use a version of the IECC (BECP 2015). The Commercial Energy Efficiency chapter in the 2015 IECC (International Code Council, ICC 2015a) allows users to either follow the provisions in the IECC or use Standard 90.1-2013 as an alternative compliance path. This report provides an assessment as to whether new buildings constructed to the commercial energy efficiency provisions of the 2015 IECC would save energy and energy costs compared to the 2012 IECC (ICC 2012). Because PNNL used the same methodology for both this 2015 IECC analysis and the previous Standard 90.1-2013 analysis, comparisons between the estimated energy performance of the 2015 IECC and that of its referenced Standard 90.1-2013 are presented in Appendix B of this report. The goal of this analysis is to help states and local jurisdictions make informed decisions regarding model code adoption.

This report documents the approach and results for PNNL's analysis for energy and energy cost savings of the 2015 IECC for commercial buildings. PNNL first reviewed all code changes from the 2012 to 2015 IECC and identified those having a quantifiable impact. PNNL then used two suites of building prototypes, each suite complying with one edition of the IECC. Each suite consists of 240 building prototypes; a combination of 16 building prototypes in all 15 U.S. climate zones. The 2012 IECC prototypes were taken from PNNL's previous analysis of the energy performance of the 2012 IECC compared to its previous editions which was documented in *Energy and Energy Cost Savings Analysis of the IECC for Commercial Buildings* (Zhang et al. 2013), referred to here as *Analysis of the 2012 IECC*.

The current report is organized as follows: Section 2.0 summarizes the general methodology about the building prototypes, their development, and simulation for their energy use and cost. The same methodology was applied in the previous *Analysis of the 2012 IECC* and the Standard 90.1-2013 determination (Halverson et al. 2014). Section 3.0 describes how PNNL developed the 2015 IECC prototypes using the 2012 IECC prototypes as a basis. Finally, Section 4.0 summarizes the results of the comparison of the two editions of the IECC. Appendix A summarizes the identified code changes between the 2012 and 2015 IECC (with quantified energy impacts) and identifies which building prototypes are impacted by each change. Appendix B provides energy and energy cost comparisons between Standard 90.1-2013 and the 2015 IECC.

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air- Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

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

2.0 Methodology

To support the development and implementation of building energy codes, PNNL researchers have developed building prototypes that comply with various editions of energy codes including both Standard 90.1 and IECC. These building prototypes represent the majority of new commercial building stock and were developed using DOE's *EnergyPlus Version 8.0* building energy simulation software (DOE 2013). The results allow comparison of the national weighted average savings of one code to its earlier edition and the relative performance differences between the codes. This section summarizes the general methodology used for this 2015 IECC analysis, which is consistent with that used for the *Analysis of the 2012 IECC*.

2.1 Building Prototypes

For this analysis, PNNL used a suite of building prototypes representing the first seven principal building activities in the Commercial Buildings Energy Consumption Survey (CBECS; EIA 2003). These seven principal building activities represent 76% of the building energy usage of commercial buildings. In addition, two multifamily prototypes (Mid-Rise and High-Rise Apartments) which are not included in CBECS were added into the suite of prototypes. These two prototypes were included in the analysis because they are regulated by the commercial provisions of the IECC. Table 2.1 shows the seven principal activities as defined in CBECS and the added apartment activity. These eight building activities were further divided into 16 building prototypes as listed in Table 2.1 along with their floor area, representing 80% of new construction floor area in the United States. Detailed descriptions of these prototypes and enhancements are documented in Thornton et al. (2011) and Goel et al. (2014).

2.2 Climate Zones

The climate zone and moisture regime definitions used by the IECC include eight zones (climate zones 1 through 8) and three moisture regimes (A – moist, B – dry, and C – marine). Each combination of climate zone and moisture regime defines a climate subzone. For this analysis, a specific climate (city) is selected (representing 15 climate subzones covering the entire United States) as shown in Figure 2.1 (Briggs et al. 2003). The term climate zone is used interchangeably with climate subzone in this report.

Table 2.1. Building Prototypes

Building Activity	Building Prototype	Prototype Floor Area (ft^2)
Office	Small Office	5,500
	Medium Office	53,630
	Large Office	498,640
Retail	Standalone Retail	24,690
	Strip Mall	22,500
Education	Primary School	73,970
	Secondary School	210,910
Healthcare	Outpatient Healthcare	40,950
	Hospital	241,410
Lodging	Small Hotel	43,210
	Large Hotel	122,120
Warehouse	Warehouse	52,050
Food Service	Quick-Service Restaurant	2,500
	Full-Service Restaurant	5,500
Apartment	Mid-Rise Apartment	33,740
	High-Rise Apartment	84,360

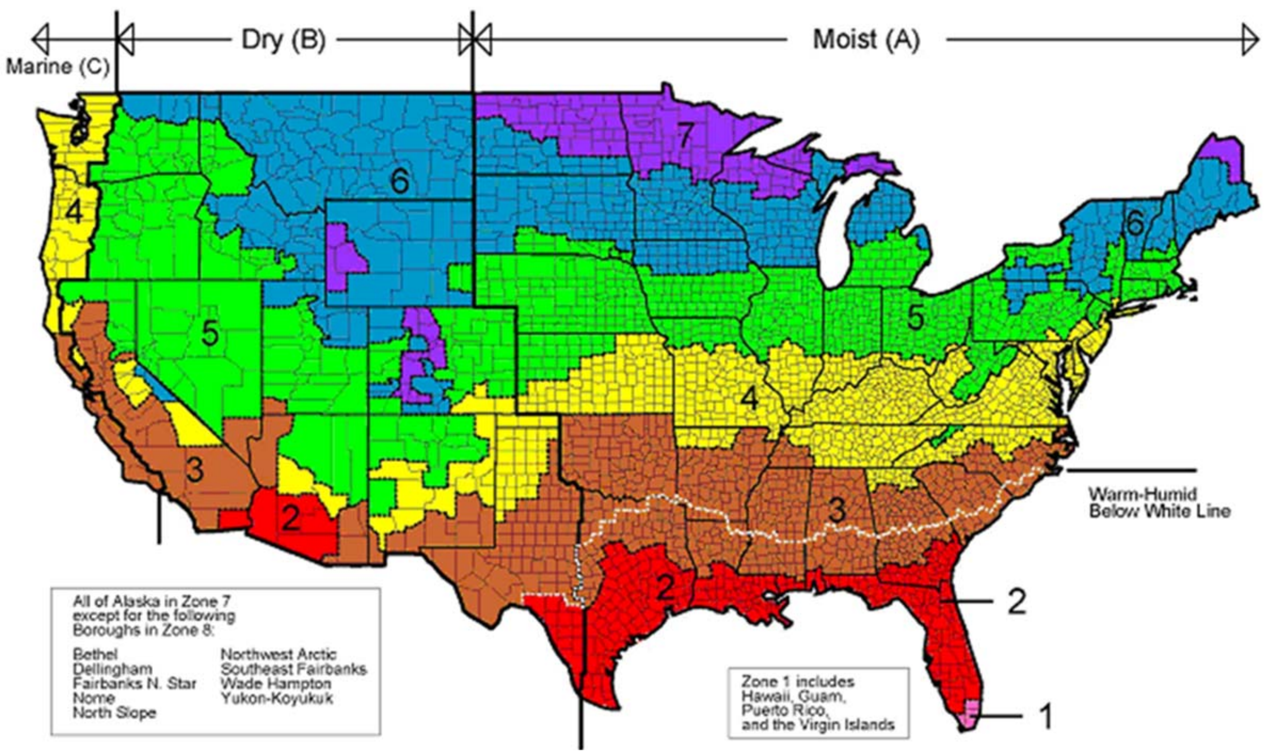


Figure 2.1. Climate Zone Map (Briggs et al. 2003)

The 15 climate locations representing the climate zones are:

- 1A: Miami, Florida (very hot, humid)
- 2A: Houston, Texas (hot, humid)
- 2B: Phoenix, Arizona (hot, dry)
- 3A: Memphis, Tennessee (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Francisco, California (warm, marine)
- 4A: Baltimore, Maryland (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Salem, Oregon (mixed, marine)
- 5A: Chicago, Illinois (cool, humid)
- 5B: Boise, Idaho (cool, dry)
- 6A: Burlington, Vermont (cold, humid)
- 6B: Helena, Montana (cold, dry)
- 7: Duluth, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

2.3 Comparison Metrics and Construction Weights

Annual electricity and natural gas energy use in each building prototype was simulated across 240 buildings, a combination of 16 prototypes in all 15 U.S. climate zones. This simulated energy use is utility electricity and natural gas delivered and used at the building site. The site energy use was converted to site energy use intensity (site EUI, or energy use per unit floor area).

To estimate the energy cost, PNNL used annual national average commercial building energy prices of $0.1029/kWh of electricity and $8.17 per 1000 cubic feet ($0.796/therm) of natural gas. These prices were available from the Energy Information Administration (EIA) and are listed in Table 2, "U.S. Energy Prices," of the February 2014 Short Term Energy Outlook for commercial sector natural gas and electricity[1]. The same set of prices was used for all prototypes and in all climate zones. The annual energy costs for each building were calculated for each fuel type (electricity and natural gas) by using the energy prices for all buildings. These costs were converted to energy cost index (ECI, or energy cost per unit floor area) for each building.

The EUI and ECI results of each building are weighted by construction volume for each building prototype and climate zone to calculate the national weighted average EUI and ECI. Weighting factors developed by building type and climate-related geographic areas in the United States were derived from 5 years of recent construction data (Jarnagin and Bandyopadhyay 2010). Table 2.2 lists the weighting factors assigned to each prototype in all 15 U.S. climate zones.

[1] EIA Short Term Energy Outlook available at http://www.eia.gov/forecasts/steo/report/.

Table 2.2. Construction Area Weights by Building Prototype and Climate Zone (Jarnagin and Bandyopadhyay 2010)

	1A (%)	2A (%)	2B (%)	3A (%)	3B (%)	3C (%)	4A (%)	4B (%)	4C (%)	5A (%)	5B (%)	6A (%)	6B (%)	7 (%)	8 (%)	Weights by Building Type (%)
Small Office	0.084	1.064	0.289	0.963	0.475	0.078	0.936	0.047	0.123	0.920	0.322	0.241	0.030	0.032	0.005	5.608
Medium Office	0.129	0.813	0.292	0.766	0.715	0.136	1.190	0.036	0.196	1.060	0.342	0.298	0.035	0.033	0.007	6.047
Large Office	0.102	0.326	0.061	0.445	0.285	0.117	1.132	0.000	0.154	0.442	0.121	0.133	0.000	0.011	0.000	3.327
Standalone Retail	0.224	2.220	0.507	2.386	1.250	0.191	2.545	0.119	0.428	3.429	0.792	0.948	0.091	0.109	0.014	15.254
Strip Mall	0.137	0.991	0.254	1.021	0.626	0.103	1.008	0.023	0.107	1.023	0.201	0.153	0.016	0.007	0.001	5.669
Primary School	0.064	0.933	0.164	0.944	0.446	0.048	0.895	0.030	0.094	0.920	0.224	0.168	0.037	0.023	0.003	4.994
Secondary School	0.160	1.523	0.230	1.893	0.819	0.109	2.013	0.063	0.243	2.282	0.438	0.415	0.086	0.075	0.012	10.361
Outpatient Healthcare	0.037	0.567	0.134	0.581	0.275	0.061	0.818	0.023	0.181	1.058	0.218	0.342	0.033	0.039	0.002	4.371
Hospital	0.040	0.479	0.096	0.468	0.273	0.039	0.615	0.022	0.106	0.812	0.218	0.221	0.024	0.034	0.001	3.448
Small Hotel	0.010	0.288	0.030	0.268	0.114	0.022	0.315	0.020	0.039	0.365	0.089	0.107	0.031	0.020	0.004	1.721
Large Hotel	0.109	0.621	0.125	0.635	0.793	0.106	0.958	0.037	0.123	0.919	0.200	0.227	0.058	0.038	0.004	4.951
Warehouse	0.349	2.590	0.580	2.966	2.298	0.154	2.446	0.068	0.435	3.580	0.688	0.466	0.049	0.043	0.002	16.716
Quick-Service Restaurant	0.008	0.092	0.020	0.102	0.063	0.007	0.089	0.005	0.014	0.128	0.026	0.025	0.003	0.004	0.000	0.587
Full-Service Restaurant	0.009	0.106	0.025	0.111	0.047	0.006	0.127	0.006	0.010	0.143	0.031	0.031	0.004	0.004	0.000	0.660
Mid-Rise Apartment	0.257	1.094	0.093	0.825	0.862	0.260	1.694	0.022	0.371	1.122	0.318	0.313	0.056	0.032	0.000	7.321
High-Rise Apartment	1.521	1.512	0.076	0.652	0.741	0.173	2.506	0.000	0.358	1.163	0.115	0.125	0.016	0.008	0.000	8.967
Weights by Climate Zone	**3.242**	**15.217**	**2.975**	**15.025**	**10.081**	**1.609**	**19.286**	**0.522**	**2.981**	**19.366**	**4.344**	**4.214**	**0.569**	**0.513**	**0.056**	**100**

2.4 Enhancements to the 2012 IECC Building Prototypes

The 2012 IECC prototypes from the *Analysis of the 2012 IECC* served as a starting point for developing the 2015 IECC prototypes. In this analysis, PNNL made enhancements to the 2012 IECC prototypes for several reasons. The major ones, grouped by reason, include:

1) Improvements to simulation accuracy
   a. added multilevel automatic daylighting control to the multipurpose room in Primary School;
   b. revised modeling strategy for demand control ventilation in Primary School and Secondary School;
   c. revised modeling inputs for pipe heat loss of service water heating (SWH) for all prototypes;

2) Simulation infrastructure updates
   a. updated simulation models of the prototypes from DOE *EnergyPlus Version 6.0* to *8.0*;
   b. updated the weather files from typical meteorological year (TMY) 2 to TMY3;

3) Enhancements to provide more detail to capture new requirements
   a. added additional infiltration loads to selected guestrooms in Small Hotel and Large Hotel to reflect balcony door opening;
   b. revised thermostat setpoints during the morning warmup hours for heating, ventilation, and air-conditioning (HVAC) systems in Small Office, Large Office, Primary School, Secondary School, Quick-Service Restaurant, Full-Service Restaurant, Mid-Rise Apartment, and High-Rise Apartment;
   c. revised part-load curves of boilers in Large Office, Primary School, Secondary School, Outpatient Healthcare, Hospital, and High-Rise Apartment;
   d. added plug-in lights to Mid-Rise and High-Rise Apartments; and
   e. added retail display lighting allowance for Strip Mall.

In addition, there are code changes in the 2015 IECC which reflect changes to DOE's Appliance and Commercial Equipment Standards for HVAC, SWH, and refrigeration equipment[1]. These standards were previously developed by DOE or enacted independently through federal legislation. Because the energy savings attributable to these would accrue no matter what edition of the IECC is complied with, they were not considered as code changes contributing to energy savings in this analysis. Therefore, PNNL updated the efficiency of the affected products in the 2012 IECC prototypes to match requirements in the 2015 IECC as follows:

- refrigerators, freezers, and walk-in coolers and freezers in Primary School, Secondary School, Hospital, Large Hotel, Quick-Service Restaurant, and Full-Service Restaurant; and
- gas-fired boiler with capacity under 300,000 British thermal unit(s) per hour (Btu/h) in Outpatient Healthcare.

[1] Energy efficiency standards for appliances and equipment established by DOE are available at the http://energy.gov/eere/buildings/appliance-and-equipment-standards-program

Table 2.3 shows the site EUI for the 2012 IECC before and after the enhancements were made to the prototypes. Although these enhancements show different levels of impacts on the results on a prototype - by- prototype basis, the impacts on the national weighted average site EUI is small, from 62.1 to 61.4 thousand British thermal units per square foot per year (kBtu/ft^2-yr).

Table 2.3. Site EUI of the 2012 IECC Before and After Enhancements

Building Type	Building Prototype	Floor Area Weight %	Site EUI (kBtu/ft^2-yr) Pre-Enhancements	Site EUI (kBtu/ft^2-yr) Post-Enhancements
Office	Small Office	5.6	30.5	31.1
	Medium Office	6.0	36.2	35.5
	Large Office	3.3	77.7	76.2
Retail	Standalone Retail	15.3	53.8	54.1
	Strip Mall	5.7	55.8	58.3
Education	Primary School	5.0	63.3	62.3
	Secondary School	10.4	51.2	51.8
Healthcare	Outpatient Healthcare	4.4	147.9	137.2
	Hospital	3.4	173.4	172.2
Lodging	Small Hotel	1.7	66.2	66.4
	Large Hotel	5.0	109.3	109.5
Warehouse	Warehouse	16.7	15.6	15.0
Food Service	Quick-Service Restaurant	0.6	609.5	602.5
	Full-Service Restaurant	0.7	412.2	405.6
Apartment	Mid-Rise Apartment	7.3	44.6	45.0
	High-Rise Apartment	9.0	51.5	49.1
National Weighted Average		**100**	**62.1**	**61.4**

3.0 2015 IECC Building Prototype Development

The starting point for the 2015 prototypes was the enhanced versions of the 2012 prototypes as described in the preceding section. In this section, PNNL compares code changes in commercial energy efficiency provisions between the 2012 and 2015 IECC and documents how they were implemented in the 2015 IECC prototypes and modeled in *EnergyPlus*. Where an implementation approach is similar to one described in previous PNNL reports (e.g., Thornton et al. 2011, Zhang et al. 2013, Goel et al. 2014, and Halverson et al. 2014), reference is made to these reports rather than reproducing the text here.

3.1 Review of Code Changes

Chapter 4 Commercial Energy Efficiency of the IECC provides three alternative paths for a new building to show compliance: (1) the mandatory and prescriptive requirements in the IECC; (2) the mandatory and total building performance requirements in the IECC; or (3) the requirements in the referenced Standard 90.1. This analysis looks only at compliance path (1), comparing the energy performance of the 2012 requirements relative to the 2015 requirements.

PNNL classified code changes into three categories, including 1) clarify requirements without changing their efficiency; 2) result in energy efficiency impacts but cannot be quantified using the building prototypes; and 3) result in energy efficiency impacts that can be quantified. Only those in the third category (see Appendix A) were incorporated into the 2015 IECC building prototypes. The most common reason why a change in the second category was not implemented was that the class of equipment or the particular requirements impacted by the change were not represented in the building prototypes. Other reasons were if *EnergyPlus* was not able to simulate the change or the change applied only to existing buildings instead of new buildings.

3.2 Building Envelope

Section C402 of the 2012 and 2015 IECC specifies requirements for building thermal envelope performance. The code as it relates to the envelope was modified in three areas: opaque envelope performance, fenestration area, and continuous air barrier. Because the fenestration area requirements are related to code changes for daylight responsive controls, these changes are discussed in Section 3.5.3 of this report.

3.2.1 Opaque Envelope Performance

Table C402.1.2 in the 2012 IECC becomes Table C402.1.4 in the 2015 IECC. This table lists opaque thermal envelope assembly requirements using U-factor, C-factor and F-factor-based method. The code changes in the U-factor requirements for roof (insulation entirely above deck type) and exterior wall (mass wall type) are applicable to all building prototypes, except for Small Office, Quick-Service Restaurant, and Full-Service Restaurant. PNNL calculated the R-value of the insulation layer in the wall or roof construction assembly in a prototype by using the changed U-factor requirements. PNNL implemented this R-value in the simulation models of the 2015 IECC prototypes.

3.2.2 Continuous Air Barrier

Section C402.4 of the 2012 IECC addresses the air leakage requirements. A continuous air barrier (CAB) is needed throughout the building envelope except for buildings in climate zones 1 through 3. Three compliance options are provided: (1) materials, (2) assemblies, and (3) whole building air leakage test. In this study, PNNL assumed a prototype has an air leakage rate of 1.8 cfm/ft^2 of exterior wall under a pressure differential of 0.30 in. water column (w.c.) if it is exempted from the CAB requirement. We assumed a rate of 1.0 cfm/ft^2 when the CAB requirement applied. These values were derived in previous analysis (see Section 5.2.1.1 of Thornton et al 2011).

The 2015 IECC (Section C402.5) only allows climate zone 2B to be exempted from the CAB requirement. To implement the code change, PNNL extended CAB to the 2015 IECC prototypes in climate zones 1A, 2A, 3A, 3B, and 3C by using an air leakage rate of 1.0 cfm/ft^2.

3.3 Building Mechanical Systems

Section C403 of the 2012 and 2015 IECC specifies requirements for building mechanical systems. There are several code changes to the Section C403, such as changes to minimum equipment efficiency, controls of HVAC equipment, and extension of the scope to cover more equipment types. Because the building prototypes only cover limited types of equipment and systems with certain capacity ranges, this analysis only estimates the code changes that are applicable to the prototypes.

3.3.1 Heating, Ventilating, and Air-Conditioning Equipment Performance Requirements

Section C403.2.3 of the 2012 IECC specifies minimum efficiency requirements for various HVAC equipment types. The requirements for the following types of equipment were changed from the 2012 to 2015 IECC:

- air-cooled unitary air conditioners (single package, size category of <65 thousand British thermal units per hour, or kBtu/h),
- air-cooled unitary heat pumps (single package, both heating and cooling modes, size category of <65 kBtu/h),
- water-to-air water loop heat pumps (cooling mode, size categories of <17 kBtu/h, 17-65 kBtu/h, and 65-135 kBtu/h),
- water-to-air water loop heat pumps (heating mode, size category of <135 kBtu/h),
- packaged terminal air conditioners (all sizes),
- hot water boilers (gas-fired, size category of <300 kBtu/h),
- air-cooled chillers (all sizes),
- water-cooled chillers (all sizes), and
- axial fan for open-circuit cooling tower (all sizes).

The changed efficiency was modeled in the 2015 IECC prototypes using the same methodology as in the 2012 IECC prototypes. Required equipment efficiency is based on equipment capacity that was calculated for each prototype at each climate zone using a design day sizing simulation in *EnergyPlus*. PNNL used this capacity to identify the required efficiency in the IECC and then ran an annual simulation using this efficiency. When efficiency values vary by effective dates in the IECC, PNNL used the values with latest dates. For example, Table C403.2.3(1) in the 2015 IECC lists single package air-cooled air conditioners under 65,000 Btu/h to have a minimum efficiency of 13 seasonal energy efficiency ratio (SEER) before January 1, 2016, and 14 SEER as of January 1, 2016. Efficiency of 14 SEER was used in this analysis.

While there is an increase in efficiency requirements for gas-fired hot water boilers with capacity less than 300 kBtu/h from the 2012 to 2015 IECC, this reflects the minimum federally mandated equipment efficiency for this type of boilers. Therefore, the higher boiler efficiency listed in the 2015 IECC was applied to both the 2012 and 2015 IECC building prototypes. Only Outpatient Healthcare has boilers smaller than 300,000 Btu/h.

3.3.2 Hot Water Boiler Outdoor Temperature Setback Control

Section C403.2.5 of the 2015 IECC introduces a new requirement that hot water boilers shall have a control that can automatically lower the boiler water temperature setpoint based on the outdoor air temperature. Section C403.4.2.4 of the 2012 IECC requires that hydronic heating systems have either a temperature reset control or variable flow.

Six building prototypes, i.e., Large Office, Secondary School, Outpatient Healthcare, Hospital, Large Hotel, and High-Rise Apartment, use hot water boilers for heating. Because the 2012 IECC buildings all use variable flow hydronic heating systems, temperature reset control was not implemented.

For the 2015 IECC, PNNL applied outdoor temperature setback control to Large Office, Secondary School, Outpatient Healthcare, Hospital, and Large Hotel. The implemented control is that boiler temperature setpoint is

- equal to the design supply temperature if the outdoor temperature is below 20°F,
- reset by 25% of the design supply-to-return water temperature difference if the outdoor temperature is above 50°F, and
- reset to a value that is linearly interpolated between the two setpoint temperatures above if the outdoor temperature is between 20°F and 50°F.

High-Rise Apartment uses a closed-loop water source heat pump (WSHP) system to provide both heating and cooling to the space. The recirculated water in WSHP serves as heating and cooling source for the water-to-air heat pump in each zone. The water temperature is maintained between two setpoints: 68°F and 86°F by a central fluid cooler and a central boiler. No central heating or cooling is needed if the temperature is within this range. Even when the water temperature is at the lower setpoint of 68°F, the water could serve as both heating and cooling sources for different zones at the same time. Therefore, resetting the setpoint from 68°F to a lower value is not desired. As such, PNNL did not implement this control requirement to High-Rise Apartment for the 2015 IECC. An exception to this hot water boiler outdoor temperature setback control requirement may be added for WSHP systems in the future edition of the IECC.

3.3.3 Energy Recovery Ventilator

Section C403.2.6 of the 2012 IECC specifies the energy recovery ventilator (ERV) requirements by climate zone for different outdoor air fraction and design supply fan size thresholds. These requirements are for systems with outdoor air fractions above 30%. The changes from the 2012 to 2015 IECC, in Table C403.2.7(1) in Section C403.2.7, reduced the fraction threshold to 10% in climate zones 1A, 2A, 3A, 4A, 5A, 6A, 6B, 7, and 8. Additionally, the requirements for climate zones 3B, 3C, 4B, 4C, and 5B for systems with the outdoor air fraction above 70% were removed from the 2012 to 2015 IECC. Finally, Table C403.2.7(2) in the 2015 IECC adds a new set of requirements for ventilation systems operating more than 8,000 hours per year.

Based on the HVAC system sizing information from the *EnergyPlus* design day simulation, each air handling unit (AHU) of the building prototypes in each climate zone was checked to determine whether an ERV should be required by the 2015 IECC. Hospital and Large Hotel are assumed to operate more than 8,000 hours per year. This code change was implemented in Medium Office, Large Office, Standalone Retail, Strip Mall, Primary School, Secondary School, Outpatient Healthcare, Hospital, and Large Hotel.

AHUs in Mid-Rise Apartment, High-Rise Apartment, and Small Hotel in certain climate zones meet the trigger for the ERV requirements in the 2015 IECC. However, ERVs were not added to these prototypes because ERV products are usually not available for those small AHUs. An exception to this ERV requirement may be added in the future edition of the IECC for systems with very low outdoor air intake.

3.3.4 Kitchen Exhaust Systems

The 2012 IECC does not have requirements for kitchen exhaust hoods and kitchen ventilation systems. Baseline assumptions were made in previous analysis (Zhang et al. 2013) for kitchens in Primary School, Secondary School, Quick-Service Restaurant, Full-Service Restaurant, Large Hotel, and Hospital based on engineering judgment and a review of actual kitchen designs for these building types.

The 2015 IECC introduces new requirements for all kitchen exhaust systems, as listed in Section C403.2.8. The requirements that were implemented to the 2015 IECC prototypes are:

- All available transfer air from adjacent spaces shall be used before any other makeup air is introduced to the kitchen for any size hood.
- All hoods shall meet maximum net exhaust flow rate requirements listed in Table C403.2.8 if the total kitchen exhaust airflow rate in the kitchen/dining facility is greater than 5,000 cfm.
- Kitchen/dining facilities with total kitchen hood exhaust airflow rate larger than 5,000 cfm shall meet one of three options: (a) at least 50% of replacement air from transfer air; (b) cooking-load-based demand control ventilation; and (c) energy recovery devices on exhaust airflow.

Changes to building prototypes for the 2015 IECC include the use of transfer air, reduction of exhaust airflow rate, and the use of demand control ventilation. These changes vary by prototype and by climate zone.

3.3.5 Fan Power Limitation Adjustment Credits

The 2012 IECC specifies maximum allowable fan power limits for HVAC systems at their fan system design conditions. Depending on the devices used in the systems, which affect the system air pressure drop, the IECC allows adjustments (credits) to the allowable limits using Table C403.2.10.1(2).

The 2015 IECC adds new adjustment items (deductions) to the table, Table C403.2.12.1(2). With this code change, systems without a central cooling coil are required to deduct 0.6 in. w.c. from their fan power limits. Systems without a central heating coil are required to deduct 0.3 in. w.c. Finally, systems with a central electric resistance heating element are required to deduct 0.2 in. w.c.

All building prototypes have central cooling coils but none has central electric resistance coils. Therefore, the code changes only affect those without central heating coils. All single-zone HVAC systems in the building prototypes need central heating coils. Hospital, Large Hotel, Large Office, Medium Office, Outpatient Healthcare, Primary School, and Secondary School have multiple-zone variable air volume (VAV) systems. A central heating coil in a VAV system serves to heat the mixed return and outdoor ventilation air from a mixed air temperature (MAT) to a supply air temperature (SAT) setpoint of 55°F. If the MATs never drop below 55°F, the VAV system does not need a central heating coil.

To determine the systems that must take the deduction to their fan power limits, PNNL calculated the lowest MAT for each prototype in each climate zone by using their heating design outdoor air temperature, return air temperature, and design outdoor air fraction. For those systems with the calculated lowest MATs higher or equal to 55°F, PNNL reduced their fan power limits by 0.3 in. w.c. in the 2015 IECC prototypes.

3.3.6 Reach-in Refrigerator and Freezer

The 2012 IECC does not prescribe requirements for commercial refrigerators and freezers. The 2015 IECC expands the scope of the code to add requirements for such equipment in Section C403.2.14. These new requirements reflect changes to national manufacturing standards per 10 Code of Federal Regulations (CFR) part 431, which went into effect on January 1, 2012. Because the energy savings that are attributable to these national manufacturing standards would accrue no matter what edition of the IECC is used, PNNL applied the same efficiency requirements in the 2015 IECC to both the 2012 and 2015 IECC building prototypes.

PNNL assumed that solid-door commercial refrigerators and freezers are used in the kitchens of Quick-Service Restaurant, Full-Service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. Table 3.1 shows the sizes and numbers of commercial freezers and refrigerators in the building prototypes. The efficiency requirements, in kWh/day, were modelled as a plug load with a constant operation schedule in *EnergyPlus*. Table 3.2 shows the energy use limits used to calculate the input power of commercial refrigerators and freezers for both the 2012 and 2015 IECC.

Table 3.1. Commercial Solid-Door Refrigerators and Freezers in Prototypes

Building Prototype	Number of Freezers (typical volume V=24 ft^3)	Number of Refrigerators (typical volume V=48 ft^3)
Quick-Service Restaurant	1	2
Full-Service Restaurant	1	2
Hospital	2	3
Large Hotel	1	1
Primary School	2	2
Secondary School	2	2

Table 3.2. The 2015 IECC Requirements for Commercial Refrigerators and Freezers in Prototypes

Equipment	Energy Use Limits (kWh/day)
Reach-in refrigerators with solid doors	0.10V + 2.04
Reach-in freezers with solid doors	0.40V + 1.38

3.3.7 Manufactured Walk-in Cooler and Freezer

The 2012 IECC does not have any requirements for walk-in coolers and freezers. The 2015 IECC expands the scope of the code to add requirements for such equipment as defined in Section C403.2.15. The new requirements have been defined and legislated as the national manufacturing standard and described in 10 CFR 431.306. The requirements are for cover doors, insulation, evaporator fan motor, lighting, anti-sweat heater, condenser fan motor, and their controls.

The code change affects six building prototypes with commercial kitchens: Quick-Service Restaurant, Full-Service Restaurant, Hospital, Large Hotel, Primary School, and Secondary School. PNNL assumed that the walk-in coolers and freezers in these prototypes are manufactured as opposed to site-assembled or site-constructed. We also assumed them to be packaged equipment without remote compressors and condensers.

Navigant (2009) developed characteristics of baseline walk-in coolers and freezers, which show typical efficiency levels of the equipment before the new manufacturing standard. PNNL found that these characteristics either meet or exceed most requirements in the 2015 IECC, except for the evaporator fan motor and the lighting requirements. To capture these new requirements, the evaporator fan motors in the prototypes were assumed to be electronically commutated (EC) motors with an average motor efficiency of 70%, which was determined by surveying typical efficiencies listed in manufacturer catalogs. The efficiency was modelled as the fan power inputs in *EnergyPlus* models of the prototypes. The impact of the lighting control requirement was modeled as a 10% reduction in the hourly lighting schedule from the baseline models. This simulates the energy saving benefits from an occupancy-sensor-based lighting control. Because the energy savings that are attributable to the national manufacturing standards would accrue no matter what edition of the IECC is used, PNNL applied the same efficiency requirements to both the 2012 and 2015 IECC building prototypes.

3.3.8 Economizer

There are several changes to the economizer requirements from the 2012 (Section C403.3.1 and C403.4.1) to 2015 IECC (Section C403.3) including capacity threshold increase, water economizer requirements, and combined requirements for simple and complex systems (previously separate in the 2012 IECC). This section describes the implementation for capacity threshold increase; Sections 3.3.9 and 3.3.10 discuss other code changes related to economizers in the prototypes.

To capture the energy impacts of the increased thresholds, first, a sizing simulation was conducted for each prototype with air economizers disabled in *EnergyPlus* to determine the cooling capacity of each direct expansion (DX) coil in the prototype. Second, the prototype was modified to enable the air economizer if the capacity exceeded the thresholds in the IECC. If the capacity was below the thresholds, the economizer remained disabled. This two-step procedure was followed for both the 2012 and 2015 IECC prototypes, and the differences between them are the thresholds shown in Table 3.3.

Table 3.3. Economizer Requirements by Cooling Capacity Thresholds and Climate Zones

Cooling Capacity Threshold (Btu/hr)	2012 IECC (climate zone)	2015 IECC (climate zone)
No requirement	1A, 1B	1A, 1B
>=33,000	2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8	
>=54,000		2A, 2B, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7, 8

3.3.9 Staged Cooling

Section C403.3.1 in the 2015 IECC introduces a new staged cooling requirement for DX units, which is not contained in the 2012 IECC. According to item 3 under Section C403.3.1, for DX units that control 75,000 Btu/h or greater of rated capacity directly based on occupied space temperature (usually serving a single zone), a minimum of two stages of mechanical cooling capacity are required. Another related new code requirement (see Section 3.3.10 of this report) in Table C403.4.1.1 of the 2015 IECC requires a two-stage fan control for DX units with cooling capacity over 65,000 Btu/h (after January 1, 2016). In practice, a DX unit would either have both staged cooling and staged fan controls together or neither of them. For this reason, PNNL used 65,000 Btu/h as the threshold for the staged cooling requirement instead of 75,000 Btu/h.

Eight building prototypes use packaged single-zone DX cooling units: Standalone Retail, Strip Mall, Quick-Service Restaurant, Full-Service Restaurant, Primary School, Secondary School, Small Hotel, and Warehouse. For the 2012 IECC, these prototypes all use single-stage cooling control. For the 2015 IECC, except for the single-zone units in Small Hotel and Warehouse, the cooling capacities of DX units found in the prototypes are larger than 65,000 Btu/h in most climate zones; therefore, they were modelled with two-stage cooling. For units required to have two-stage cooling, the low-stage capacity was assigned to be half of the full capacity.

Improved economizer integration is a source of energy savings from the new staged cooling requirement in the 2015 IECC. When two-stage cooling and air economizer controls are both required in a 2015 IECC building prototype, economizer operation was modeled to represent increased economizer effectiveness. The fraction of time spent by the system in each mode—full economizer, partial economizer, and full mechanical cooling—was used to calculate an average economizer effectiveness for a given time step. PNNL adjusted the economizer effectiveness by changing the maximum outside air schedule that controls the amount of outside air available at a simulation time step. PNNL implemented this modeling strategy using the *EnergyPlus* energy management system (EMS) feature. The implementation is described in more detail in Section 5.2.2.6 of the PNNL report (Halverson et al. 2014).

3.3.10 Fan Airflow Control

Fan airflow control is another new requirement introduced in the 2015 IECC. Section C403.4.1.1 and Table C403.4.1.1 require two stages of fan control for DX units (capacity larger than 65,000 Btu/h) that control cooling capacity directly based on space temperature (usually serving a single zone). The requirement states that low or minimum fan speed shall not be greater than 66% of full speed. Section C403.4.1.1 of the 2015 IECC also requires that units with air economizers shall have a minimum of two speeds of fan control during economizer operation.

Six building prototypes, i.e., Standalone Retail, Strip Mall, Quick-Service Restaurant, Full-Service Restaurant, Primary School, and Secondary School, qualify for this requirement because they have packaged single-zone DX cooling units with capacity larger than 65,000 Btu/h. The requirements in the 2015 IECC are identical to those in Standard 90.1-2013 and their implementation in the prototype models has been described in a previous analysis (Halverson et al. 2014). The same modeling strategy applies to the 2012 and 2015 IECC models.

3.3.11 Part-load Controls for Hydronic Systems

Section C403.4.3.4 in the 2012 IECC requires hydronic heating and cooling systems with capacity over 300,000 Btu/h to include either supply-water temperature reset or variable flow controls. The 2015 IECC (Section C403.4.2.4) changes the capacity threshold to 500,000 Btu/h. Additionally, the code is changed from requiring one of these two controls to requiring both of them, plus a variable (or stepped) pumping control.

Six building prototypes, i.e., Large Office, Secondary School, Outpatient Healthcare, Hospital, Large Hotel, and High-Rise Apartment, have variable flow hydronic heating systems with variable flow pumps. Based on engineering judgment, PNNL assumed this type of system to be typical design in these prototypes no matter what edition of the IECC is used.

Four building prototypes, Large Office, Hospital, Secondary School, and Large Hotel, have primary-secondary variable-flow chilled water systems with variable-flow secondary pumps. Based on engineering judgment, PNNL assumed this type of system to be a typical design. Therefore, these prototypes meet the part-load control requirements for hydronic heating and cooling systems in the 2012 IECC.

For the 2015 IECC, the hydronic heating systems in the six prototypes already have the variable flow, variable pumping, and supply-water temperature reset (described in Section 3.3.2). As such, they meet the requirements in 2015 IECC already. For the hydronic cooling systems in the four prototypes, PNNL implemented supply-water temperature setpoint reset using the following reset rule, the setpoint is:

- the design supply temperature if the outdoor temperature is below 80°F,
- reset by 25% of the design supply-to-return water temperature difference if the outdoor temperature is above 60°F, and
- linearly interpolated between the two setpoint temperatures above if the outdoor temperature is between 60°F and 80°F.

The capacities of all hydronic systems in the building prototypes exceed the increased threshold of 500,000 Btu/h in the 2015 IECC. Therefore, the impact of the threshold change was not captured in the simulations.

3.3.12 Boiler Turndown

Section C403.4.2.5 in the 2015 IECC adds a boiler turndown requirement, which does not exist in the 2012 IECC. The new section requires that boiler systems with design input of 1,000,000 Btu/h or more comply with different turndown ratios, as shown in Table 3.4, using multiple single input boilers, one or more modulating boilers, or a combination of single input and modulating boilers.

Table 3.4. Boiler Turndown in Table C403.4.2.5 of the 2015 IECC

Boiler System Design Input (Btu/h)	Minimum Turndown Ratio
≥ 1,000,000 and less than or equal to 5,000,000	3 to 1
> 5,000,000 and less than or equal to 10,000,000	4 to 1
> 10,000,000	5 to 1

The following building prototypes use boilers that may be affected by the turndown requirements: Large Office, Hospital, Primary School, Secondary School, Large Hotel, High-Rise Apartment, and Outpatient Healthcare. PNNL assumed single-stage capacity control to be typical design in the 2012 IECC building prototypes based on a review of the certified boilers in the American Heating and Refrigeration Institute (AHRI) directory[1]. For the 2015 IECC, PNNL assumed that the prototypes would use modulating boiler capacity control, one of the three compliance options required by the 2015 IECC, if the building's system capacity was greater than 1,000,000 Btu/h.

EnergyPlus models boiler's part-load performance with a part-load efficiency (through a part-load curve as function of part load ratio (PLR)), which describes the normalized heating efficiency (as a fraction of nominal thermal efficiency) of the boiler's burner. PNNL modelled all boilers in the 2012 IECC prototypes using the curve described in Equation 3-1. For the 2015 IECC, PNNL applied Equation 3-1 curve to boilers with input capacity ≤1,000,000 Btu/h and Equation 3-2 curve to those with input

[1] AHRI's Directory of Certified Product Performance database. Last accessed in May 2013 at http://www.ahridirectory.org/ahridirectory/pages/cblr/defaultSearch.aspx

capacity >1,000,000 Btu/h. These curves are based on research by Bertagnolio and Andre (2010). Although these curves were only developed for PLR in the range of minimum turn down load and full load, *EnergyPlus* could allow a boiler to work at a PLR below the range. PNNL implemented an *EnergyPlus* EMS algorithm in the simulation models to adjust curve outputs when the PLR was lower than the range.

$$Curve_{\text{single-stage control}} = 0.907 + 0.320 * PLR - 0.420 * PLR^2 + 0.193 * PLR^3 \quad (3\text{-}1)$$

$$Curve_{\text{modulating control}} = 0.975+0.305 * PLR-0.527 * PLR^2+0.249 * PLR^3 \quad (3\text{-}2)$$

3.3.13 Heat Rejection Equipment

The 2015 IECC includes two major changes for heat rejection as compared to the 2012 IECC: fan control for multi-cell heat rejection equipment (Section C403.4.3.2.2) and open-circuit cooling tower fan flow turndown (Section C403.4.3.2.1). The second change also requires that the maximum number of fans to operate in multi-cell heat rejection equipment to minimize energy. It is more energy efficient to operate all fans in tandem at the same (lower) fan speed than to have an on/off or sequenced fan operation (operating a select number of cells at full speed to meet load). Using more cells also increases heat transfer area and more heat can be rejected with less airflow and fan speed.

Large Office and Hospital use open-circuit cooling towers. Each prototype has two variable-speed cooling towers. Each tower has one dedicated condenser water pump and two cells. Because the two cooling towers are equally sized, the two condenser water pumps have the same design flow rate. In the 2012 IECC building prototypes, the number of operating cooling towers and condenser water pumps corresponds to the number of operating chillers. When one chiller operates, one cooling tower operates and the corresponding condenser water pump operates. When both chillers are running, both cooling towers and both condenser water pumps are running.

The 2015 IECC requires that the maximum number of fans operate to minimize fan energy. This means that when one chiller is running, all four cell fans in the two cooling towers will be operating unless the fan in one cooling tower already runs at its minimum speed. Running two towers implies that the condenser water flow will be reduced by 50% for each cell in comparison with running one tower.

The strategy for modeling the cooling tower control requirements in the 2015 IECC includes the following:

- Change the cell control strategy for variable-speed cooling towers in *EnergyPlus* from “minimum cells” to “maximum cells.”
- For each time step, find the number of operating chillers.
- If one chiller is running and the current airflow ratio is greater than the minimum, run the two towers in parallel. Use the *EnergyPlus* EMS to halve the airflow ratio, which is then used to calculate the fan power according to the cubic power law. The EMS control is necessary because the *EnergyPlus* native control algorithms cannot run both towers in parallel while delivering the condenser water flow for just one chiller if there are two chillers in the plant.
- If two chillers are running or the current airflow is at the minimum when one chiller is running, the EMS algorithm will not override the tower fan curve input and output.

3.3.14 VAV Reheat Control

Section 403.4.5 in the 2012 IECC specifies requirements for zone airflow under multiple zone VAV systems. Thirty percent (30%) of the maximum supply air to each zone is required as the minimum zone supply airflow to reduce VAV reheat at the zone terminals. The 2015 IECC (Section C403.4.4) adds a new exception (item 4) to the 30% minimum; it states that a rate higher than 30% is allowed if it can be demonstrated to reduce overall system annual energy use by offsetting reheat/recool energy losses through a reduction in outdoor air intake for the system. Standard 90.1-2013 has a similar exception and PNNL has established a modeling strategy to determine the minimum zone supply airflow to meet this requirement. The calculation procedure includes four steps: (1) calculate zone ventilation efficiency; (2) calculate system ventilation efficiency; (3) increase the minimum damper fraction (i.e., ratio of minimum to maximum zone supply airflow) from 30% to a new value based on a target value of system ventilation efficiency; and (4) calculate the system design outdoor air intake.

In the 2012 IECC prototypes, only Steps 1, 2, and 4 were applied. For the 2015 IECC, all four steps were followed, which resulted in different minimum damper fractions and system design outdoor airflow rates from those in the 2012 IECC prototypes. The implementation of the four-step methodology is described in detail in Section 5.2.2.21 of Thornton et al. (2011) and Section 2.2.6 of Goel et al. (2014). All prototypes with multiple-zone VAV systems are affected by the code change related to VAV reheat control (i.e., Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, and Hospital).

3.3.15 VAV System for Critical Area in Healthcare Facility

Section C403.4.5 in the 2012 IECC includes Exception (1) to the VAV system requirement for supply air systems serving multiple zones. This exception is for “zones where special pressurization relationships or cross-contamination requirements are such that VAV systems are impractical”. This exception allows designers to use constant volume reheat systems in critical areas of hospitals and similar spaces needing pressure differentials with adjacent areas.

The exception for the VAV requirement is removed in the 2015 IECC (Section C403.4.4). Instead, the 2015 IECC adds an allowance to the airflow rate that can be reheated to achieve reasonable energy savings in these types of spaces, while not compromising health and safety. A new compliance option is to reduce the zone primary air supply to “the airflow rate required to comply with applicable codes or accreditation standards, such as pressure relationships or minimum air change rates”. The code changes mean that if the peak design airflow to any of these spaces is greater than the required minimum air change rate or the minimum rate required maintaining pressure differentials, the system must use VAV, reducing airflow as much as possible before reheat is allowed. Also, if the minimum air change rate is only required during occupied periods (as in operating rooms), the airflow must be reduced during those unoccupied periods before reheat is allowed.

The Hospital and Outpatient Healthcare prototypes include critical spaces that are affected by the changes from the 2012 to 2015 IECC. In the 2012 IECC Hospital and Outpatient Healthcare prototypes, critical spaces, such as operating rooms, patient rooms, intensive care units, and laboratories, were modelled to receive constant airflow with terminal reheat. To capture the impacts of the new requirement, PNNL compared the design airflow to the critical spaces with minimum airflow requirements according to the most commonly used accreditation standard, *AIA Guidelines for Design and Construction of*

Hospital and Health Care Facilities (American Institute of Architects, AIA 2001). PNNL determined that the operating rooms (during unoccupied periods) and patient rooms should be changed to use VAV systems for the 2015 IECC.

3.3.16 Fractional HP Fan Motors

The 2015 IECC adds a new Section C403.4.4.4 that requires motors from 1/12 horsepower (hp) to under 1 hp to be EC motors or have a minimum efficiency of 70%. The intention is to replace standard permanent-split capacitor (PSC) motors having efficiencies in the range of 15% to 65% with more-efficient EC motors. The intended applications are toilet exhaust fans, small kitchen exhaust fans, series fan-powered VAV boxes, and fan-coil units. The following motors are exempt under the new requirement: motors in an airstream where only heating is provided, motors in packaged equipment, poly-phase small motors, and capacitor-start capacitor-run and capacitor-start induction-run motors that are covered by Table C405.8(3) and Table C405.8(4) in the 2015 IECC.

In the building prototypes, the new requirements apply to fan-coil units, exhaust fans, kitchen exhaust fans, and elevator fans. Table 3.5 provides details on the building prototypes and fans to which the new requirements apply.

Table 3.5. Prototype Buildings Affected by Section C403.4.4.4 in the 2015 IECC

Prototype Building	Fan-Coil Unit	Exhaust Fan	Kitchen Exhaust Fan	Elevator Fan
High-Rise Apartment				Yes
Mid-Rise Apartment				Yes
Hospital			Yes	Yes
Large Hotel	Yes	Yes	Yes	Yes
Small Hotel				Yes
Large Office				Yes
Medium Office				Yes
Outpatient Healthcare		Yes		Yes
Quick-Service Restaurant		Yes	Yes	
Full-Service Restaurant		Yes	Yes	
Primary School		Yes	Yes	
Secondary School		Yes		Yes

To determine the motors whose efficiency must be changed, a set of criteria was established based on motor size. From a review of catalogs, motors in the smallest fans were selected from standard fractional horsepower motor sizes even if the required brake horsepower (bhp) is much lower. Therefore, maximum bhp is set at 90% of 3/4 hp or 560 W (above 90% of 3/4 hp, a 1 hp or larger motor would be used) and minimum bhp is set at 25% of 1/12 hp, or 14 W. Motors between the minimum and maximum bhp are considered to be applicable to the new IECC requirements.

To implement the new requirements, motor efficiency was changed in the prototypes. A motor efficiency of 29% was used in the 2012 IECC prototypes based on an intermediate value between highest potential efficiency and lowest efficiency found through literature review. For the 2015 IECC, the motor efficiency was set to 70%, which is close to the average typical EC motor efficiency.

3.3.17 Outdoor Air Ventilation Optimization Control

The 2015 IECC adds a multiple-zone VAV system ventilation optimization control requirement in Section C403.4.4.6. Under this requirement, multiple-zone VAV systems shall have automatic controls to reduce outdoor air intake flow from the design rates in response to dynamic system ventilation efficiency as defined by the 2015 International Mechanical Code (IMC) (ICC 2015b). According to Exception (2), a system having an ERV, as described in Section 3.3.3, is exempted from this requirement. Without such a requirement, the VAV systems in the 2012 IECC prototypes maintain constant outdoor air intake flowrate at the design level. This is a waste of energy to condition excess outdoor air intake.

To capture the savings of the 2015 IECC requirement, the Controller:MechanicalVentilation object in *EnergyPlus* was used with the System Outdoor Air field set to ventilation rate procedure. This is the option for meeting ventilation requirements in the 2015 IMC. Under these modeling settings, *EnergyPlus* implements the multiple-zone calculation per the 2015 IMC at each simulation time step and calculates system efficiency and system outdoor air intake, which is a reduced airflow from the design level. When a system has an ERV, the ventilation optimization control was not implemented; therefore, the system outdoor air intake remains at its design level. The energy savings impacts of the new 2015 IECC requirements were captured in Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, and Hospital.

3.4 Service Water Heating

PNNL reviewed all code changes under Section C404 Service Water Heating and determined that only the new demand-based control requirements for recirculation SWH systems have energy impacts that can be quantified using the building prototypes.

3.4.1 Demand-based Controls for Recirculated Service Water Heating Systems

Section C404.6.1 in the 2015 IECC adds new control requirements for buildings with recirculated SWH systems. The controls shall automatically turn off the circulation pumps when the water temperature in the circulation loop is either at or above the desired setpoint or when there is no hot water demand. These controls are not required in the 2012 IECC.

A recirculated SWH system provides more instant hot water at the water taps but energy losses are greater through pipe thermal losses and pump energy losses than a non-recirculated system. Ten prototypes use recirculated SWH systems. PNNL assumed that the SWH pumps in the 2012 IECC prototypes are always on at constant speed and the SWH temperatures are always maintained at their design setpoint. For each prototype, PNNL estimated the SWH pipe heat loss (kBtu/h) based on the average temperature difference between the water and indoor spaces, total pipe surface area, and pipe insulation. This loss was converted to SWH energy consumption inputs in the *EnergyPlus* models. Pump power in each prototype was also estimated based on pipe design, flow rate, and SWH system operations. This power was converted to pump pressure head in the *EnergyPlus* models. Details of the inputs are available in Section 2.1.4 of Goel et al. (2014). To estimate the energy savings impacts of the 2015 IECC requirements, reductions to the pipe heat loss inputs and recirculation pump power inputs were applied to the 2015 IECC building prototypes based on the baseline inputs in the 2012 IECC prototypes, as shown in Table 3.6. PNNL estimated the savings based on assumed SWH demand profiles in these prototypes.

Although Hospital, Small Hotel, and Large Hotel use recirculated SWH systems, PNNL did not quantify the impacts of the new requirements on them because we assumed the occupants in these building always have SWH demand.

Table 3.6. Percent Energy Savings of the 2015 IECC Controls Attributable to Reductions in Pipe Thermal Losses and Pump Energy Savings (as based on the 2012 IECC Building Prototypes)

Building Prototype	Energy Savings Attributable to Reductions in Pipe Thermal Loss	Savings Attributable to Pump Energy Savings
Medium Office	57%	89%
Large Office	57%	89%
Primary School	48%	90%
Secondary School	48%	90%
Outpatient Healthcare	57%	89%
High-Rise Apartment	44%	90%

3.5 Electrical Power and Lighting Systems

Section C405 of the 2012 and 2015 IECC specifies requirements for electrical power and lighting systems. Through review of the code changes, PNNL identified changes in several areas that have energy impacts and can be quantified using the building prototypes. Some of these changes are related to code changes in other areas, e.g., daylight responsive control is related to skylight and window areas and thermal performance of the fenestration components. These are also related to the changes in Section C406 (additional efficiency package options) of the two editions.

3.5.1 Additional Efficiency Package Options

Section C406 of the 2012 IECC requires choosing one from three additional efficiency package options:

1. Efficiency HVAC performance (Section C406.2),
2. Efficient lighting system (Section C406.3), and
3. On-site supply of renewable energy (Section C406.4).

The 2015 IECC modifies these options and adds three more options in Section C406. The six options are:

1. More efficient HVAC performance (Section C406.2),
2. Reduced lighting power density (LPD) system (Section C406.3),
3. Enhanced lighting controls (Section C406.4),
4. On-site supply of renewable energy (Section C406.5),
5. Provision of a dedicated outdoor air system for certain HVAC equipment (Section C406.6), and
6. High-efficiency service water heating (Section C406.7).

In the *Analysis for the 2012 IECC*, PNNL chose the high-efficiency lighting for the 2012 IECC prototypes because this option is more likely to be chosen for most building designs than the on-site supply of renewable energy option (Section C406.4). The efficient HVAC performance option (Section C406.2) was not chosen because this option would not allow a comparison of the 2012 IECC with its referenced Standard 90.1 with the HVAC equipment at the same minimum efficiencies addressed in the National Appliance Energy Conservation Act (NAECA), Energy Policy Act (EPAct), and the Energy Independence and Security Act (EISA). For the same reason and for keeping consistent choices for this analysis, PNNL chose the corresponding reduced LPD system option (Section C406.3 in the 2015 IECC) for the 2015 IECC prototypes. The impacts of the code changes in the selected option are related to daylight responsive control, skylights and window areas, and thermal performance of the fenestration components in the prototypes, and are discussed in Sections 3.5.3 and 3.5.6.1 in this report.

3.5.2 Occupant Sensor Controls

Section C405.2.2.2 in the 2012 IECC requires occupancy sensors in classrooms, conference/meeting rooms, employee lunch and break rooms, private offices, restrooms, storage rooms, janitorial closets, and other areas less than 300 ft^2 enclosed by floor-to-ceiling partitions. The control devices need to turn the lights off within 30 minutes of the occupants leaving the space and can be either manually turned on or automatically controlled to turn the lighting on to no more than 50% power. Full automatic-on controls are allowed in some specified areas.

The 2015 IECC (Section C405.2.1) extends the occupancy sensor control requirements to copy/print rooms, lounges, locker rooms, and warehouses.

An outline of the procedure for determining savings from occupancy sensors is as follows.

- Appropriate building areas that fall into the occupancy sensor requirements were identified.
- In prototypes like the Small, Medium, and Large Offices and Standalone Retail, where detailed zoning is unavailable, appropriate building areas were determined using the National Commercial Construction Characteristics database.[1] This database provides a compilation of the building prototypes and the proportion of common building areas.
- Percent lighting energy reduction from the use of occupancy sensors was determined for all qualifying areas based on literature review.
- This percentage reduction was applied to the occupied hour values of the lighting schedule used by the specific zone.
- Where a separate zone does not exist in the model for a particular space, the reduction factor was calculated as a product of (1) space area as a fraction of whole-building area from the National Commercial Construction Characteristics database, and (2) target lighting energy savings percentage. This reduction was similarly applied to the occupied hours of the whole-building lighting schedule.

[1] National Commercial Construction Characteristics Database (NC^3), an internal PNNL database of nationwide commercial construction energy-related characteristics.

3.5.3 Daylight Responsive Controls and Fenestration Area

The daylight control requirements in the IECC are related to several other requirements, such as window size, fenestration performance, and lighting power density. The requirements and their implementation in the prototypes are separately discussed in this section for sidelight (daylight through windows) and toplight (daylight through skylights).

3.5.3.1 Sidelighting Area and Control Requirements in the 2012 IECC

The 2012 IECC defines daylight zone adjacent to vertical fenestration in Chapter 2 and specifies control options for sidelight daylight zone in Section C405.2.2.3. However, automatic daylighting controls are not required. However, because the efficient lighting system option was chosen (see Section 3.5.1 and 3.5.6.1), an LPD of 0.9 W/ft^2 from Table C406.3 was selected to meet the reduced LPD requirements for the Small Office and Medium Office prototypes. This triggered Footnote (b) of the table to apply. Therefore, two prototypes, which have sidelight daylight zones over 30% of their total conditioned floor area, are required to have automatic daylighting controls. Automatic stepped daylight controls were implemented in the two prototypes for all climate zones for the 2012 IECC.

A window provides a path for daylight entering the space. The 2012 IECC (Section 402.3.1) limits maximum window-to-wall ratio (WWR) of 30%. In climate zones 1 through 6, a maximum WWR of 40% is allowed if 50% of the conditioned floor area is within a daylight zone (including sidelight and toplight areas) and automatic daylighting controls are installed. Through a literature review, PNNL defined typical WWR for each prototype, which is assumed in its design characteristic. Such characteristics remain the same unless certain code provision requires them to be changed. Most prototypes have WWRs of less than 30% as their characteristics. However, four prototypes (Primary School, Secondary School, Medium Office, and Large Office) have typical WWRs between 30% and 40%. PNNL verified that the 40% limit does not apply to these prototypes because they do not have sufficient daylight area. Therefore, their WWRs were reduced from their typical values to 30% for the 2012 IECC prototypes.

In summary, Small Office and Medium Office prototypes were implemented with automatic controls for general lighting in their sidelight daylight zones. In addition, the WWRs of Primary School, Secondary School, Medium Office, and Large Office were set to 30% for the 2012 IECC.

3.5.3.2 Sidelighting Area and Control Requirements in the 2015 IECC

The 2015 IECC (Section C405.2.3) requires automatic daylight responsive controls for sidelight daylight area as opposed to manual controls (an allowed option in the 2012). It specifies 150 Watts of general lighting within sidelight daylight zone as the minimum threshold to apply the control requirement. As such, many sidelight zones in the 2015 prototypes were implemented with automatic daylight controls, such as Small Office, Medium Office, Large Office, Primary School, Secondary School, Outpatient Healthcare, Hospital, Small Hotel, Large Hotel, Warehouse, Quick-Service Restaurant, and Full-Service Restaurant.

In addition, the 2015 IECC specifies control settings for different space types. Where located in offices, classrooms, laboratories and library reading rooms, daylight responsive controls shall dim lights continuously from full light output to 15% of full light output or lower. Daylight responsive controls shall be capable of a complete shutoff of all controlled lights. For these space types, continuous dimming controls were used and for others, stepped controls were used.

Similar to the 2012 IECC, the 2015 IECC (Section C402.4.1.1) limits the maximum WWR to 30% but allows buildings in climate zones 1 through 6 to use WWR up to 40% if a certain amount of floor area falls under daylight zones. Code changes were made to the criteria for which the 40% limit applies. For buildings with two stories or less, the area in daylight zones must be at least 50% of the net floor area. For buildings with more than two stories, at least 25% of the net floor area must be in a daylight zone. Net floor area excludes corridors, stairwells, bathrooms and mechanical rooms from the conditioned floor area. As mentioned earlier, 30% WWR limit was implemented to Large Office, Medium Office, Primary School, and Secondary School for the 2012 IECC. PNNL checked these prototypes against the changed criteria and compared the ratio of the daylight area (including both sidelight and toplight areas) to the net floor area with the new criteria. It was found that the WWR of Medium Office can be changed to its characteristic size, i.e., WWR of 33%. This was implemented to this prototype in climate zones 1 through 6. In addition, the visible transmittance (VT) of these changed windows was changed to 1.1 times solar heat gain coefficient (SHGC) to meet Section C402.4.1.1 (4) requirement. The WWR remains at 30% in Medium Office (same as the 2012 IECC counterparts) in climate zones 7 and 8.

3.5.3.3 Toplighting Area and Control Requirements in the 2012 IECC

Skylight Area

Section C402.3.2 of the 2012 IECC requires a minimum skylight area in certain spaces larger than 10,000 ft^2 to provide toplight daylight area under skylights to be at least 50% of the space area. The skylight area shall not be less than 3% of this daylight area. Buildings in climate zones 6 through 8 are exempted.

Spaces in some of the building prototypes have skylights in their typical design, i.e., skylights are a characteristic of the prototype. Such characteristics remain the same unless certain code provisions require them to be changed. The spaces in these prototypes with skylights are listed in Table 3.7 along with other design characteristics related to daylight area under skylights. As seen in the table, the zones in Primary School and Secondary School meet the minimum skylight area requirements in Section C402.3.2 of the 2012 IECC.

Footnote (c) of Table C406.3 in the efficient light system option, used in the 2012 IECC prototype, as discussed in Section 3.5.6.1, requires 70% of floor area in warehouse and 30% in retail to be in the daylight zone. Because of this requirement, PNNL increased the number of skylights in the 2012 IECC Warehouse and Standalone Retail prototypes.

Daylight Responsive Control in Toplight Daylight Area

Section C402.3.2.1 in the 2012 IECC requires all lighting in the toplight daylight zone to be controlled by multilevel lighting controls except for climate zones 6 through 8. For Warehouse and Standalone Retail prototypes, Footnotes (b) and (c) of Table C406.3 require automatic daylighting control without climate zone exceptions. Therefore, these multilevel lighting controls were implemented to zones listed in Table 3.7 for Primary School and Secondary School in climate zones 1 through 5. Warehouse and Standalone Retail in all climate zones were modelled with automatic daylighting control.

Thermal Performance of Skylights

Sections C402.3.3.3 in the 2012 IECC allows skylights to have an increased SHGC from the requirements in Table C402.3 in climate zones 1 through 6 where the toplight daylight area under the skylights has automated daylighting controls. Similarly, according to Section C402.3.3.4, these skylights can use increased U-factor in all climate zones. These increased SHGC and U-factor requirements were implemented to the prototypes as they apply.

Table 3.7. Typical Skylight and Toplight Area in the Building Prototypes

Prototype	Zone Name	Zone Area (ft^2)	Skylight Area (ft^2)	Toplight Daylight Area (ft^2)	Toplight Daylight Area / Zone Area (%)	Skylight Area / Toplight Daylight Area (%)
Primary School	Multipurpose Room	3843	144	3843	100%	4%
Secondary School	Gymnasium	21269	864	21269	100%	4%
	Auxiliary Gymnasium	13433	576	13433	100%	4%
Warehouse	Bulk Storage [a, b]	34497	160	4876	14%	0%
	Fine Storage [a, b]	15000	0	0	0%	0%
Standalone Retail	Core Retail [a, b]	17227	72	2584	15%	0%

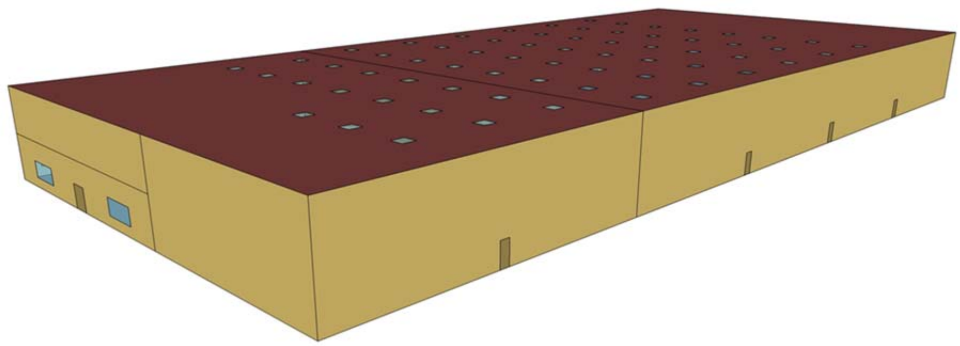
a. Daylight areas were increased to 70% (Warehouse) and 30% (Standalone Retail) of the zone area for all climate zones to meet the requirements of Footnotes (b) and (c) of Table C406.3 in the 2012 IECC.
b. Daylight areas were set to 50% to meet the requirements of Section C402.4.2 in the 2015 IECC for climate zones 1-5. They remain as values shown in this table for climate zone 6-8.

3.5.3.4 Toplight in the 2015 IECC

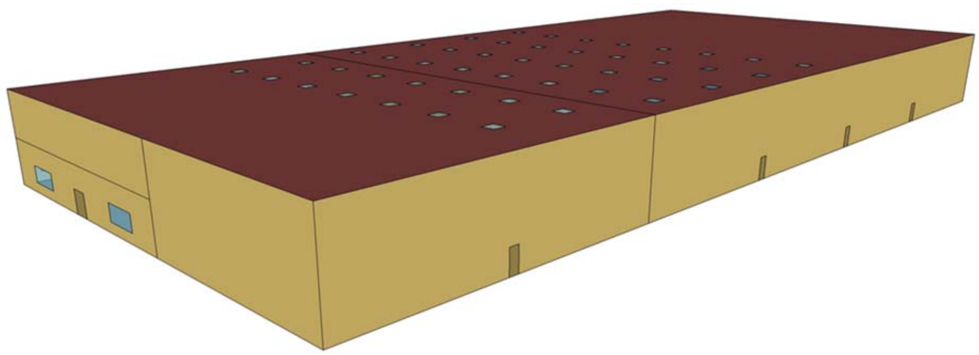
Skylight Area

To save energy from use of daylight responsive control, the requirements of minimum skylight area were modified in the 2015 IECC (Section C402.4.2). The size threshold of a zone, for which the requirements applies, was changed from 10,000 ft^2 to 2,500 ft^2. As shown in Table 3.7, this new threshold does not affect the Primary School and Secondary School because their skylight areas already exceed the requirements.

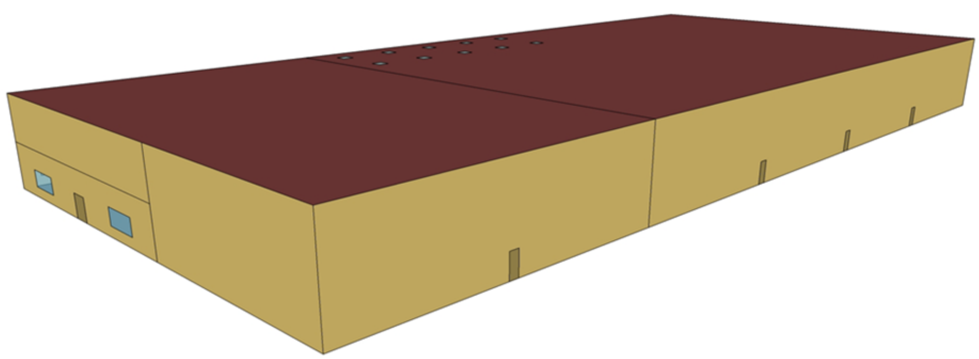
The reduced lighting power density system, Section C406.3 used in the 2015 IECC prototype, as discussed in Section 3.5.1 of this report, was changed from specifying requirements for LPD, minimum daylight area, and daylighting controls to LPD only. As such, the minimum skylight area requirements in Section C402.4.2 of the 2015 IECC were implemented to Warehouse and Standalone Retail with respect to their skylight areas. PNNL set the toplight daylight area in the bulk and fine storage zones in Warehouse and core retail zone in Standalone Retail in climate zones 1 through 5 to 50% of the zone area. The skylight areas remain the same as values shown in the Table 3.7 for those building prototypes located in climate zones 6 through 8. PNNL implemented the daylight area by changing the number of skylights on the roof. As illustrated in Figure 3.1 these changes resulted in a decrease in the number of skylights in Warehouse from the 2012 and the 2015 IECC buildings. The major impacts of these changes on energy performance of the warehouse include envelope thermal performance, daylight responsive control, and HVAC system sizes.



Warehouse for the 2012 IECC in all climate zones



Warehouse for the 2012 IECC in climate zones 1 through 5



Warehouse for the 2015 IECC in climate zones 6 through 8

Figure 3.1. Schematic of Skylights in the Warehouse Prototype

Daylight Responsive Control in Toplight Daylight Area

Section C402.4.2.1 in the 2015 IECC requires all lighting in the toplight daylight zone to be controlled for all climate zones, as opposed to having exceptions in climate zones 6 through 8. Section C405.2.3 also defines a new threshold of 150 watts of general lighting within the zone to qualify daylight responsive control defined in the 2015 IECC.

Section C405.2.3.1 in the 2015 IECC specifies continuously dimming control from full light output for offices, classrooms, laboratories, and library reading rooms. PNNL used a stepped control setting in *EnergyPlus* to model this requirement for all toplight daylight areas in zones listed in Table 3.7 in all climate zones.

Thermal Performance of Skylights

Similar to the 2012 IECC, the 2015 IECC permits increased SHGC and U-factor from values in Table C402.4 for skylights where located above daylight area with daylight controls. Requirements do not change from the 2012 to 2015. However, toplight daylight controls were not implemented in Primary School and Secondary School located in climate zones 6 through 8 for the 2012 IECC but were implemented for the 2015 IECC. These differences resulted in different U-factor inputs in the simulation models of these two schools between the two editions of the IECC.

3.5.4 Guestroom Lighting Controls

Section C405.2.4 in the 2015 IECC modified the existing requirement in the 2012 IECC (Section C405.2.4) for hotel and motel sleeping units and guest suites. The requirement changed from manual control to automatically switching off all installed luminaires and switched receptacles within 20 minutes after all occupants leave the room.

The new requirement affects Small Hotel and Large Hotel. The implementation assumes 10% reduction in lighting energy in bathroom lighting and that the bathroom lighting contributes 31% of the guestroom lights. Besides lighting control, the new requirement also applies to the switched receptacles in guestrooms. A new schedule for guestroom lighting was calculated using the hourly reduction fraction for guestroom lighting in the advanced case in the *Technical Support Document: 50% Energy Savings Design Technology Packages for Highway Lodging Buildings* (Jiang et al. 2009). The daily weighted reduction in the lighting power using this schedule is 38%. The hourly reduction fraction for guestroom receptacles in advanced models from Jiang et al. (2009) was used to calculate the 2015 IECC savings. This results in a daily weighted reduction of 17% in equipment energy consumption.

3.5.5 Exterior Lighting Automatic Controls

Section C405.2.4 in the 2012 IECC requires that lighting not designated for dusk-to-dawn operation shall be controlled by either a combination of a photosensor and a time switch, or an astronomical time switch. Lighting designated for dusk-to-dawn operation shall be controlled by an astronomical time switch or photosensor. These requirements mean the exterior lights are off during daytime but do not enforce light power to be reduced at night. The 2015 IECC (Section C405.2.5) requires exterior facade and landscape lighting to be automatically turned off as a function of dawn/dusk and a set business opening and closing time. Exterior lighting not specified as facade or landscape lighting is to be automatically reduced by 30% of its peak power from between no later than midnight to 6 a.m., or from 1 hour after business closing to 1 hour before business opening, or during any period when activity has not been detected for a time longer than 15 minutes.

The code changes have energy savings impacts on all prototypes except for those that are open 24 hours a day, such as Hospital, Outpatient Healthcare, Small Hotel, Large Hotel, Mid-Rise Apartment, and

High-Rise Apartment. Exterior lighting operating schedules were changed to reflect the minimum required power reduction at night. The exterior lighting schedule was separated into a facade schedule with lights off at night and the rest of the exterior lighting schedule with lights reduced by 30% at night.

3.5.6 Interior Lighting Power

The IECC requirements related to the interior lighting power were modified in three areas: general LPD, additional lighting power allowance for retail display lighting, and sleeping unit LPD.

3.5.6.1 Interior Lighting Power Density

The 2012 and 2015 IECC specify total interior lighting power allowance through Section C405. However, the building prototypes need to meet more stringent requirements in Section C406.3 because the efficient lighting system option (Section C406.3 in the 2012 IECC and Section C406.4 in the 2015 IECC) was selected. The reasons for the selection are discussed in Section 3.5.1 of this report.

Section C406.3 in the 2012 IECC specifies LPD allowance using the building area method. The LPDs listed in Table C406.3 were used to model the lighting systems in the prototypes. There are two spaces types, i.e., office and retail, that are each provided with two LPDs in the table. The table allows the higher LPD to be used if daylight zones comprise more than 30% of the total conditioned floor area in the building. It also requires that the daylight zone be controlled by automatic controls. Standalone Retail, Small Office, and Medium Office prototypes have daylight zones comprising 30% or more of the total conditioned floor area in the building. Therefore, the higher LPDs (0.9 W/ft^2 for office and 1.4 W/ft^2 for retail) were used in these prototypes. The implementation for the daylighting control requirements is described in Section 3.5.3 of this report.

The 2015 IECC has both space-by-space and building area methods to calculate the allowance in Section C406.3. PNNL switched the approach from building area method used in the 2012 IECC prototypes to the space-by-space method to develop the 2015 IECC prototypes for two reasons:

1. the space-by-space method allows use of zone-specific lighting powers, which help better capture the energy impacts of zone-specific lighting control requirements; and
2. the space-by-space method was used for the analysis for Standard 90.1-2013 (Halverson et al. 2014). Using the same method in the analysis for 2015 IECC means that PNNL kept consistent choices between these two analyses.

According to Section C406.3, the LPDs in the 2015 IECC prototypes were calculated by multiplying values from Table C405.4.2(2) by 90%. Table 3.8 shows a side-by-side comparison of the area-weighted prototype building LPD between the 2012 and 2015 IECC building prototypes. In the simulation models for the prototypes, space-specific LPDs were used as inputs and Table 3.8 shows their area-weighted average LPD for each prototype. LPD for dwelling units in Mid-Rise Apartment and High-Rise Apartment, sleeping units in Small Hotel and Large Hotel, and additional display lighting in Strip Mall were not included when calculating the average LPD. As shown in Table 3.8 , there are reductions in average LPD in all prototypes except for Warehouse and the two apartment prototypes. The changes in LPD (including all buildings) are partly because PNNL applied different methods. For the 2012 IECC prototypes, the building area method was used, which is the only method in the 2012 IECC. For the 2015 IECC prototypes, the space-by-space method was used. Table 3.9 shows an example of zone-specific

LPDs in Warehouse. This is a small difference (0.03 w/ft^2) in area-weighted average LPD between the two prototypes but the difference by zone is larger; for example, fine storage has an LPD of 0.59 W/ft^2 for the 2012 IECC and 0.86 W/ft^2 for the 2015 IECC. This can impact the whole- building energy performance when different zone-specific lighting controls are applied to these spaces.

Table 3.8. Area-weighted LPD of General Lighting in the 2012 and 2015 IECC Prototypes

Building Prototype	2012 IECC, LPD (W/ft^2)	2015 IECC, LPD (W/ft^2)
Small Office	0.9	0.74
Medium Office	0.9	0.74
Large Office	0.9	0.74
Standalone Retail	1.4	1.30
Strip Mall	1.3	1.22
Primary School	0.99	0.96
Secondary School	0.99	0.85
Outpatient Healthcare	0.87	0.92
Hospital	1.1	0.88
Small Hotel	0.88	0.71
Large Hotel	0.88	0.84
Warehouse	0.6	0.63
Quick-Service Restaurant	0.9	0.84
Full-Service Restaurant	0.89	0.88
Mid-Rise Apartment	0.6	0.68
High-Rise Apartment	0.6	0.64

Table 3.9. Comparison of LPDs in Warehouse Prototype Built to the 2012 and 2015 IECC

Zone Name	Area (ft^2)	2012 IECC, LPD (W/ft^2)	2015 IECC, LPD (W/ft^2)
Office	2549	0.74	0.74
Fine Storage	14993	0.59	0.86
Bulk Storage	34484	0.59	0.52
Area-Weighted Average		**0.60**	**0.63**

3.5.6.2 Additional Lighting Power Allowance for Retail Display Lighting

The 2012 IECC is not very clear whether the additional lighting power allowance for retail display lighting applies if the efficient lighting system option (Section C406.3 in the 2012 IECC) is selected. In the 2012 IECC prototypes, PNNL did not model the allowed display lighting in Strip Mall, in which some sales areas of certain merchandise qualify for the allowance.

Section C405.4.2.2.1 in the 2015 IECC indicates areas in Strip Mall that are allowed to have additional lighting power for display lighting. This provision applies when the reduced lighting power density option, Section C406.3, is selected. In addition, the base allowance (Equation 4-10 in the 2015 IECC) is changed from 1000 Watts in the 2012 IECC to 500 Watts.

To capture this code change, PNNL enhanced the Strip Mall prototype built to the 2012 IECC to add the allowance. The code change was captured by applying different display lighting power in the prototypes.

3.5.6.3 Sleeping Unit Lighting Power Density

Sleeping unit lighting in hotels is exempted from the interior LPD requirements in the 2012 IECC according to Exception 1.2 to Section C405.5.1. For the 2012 IECC, PNNL assumed an LPD of 1.1 W/ft^2 for guestrooms in Small and Large Hotel based on the early edition of Standard 90.1.

The 2015 IECC modified the provision (Exception 1.2 to Section C405.4.1) that this exemption applies, but 75% of permanently installed light fixtures must be fitted with high-efficacy lamps.

PNNL applied a reduction factor of 0.25 to 75% of the baseline. This factor is based on an assumption that the 60-Watt incandescent lamps in the 2012 IECC prototypes are switched to 15-Watt compact fluorescent lamps to meet the 2015 IECC requirement. Therefore, the LPD in the 2015 IECC hotel guestrooms is 75% x 1.1 W/ft^2 x 0.25 + 25% x 1.1 W/ft^2 = 0.48 W/ft^2.

3.5.7 Exterior Lighting Power

The building façade lighting power allowance in Table C405.6.2(2) of the 2012 IECC is modified in the 2015 IECC (Table C405.5.2(2)) to reduce allowance in lighting zones 2 through 4. The code change applies to all building prototypes. The reduced allowance was implemented using the modelled façade lighting power inputs in *EnergyPlus*.

3.5.8 Elevator Lighting and Ventilation

The 2012 IECC does not have requirements for elevators. Section C405.9.1 in the 2015 IECC does have such requirements. These include: 1) the cab lighting to have efficacy of not less than 35 lumens per Watt; 2) ventilation fans in elevators without air-conditioning systems shall not consume more than 0.33 watts/cfm at the maximum fan speed; and, 3) the cab lighting and ventilation should be off when the elevator is not used for over 15 minutes.

Medium Office, Large Office, Secondary School, Outpatient Healthcare, Hospital, Small Hotel, Large Hotel, Mid-Rise Apartment, and High-Rise Apartment have elevators. To analyze the energy savings of the code changes, the 2012 IECC baseline assumptions for elevator lights, fans, and their operation schedules are set and then modified lighting power, fan power, and operation schedules reflecting the code changes are used as the 2015 IECC model inputs. The same modeling strategy was used to quantify similar changes from Standard 90.1-2007 to Standard 90.1-2010. Details of the modeling assumptions can be found in Thornton et al. (2011).

4.0 Site Energy and Energy Cost Savings Results

This section summarizes the estimated site energy and energy cost savings for the 2015 IECC compared to the 2012 IECC. The results of the analysis are summarized in Table 4.1. This table groups the building prototypes by their principal activity and shows the construction weighting factors by building prototype. The table provides a side-by-side comparison of the site energy use intensity (EUI) and energy cost index (ECI) for the 2012 and 2015 editions of the IECC. Site energy is utility electricity and natural gas delivered and used at the building site. The EUI and ECI shown in Table 4.1 for each prototype are national weighted averages across climate zones in the United States. The percent savings (reduction) in EUI and ECI are presented as well. Negative percentages reflect increases in EUI or ECI. The last row of Table 4.1 shows the national weighted average results from all 16 prototypes and 15 climate zones using the construction weighting factors (see Table 2.2 in this report). As shown in Table 4.1, on a weighted national basis, the 2015 IECC results in 11.1% energy savings and 11.5% energy cost savings over the 2012 IECC. As a result of federally mandated efficiency improvements of appliances and equipment that have taken effect since (but independent of) the publication of the 2012 IECC, the actual EUI and ECI savings would be higher for most new buildings subject to the 2015 IECC than the results indicate. The savings attributed to DOE's Appliance and Commercial Equipment Standards are not included in the results in Table 4.1 as discussed in Section 2.4.

Table 4.1. Site Energy and Energy Cost Savings between the 2012 and 2015 IECC

Building Activity	Building Prototype	Floor Area Weight (%)	Site EUI ($kBtu/ft^2$-yr)		Site EUI Savings (%)	ECI ($\$/ft^2$-yr)		ECI Savings (%)
			2012 IECC	2015 IECC		2012 IECC	2015 IECC	
Office	Small Office	5.6	31.1	29.6	4.8	0.93	0.88	4.8
	Medium Office	6.0	35.5	34.6	2.5	0.99	0.97	1.9
	Large Office	3.3	76.2	71.7	6.0	2.15	2.04	5.2
Retail	Standalone Retail	15.3	54.1	47.3	12.6	1.44	1.21	16.0
	Strip Mall	5.7	58.3	54.0	7.4	1.54	1.39	9.7
Education	Primary School	5.0	62.3	55.5	10.9	1.52	1.34	11.4
	Secondary School	10.4	51.8	42.8	17.4	1.35	1.12	16.8
Healthcare	Outpatient Healthcare	4.4	137.2	117.6	14.3	3.53	3.07	13.0
	Hospital	3.4	172.2	128.0	25.7	3.72	2.98	20.0
Lodging	Small Hotel	1.7	66.4	60.4	9.2	1.49	1.3	12.6
	Large Hotel	5.0	109.5	87.9	19.8	2.37	1.81	23.9
Warehouse	Warehouse	16.7	15.0	15.5	-3.1	0.34	0.36	-5.2
Food Service	Quick-Service Restaurant	0.6	602.5	582	3.4	9.66	8.83	8.6
	Full-Service Restaurant	0.7	405.6	373.8	7.8	7.22	6.44	10.8
Apartment	Mid-Rise Apartment	7.3	45.0	44.2	1.7	1.23	1.22	1.0
	High-Rise Apartment	9.0	49.1	47.6	3.0	1.14	1.11	3.1
National Weighted Average		**100**	**61.4**	**54.5**	**11.1**	**1.49**	**1.31**	**11.5**

As can be seen from Table 4.1, the savings vary significantly by prototype. This is expected because code requirements are different by building type and by climate. PNNL did not separately quantify the national impacts of individual code changes because that would require substantial additional resources. Although this approach does not allow us to rank the code changes based on their energy savings impacts, we can still identify a few high impact changes resulting in significant energy savings as listed below:

a. Envelope: Changes to opaque envelope (see Section 3.2.1 in this report) and continuous air barrier (see Section3.2.2).
b. HVAC: Equipment efficiency improvements (Section 3.3.1), ERV (see Section 3.3.3), kitchen exhaust systems (Section 3.3.4), staged cooling (see Section 3.3.9), fan airflow control (see Section 3.3.10), VAV reheat control (see Section 3.3.14), VAV system for critical area in healthcare facility (see Section 3.3.15), and outdoor air ventilation optimization (see Section 3.3.17).
c. Lighting: Daylight responsive control (see Section 3.5.3), exterior lighting control (see Section 3.5.5), interior lighting power (see Section 3.5.6), and exterior lighting power (see Section 3.5.7).

The analysis also indicates that all building prototypes, except the Warehouse prototype, use less energy under the 2015 IECC. The Warehouse prototype uses more energy because the requirements in the 2015 IECC resulted in reduced daylit area under control compared to the 2012 IECC (see Section 3.5.3.4 in this report). These changes are specific to the Warehouse prototype and are more pronounced because lighting energy is a large portion of the total energy consumption in the Warehouse prototype.

Figures 4.1 and 4.2 illustrate the weighted EUI and ECI for each prototype and the national weighted EUI and ECI for the 2012 and 2015 editions of the IECC, respectively.

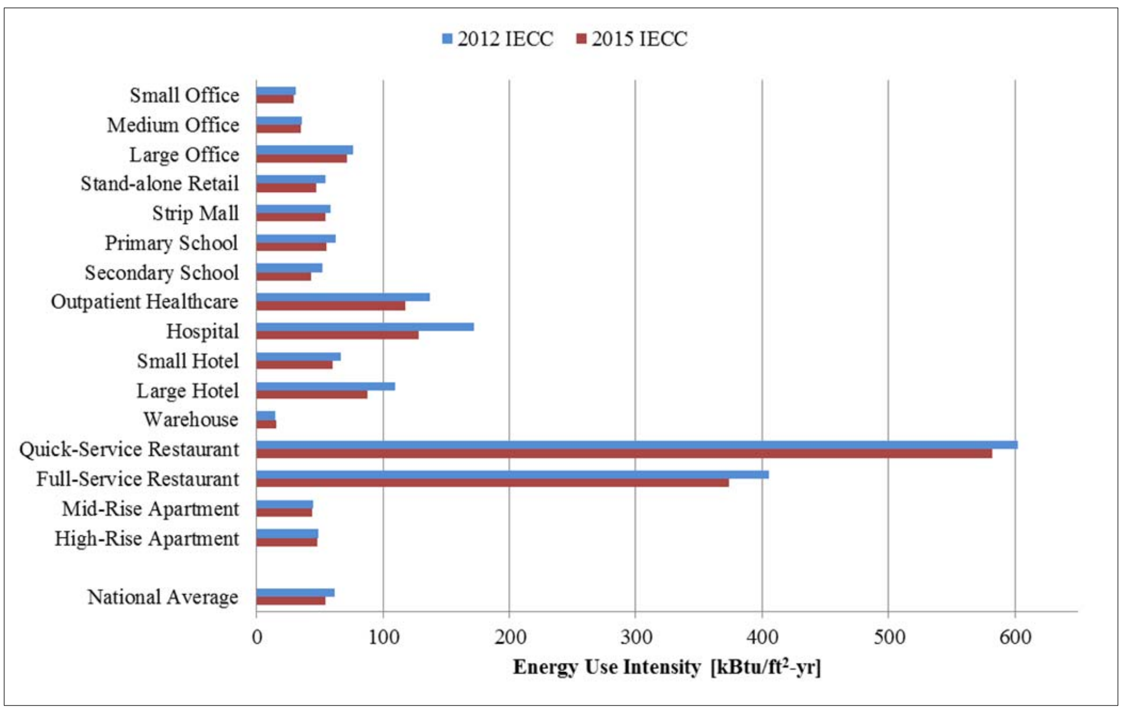


Figure 4.1. National Average Energy Use Intensity for all IECC Prototypes

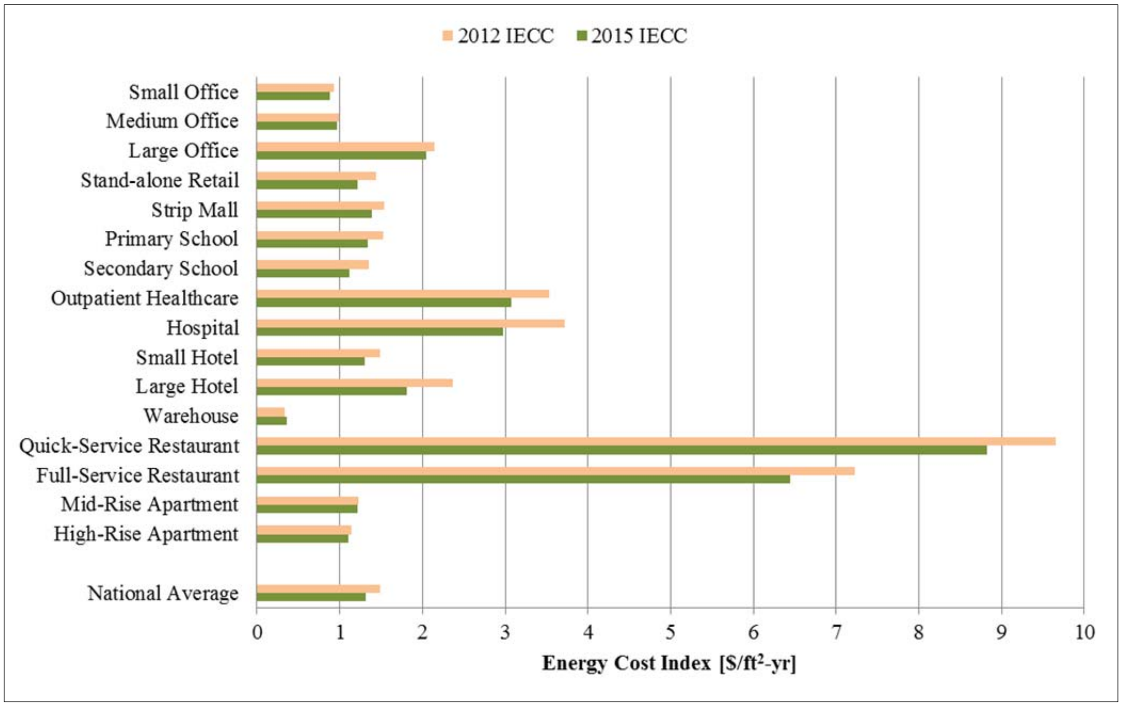


Figure 4.2. National Average Energy Cost Index for all IECC Prototypes

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Appendix A

Code Changes from the 2012 to 2015 IECC Included in Analysis and their Impact on Building Prototypes

Appendix A

Code Changes from the 2012 to 2015 IECC Included in Analysis and their Impact on Building Prototypes

Table A.1. Changes between the 2012 and 2015 IECC with Quantified Energy Impacts

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C402.1.4 Assembly U-factor, C-factor or F-factor-based method	Modifies the building envelope requirements for opaque assemblies using U-factor, C-factor or F-factor-based method in Table C402.1.4.		x	x	x	x	x	x	x	x	x	x	x			x	x
C402.4.1.1 Increased vertical fenestration area with daylight responsive controls	Modifies minimum daylighting area thresholds above which the maximum window-to-wall ratio of 40% is permitted.		x														
C402.4.2.1 Lighting controls in daylight zones under skylights	Removes the exception to responsive daylighting controls in daylighting zones under skylights in climate zones 6 through 8.				x		x	x					x				
C402.5.1 Air barriers	Extends continuous air barrier requirements to include climate zones 1, 2A, and 3.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.2.3 HVAC equipment performance requirements	Improves HVAC equipment efficiency.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C403.2.5 Hot water boiler outdoor temperature setback control	Requires boiler temperature setback control based on the outdoor temperature.			x				x	x	x		x					
C403.2.7 Energy recovery ventilation systems	Reduces the system size and outdoor air thresholds at which ERV is required. Relaxed in some climate zones. Adds new thresholds for systems that operate more than 8000 hours per year.		x	x	x		x	x	x	x		x					
C403.2.8 Kitchen exhaust systems	Modifies the requirements for kitchen hood exhaust and make-up air systems.						x	x		x		x		x	x		
C403.2.12.1 Allowable fan floor horsepower	Adjusts fan power limitation credits.		x	x			x	x	x	x		x					
C403.2.14 Refrigeration equipment performance	Adds efficiency requirements for commercial refrigerators, freezers and refrigeration equipment.						x	x		x		x		x	x		
C403.2.16 Walk-in coolers and walk-in freezers	Adds requirements for walk-in coolers and freezers and refrigerated display cases.						x	x		x		x		x	x		

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.3 Economizers (Prescriptive) Exception 2	Increases cooling capacity threshold for air economizer to be required in DX cooling systems from 33,000 Btu/h to 54,000 Btu/h.	x	x		x	x	x	x	x				x	x	x		
C403.3.1 Integrated economizer control	Enhances the requirements for integrated economizer control and defines DX unit capacity staging requirements.				x	x	x	x						x	x		
C403.4.1.1 Fan airflow control	Extends the requirements for fan speed control for unitary direct expansion systems based on cooling capacity and enhances the requirements for integrated economizer control.				x	x	x	x						x	x		
C403.4.2.4 Part-load controls	Increases capacity threshold for hydronic system part-load controls and extends the control types.			x				x		x		x					
403.4.2.5 Boiler turndown	Establishes minimum turndown for boilers and boiler plants with design input power of at least 1,000,000 Btu/h.			x			x	x	x	x		x					x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.4.3 Heat rejection equipment	Modifies heat rejection equipment (cooling tower) requirements to require that variable speed drive controlled fans operate all fans at the same speed instead of sequencing them, and require that open-circuit towers with multiple cells operate all cells in parallel down to 50% of design flow.			x						x							
C403.4.4 Requirements for complex mechanical systems serving multiple zones	Allows optimization of minimum damper positions based on multiple-zone calculation.		x	x			x	x	x	x		x					
C403.4.4 Requirements for complex mechanical systems serving multiple zones	Removes exception for VAV turndown for zones with special pressurization requirements.								x	x							
C403.4.4.4 Fractional hp fan motors	Requires fractional horsepower motors ≥1/12 hp to be EC motors or have a minimum 70% efficiency in accordance with DOE 10 CFR 431. Also requires adjustable speed or other method to balance airflow.		x	x			x	x	x	x	x	x		x	x	x	x

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C403.4.4.6 Multiple-zone VAV system ventilation optimization control	Requires multi-zone VAV systems to have controls that optimize ventilation.		x	x			x	x	x	x		x					
C404.6.1 Circulation systems	Adds temperature maintenance and demand control for circulation pump.		x	x			x	x	x								x
C405.2.1 Occupant sensor controls	Adds lounge, locker room, and warehouse spaces to the list for occupancy sensor controls.	x	x	x	x		x	x	x	x	x	x	x		x		
C405.2.3 Daylight-responsive controls	Modifies control functions and threshold for both sidelight and toplight daylight controls.	x	x	x	x		x	x	x	x	x	x	x	x	x		
C405.2.4 Specific application controls	Requires automatic light controls for hotel and motel sleeping units										x	x					
C405.2.5 Exterior lighting controls	1. Requires exterior lighting controls rather than just control capability. 2. Adds bi-level controls for general all-night applications such as parking lots to reduce lighting when not needed. 3. Adds control of facade and landscaping lighting not needed after midnight.	x	x	x	x	x	x	x					x	x	x		

Section Number in the 2015 IECC	Description of Code Changes	Small Office	Medium Office	Large Office	Standalone Retail	Strip Mall	Primary School	Secondary School	Outpatient Healthcare	Hospital	Small Hotel	Large Hotel	Warehouse	Quick-Service Restaurant	Full-Service Restaurant	Mid-Rise Apartment	High-Rise Apartment
C405.4.1 Total connected interior lighting power	Modifies sleeping unit exception to lighting power limits. They need to meet R404.1.										x	x					
C405.5.1 Exterior building lighting power	Changes façade lighting power in Table C405.5.2(2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
C405.9.1 Elevator cabs	Adds requirements for elevator fan and lights.		x	x				x	x	x	x	x				x	x
C406.3 Reduced lighting power density	1. Replaces LPD table in the 2012 IECC with 10% increase in efficiency over the base LPD requirements for whole building or space-by-space. 2. Adds space-by-space method option to provides flexibility. 3. removes the daylighting control requirements in 2012 IECC table footnotes. 4. Removes additional skylight requirements (footnote c) in the 2012 for warehouse.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Appendix B

Energy and Energy Cost Savings for the 2015 IECC and Corresponding Standard 90.1-2013

Appendix B

Energy and Energy Cost Savings for the 2015 IECC and Corresponding Standard 90.1-2013

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

In support of DOE's determination, PNNL conducted an energy savings analysis for Standard 90.1-2013 compared to Standard 90.1-2010 (Halverson et al. 2014). Based on that analysis, DOE issued a determination that Standard 90.1-2013 would achieve greater energy efficiency in buildings compared to the 2010 edition of the standard.

As many states have historically adopted the IECC for both residential and commercial buildings, PNNL has also compared energy performance of Standard 90.1-2013 with the 2015 IECC to help states and local jurisdictions make informed decisions regarding model code adoption. Of the 47 States with statewide commercial building energy codes currently, 37 use a version of the IECC (BECP 2015).

Table B.1 shows side-by-side comparisons of the site EUI and ECI for Standard 90.1-2013 and the 2015 IECC for each of 16 prototype buildings along with the percent difference between the two. The national weighted average of all prototypes combined is also shown. Figures B.1 and B.2 show the same results graphically. Negative percentage differences indicate higher energy or energy costs for buildings designed to the 2015 IECC compared to those designed to Standard 90.1-2013. For most prototypes, both EUIs and ECIs were slightly lower using Standard 90.1-2013. One notable exception is the Warehouse prototype where the 2015 IECC resulted in lower energy use and energy costs. This difference is because Standard 90.1-2013 has a category for semi-heated spaces allowing relaxed levels of insulation, while the 2015 IECC does not.

The comparisons show the combined energy impacts of differences between the 2015 IECC and Standard 90.1-2013. Although the current analysis does not compare or rank the individual differences based on their energy savings, a few high impact differences by category can be identified as follows:

a. Envelope
   - Prescriptive WWR limit: the 2015 IECC allows a WWR up to 30% unless a significant portion of the building is equipped with daylight responsive controls, in which case up to 40% is allowed. Standard 90.1-2013 requires WWR less than 40%.
   - Semi-heated space envelope requirements: the 2015 IECC does not have separate envelope requirements for semi-heated spaces. Semi-heated spaces are required to follow conditioned space requirements. Standard 90.1-2013 has less stringent insulation requirements for semi-heated spaces.

- Vertical fenestration U-factor independent of frame material: the U-factor requirements for vertical fenestrations in the 2015 IECC are independent of the frame material. Standard 90.1-2013 has higher U-factors for metal-framed fenestrations than for nonmetal-framed fenestrations.

- SHGC for north-oriented vertical fenestrations: the 2015 IECC sets higher maximum SHGCs for north-oriented fenestrations than those facing other orientations. Standard 90.1-2013 allows a much smaller relaxation of SHGC (SHGC-0.05) for north-oriented fenestrations. The impact of this difference is not captured in the current analysis because the prototype building facades are all facing true east, south, west, or north and the energy impact is negligible for true north-oriented facades. However, both the 2015 IECC and Standard 90.1-2013 define north-oriented fenestration as that which is facing within 45 degrees of true north in the northern hemisphere. For fenestration offset from true north by up to 45 degrees, the relaxation of SHGC may be significant.

- Vestibule exceptions: the 2015 IECC exempts building entrance doors that open up to a space less than 3,000 sf; Standard 90.1-2013 does not. The 2015 IECC also includes an exception from vestibule requirements if an air curtain is installed instead; Standard 90.1-2013 does not have such an exception.

- Fenestration orientation: the 2015 IECC does not limit the distribution of fenestration area. Standard 90.1-2013 limits the fenestration area on the east and west façades.

b. Building mechanical systems

- Shutoff damper controls: the 2015 IECC exempts buildings with less than 3 stories from the motorized damper requirements for ventilation air intakes; Standard 90.1-2013 does not have such an exception.

c. Lighting

- Dwelling unit (apartment) lighting power: the 2015 IECC requires 75% of all permanently installed luminaires in dwelling units to be high efficacy. Standard 90.1-2013 exempts dwelling units from lighting power requirements.

- Controls for secondary daylight zone: the 2015 IECC does not require secondary daylight zones to have daylight responsive controls; Standard 90.1-2013 does.

d. Additional efficiency package options

- The 2015 IECC requires one of the six high efficiency package options to be included; Standard 90.1-2013 does not have such options.

On a national average basis for all prototypes combined, the 2015 IECC and Standard 90.1-2013 are within 1% for both energy use and energy costs. The 2015 IECC has a national weighted EUI of 54.5 kBtu/ft^2-yr while the corresponding number for Standard 90.1-2013 is 54.1 kBtu/ft^2-yr. Likewise, the ECIs are very close between the 2015 IECC (1.31 \$/ft^2-yr) and Standard 90.1-2013 (1.30 \$/ft^2-yr).

Table B.1. Site Energy and Energy Cost Savings between Standard 90.1-2013 and the 2015 IECC

Building Prototype	Site EUI			ECI		
	Standard 90.1-2013 (kBtu/ft²/yr)	2015 IECC (kBtu/ft²/yr)	2015 IECC compared to 90.1-2013 (%)	Standard 90.1-2013 ($/ft²/yr)	2015 IECC ($/ft²/yr)	2015 IECC compared to 90.1-2013 (%)
Small Office	29.4	29.6	-0.7	0.88	0.88	0.0
Medium Office	34.1	34.6	-1.5	0.95	0.97	-2.1
Large Office	70.8	71.7	-1.3	2.01	2.04	-1.5
Standalone Retail	45.9	47.3	-3.1	1.20	1.21	-0.8
Strip Mall	55.1	54.0	2.0	1.42	1.39	2.1
Primary School	54.2	55.5	-2.4	1.28	1.34	-4.7
Secondary School	41.7	42.8	-2.6	1.08	1.12	-3.7
Outpatient Healthcare	115.8	117.6	-1.6	3.00	3.07	-2.3
Hospital	123.7	128.0	-3.5	2.85	2.98	-4.6
Small Hotel	60.0	60.4	-0.7	1.29	1.30	-0.8
Large Hotel	89.0	87.9	1.2	1.81	1.81	0.0
Warehouse	17.1	15.5	9.4	0.38	0.36	5.3
Quick-Service Restaurant	576.4	582.0	-1.0	8.78	8.83	-0.6
Full-Service Restaurant	372.5	373.8	-0.3	6.41	6.44	-0.5
Mid-Rise Apartment	43.9	44.2	-0.7	1.21	1.22	-0.8
High-Rise Apartment	46.9	47.6	-1.5	1.08	1.11	-2.8
National Weighted Average	**54.1**	**54.5**	**-0.7**	**1.30**	**1.31**	**-0.8**

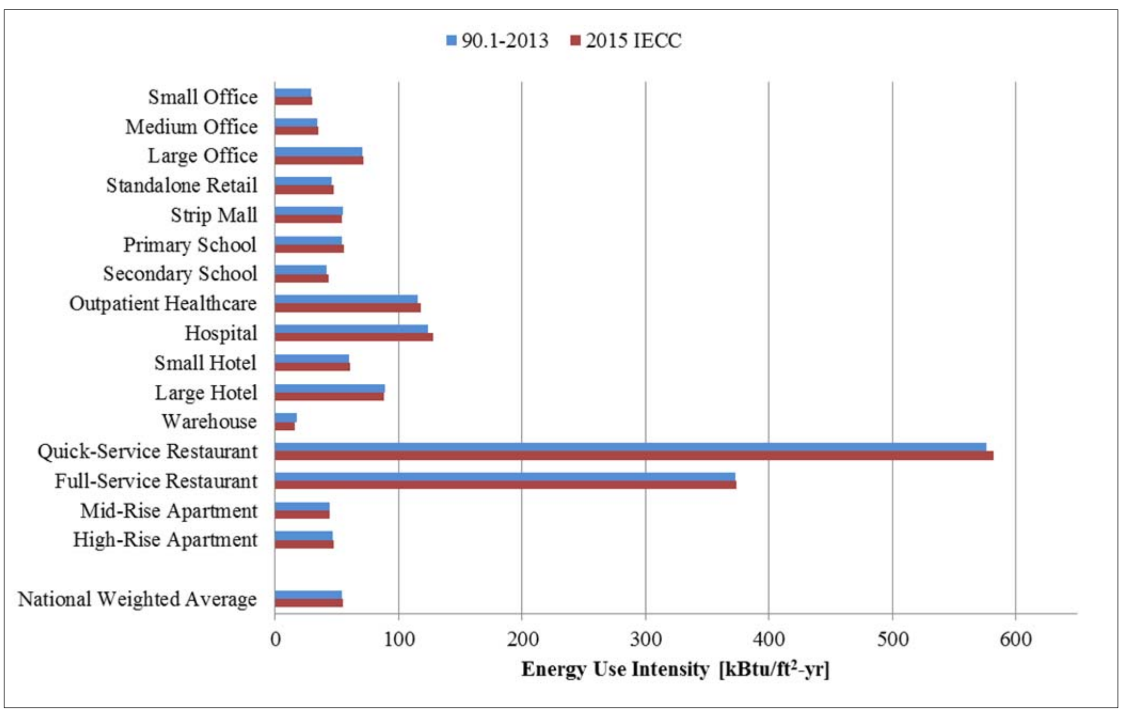

Figure B.1. National Average Energy Use Intensity for Standard 90.1 and IECC Prototypes

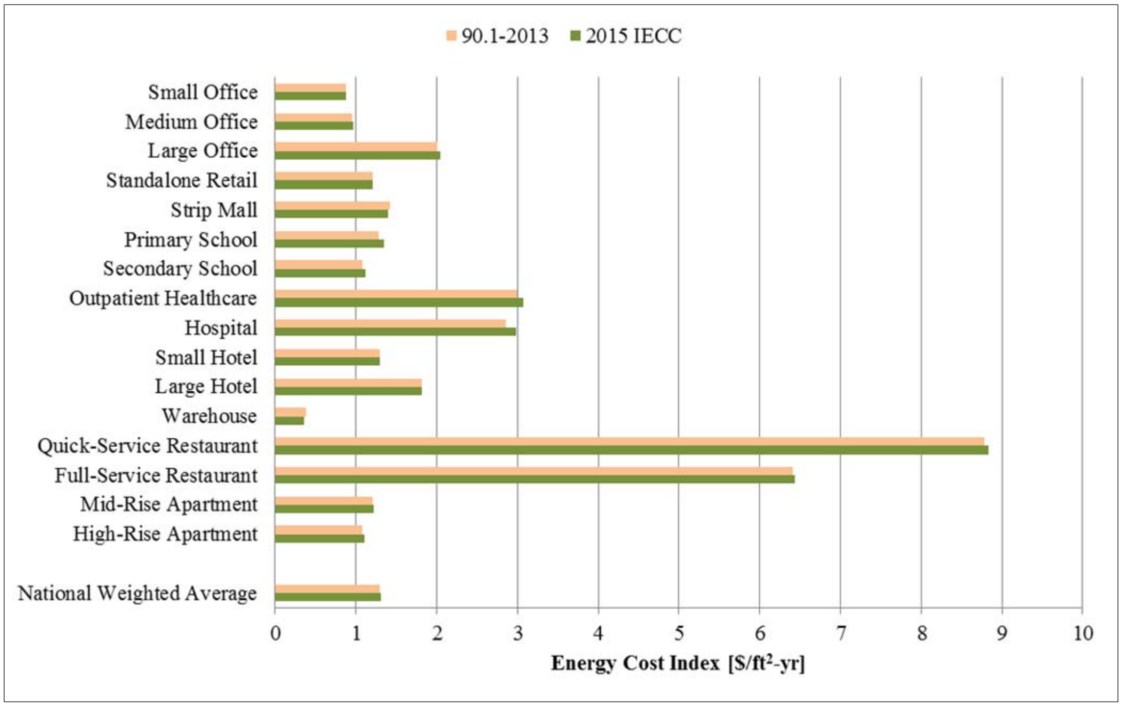

Figure B.2. National Average Energy Cost Index for Standard 90.1 and IECC Prototypes

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