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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016

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List of Acronyms

AEO	Annual Energy Outlook
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CBECS	Commercial Building Energy Consumption Survey
CFL	compact fluorescent lamp
DDC	direct digital control
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
ECI	energy cost intensity
ECPA	Energy Conservation and Production Act
EIA	Energy Information Administration
EMS	energy management system
ERV	energy recovery ventilator
EUI	energy use intensity
HVAC	Heating, Ventilating, and Air Conditioning
HVACR	Heating, Ventilating, Air Conditioning and Refrigerating
IEER	integrated energy efficiency ratio
IES	Illuminating Engineering Society
LPD	lighting power density
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient
SSPC	Standing Standards Project Committee
SWH	service water heating
VAV	variable air volume
VFD	variable frequency drive
VRF	variable-refrigerant-flow
VSD	variable speed drive
Wh	Watt-hour

Executive Summary

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for building energy conservation standards, administered by the DOE Building Energy Codes Program. (42 U.S.C. 6831 et seq.) Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA Standard 90.1-1989 (Standard 90.1-1989 or 1989 edition), or any successor to that code, is revised, the Secretary of Energy (Secretary) must make a determination, not later than 12 months after such revision, whether the revised code would improve energy efficiency in commercial buildings, and must publish notice of such determination in the Federal Register. (42 U.S.C. 6833(b)(2)(A))

Standard 90.1 is developed under ANSI-approved consensus procedures, and is under continuous maintenance by a Standing Standard Project Committee (commonly referenced as SSPC 90.1). ASHRAE has an established program for regular publication of addenda, or revisions, including procedures for timely, documented, consensus action on requested changes to the Standard.[1] Standard 90.1-2016 was published in October 2016, triggering the statutorily-required DOE review process.

To meet the statutory requirement, DOE conducted an analysis to quantify the expected energy savings associated with Standard 90.1-2016. This report documents the methodology used to conduct the analysis below.

Based on the analysis, DOE has determined that the 2016 edition of the ANSI/ASHRAE/IES Standard 90.1 would improve overall energy efficiency in buildings subject to the code compared to the 2013 edition of Standard 90.1.

Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analysis and determinations, and is based on a combination of *qualitative* and *quantitative* assessments:

- **Qualitative**: The first phase of analysis was a comparative review of the textual requirements of the Standard, examining specific changes (known as 'addenda') made between Standard 90.1-2016 and the previous 2013 edition. ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard, and then bundles them together to form the next published edition. Addenda with direct impact on energy use were identified, and their anticipated impact on energy use was determined.
- **Quantitative**: The second phase of analysis examined the impact of addenda having a direct impact on energy use. The quantitative phase uses whole-building energy simulation and relies upon the established DOE methodology for energy analysis, which is based on sixteen representative building types across all U.S. climate zones, as defined by Standard 90.1. Energy use intensities (EUIs) by fuel type and by end-use were developed for each building type, and weighted by the relative square footage of construction to estimate the difference between the aggregated national energy use under Standard 90.1-2013, which serves as the baseline, and Standard 90.1-2016.

Results

In creating Standard 90.1-2016, ASHRAE published 121 addenda in total, of which:

- 46 are expected to *decrease* energy use (i.e., increased energy savings);
- 5 are expected to *increase* energy use (i.e., decreased energy savings), and;
- 70 are expected to have *no direct impact* on energy savings (such as administrative or clarifications or changes to alternative compliance paths).

[1] More information on ANSI/ASHRAE/IES Standard 90.1-2016 is available at: https://www.ashrae.org/resourcespublications/bookstore/standard-90-1.

New commercial buildings meeting the requirements of Standard 90.1-2016 that were analyzed in the Quantitative Analysis exhibit national savings of approximately (compared to Standard 90.1-2013):

- 8.3 percent energy *cost* savings;
- 7.9 percent *source* energy savings, and;
- 6.8 percent *site* energy savings.

The quantitative analysis relies upon prototype buildings reflecting a mix of typical U.S. building types and construction practices. In creating its prototypes, DOE leverages recent U.S. construction data which is mapped to the commercial building types defined by the Energy Information Administration (EIA) and adapted for use by Standard 90.1. In combination with resulting building type weighting factors, the prototypes represent approximately 80 percent of the total square footage of new commercial construction (Jarnagin and Bandyopadhyay 2010).

Energy cost indices (ECIs) and EUIs by building type are shown in Table ES.1 and Table ES.2 for Standard 90.1-2013 and Standard 90.1-2016, respectively, including site and source energy. Percentage savings aggregated at the national level are shown in Figure ES.1 and analogous tables aggregated by climate zone are included in Section 4.2.

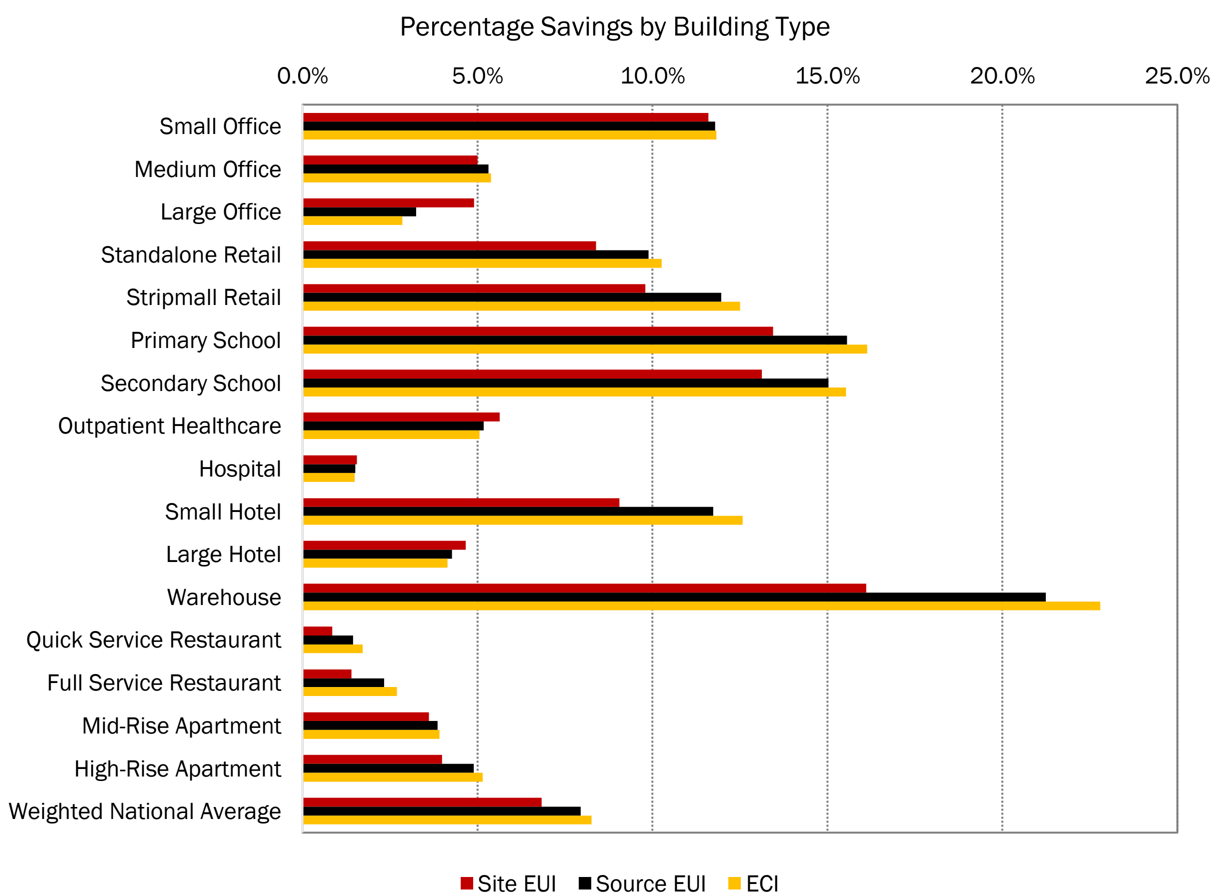

Figure ES.1. Percentage Savings by Building Type from 90.1-2013 to 90.1-2016

Table ES.1. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	29.4	85.8	$0.88
	Medium Office	6.05	33.4	93.1	$0.95
	Large Office	3.33	70.6	197.5	$2.01
Retail	Stand-Alone Retail	15.25	45.7	119.2	$1.19
	Strip Mall	5.67	57.6	152.6	$1.53
Education	Primary School	4.99	50.4	124.7	$1.23
	Secondary School	10.36	42.1	107.3	$1.07
Healthcare	Outpatient Health Care	4.37	118.8	303.6	$3.02
	Hospital	3.45	122.0	286.2	$2.78
Lodging	Small Hotel	1.72	60.5	134.6	$1.29
	Large Hotel	4.95	89.4	191.0	$1.80
Warehouse	Non-Refrigerated Warehouse	16.72	17.6	39.9	$0.38
Food Service	Quick Service Restaurant	0.59	569.5	971.8	$8.41
	Full Service Restaurant	0.66	371.3	694.9	$6.25
Apartment	Mid-Rise Apartment	7.32	43.6	123.2	$1.26
	High-Rise Apartment	8.97	47.2	113.9	$1.12
National		100.00	54.1	132.3	$1.30

Table ES.2. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype	Floor Area Weight (%)	Whole Building Energy Metrics: Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	26.0	75.7	$0.78
	Medium Office	6.05	31.8	88.2	$0.90
	Large Office	3.33	67.2	191.1	$1.95
Retail	Stand-Alone Retail	15.25	41.8	107.4	$1.07
	Strip Mall	5.67	51.9	134.3	$1.34
Education	Primary School	4.99	43.6	105.3	$1.03
	Secondary School	10.36	36.6	91.2	$0.90
Healthcare	Outpatient Health Care	4.37	112.1	287.9	$2.87
	Hospital	3.45	120.1	281.9	$2.74
Lodging	Small Hotel	1.72	55.0	118.8	$1.12
	Large Hotel	4.95	85.2	182.8	$1.73
Warehouse	Non-Refrigerated Warehouse	16.72	14.8	31.5	$0.30
Food Service	Quick Service Restaurant	0.59	564.6	957.7	$8.27
	Full Service Restaurant	0.66	366.1	678.7	$6.08
Apartment	Mid-Rise Apartment	7.32	42.0	118.5	$1.21
	High-Rise Apartment	8.97	45.4	108.3	$1.06
National		100.00	50.4	121.8	$1.19

Table ES.3. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Building Type

Building Type	Prototype	Floor Area Weight (%)	Savings (%)		
			Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.6	11.8	11.8
	Medium Office	6.05	5.0	5.3	5.4
	Large Office	3.33	4.9	3.2	2.9
Retail	Stand-Alone Retail	15.25	8.4	9.9	10.3
	Strip Mall	5.67	9.8	12.0	12.5
Education	Primary School	4.99	13.4	15.6	16.1
	Secondary School	10.36	13.1	15.0	15.5
Healthcare	Outpatient Health Care	4.37	5.6	5.2	5.1
	Hospital	3.45	1.6	1.5	1.5
Lodging	Small Hotel	1.72	9.1	11.7	12.6
	Large Hotel	4.95	4.7	4.3	4.1
Warehouse	Non-Refrigerated Warehouse	16.72	16.1	21.2	22.8
Food Service	Quick Service Restaurant	0.59	0.8	1.4	1.7
	Full Service Restaurant	0.66	1.4	2.3	2.7
Apartment	Mid-Rise Apartment	7.32	3.6	3.9	3.9
	High-Rise Apartment	8.97	4.0	4.9	5.1
National		100.00%	6.8%	7.9%	8.3%

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1. Introduction

ANSI/ASHRAE/IES Standard 90.1 is recognized by the U.S. Congress as the national model energy code for commercial buildings under the Energy Conservation & Production Act (ECPA), as amended, (42 USC 683). With each new edition of Standard 90.1, Section 304(b) of ECPA directs the Secretary of Energy to make a *determination* as to whether the update would improve energy efficiency in commercial buildings.

Standard 90.1-2016 (ASHRAE 2016), the most recent edition, was published in October 2016, triggering the statutorily-required DOE review and determination process. A notice of the determination must be published in the Federal Register not later than 12 months after such revision. (42 U.S.C. 6833 (b)(2)(A)). Within two years of publication of the determination, each State is required to certify that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency with respect to the revised or successor code and to include in its certification a demonstration that the provisions of its commercial building code, regarding energy efficiency, meet or exceed the revised Standard. (42 U.S.C. 6833(b)(2)(B)(i))

On September 26, 2014, DOE issued an affirmative determination of energy savings for Standard 90.1-2013 (ASHRAE 2013a), which concluded that it would achieve greater overall energy efficiency in commercial buildings required to meet the standards than the previous edition, Standard 90.1-2010 (79 FR 57900 2014). Through this determination, Standard 90.1-2013 became the national model energy code for commercial buildings. Consequently, and consistent with previous determinations, it also then represents the baseline to which future changes are compared, including the current review of Standard 90.1-2016. In performing its determination, DOE recognizes that not all states adopt the national model energy code directly, and many states adopt and update their codes at different rates. Instead of adopting Standard 90.1 directly, many states adopt the International Energy Conservation Code which includes the option to comply with Standard 90.1 by reference (ICC 2015). The DOE Building Energy Codes Program tracks the status of state code adoption (DOE 2018).

To fulfill its statutory directive, DOE analyzed Standard 90.1-2016 to understand its overall impact on energy efficiency in commercial buildings required to meet the standard. Section 2 of this report summarizes the addenda included in Standard 90.1-2016; Section 3 documents the qualitative and quantitative analysis methodology; Section 4 presents the analysis results. In addition, Appendix A: discusses addenda not included in the quantitative analysis. Appendix A: details the modeling strategies for individual addenda included in the quantitative analysis.

1.1 Compliance with Standard 90.1

Standard 90.1-2016 includes several paths for compliance in order to provide flexibility to users of the Standard. The prescriptive path, which is widely considered the most traditional, establishes criteria for energy-related characteristics of individual building components such as minimum insulation levels, maximum lighting power, and controls for lighting and HVAC&R systems. Some of those requirements are considered "mandatory", meaning that they must be met even when one of the other optional paths are utilized (e.g., performance path). These other optional paths are further described below.

In addition to the prescriptive path, Standard 90.1 includes two optional whole building performance paths. The first, known as the *Energy Cost Budget* (ECB) method, provides flexibility in allowing a designer to "trade-off" compliance. This effectively allows a designer to not meet a given prescriptive requirement if the impact on energy cost is offset by exceeding other prescriptive requirements, as demonstrated through established energy modeling protocols. A building is deemed in compliance when the annual energy cost of the proposed design is no greater than the annual energy cost of the reference building design (baseline). In addition, Standard 90.1-2016 includes a second performance approach, Appendix G, the *Performance Rating Method*. In previous editions of Standard 90.1 (i.e., prior to the current 2016 edition), Appendix G has been used to rate the performance of buildings that exceed the requirements of Standard 90.1 for "beyond code" programs, including the LEED Rating System, ASHRAE Standard 189.1, the International Green Construction Code (IgCC), and other above-code programs. Beginning with the 2016 edition of Standard 90.1, Appendix G also adds the capability to demonstrate minimum energy code compliance.

2. Summary of Addenda Included in Standard 90.1-2016

ASHRAE publishes changes to Standard 90.1 as individual addenda to the preceding Standard, and then bundles them together to form the next published edition. In creating the 2016 edition, ASHRAE published 121 addenda in total (listed in Appendix H of Standard 90.1-2016). Review drafts and additional information for each addendum can be found on the ASHRAE website (ASHRAE 2016b).

Table 1 shows the number of addenda included in Standard 90.1-2016 grouped into the primary sections of the standard they impact.

Table 1. Number of Addenda affecting Various Sections in Standard 90.1-2016

Section	Number of Addenda
5. Building Envelope	19
6. Heating, Ventilating, and Air Conditioning	43
7. Service Water Heating	4
8. Power	2
9. Lighting	18
10. Other Equipment	3
Addenda Affecting Performance Paths (including Appendices C and G)	29
Normative References	1
Various	2
Total	121

More broadly, DOE characterized the individual addenda into four categories which helped guide the analysis. Those that:

1. are clarifications, administrative, or update references to other documents;
2. modify prescriptive and mandatory design and construction requirements for the envelope, HVAC, service water heating (SWH), power, lighting, and other equipment sections of the standard;
3. modify the performance path options for compliance (the energy cost budget, building envelope trade-off option, and performance rating method sections of Standard 90.1), or;
4. modify normative references.

3. Methodology

3.1 Overview

The *qualitative* phase of the analysis made initial assessments as to whether an individual change decreased energy use, increased energy use, or did not affect energy use in a direct manner. The *quantitative* phase then used whole-building energy modeling and simulation to quantify the impact of the collection of addenda on overall energy use. The following steps provide a general overview of the process:

Qualitative Analysis:

1. Determine whether each addendum was applicable to the *prescriptive* and *mandatory* requirements of Standard 90.1-2016.

2. Determine whether each addendum applicable to the prescriptive path directly impacts energy use.

3. Of the addenda that directly impact energy use, determine whether they increase or decrease energy use.

Quantitative Analysis:

4. Of the addenda that directly impact energy use, determine those that should be captured in the quantitative analysis.

5. Quantify the national impact on energy use of the addenda in step 4.

Additional detail on each phase of the analysis is provided in Sections 3.2 and 3.3.

3.2 Qualitative Analysis

Expanding upon the steps presented in the previous section, the first and second steps of the qualitative analysis are used to filter out addenda that were considered to not directly impact energy use (within the context of this analysis). Addenda were excluded if they:

1. Were not applicable to the *prescriptive* and *mandatory* requirements of the Standard, meaning they only applied to the performance paths in Standard 90.1: Section 11 (Energy Cost Budget Method), Appendix C (Methodology for Building Envelope Trade-off Option), and Appendix G (The Performance Rating Method). The performance paths are intended to provide equivalent performance to the prescriptive path. As the stringency of the prescriptive path is increased, the performance path rules and targets are changed to mirror that increase. Using the prescriptive and mandatory requirements therefore effectively represents changes to the entire standard. Additionally, the purpose of the performance paths is to give designers and builders flexibility which they do by allowing an almost limitless number of trade-off combinations which will comply with the Standard. Analytically, it is not practical or possible to model all these combinations.

2. Affected the prescriptive path but had no impact on energy use or an undetermined impact within the scope of the analysis. Addenda with no impact include administrative changes or clarifications, updates of references to other documents, and other text changes that may improve the usability of Standard 90.1. Addenda with undetermined impact include those related to metering, to equipment that could be subject to future federal rulemaking, and to those whose impact on energy is highly dependent on occupant behavior.

The addenda that were considered to not have a direct impact on energy use, as described above, are compiled in Appendix A:. The remaining addenda were passed to the next step in the qualitative analysis, which was to make a determination of the anticipated impact on energy use, i.e., whether the addendum will decrease or increase energy use. Section 4.1 presents the results of the qualitative analysis.

3.3 Quantitative Analysis

The present quantitative analysis builds on previous work by DOE to assess the energy performance of new editions of Standard 90.1. As described in the previous section, whole-building energy models were used to quantify the impact of addenda on energy use. Individual building models were created to represent each unique combination of the mandatory and prescriptive requirements for Standard 90.1-2013 for each of 16 prototype building types in each of 16 climate zones. Each of these compliant models was then duplicated, with the second version amended only to incorporate the new requirements of 90.1-2016. Additional details of the implementation into the prototype building models for each of the 21 addenda are provided in Appendix B.

The models were simulated using *EnergyPlus Version 8.0* (DOE 2013). Those addenda that were not captured through the quantitative analysis were filtered out and are labeled as such in Table 4 in Section 4.1. Addenda were not included in the quantitative analysis when they:

1. Impact features not found in typical building designs: As explained below in Section 3.3.1, the prototype models include the most common design features found in each building type in the U.S. Therefore, there are many less common features that are not represented in the prototypes, such as variable refrigerant systems, swimming pools, underground parking garages, and so on. Addenda affecting these features of buildings were not be captured via the prototypes in order to preserve representation of the typical building stock.

2. Impact only existing buildings: This analysis is primarily equipped to assess the impact of Standard 90.1 on new commercial building construction (relative to a previous model code edition). Standard 90.1 includes provisions applicable to existing buildings and can be applied in commercial additions, alterations and renovations. While it is recognized that Standard 90.1 is commonly applied in these situations, provisions applying to existing buildings are generally omitted from the quantitative portion of the DOE analysis. This is because the conditions for the baseline building are highly specific to the individual building being modified, and can vary significantly depending upon the age of the building baseline systems, and past modifications. Further, analytical infrastructure does not currently exist that would yield reasonable levels of precision and certainty relative to the new construction analysis. Therefore, while Standard 90.1 provisions impacting existing buildings certainly have an impact at the building level, they are not currently included in the quantitative analysis.

3. Adopt standard practice: The systems and their configuration in the prototype models is based on standard practice that has been widely adopted in the U.S. When an addendum incorporated such standard practice into the code, it did not trigger a change to the prototypes and thus, had no affect within the quantitative analysis.

4. Were related to verification or commissioning: Addenda related to verification, commissioning, and fault-detection generate savings only when there is imperfect operation. Because the models and simulation assume ideal operation, including these addenda would have no impact.

5. Incorporated federal minimum equipment standards: These addenda will improve efficiency even in the absence of Standard 90.1-2016, and therefore, they were left out of the quantitative analysis. Additional discussion is provided in Section 3.3.4.

3.3.1 Building Types and Model Prototypes

The sixteen prototype buildings used in the quantitative analysis largely correspond to a classification scheme established in the 2003 DOE/Energy Information Administration (EIA) Commercial Building Energy

Consumption Survey (CBECS) (EIA 2003). CBECS separates the commercial sector into 29 categories and 51 subcategories using the two variables “principal building activity” (PBA) and “detailed principal building activity” (PBAplus, for more specific activities). DOE relied heavily on these classifications in determining the buildings to be represented by the set of prototype building models. By mapping CBECS observations to each prototype building, DOE also used the CBECS building characteristics data to develop prototypes that could best represent the building stock.

The exception to this is multi-family housing buildings which are not included in CBECS but are covered by Standard 90.1, if more than three stories high. Consequently, DOE developed mid-rise and high-rise multi-family prototype buildings to add to the 14 prototype buildings identified through the review of CBECS. The characteristics of the mid-rise and high-rise multi-family buildings were developed using data from a separate study by Pacific Northwest National Laboratory (PNNL) (Gowri et al. 2007).

Table 2 lists the broad building category, the prototype building, floor area of the prototype building, and its construction weight relative to the other building types. DOE developed three sizes and form factors characteristic of small, medium, and large office buildings to reflect the wide variation in office building design. Similarly, retail, education, healthcare, lodging, food service, and apartments have two representative prototypes each.

The sixteen prototype buildings are representative of the characteristics of new construction in the U.S. It is not feasible to simulate all building types and possible permutations of building design. Further, data are simply not available to correctly weight each possible permutation in each U.S. climate zone as a fraction of the national building construction mix. Hence, the quantitative analysis focuses on the use of prototype buildings that reflect a representative mix of typical construction practices. Together with the construction weighting factors (described in Section 3.3.3), the 16 prototypes represent approximately 80% of the total square footage of new commercial construction, including multi-family buildings more than three stories tall, consistent with the scope of Standard 90.1 (Jarnagin and Bandyopadhyay 2010).

Table 2. Commercial Prototype Building Models

Building Type	Prototype Building	Floor Area (ft^2)	Floor Area (%)
Office	Small Office	5,502	5.61
	Medium Office	53,628	6.05
	Large Office	498,588	3.33
Retail	Stand-Alone Retail	24,692	15.25
	Strip Mall	22,500	5.67
Education	Primary School	73,959	4.99
	Secondary School	210,887	10.36
Healthcare	Outpatient Health Care	40,946	4.37
	Hospital	241,501	3.45
Lodging	Small Hotel	43,202	1.72
	Large Hotel	122,120	4.95
Warehouse	Non-Refrigerated Warehouse	52,045	16.72
Food Service	Quick Service Restaurant	2,501	0.59
	Full Service Restaurant	5,502	0.66
Apartment	Mid-rise Apartment	33,741	7.32
	High-rise Apartment	84,360	8.97
Total		1,515,674	100.00

3.3.2 Climate Zones

Building models were analyzed in standardized climate zones described in ASHRAE Standard 169-2013 (ASHRAE 2013b). Standard 169-2013 includes nine thermal zones and three moisture regimes. The United States climate zones and moisture regimes are shown in Figure 1.

For this analysis, a specific climate location (city) was selected as a representative of each of the 16 climate/moisture zones found in the U.S. These are also consistent with representative cities approved by the Standing Standards Project Committee (SSPC) 90.1 for setting the criteria for 90.1-2016.

The 16 cities used in the current analysis are:

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

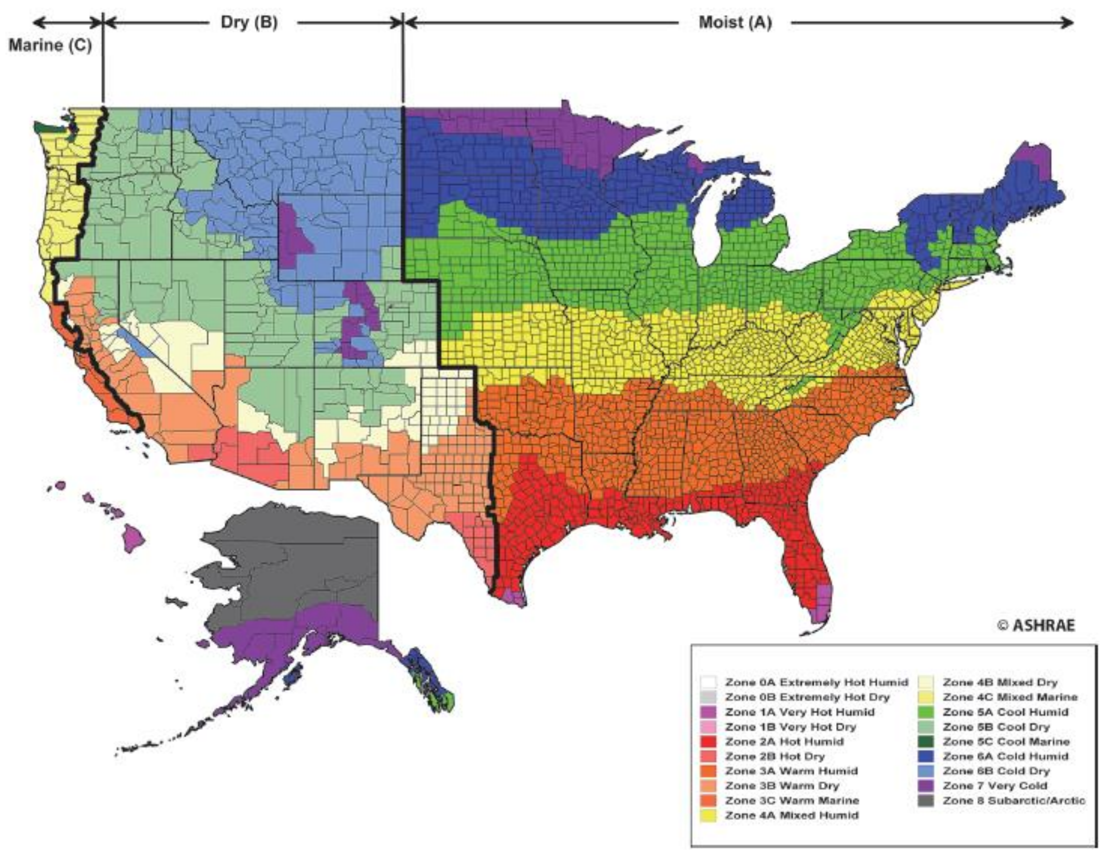

Figure 1. United States Climate Zone Map

The climate zones included in Standard 90.1-2016 are defined by ASHRAE Standard 169-2013 (ASHRAE 2013b), which is incorporated into Standard 90.1 by reference. Standard 169 was recently updated (to the 2013 edition), which resulted in changes to climate zone assignments for some locations in Standard 90.1, as well as the incorporation of a new Climate Zone 0. While the revision of Standard 169 is not the focus of the current analysis, this change indirectly affects how climate zones are defined and applied through Standard 90.1. For example, the recent update shifted a relatively small number of locations to warmer climate zones where they were typically subject to less stringent requirements, therefore increasing energy use in those instances. These impacts, as well as the overall effects resulting from the incorporation of Standard 169-2013, are captured in the quantitative analysis.

3.3.3 Development of Weighting Factors

Weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level were developed from construction data purchased from McGraw Hill. This data represents all new buildings, as well as additions to existing facilities, over a period of five years (2003-2007), and based on a set of 254,158 individual records of commercial building construction across the U.S. covering a total of 8.2 billion square feet. Details of their development are further discussed in a PNNL report (Jarnagin and Bandyopadhyay 2010).[2] Table 3 lists the resulting weighting factors by climate and by prototype building used in the analysis. These data are used to develop the relative fractions of new construction floor space represented by prototype building and within the 16 climate zones.

Using the EUI statistics from each building simulation and the corresponding relative fractions of new construction floor space, DOE developed floor-space-weighted national EUI statistics by energy type for each building type and standard edition. DOE then summed these energy type-specific EUI estimates to obtain the national site energy EUI by building type and standard edition. DOE also applied national data for average energy prices and average source energy conversion rates to the energy type-specific EUI data to obtain estimates of national source energy EUI and national energy cost intensity (ECI), again by building type and by standard edition.

3.3.4 Treatment of Federal Minimum Equipment Standards

Standard 90.1 contains requirements for specific types of equipment that are regulated by federal efficiency standards for manufacturing and import. As mentioned in Section 3.2, addenda that adopted federal efficiency standards were excluded from the analysis to ensure that savings from energy codes and efficiency standards were not double counted, and to avoid speculating on future rulemaking processes. In the quantitative analysis, this was accomplished by assuming current minimum federal equipment efficiencies (i.e. as published in Standard 90.1-2016) in both the 2013 and 2016 prototype building models, which is consistent with historical DOE determination analyses.

[2] The original weighting factors were based on the climate to county mapping in Standard169-2006. This analysis uses updated mapping from 169-2013 and the construction weights were updated accordingly. The impact of changing construction weights is described in Athalye et al. (2016).

Table 3. Relative Construction Volume Weights for 16 Prototype Buildings by Climate Zone (percent)

Building Type	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	Weights by Bldg Type
Large Office	0.13	0.39	0.06	0.49	0.28	0.12	1.05	0.00	0.15	0.44	0.12	0.00	0.08	0.00	0.01	0.00	3.33
Medium Office	0.21	0.85	0.29	0.83	0.72	0.14	1.16	0.04	0.19	1.00	0.35	0.01	0.21	0.03	0.02	0.01	6.05
Small Office	0.17	1.13	0.29	1.02	0.47	0.08	0.84	0.06	0.12	0.89	0.32	0.01	0.18	0.03	0.02	0.00	5.61
Stand-Alone Retail	0.41	2.33	0.51	2.57	1.25	0.19	2.44	0.13	0.41	3.36	0.79	0.02	0.69	0.08	0.06	0.01	15.25
Strip Mall	0.20	1.08	0.25	1.11	0.63	0.10	0.89	0.02	0.11	0.96	0.20	0.00	0.09	0.01	0.00	0.00	5.67
Primary School	0.16	0.99	0.16	0.96	0.45	0.05	0.87	0.03	0.09	0.82	0.23	0.00	0.12	0.03	0.02	0.00	4.99
Secondary School	0.32	1.59	0.23	1.99	0.82	0.11	1.97	0.06	0.23	2.15	0.45	0.01	0.30	0.08	0.05	0.01	10.36
Hospital	0.06	0.51	0.10	0.49	0.27	0.04	0.66	0.03	0.10	0.80	0.21	0.00	0.12	0.02	0.03	0.00	3.45
Outpatient Health Care	0.08	0.62	0.13	0.63	0.28	0.06	0.81	0.02	0.17	1.06	0.22	0.01	0.23	0.03	0.03	0.00	4.37
Full Service Restaurant	0.02	0.11	0.02	0.12	0.05	0.01	0.12	0.01	0.01	0.13	0.03	0.00	0.02	0.00	0.00	0.00	0.66
Quick Service Restaurant	0.02	0.10	0.02	0.10	0.06	0.01	0.09	0.01	0.01	0.12	0.03	0.00	0.02	0.00	0.00	0.00	0.59
Large Hotel	0.13	0.69	0.12	0.70	0.79	0.11	0.90	0.04	0.12	0.90	0.20	0.00	0.16	0.05	0.03	0.00	4.95
Small Hotel	0.03	0.30	0.03	0.27	0.11	0.02	0.32	0.02	0.04	0.35	0.09	0.00	0.08	0.03	0.02	0.00	1.72
Non-Refrigerated Warehouse	0.51	3.07	0.58	2.70	2.30	0.15	2.84	0.08	0.43	3.01	0.70	0.00	0.29	0.03	0.03	0.00	16.72
High-rise Apartment	1.69	1.48	0.08	0.62	0.74	0.17	2.38	0.00	0.36	1.25	0.12	0.00	0.06	0.02	0.01	0.00	8.97
Mid-rise Apartment	0.34	1.19	0.09	0.82	0.86	0.26	1.58	0.02	0.36	1.15	0.32	0.01	0.23	0.06	0.03	0.00	7.32
Weights by Zone	4.46	16.43	2.98	15.42	10.08	1.61	18.92	0.57	2.92	18.39	4.37	0.07	2.89	0.49	0.37	0.05	100.00

3.4 Comments on Methodology

The goal of this analysis was to determine if the 2016 edition of 90.1 is more energy-efficient relative to the 2013 edition. The approach selected to make this determination has certain limitations. These limitations are outlined below.

State Code Adoption: As discussed in the Introduction (Section I), states adopt and update their energy codes in a variety of different manners. Some states adopt updated model codes as published while others draft state-level amendments to modify the model code. States also adopt codes at varying rates, with some states updating relatively quickly after a new edition is available, while others may remain on older editions for a longer duration. While these variables are not included in the DOE determination analysis, they ultimately affect the impacts of the model codes as applied across adopting states and localities

Prototype Representation: Not all the addenda impacting energy use can be captured by the quantitative analysis due to the fixed nature of the prototypes, as explained in Section 3.3.1. Thus, the impact resulting from the quantitative analysis can be considered conservative. At the same time, the impact could be considered generous because the addenda that were included impacted all buildings of a given type, i.e., the weighting factors carried the impact to all buildings of a given type in a climate zone even though some of those buildings may not fit the descriptions of the prototype buildings. For example, the analysis assumes all large office buildings have water-cooled chillers—a property of the Large Office prototype. In reality, some have air-cooled, some have packaged equipment, some have variable refrigerant volume systems, etc. If the water-cooled chiller efficiency improved more than the other systems, the analysis overestimates savings, whereas, if the efficiency improved less than the other systems, the analysis will have underestimated savings.

Combination of Qualitative & Quantitative Analysis: In any high-level analysis there is a need to balance precision, accuracy and practicality. The approach selected here addresses that by performing both a qualitative and quantitative analysis. The quantitative analysis taken together with the qualitative analysis provides a more robust and defensible determination. If the qualitative analysis determines that a large majority of addenda are expected to decrease energy use, and the quantitative analysis also shows a reduction in energy use from addenda impacting representative building designs, then taken together, the determination can be said to be more robust and reliable.

4. Results

4.1 Qualitative Analysis Results

The qualitative analysis concluded that 51 of the 121 addenda had a direct impact on energy use as defined in Section 3.2 — 46 decrease energy use in commercial buildings, while 5 lead to increased energy use. The 70 remaining changes were determined to have no direct impact on energy use. A graphical summary of the qualitative analysis results is shown in Figure 2. The 51 addenda with a direct impact are shown in Table 4, while the remainder are shown in Appendix A:. Six columns of information are listed for each addendum in Table 4:

1. **Addendum**: the letter addenda designation assigned by ASHRAE.
2. **Code Section(s)**: a list of the section numbers in Standard 90.1-2016 that are affected by the addendum.
3. **Description of Change**: a brief description of the change made by the addendum.
4. **Impact on Energy Use**: the anticipated impact of the addendum on energy use.
5. **Included in Quantitative Analysis**: whether the addendum can be included in the forthcoming Quantitative Analysis (see Section 4.2).
6. **Discussion**: how the impact on energy use was determined (and why the addendum was excluded from the quantitative analysis, if applicable).

The DOE determination analysis accounts for *all* changes regardless of whether the individual change is expected to increase or decrease energy use. While the vast majority of changes are found to decrease energy use, changes increasing energy use are occasionally incorporated into the Standard based on updated data sources or to reflect the evolution of standard engineering practices From the perspective of the DOE determination analysis, and to best understand the interative nature of individual code provisions, it is important to consider all changes both increasing and decreasing energy use.

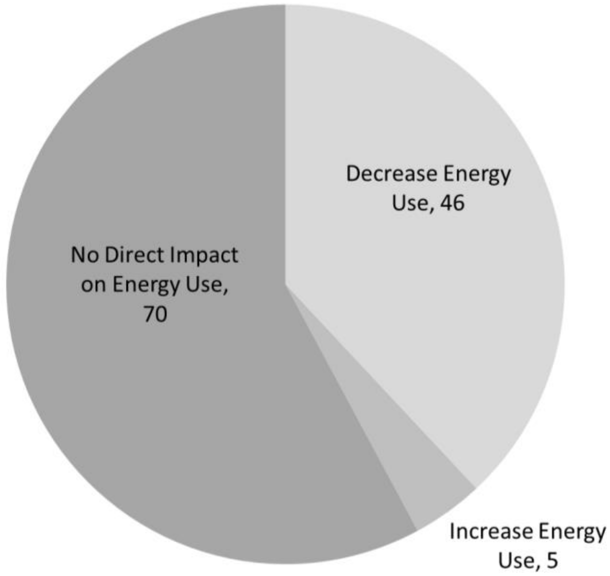

Figure 2. Categorization of Addenda

Table 4. Results of Qualitative Analysis of Standard 90.1-2016

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
a	3.2, 5.1.2.1	Modifies the definition of conditioned space and modifies the heated space criteria table.	Decreases Energy Use	No	Lowers the threshold for spaces to be considered heated resulting in a requirement for additional insulation. Excluded from quantitative analysis because the prototype space classifications are held constant from one edition of the standard to the next.
d	6.3.2, 6.4.3.3	Requires deeper thermostat setback for networked guestrooms or those unoccupied for more than 16 hours/day. Also requires ventilation to be turned off when guestrooms are unoccupied.	Decreases Energy Use	Yes	Increases stringency of hotel/motel guest room control.
e	9.1.2	Increases requirements for alterations to existing building lighting systems.	Decreases Energy Use	No	Excluded from quantitative analysis because the analysis considers new construction only and this applies only to existing buildings.
f	9.4.1.1	Changes an exception to the automatic daylight control requirements for daylight areas under skylights from visible transmittance to effective aperture.	Decreases Energy Use	No	Changes an exception that increases stringency. Excluded from quantitative analysis because typical designs as represented by the prototypes do not qualify for the exception.
i	6.5.1	Eliminates separate cooling capacity thresholds for requiring an economizer in computer rooms. Computer rooms will be required to follow the same thresholds and climate zone requirements as comfort cooling applications.	Decreases Energy Use	Yes	Smaller computer rooms will now need economizers.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
j	6.5.3.3	Requires variable air volume (VAV) system ventilation optimization even when energy recovery ventilator (ERV) is installed.	Decreases Energy Use	Yes	Removes the ventilation optimization exception for ERV, making the requirement more stringent.
l	4.2.4, 4.2.5, 5.2.1, 5.2.9 (new section)	Adds verification requirements for envelope components, including insulation, fenestration, doors, and air leakage.	Decreases Energy Use	No	Excluded from quantitative analysis because the analysis does not take credit for verification or commissioning.
n	Tables 6.8.1-9, 6.8.1-10	Modifies integrated energy efficiency ratio (IEER) values for air-cooled variable refrigerant flow (VRF) air conditioners and heat pumps above 65,000 Btu/h. The new IEERs are between 15% and 20% more stringent.	Decreases Energy Use	No	Excluded from quantitative analysis because typical designs, as represented by the established prototypes, do not include VRF systems.
q	Table 6.5.3.1-2	Allows only the following systems to use the fan power allowance for fully ducted return and/or exhaust systems: (1) systems required to be fully ducted by code or accredited standards; (2) systems required to maintain air pressure differentials between adjacent rooms.	Decreases Energy Use	No	Reduces fan energy through improved efficiency in other components in designs that utilize ducted return or exhaust by choice. Excluded from quantitative analysis because typical designs as represented by prototypes do not utilize this extra return or exhaust duct credit.
s	6.5.2.1	Relieves parallel fan powered box and dedicated outdoor air system (DOAS) with direct digital control (DDC) from requirements c & d in exception 2 of Section 6.5.2.1.	Increases Energy Use	No	Increases energy use because it allows some designs to avoid a requirement for two stages of heating. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include perimeter heating or parallel fan-powered terminal units.
u	6.5.7	Applies transfer air requirements more broadly than to just kitchen exhaust systems, and clarifies the sources of transfer air.	Decreases Energy Use	Yes	Makes transfer air requirements more stringent.
v	5.5.4.5	Deletes exception 2 of the fenestration orientation requirement for obstructions to south-facing glazing.	Decreases Energy Use	No	Deletes the exception increasing stringency. Excluded from quantitative analysis because obstructions are not modeled in the prototypes.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
w	Multiple, Chapters 3, 4, 5, 6, 9, 12, Appendices A, B, D, E, G, Reference Standard Reproduction Annex (new)	Refers 90.1 to new climatic data based on Standard 169-2013 resulting in changes to climate zone assignments for some locations, the creation of a new climate zone 0, and the addition of criteria for climate zone 0. Adds method for rating the solar reflectance index of walls with glass spandrel area and adjusts criteria for minimum skylight area in climate zone 0.	Increases Energy Use	Yes	This change indirectly affects how climate zones are defined and applied through Standard 90.1. For example, the recent update shifted a relatively small number of locations to warmer climate zones where they were typically subject to less stringent requirements, therefore increasing energy use in those instances.
ac	A9.4	Allows the use of the R-value of an airspace in enclosed cavities with or without insulation (Appendix A). Expands the R-value table in Appendix A (based on Chapter 26 of the 2009 Handbook of Fundamentals).	Decreases Energy Use	No	Sets criteria limiting when the R-value of air spaces may be included in calculations. Excluded from quantitative analysis because it did not change opaque envelope U-factors if assemblies modeled in the prototypes.
ag	6.4.3.9	Limits mechanical cooling to 85°F for vestibules, except when the vestibule is tempered with transfer air or heated with recovered energy.	Decreases Energy Use	No	Limits cooling setpoint in vestibules. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include vestibules with cooling.
ah	9.4.1.1	Clarifies that all lighting, including egress lighting on emergency circuits, shall be turned off when the space is unoccupied with 0.02 W/sf in exception.	Decreases Energy Use	Yes	Increases application of controls for emergency lighting.
ai	5.5.4.1, Tables 5.5-0 through 5.5-8	Prescribes lower solar heat gain coefficient (SHGC) for vertical fenestration in climate zone 0 and lower U-factors for vertical fenestration in climate zones 4 through 8.	Decreases Energy Use	Yes	Requires more stringent window U-factor and SHGC.
aj	6.5.3.2.1, 6.5.3.2.4	Requires return and relief fans larger than 0.5 hp to have variable frequency drive (VFD) control, to maintain building pressure, and to avoid disabling of economizer operation.	Decreases Energy Use	No	Ensures proper pressurization that allows economizers to function more efficiently. Excluded from quantitative analysis because return and relief fans are not explicitly modeled in the prototypes.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
ak	6.5.4.1, 6.5.4.3	Addresses a number of issues with hydronic section (6.5.4.1) including removal of the pump power threshold, limiting Section 6.5.4.1 to heating and cooling hydronic systems only, lowering the flow limit exception, and other changes.	Decreases Energy Use	No	Increases application of variable flow hydronic systems and reduces the required minimum flow. Excluded from quantitative analysis because the requirement is standard practice that was already assumed in the prototypes.
al	5.4.3.2	Prescribes air leakage criteria for metal coiling doors in semi-heated spaces.	Decreases Energy Use	Yes	Adds coiling door air leakage requirements.
am	9.4.1.2	Increases the parking garage lighting reduction from 30% to 50% in response to no occupancy, specifies a 50% reduction in lighting power in response to the presence of daylighting, and removes a duplicate exception.	Decreases Energy Use	No	Excluded from quantitative analysis because the prototypes do not include parking garages.
as	9.4.1.4	Requires luminaires in parking areas with input power greater than 78W and mounting height less than 24 ft to reduce power by 50% in response to occupancy.	Decreases Energy Use	Yes	Adds parking lot occupancy controls, thereby reducing parking lot lighting use.
aw	6.5.6.1	Clarifies and limits the exceptions to exhaust air energy recovery requirements (6.5.6.1).	Decreases Energy Use	No	Excluded from quantitative analysis because the exceptions are not used by typical designs as represented by the prototypes.
ay	5.4.3.1.3	Allows non-adhered single-ply roof membranes to qualify as an air barrier material.	Increases Energy Use	No	Increases energy use because it potentially increases heat loss through fluttering. Excluded from quantitative analysis because single-ply non-adhered roofing membranes are not included in the prototypes.
bc	Tables 5.5.0 through 5.5.8	Lowers U-factor criteria for doors.	Decreases Energy Use	Yes	
bi	6.5.2.6	Limits ventilation air heating (DOAS systems).	Decreases Energy Use	No	Limits simultaneous heating and cooling. Excluded from quantitative analysis because the DOAS system in the Large Hotel prototype already meets this requirement.
bj	6.5.4.7	Establishes minimum chilled water coil selection delta T.	Decreases Energy Use	Yes	Reduces pumping energy.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
bk	6.5.3.4	Specifies control of fans in fan powered parallel VAV boxes	Decreases Energy Use	No	Includes several control strategies that reduce energy use in fan powered terminal units. Excluded from quantitative analysis because typical design as represented by the prototypes does not employ parallel fan-powered terminal units.
bn	6.3.2, 6.5.3.6	Requires heat recovery when design calls for greater than 135 percent of industry-accepted ventilation levels.	Decreases Energy Use	No	Requires heat recovery to mitigate to energy impacts of ventilation exceeding industry-accepted levels. Excluded from quantitative analysis because prototype OA is set at ASHRAE Standard 62.1 limits and is already below the maximum.
bs	Table 6.8.1-10	Increases water-cooled VRF efficiencies.	Decreases Energy Use	No	Excluded from quantitative analysis because typical designs as represented by the prototypes do not include VRF systems.
bt	Table 8.4.4	Updates transformer efficiency requirements.	Decreases Energy Use	No	Excluded from quantitative analysis because transformers are a federally-regulated product.
by	7.4.3	Requires insulation of the first 8 ft of branch piping from recirculating SWH systems.	Decreases Energy Use	Yes	Reduces heat loss from SWH branch piping.
ca	6.5.2.2.1	Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp. Eliminates the exception for climate zones 1 and 2.	Decreases Energy Use	Yes	
cb	6.4.4.1.2, Tables 6.8.2-1, 6.8.2-2, 6.8.2	Increases ductwork insulation requirements.	Decreases Energy Use	No	Increases required duct insulation. Excluded from quantitative analysis because duct heat loss is not accounted for in the prototypes.
ce	Tables 6.5.6.1-1 and 6.5.6.1-2	Raises minimum threshold for energy recovery.	Increases Energy Use	Yes	Raises minimum exhaust air energy recovery threshold resulting in fewer systems subject to the requirement.
cf	6.1.1.3.1	Requires replacement HVACR equipment to meet most Section 6 requirements.	Decreases Energy Use	No	Requires replacement equipment to be more energy-efficient. Excluded from quantitative analysis because analysis considers new construction only.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
cg	9.4.2	Reduces exterior lighting power allowances.	Decreases Energy Use	Yes	
ch	Tables 9.5.1 and 9.6.1	Reduces interior lighting power allowances.	Decreases Energy Use	Yes	
ci	5.5.4.5	Modifies fenestration orientation requirements.	Decreases Energy Use	Yes	Increases stringency of fenestration orientation requirements.
cq	6.5.5.2.1	Bases variable speed thresholds for heat rejection fans on motor power, including service factor.	Decreases Energy Use	Yes	Includes service factor in the heat rejection VFD threshold, effectively lowering the threshold.
cv	3.2, 10.4.1, Tables 10.8.1, 10.8.2, and 10.8.3	Increases motor efficiencies.	Decreases Energy Use	No	Excluded from quantitative analysis because motors are a federally regulated product not captured in determination.
cy	3.2, 6.4.1.1, Table 6.8.1-14	Adds definition for indoor pool dehumidifier and moisture removal efficiency. Adds new table with efficiency requirements and rating conditions.	Decreases Energy Use	No	Adds new requirements for pool dehumidifiers. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include indoor pools.
dd	6.5.4.2, Table 6.5.4.2	Reduces the threshold for variable flow pumping requirements for chilled water pumps and adds requirement for heating water pumps.	Decreases Energy Use	Yes	
dg	5.4.3.2	Establishes leakage requirements for glazed, power-operated sliding and folding doors. Provides default U-factors for unlabeled metal coiling and other metal non-swinging doors.	Increases Energy Use	No	Allows higher air leakage for glazed, power-sliding and folding doors, thus increasing energy use. Excluded from quantitative analysis because typical designs as represented by the prototypes do not include these doors.
dk	TABLE 6.8.1-7	Increases the minimum efficiency for axial fan closed circuit cooling towers.	Decreases Energy Use	No	Excluded from quantitative analysis because closed circuit cooling towers are not included in the prototypes.
do	9.4.1	Adds efficacy requirements for lighting installed in dwelling units.	Decreases Energy Use	Yes	Requires high efficiency dwelling unit lighting.

Table 4. (continued)

Addendum	Sections Affected	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
dp	9.4.1.1	Adds exception to restriction on automatic energizing of lighting for open office spaces.	Decreases Energy Use	No	Allowing the use of available advanced control systems that were previously not possible to install without the exception. Excluded from quantitative analysis because the exception is not used by typical designs as represented by the prototypes.
dq	9.6.2	Reduces retail display lighting adder.	Decreases Energy Use	Yes	
dr	3.2, 9.6.2	Reduces decorative lighting adder.	Decreases Energy Use	No	Excluded from quantitative analysis because the prototypes do not include decorative lighting.
du	6.5.1	Requires water-side economizers for chilled water systems including non-fan systems, such as radiant cooling or passive chilled beam systems.	Decreases Energy Use	No	Expands the application of economizers which reduces the reliance on mechanical cooling for more systems. Excluded from quantitative analysis because typical designs do not include radiant cooling or passive chilled beams.
el	6.3.2, 6.4.3, 6.4.3.12	Adds fault detection requirements for DX equipment with economizers.	Decreases Energy Use	No	Allows fault detection to notify operators that systems are malfunctioning. Excluded from quantitative analysis because the analysis does not take credit for verification or commissioning.

4.2 Quantiative Analysis Results

The quantitative analysis only includes those addenda that have a direct impact on energy use as described in Section 3.2 and Section 3.3. A graphical summary of the addenda included in the quantitative analysis is shown in Figure 3. The category labeled "Unquantified Energy Impact" includes those addenda that were determined to have a direct impact on energy use but are not be included in the quantitative analysis. Appendix B describes the implementation of addenda into the prototype models.

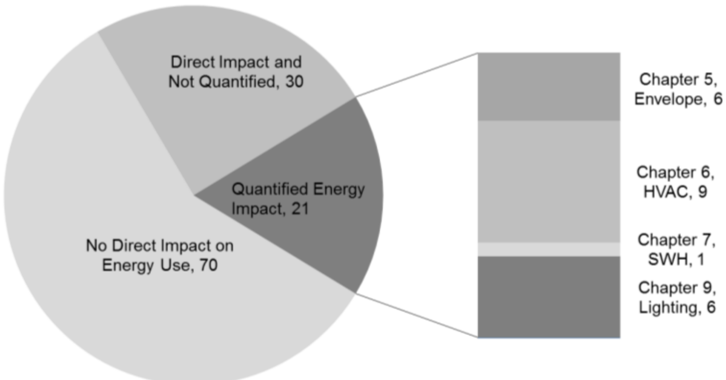

Figure 3. Categorization of Quantified Addenda

Table 5 through Table 8 show the quantitative analysis results by building type and climate zone for Standard 90.1-2013 and 90.1-2016, respectively. The results were aggregated on a national basis for each Standard, based on the weighting factors discussed in Section 3.3.3. In these tables, site energy refers to the energy consumed at the building site, source energy (or primary energy) refers to the energy required to generate and deliver energy to the site. To calculate source energy, conversion factors were applied to the electricity and natural gas consumption. Development of these conversion factors is explained below.

The electric energy source conversion factor of 10,072 was calculated from EIA's Annual Energy Outlook (AEO) 2017 Table A2[3] as follows:

- Delivered commercial electricity, 2016: 4.64 quads
- Commercial electricity related losses, 2016: 9.06 quads
- Total commercial electric energy use, 2016: 13.70 quads
- Commercial electric source ratio, U.S. 2016: 2.95
- Source electric energy factor (3413 Btu/kwh site) 10,072 Btu/kWh[4]

Natural gas EUIs in the prototype buildings were converted to source energy using a factor of 1.088 Btu of source energy per Btu of site natural gas use, based on the 2016 national energy use estimate shown in Table A2 of the AEO 2017 as follows:

- Delivered total natural gas, 2016: 26.27 quads
- Natural gas used in well, field and pipeline: 2.31 quads
- Total gross natural gas use, 2016: 28.58 quads
- Total natural gas source ratio, U.S. 2016: 1.088
- Source natural gas energy factor (100,000 Btu/therm site): 108,800 Btu/therm

[3] Available at https://www.eia.gov/outlooks/aeo/
[4] The final conversion value of 10,072 is calculated using the full seven digit values available in Table A2 of AEO2017. Other values shown in the text are rounded.

To calculate the energy cost, DOE relied on national average commercial building energy prices based on EIA statistics for 2016 in Table 2, "U.S. Energy Prices," of the March 2017 Short Term Energy Outlook for commercial sector natural gas and electricity[5] of:

- $0.1037/kWh of electricity
- $7.26 per 1000 cubic feet ($0.701/therm) of natural gas

DOE recognizes that actual energy costs will vary somewhat by building type within a region, and even more across regions. However, the use of national average figures sufficiently illustrates energy cost savings and the effect on energy efficiency in commercial buildings, as is the purpose of the DOE determination.

Table 9 and Table 10 present the estimated percent energy and energy cost savings between the 2013 and 2016 editions of Standard 90.1 by building type and climate zone respectively.

Overall, the analysis indicates that Standard 90.1-2016 will result in increased energy efficiency in commercial buildings. On a weighted national average basis, Standard 90.1-2016 saves 7.9% of source energy, 6.8% site energy, and 8.3% of energy cost. Weighted national average savings results by building type and climate zone are shown in Figure 4 and Figure 5.

Table 5. Estimated Energy Use Intensity by Building Type – Standard 90.1-2013 (national weighted average)

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics		
			Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	29.4	85.8	$0.88
	Medium Office	6.05	33.4	93.1	$0.95
	Large Office	3.33	70.6	197.5	$2.01
Retail	Stand-Alone Retail	15.25	45.7	119.2	$1.19
	Strip Mall	5.67	57.6	152.6	$1.53
Education	Primary School	4.99	50.4	124.7	$1.23
	Secondary School	10.36	42.1	107.3	$1.07
Healthcare	Outpatient Health Care	4.37	118.8	303.6	$3.02
	Hospital	3.45	122.0	286.2	$2.78
Lodging	Small Hotel	1.72	60.5	134.6	$1.29
	Large Hotel	4.95	89.4	191.0	$1.80
Warehouse	Non-Refrigerated Warehouse	16.72	17.6	39.9	$0.38
Food Service	Quick Service Restaurant	0.59	569.5	971.8	$8.41
	Full Service Restaurant	0.66	371.3	694.9	$6.25
Apartment	Mid-Rise Apartment	7.32	43.6	123.2	$1.26
	High-Rise Apartment	8.97	47.2	113.9	$1.12
National		100.00	54.1	132.3	$1.30

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

Table 6. Estimated Energy Use Intensity by Building Type – Standard 90.1-2016

Building Type	Prototype Building	Floor Area Weight (%)	Whole Building Energy Metrics Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)
Office	Small Office	5.61	26.0	75.7	$0.78
	Medium Office	6.05	31.8	88.2	$0.90
	Large Office	3.33	67.2	191.1	$1.95
Retail	Stand-Alone Retail	15.25	41.8	107.4	$1.07
	Strip Mall	5.67	51.9	134.3	$1.34
Education	Primary School	4.99	43.6	105.3	$1.03
	Secondary School	10.36	36.6	91.2	$0.90
Healthcare	Outpatient Health Care	4.37	112.1	287.9	$2.87
	Hospital	3.45	120.1	281.9	$2.74
Lodging	Small Hotel	1.72	55.0	118.8	$1.12
	Large Hotel	4.95	85.2	182.8	$1.73
Warehouse	Non-Refrigerated Warehouse	16.72	14.8	31.5	$0.30
Food Service	Quick Service Restaurant	0.59	564.6	957.7	$8.27
	Full Service Restaurant	0.66	366.1	678.7	$6.08
Apartment	Mid-Rise Apartment	7.32	42.0	118.5	$1.21
	High-Rise Apartment	8.97	45.4	108.3	$1.06
National		100.00	50.4	121.8	$1.19

Table 7. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2013

Climate Zone	Climate Zone Floor Area Weight %	Whole Building EUI Data for Building Population Site EUI kBtu/ft2-yr	Source EUI kBtu/ft2-yr	ECI $/ft2-yr
1A	4.46	49.2	131.1	$1.32
2A	16.43	51.3	134.4	$1.34
2B	2.98	50.7	133.0	$1.33
3A	15.42	52.6	130.9	$1.29
3B	10.08	48.1	121.7	$1.21
3C	1.61	46.9	120.4	$1.20
4A	18.92	54.9	132.3	$1.30
4B	0.57	56.2	135.2	$1.32
4C	2.92	50.6	121.5	$1.19
5A	18.39	59.8	135.8	$1.31
5B	4.37	56.2	132.5	$1.29
5C	0.07	52.7	128.8	$1.27
6A	2.89	69.0	153.4	$1.47
6B	0.49	64.0	145.3	$1.40
7	0.37	76.8	165.2	$1.56
8	0.05	72.8	147.8	$1.37
National	100.00	54.1	132.3	$1.30

Table 8. Estimated Energy Use Intensity by Climate Zone – Standard 90.1-2016

		Whole Building EUI Data for Building Population		
Climate Zone	Climate Zone Floor Area Weight %	Site EUI kBtu/ft2-yr	Source EUI kBtu/ft2-yr	ECI $/ft2-yr
1A	4.46	46.0	121.8	$1.22
2A	16.43	47.4	123.1	$1.23
2B	2.98	47.0	122.2	$1.22
3A	15.42	48.5	119.2	$1.17
3B	10.08	44.9	112.6	$1.11
3C	1.61	44.0	112.1	$1.11
4A	18.92	51.4	122.6	$1.20
4B	0.57	53.0	125.7	$1.23
4C	2.92	47.6	112.6	$1.10
5A	18.39	55.9	124.9	$1.20
5B	4.37	52.9	122.6	$1.19
5C	0.07	49.1	118.7	$1.16
6A	2.89	64.6	141.5	$1.35
6B	0.49	59.3	133.1	$1.28
7	0.37	72.1	153.2	$1.44
8	0.05	66.5	133.0	$1.23
National	100.00	50.4	121.8	$1.19

Table 9. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Building Type

Building Type	Prototype Building	Floor Area (%)	Savings (%) Site EUI	Source EUI	ECI
Office	Small Office	5.61	11.6	11.8	11.8
	Medium Office	6.05	5.0	5.3	5.4
	Large Office	3.33	4.9	3.2	2.9
Retail	Stand-Alone Retail	15.25	8.4	9.9	10.3
	Strip Mall	5.67	9.8	12.0	12.5
Education	Primary School	4.99	13.4	15.6	16.1
	Secondary School	10.36	13.1	15.0	15.5
Healthcare	Outpatient Health Care	4.37	5.6	5.2	5.1
	Hospital	3.45	1.6	1.5	1.5
Lodging	Small Hotel	1.72	9.1	11.7	12.6
	Large Hotel	4.95	4.7	4.3	4.1
Warehouse	Non-Refrigerated Warehouse	16.72	16.1	21.2	22.8
Food Service	Quick Service Restaurant	0.59	0.8	1.4	1.7
	Full Service Restaurant	0.66	1.4	2.3	2.7
Apartment	Mid-Rise Apartment	7.32	3.6	3.9	3.9
	High-Rise Apartment	8.97	4.0	4.9	5.1
National		100.00	6.8	7.9	8.3

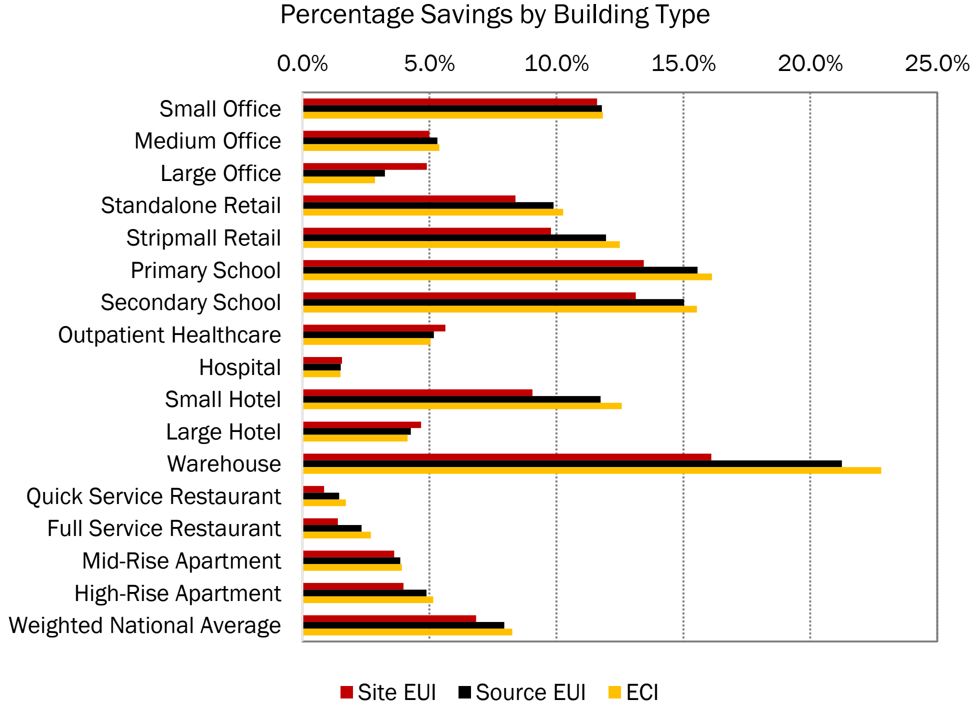

Figure 4. Percentage Savings by Building Type from 90.1-2013 to 90.1-2016

Table 10. Estimated Percent Energy Savings between 2013 and 2016 Editions of Standard 90.1 – by Climate Zone

Climate Zone	Climate Zone Floor Area Weight %	Savings (%)		
		Site EUI	Source EUI	ECI
1A	4.46	6.5	7.1	7.2
2A	16.43	7.6	8.4	8.6
2B	2.98	7.4	8.1	8.3
3A	15.42	7.7	8.9	9.3
3B	10.08	6.6	7.5	7.8
3C	1.61	6.2	6.9	7.1
4A	18.92	6.4	7.4	7.7
4B	0.57	5.8	7.0	7.3
4C	2.92	5.9	7.3	7.8
5A	18.39	6.5	8.1	8.5
5B	4.37	6.0	7.5	7.9
5C	0.07	6.8	7.8	8.0
6A	2.89	6.4	7.8	8.2
6B	0.49	7.4	8.4	8.7
7	0.37	6.2	7.3	7.6
8	0.05	8.6	10.0	10.5
National	100.00	6.8	7.9	8.3

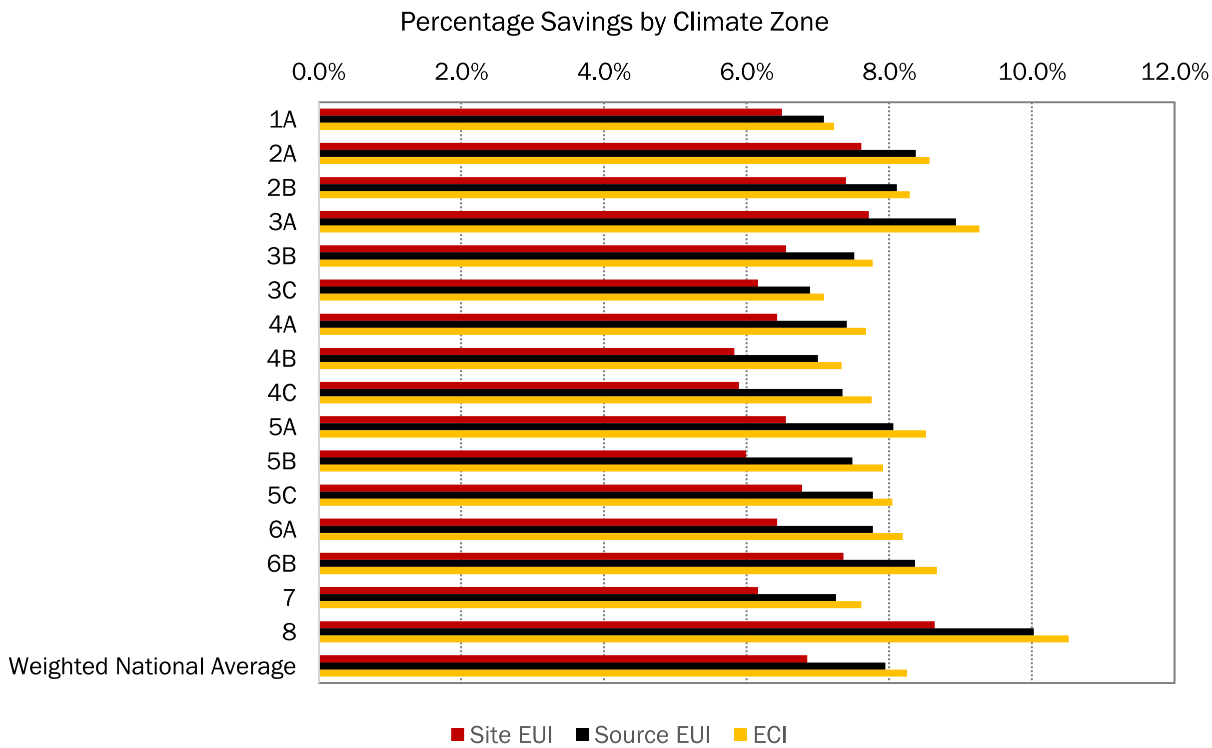

Figure 5. Percentage Savings by Climate Zone from 90.1-2013 to 90.1-2016

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Appendix A: Addenda Not Quantified in Energy Savings Analysis

Addendum	Sections Affected	Description of Change	Discussion
c	8.4	Specifies combined maximum voltage drop of 5% instead of separate voltage drops for branch (3%) and feeder (2%) circuits.	Cumulative voltage drop remains the same.
g	Table 6.5.3.1-2	Clarifies interpretation of the equation used for pressure drop adjustment calculation for energy recovery devices.	Clarification only.
h	C3.5.8	Modifies the language in Appendix C to separate fan power from the cooling and heating efficiency calculation.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
k	Table G3.1	Requires opaque assemblies in the baseline building to match the descriptions in Appendix A.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
m	10.4.1	Adds text on electric motors to identify the tables that must be followed based on size and type (Tables 10.8-4 and 10.8-5).	Clarification only.
o	6.4.4.2.1	Clarifies the wording regarding duct seal class by removing text to avoid misinterpretation.	Clarification only.
p	Table 6.8.1-7	Adds reference to Cooling Tower Institute Standard CTI STD-201 RS for testing certain equipment types in Table 6.8.1-7.	References update only.
r	G3.1.1, Table G3.1.1-3	Clarifies the hierarchy for selecting baseline HVAC systems, including what floors to count, and specifies what building type to use when no one use is predominant.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
z	G3.1.3.1	Modifies modeling of electric auxiliary heat in air-source heat pumps such that they are controlled by an outdoor air thermostat and the heat pump continues to operate while the auxiliary heat is energized.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
aa	Table G3.1	Clarifies which spaces in the proposed design can be modeled without mechanical cooling (Appendix G).	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
ab	Table A2.3	Adds a filled cavity metal building roof assembly (R-19+R-11) to Appendix A.	Adds alternative assembly only.
ad	G3.1.2.4, G3.1.3.19	Specifies baseline systems 5 through 8 to be modeled with a preheat coil.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ae	3.2, 10.4.1	Updates definition of nameplate horsepower, and relates power ratings of smaller electric motors to their output power.	Clarification.
af	Table 7.8	Specifies the rating conditions for measuring the efficiency of heat pump pool heaters.	Clarification only.
an	Table 9.6.1	Removes mandatory local control from restrooms and stairwells.	In some instances, it will increase energy use and others decrease, based on occupant behavior.
ao	Table G3.1	Requires humidification systems in the baseline building model to be non-adiabatic in buildings where humidification is required.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ap	6.5.3	Moves the minimum 5 hp threshold for fan power to individual requirements under 6.5.3 as applicable. Clarifies that fan motors smaller than 1 hp have separate requirements. Clarifies that fan power allowance does not apply to relief fans that operate only during economizer mode.	Clarification only.
aq	Tables 6.8.1-1, 6.8.1-2, 6.8.1-5	Modifies footnotes in Tables 6.8.1-1 and 6.8.1-2 and 6.8.1-5 to state that residential air conditioners, heat pumps, and furnaces are now regulated by DOE and not by The National Appliance Energy Conservation Act of 1975. Clarifies that certain efficiencies in the tables only apply to three-phase equipment.	Clarification only.
ar	3.2, Table 6.5.3.1-2, 6.5.6.1, 6.5.7.1.4, 6.5.7.2	Replaces “energy recovery effectiveness” with “energy recovery ratio,” which clarifies the intent of the Standard with regard to the performance requirements of air-to-air heat exchangers.	Clarification only.
at	9.4.1.1	Clarifies that the calibration of daylighting controls be performed such that the sensor field of view is not blocked by objects or persons conducting the calibration.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
au	G3.1.3.5, G3.1.3.10, G3.1.3.11	Specifies in greater detail the modeling of hot water pumps, chilled water pumps and heat rejection equipment in the baseline model.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
av	Multiple, Chapters 3 and 6	Adds the phrase “and be configured to” after the phrase “capable of” throughout the standard. The word “capable” does not guarantee that savings will be achieved, especially in the context of control requirements.	Clarification only.
az	Appendix G	Requires Appendix G fenestration and skylight glazing fraction to be set in G instead of referencing prescriptive requirements.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ba	Appendix G	Changes G1.2.2 end-use load note from informative to mandatory.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bb	G3.1.2.5	Modifies fan modeling for packaged HVAC.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bd	6.4.3.1.1	Requires metering on large (>1,500 ton) chiller plants.	Adds metering requirement only.
bh	8.4.3.2	Requires DDC metering and GUI display in buildings required to have DDC systems.	Adds metering requirement only.
bl	6.5.1.2.1	Clarifies that water economizers may use dry coolers.	Clarification only.
bm	Multiple, Appendix G	Allows the use of Appendix G as a compliance path. Formulates methodology for showing compliance with 90.1.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bo	5.5.4.4.1 and Table 5.5.4.4.1	Modifies the exceptions related to the SHGC credit for shading by permanent projections, eliminating credit for north facing overhangs.	Eliminated exception was developed to be energy neutral.
bp	TABLE G3.1.2.8	Modifies Appendix G economizer high limit shutoff.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
bq	G3.1.2.5 & G3.1.3.14	Sets baseline control requirements for Systems 6 & 8 (fan powered terminal units) in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
br	6.4.3.4.2, 6.5.3.4, 6.5.5.2.1, 6.5.6.1, C3.5.8, G3.1.2.11, Tables 6.4.3.4.3, 6.5.1.1, 6.5.1.2, 6.5.1.1.3, 6.5.1.2.1, 6.5.6.1.1, 6.5.6.1.2, 6.6.1, 6.8.2.1, 6.8.2.2, G3.1.1.3, G3.1.1.7, G3.4.1	Adds requirements for new climate zone 0A and 0B.	Requirements for new climate zone 0 are set at climate zone 1 levels as was the case for those locations before the introduction of climate zone 0.
bv	G3.1.4.4, G3.1.4.9	Adds hydronic reset exceptions for purchased heating and cooling.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bw	G3.1.6	Appendix G lighting controls modeling rules.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bx	G3.1.2.9.1	Appendix G design airflow rate modeling rules.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
bz	Table 6.8.1-11, 12	Computer room air conditioning (CRAC) unit efficiencies.	May be subject to future federal rulemaking that will determine the impact.
cc	3.2	Adds definition for sidelight effective aperture.	New definition only.
cd	3.2, Tables 6.8.1-14 and 6.8.1-15	Establishes a product class and efficiency requirements for DX-DOAS.	May be subject to future federal rulemaking that will determine the impact.

Addendum	Sections Affected	Description of Change	Discussion
cj	G3.1.1.2	Adds footnote about Appendix G System 11 to Table G3.1.1.2.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ck	G3.1.4.11, Table G3.1.4.11	Establishes Appendix G heat rejection leaving water temperature control modeling requirements.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
cl	Appendix F, Tables 6.8.1.1, G.8.1.2, 6.8.1.5, 7.8	Moves federally regulated air conditioner and water heating efficiency requirements to informative Appendix F.	No requirements are changed.
cm	Table A9.4.3.1	Clarifies and simplifies the default U-factors within Appendix A for wood panels and wood sub-floors, corrects the dimensional lumber sizes in the tables, and re-organizes the material list by putting similar materials together.	Clarification only.
cn	Table 4.2.1.1	Adds Climate Zone 0 to Table 4.2.1.1, Building Performance Factors for compliance with Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
co	12	Normative Reference updates.	References update only.
cp	A3.2, A9.2, A9.4.5, Table A3.2.3	Provides a U-factor calculation procedure for metal building wall assemblies with filled cavity insulation systems and adds U-factor values to Table A3.2.3 calculated using this procedure. Does not change the criteria of the standard.	Calculation procedure change only.
ct	3.2, 6.5.1, 6.5.4.5.1, 11.5.2, Tables 6.5.1.2.1, 6.5.1.3	Changes water economizer to fluid economizer to account for refrigerant-based economizers.	Clarification only.
da	4.2, Table G3.1.2	Establishes modeling rules for existing buildings in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
db	3.2, 6.5.3.1.2, 11.5.2 G1.1, G1.3, G2.5, G3.1.2.4, G3.1.2.3, G3.1.2.6, Table 11.5.1.6, Table G.3.1	Building official definition and other language clarifications.	Administrative provisions only.
dc	Table G3.1.4	Updates reference to Standard 55 in Appendix G.	References update only.
de	10.4.3.4	Requires specification of ISO use category and energy efficiency class for elevators.	No efficiency requirement is included.
dh	9.6.2	Clarifies that display lighting adder cannot be taken if display lighting exception is taken.	Clarification only.
di	Table G3.1, G3.9	Adds new table for motor efficiency for Appendix G baseline.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dl	6.4.1.2.1	Changes rating conditions for centrifugal chillers at non-standard conditions using K_{adj} formula.	The change in rating conditions does not impact the efficiency requirements.
dm	Table 6.8.1.3	Clarifies which hydronic heating and cooling pumps need variable flow controls.	Clarification only.
dn	6.5.6.1	Clarifies energy recovery requirement exceptions that apply to heating systems.	Clarification only.
ds	9.4.1.1	Specifies daylighting controls adjustment location.	This requirement makes calibration easier, but does not save energy.
dt	3.2, 9.1.2, 9.4.1.1, 9.5.1, 9.6.1, 9.6.4, C3.5.7; Tables 9.4.2.2, 9.5.1, 9.6.1, 11.5.1	Modifies the definition of lighting power density (LPD) and clarifies language related to LPD.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
dv	11.4.1.4, C3.1.4	Updates the reference to Standard 140.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dw	Appendix F, Tables G3.1, G3.9, G3.9.2, G3.9.3	Establishes baseline elevator efficiency requirements for Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dx	Tables G3.7 and G3.8	Modifies Appendix G to capture revisions from other addenda impacting prescriptive and mandatory requirements (addenda co, cr, dl to 90.1-2010).	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
dz	A.3.2.1, A9.2, A9.4.5	Clarifies metal building wall insulation descriptions.	Clarification only.
ea	3.2, 5, 6, 9, 11, Appendix A	Clarifies the definition and application of wall and exterior wall in various locations in the standard.	Clarification only.
eb	3.2; Appendices C and G	Clarifies the definition and application of wall and exterior wall in Appendices C and G.	Clarification to alternative compliance path only.
ec	Table 4.2.1.1	Corrects an error in Building Performance Factor Table.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ed	G3.1.3.18	Adds three baseline system types to the rules governing dehumidification in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
ef	Tables G3.1, G3.1.1.2	In Appendix G, clarifies that one baseline SWH system is modeled per building area type, adds two new building area types to SWH type table, and changes the SWH fuel source for two building area types.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.
eg	G3.1.2.6.1	Removes a caveat in Appendix G that airside economizers can be modeled if the simulation software does not model waterside economizers.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
ej	3.2, 3.3, 6.4.5, 9.1.2, 9.1.3, 9.1.4	Add a definition for driver as it relates to LED fixtures and makes several changes to assure lighting requirements apply to LED fixtures.	Clarification only.
ek	Tables G3.1, G3.10.1, G3.10.2	Sets baseline efficiency requirements for refrigeration system modeling in Appendix G.	Change applies to an alternative compliance path and does not affect prescriptive or mandatory requirements.

Appendix B: Modeling of Individual Addenda

This appendix details the modeling of the 21 addenda to Standard 90.1-2013 simulated for the quantitative analysis. Where individual addenda modify the same section of Standard 90.1, they are discussed together.

B.1 Addenda Implementation in Modeling

The procedures for implementing the addenda into the Standard 90.1-2013 and 90.1-2016 prototype models include identifying the changes to the prototypes required by each addendum, developing model inputs to simulate those changes, applying those changes to the prototype models, running the simulations, and extracting and post-processing the results. This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for EnergyPlus. The terms “baseline” and “advanced” are used in some cases to describe the modeling of the addenda. The baseline case is Standard 90.1-2013 and the advanced case is Standard 90.1-2016. In some instances, a new addendum to Standard 90.1-2013 identifies the need for a change to baseline 2013 models. There are generally two reasons why a baseline change was necessary: (1) in the course of modeling an addendum, an opportunity to increase the accuracy of the simulation was identified and (2) to add additional detail to the models so that the impact of a particular addendum could be captured. For example, prior to simulation of the 2016 standard, exterior doors were not explicitly simulated in most of the prototypes. In order to accurately simulate addendum *bc*, which reduced door factor requirements, explicit modeling of exterior doors was added to most prototypes.

B.1.1 Building Envelope

B.1.1.1 Addendum w: Climate Zone Reassignment

Addendum Description. Addendum *w* incorporates several changes introduced by the 2013 edition of ASHRAE Standard 169, *Climatic Data for Building Design Standards* (ASHRAE 2013a). ASHRAE 169-2013 reassigned climate zones to U.S. counties based on a more recent period of weather data and also added a new, extremely hot climate zone 0. Approximately 300 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones. Addendum *w* references ASHRAE 169-2013 for climatic data and adds a new annex that reproduces multiple sections from ASHRAE 169-2013. It also adds requirements for climate zone 0 throughout the Standard.

Modeling Strategy. Climate zone 0 is not found in the U.S. so the related requirements in addendum *w* are not applicable to this analysis (see discussion of climate zones in 3.3.2). The other change in addendum *w*—the reassignment of counties to different climate zones—does have an indirect impact because buildings constructed to ASHRAE 90.1-2016 in counties that were reassigned will now be modeled as having different requirements from those before this change, independent of specific 2016 addenda. The Standard 90.1 committee reviewed these impacts when considering whether to incorporate the updated Standard 169, and Athalye et al. (2016) quantified the energy impact of county-climate zone reassignment. At a national level it was very small, with an increase of 0.18% in the site energy consumption of buildings compared to those compliant with ASHRAE 90.1-2013. To capture the impact of the climate zone reassignment, construction weights used in the analysis were revised. New construction weights were determined for each building type in each climate zone based on the new county-climate zone mapping and are shown in Table 3. These construction weights were applied to both the baseline and advanced cases.

B.1.1.2 Addendum *ai*: Fenestration U-factors and SHGC

Addendum Description. Addendum *ai* updates the prescriptive fenestration U-factor and solar heat gain coefficient (SHGC) requirements in Tables 5.5-0 through 5.5-8 of Standard 90.1; specifically, the maximum allowable SHGC for vertical fenestration was reduced in climate zones 0, 4, and 5, the maximum allowable U-factor for vertical fenestration was reduced in climate zones 2 through 7, and the maximum allowable U-factor for skylights was reduced in climate zone 8. The addendum also changed an exception to allow area-weighting between multiple classes of construction for showing compliance, which was previously not allowed.

Modeling Strategy. All the prototypes have vertical fenestration and four have skylights (Stand-alone Retail, Primary School, Secondary School, and Warehouse). Both the 2013 and the 2016 editions of Standard 90.1 have four classes of construction for vertical fenestration: non-metal, metal fixed, metal operable, and metal entrance door. The U-factor requirements are different for different classes of construction but the SHGC requirements are the same for all classes. For each prototype building, a weighted U-factor was developed using the fenestration type weighting factors (Thornton et al. 2011). Then a layer-by-layer window construction was selected that matches the required weighted U-factor, SHGC, and visible light transmittance for the prototype as closely as possible. If a construction that closely matches the code requirements was not available, then it was created using the WINDOW software (LBNL 2016) and exported to EnergyPlus. A similar approach was followed for skylights, except that there is only one class of construction, and thus weighting was not required.

B.1.1.3 Addendum *al*: Metal Coiling Door Air Leakage

Addendum Description. Addendum *al* requires air leakage of metal coiling doors in semiheated spaces in climate zones 1-6 to not exceed 1 cfm/ft^2 at 75 Pa, where previously metal coiling doors had no requirement for air leakage in these climate zones.

Modeling Strategy. The semiheated space (Bulk Storage) in the Warehouse prototype has 15 overhead doors. Metal coiling overhead doors are typically used when the available space above the overhead door is limited. The Bulk Storage space in the Warehouse prototype is a high bay space, and therefore, the likelihood of metal coiling doors being employed in this space is low. A literature review did not find data on the proportion of metal coiling doors out of all overhead doors in typical warehouses. A representative from Door & Access Systems Manufacturers Association was contacted, who estimated the market share for metal coiling doors to be as much as 50% of all overhead doors. A conservative estimate of 25% was used to calculate the number of metal coiling doors in the Warehouse prototype Bulk Storage space.

Previously, none of the doors were assumed to be of the metal coiling variety, and so their infiltration in the closed position was equal to 0.40 cfm/ft^2 at 0.3” w.g., i.e., the current requirement in 90.1-2013 for overhead doors. After addendum *al*, 25% of the overhead doors were assumed to be metal coiling and the infiltration rates for these doors in the baseline and advanced case were determined. Table B.1 shows the air leakage rates for metal coiling doors taken from ASHRAE Research Project 1236 (McGowan 2009).

Table B.1. Air Leakage Rates for Metal Coiling Doors

Climate Zone	90.1-2013 Air Leakage Rate (cfm/ft^2)	90.1-2016 Air Leakage Rate (cfm/ft^2)
1-6	4.40	1.00
7-8	0.40	0.40

For each overhead door for 90.1-2013, the infiltration in closed position was calculated as follows:

$$(0.4\ cfm/\ ft^2 \times 0.75 + 4.4\ cfm/\ ft^2 \times 0.25) \times 8\ ft \times 10\ ft = 112\ cfm$$

For each door for 90.1-2016, the infiltration in closed position was calculated as follows:

$$(0.4\ cfm/\ ft^2 \times 0.75 + 1.0\ cfm/\ ft^2 \times 0.25) \times 8\ ft \times 10\ ft = 44\ cfm$$

Table B.2 shows the calculation of the infiltration input in the EnergyPlus models for various 90.1 editions. A single input was used for both the opaque envelope infiltration (base infiltration) and the door infiltration.

Table B.2. Infiltration Rates for Bulk Storage for Climate Zones 1-6 for 90.1-2013 and 90.1-2016

Infiltration Parameters	90.1-2013	90.1-2016
Base Infiltration (opaque envelope), cfm	1,913	1,913
Dock Door Closed Infiltration, per door, cfm	112	44
Dock Door Open Infiltration, per door, cfm	783	783
Number of Dock Doors	15	15
Number of Dock Doors Open	3.2	3.2
Total cfm	5,740	4,938

B.1.1.4 Addendum *bc*: Door U-factors

Addendum Description. Addendum *bc* reduces the U-factors of opaque doors in residential, non-residential, and semiheated buildings. It also adds exceptions for glazed, non-swinging, horizontally hinged sectional doors (garage doors).

Modeling Strategy. This addendum affects all prototypes. It involved a baseline change because only the Strip Mall and Warehouse prototypes have doors that have been explicitly modeled. For all other prototypes, exterior doors were added to capture the impact of this addendum. Assumptions developed previously to calculate exterior lighting power allowance for illuminating doors were used to calculate the number of doors in each prototype. These assumptions are based on the NC^3 database (Richman et al. 2008). Only opaque doors were added to capture the impact of addendum *bc*; glass doors were not considered. The number of opaque doors added to each prototype are summarized in Table B.3. Swinging doors were assumed to be 7 ft tall by 3 ft wide, and rollup doors were assumed to be 10 ft tall by 8 feet wide.

Table B.3. Number of Opaque Doors Added to Prototypes

Prototype	Number of Swinging Doors Added	Number of Rollup Doors Added
Full Service Restaurant	1	0
Large Hotel	5	1
Hospital	16	1
Large Office	12	0
Medium Office	6	0
Small Hotel	3	0
Outpatient Health Care	17	0
Primary School	25	0
Quick Service Restaurant	1	0
Stand-alone Retail	8	5
Secondary School	32	0

Prototype	Number of Swinging Doors Added	Number of Rollup Doors Added
Small Office	2	0
Strip Mall	0	0
Warehouse	1	12

Doors were new elements in the geometry of most prototypes and certain rules were followed to determine their location in the model:

1. Doors were not placed in exterior bathroom zones.

2. A few prototypes, such as the Medium Office, Large Office, Primary School, Secondary School, have ribbon windows spanning the entire perimeter. For these prototypes, adding doors required a break in the ribbon window. In such cases, the sill height of the window was reduced to ensure that the total glazed area remained the same, and so that there was no impact on the daylight area.

3. Zones with daylighting controls have photosensors; in such zones, care was taken to not place an opaque door near the daylighting sensor.

The U-factors in addendum *bc* were applied to the 2016 models, whereas those in the 2013 edition of 90.1 were applied to the 2013 models.

B.1.1.5 Addendum *ci*: Fenestration Orientation

Addendum Description. Addendum *ci* requires that the vertical fenestration comply with either (a) or (b) below:

(a.) $A_W \leq (A_T)/4$ and $A_E \leq (A_T)/4$

(b.) CZ 0-3:

$A_W \times SHGC_W \leq (A_T \text{ x } SHGC_C)/4$ and $A_E \times SHGC_E \leq (A_T \times SHGC_C)/4$

CZ 4-8:

$A_W \times SHGC_W \leq (A_T \times SHGC_C)/5$ and $A_E \times SHGC_E \leq (A_T \times SHGC_C)/5$

where

A_w = west-oriented *vertical fenestration area* (oriented within 45 degrees of true west to the south and within 22.5 degrees of true west to the north in the northern hemisphere; oriented within 45 degrees of true west to the north and within 22.5 degrees of true west to the south in the southern hemisphere)

A_e = east-oriented *vertical fenestration area* (oriented within 45 degrees of true east to the south and within 22.5 degrees of true east to the north in the northern hemisphere; oriented within 45 degrees of true east to the north and

within 22.5 degrees of true east to the south in the southern hemisphere)

A_T = total *vertical fenestration area*

$SHGC_C$ = *SHGC* criteria in Tables 5.5-0 through 5.5-8 for each climate zone

$SHGC_E$ = *SHGC* for east-oriented *fenestration* that complies with Section 5.5.4.4.1

$SHGC_W$ = *SHGC* for west-oriented *fenestration* that complies with Section 5.5.4.4.1

In 90.1-2013, option (a), fenestration area trade-off, above is identical, but option (b), SHGC trade-off, included a denominator of 4 on the right-hand side of the equation for all climate zones. Addendum *ci* separated out climate zones 4 through 8 and set the denominator to 5, meaning east- and west-facing fenestration will require a lower SHGC compared to 90.1-2013 when using option (b) in climate zones 4 through 8.

Modeling Strategy. The implementation of requirements within addendum *ci* was very similar to that of addendum 90.1-2010*bw* and is described by Halverson et al. (2014). As was the case with addendum *bw*, prototypes were examined to see if they first met option (a) in the fenestration orientation requirement, either with their current orientation or if rotated 90 degrees. Small Hotel, Hospital, Quick Service Restaurant, and Full Service Restaurant were the only prototypes that did not comply using option (a).

The Small Hotel prototype was rotated 90 degrees from its default orientation to meet the fenestration orientation requirements of 90.1-2013, and in this rotated form it meets the requirements of addendum *ci* as well. Thus, there is no impact on Small Hotel from addendum *ci*. Similarly, there is no impact on the Hospital prototype because after rotating 90 degrees, its east-facing fenestration meets exception 5 of the fenestration orientation requirement (Section 5.5.4.5), and the west-facing orientation meets the option (a). Similarly, this is how it was modeled to comply with the requirements in 90.1-2013.

For the Quick Service and Full Service Restaurant prototypes, the SHGCs of the east- and west-facing fenestration were calculated and then used to select the window as described in Section B.1.1.2. Table B.4 shows the new SHGC values calculated for the east- and west-facing fenestration by climate zone.

Table B.4. Calculation of SHGC for East- and West-facing Fenestration

Prototype	SHGC Type	CZ 4	CZ 5	CZ 6	CZ 7
Quick Service Restaurant	90.1-2016 Prescriptive SHGC	0.36	0.38	0.4	0.45
	Calculated East and West SHGC	0.29	0.30	0.32	0.36
Full Service Restaurant	90.1-2016 Prescriptive SHGC	0.36	0.38	0.4	0.45
	Calculated East and West SHGC	0.24	0.26	0.27	0.30

B.1.2 Mechanical Addenda

B.1.2.1 Addendum *d*: Hotel Guest Room Controls

Addendum Description. Addendum *d* requires deeper thermostat setback for networked guest rooms or those unoccupied for more than 16 hours. It also requires ventilation to be turned off when guestrooms are unoccupied. The changes appear in a new Section 6.4.3.3.5 and only apply to hotels and motels with greater than 50 guest rooms. A definition is added for networked guest room control systems. The addendum requires heating and cooling setpoints to be lowered and raised respectively by 4°F when rented rooms are unoccupied. For unrented unoccupied periods, heating and cooling setpoints are to be lowered to 60°F and raised to 80°F respectively. Ventilation and exhaust airflow must also be turned off when rooms are unoccupied. Unrented periods can be determined either by the networked guest room control system or by a longer unoccupied period up to 16 hours. Key card control systems may be used to indicate occupancy.

Modeling Strategy. This addendum only impacts the two hotel prototypes. The Small Hotel already had separate blocks of vacant guest rooms, while vacancy was managed through an average schedule in the Large Hotel. The baseline of the Large Hotel was modified to have separate blocks of rented and unrented rooms like the Small Hotel, with the quantities of each based on the prior partial occupancy schedule. The Small Hotel has 65% occupancy on average, while the Large Hotel has 58% occupancy. The ventilation for rented rooms is turned off 6 hours per day, and the ventilation for unrented rooms is turned off 23 hours per day, with a one hour daily ventilation purge. Lighting schedules remained the same as lighting controls were affected by a previous addendum in the last cycle. The baselines had minor temperature setback in occupied rooms, as this was previously required in the general thermostat requirements. The temperature setpoints and ventilation operation for the various modes are as shown in Table B.5.

Table B.5. Addendum d Guest Room Setpoints and Ventilation Control

	90.1-2013			90.1-2016		
Guest Room Condition	Heating	Cooling	Ventilation	Heating	Cooling	Ventilation
Occupied	70°F	70°F	Continuous	70°F	70°F	Continuous
Rented Unoccupied	66°F	74°F	Continuous	66°F	74°F	Off 6 hr/day
Unrented Unoccupied	66°F	74°F	Continuous	60°F	80°F	Off 23 hr/day

B.1.2.2 Addendum *i*: Separate Computer Room Economizer Thresholds Eliminated

Addendum Description. Addendum *i* eliminates separate cooling capacity thresholds when determining if economizers are required in computer rooms. The addendum deletes the old Table 6.5.1-2 and the reference to it under Section 6.5.1. The climate zones where economizers are exempt are different, and with the elimination of the separate computer room tables, economizers are required in climate zones 2a, 3a, and 4a, where there was no economizer requirement for computer rooms previously.

Modeling Strategy. This addendum only impacts the Large Office prototypes, specifically the basement data center. There are small data closets in other parts of the Large Office prototype; however, the cooling capacity for these areas is below the economizer requirement threshold in all climate zones. For the basement data center in 90.1-2016, the economizer variable is switched from “no economizer” to “differential enthalpy economizer” for all climate zones, except 1A and 1B, because the data center cooling capacity always exceeds the economizer threshold of 54,000 Btu/h. Thus economizers are required in more climate zones for the data center resulting in energy savings.

B.1.2.3 Addendum *j*: ERV with Ventilation Optimization

Addendum Description. Addendum *j* eliminates the exception to Section 6.5.3.3 that allowed systems with exhaust energy recovery to be exempt from the multi-zone variable air volume (VAV) ventilation optimization control.

Modeling Strategy. Dynamic ventilation optimization or dynamic ventilation reset was simulated using the mechanical controller object in EnergyPlus. This object has an option to turn on the ventilation rate procedure calculations for optimizing system outdoor air flow in multi-zone VAV systems. Previously, dynamic ventilation reset was only turned on when there was no energy recovery ventilator (ERV) in the system. This was done using an automated process, where Perl[6] scripts read the output of a sizing run and dynamically assign ERVs to systems where necessary, and the final model is simulated again. To implement addendum *j*, an exception was created in the script for 90.1-2016 cases so that dynamic ventilation reset was turned on even when the system required an ERV.

B.1.2.4 Addendum *u*: Expands Use of Transfer Air

Addendum Description. Addendum *u* expands the requirement for use of transfer air as make-up air by applying it more broadly than to just kitchen exhaust systems. Now, most exhaust systems, including restroom exhaust, are required to use transfer air when available. The language is in a new Section 6.5.7.1 (the kitchen exhaust section moved to 6.5.7.2) and requires that conditioned supply air be limited to the air flow required for heating, cooling, or ventilation loads, as long as the air is transferable to adjacent zones based on the Class of Air Recirculation Limitations in ASHRAE Standard 62.1 (ASHRAE 2013b). The new requirements do not apply to (1) biosafety level classified laboratories 3 or higher, (2) vivarium spaces, (3) spaces required to be maintained at positive pressure relative to an adjacent space, and (4) air from other smoke compartments, other floors, or that require more than 15 feet of ductwork. The provision saves energy by reducing the overall volume of conditioned air in a facility, saving fan power and energy for heating or cooling.

Modeling Strategy. Different methods were applied depending on how restrooms were implementation in the prototype models.

- For the Primary and Secondary Schools and Outpatient Health Care prototypes, restrooms were separately modeled with full makeup ventilation air for the exhaust, so the transfer air could be modeled directly, reducing makeup air for the restroom zones and also reducing exhaust available for heat recovery in the source zones. The restroom exhaust fan object was changed so that other makeup air was not required in the restroom zone for balancing.
- For the Hospital, Small Hotel, Large Hotel, Strip Mall, Mid-rise, and High-rise apartments and Warehouse the ventilation rate previously calculated for the baseline had transfer air already accounted for relative to restroom exhaust in the spaces, so there was no change.
- For the Full Service and Quick Service restaurants, all transfer air was used by kitchen exhaust, so there was no additional impact from restroom transfer air being required.
- For the Medium and Large Office prototypes there were not separate zones or exhaust fans set up in the baseline for the restrooms; consequently the minimum damper position according to the multi-space calculation could not be properly determined if transfer air to the restrooms was implemented, so it was not modeled.
- For the Small Office and Stand-alone Retail, there were not separate zones or exhaust fans set up in the baseline for the restrooms, and if restrooms were located on the perimeter of the building transfer air is not likely to meet thermal loads; consequently, the use of transfer was not modeled.

B.1.2.5 Addendum *bj*: Minimum Hydronic Cooling Coil Design Temperature Difference

Addendum Description. Addendum *bj* requires that hydronic cooling coils be designed for a minimum of 15°F waterside temperature difference at design conditions. The requirement is in a new Section 6.5.4.7. There are several exceptions, such as design airflow rates below 5,000 cfm, high pressure drop coils (>0.70 in.wc.),

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[6] https://www.perl.org/

constant volume air systems, chiller limitations, convective coils, high design chilled water supply temperatures (≥50ºF) and low entering air temperatures (≤65ºF). The purpose of this addendum is to reduce system chilled water flow and pump energy use; there is also potential chiller efficiency increase due to greater temperature differences.

Modeling Strategy. This addendum impacts the following prototypes with hydronic cooling systems: Large Office, Large Hotel, Secondary School, and Hospital. The design waterside temperature difference was increased from the baseline 10°F to 15°F for the coil design in the EnergyPlus model for the advanced cases.

B.1.2.6 Addendum *ca* & *cq*: Reduced Threshold for VAV Heat Rejection Fans

Addendum Description. Addendum *ca* reduces the threshold for variable flow water-cooled heat rejection device fans from 7.5 to 5 hp and eliminates the exception for climate zones 1 and 2. Addendum *cq* includes the service factor power in the determination of a 5 hp threshold. The requirements are revisions to Section 6.5.5.2.

Modeling Strategy. Addendum *ca* together with *cq* potentially impacts the following prototypes with water-cooled heat rejection: High-rise Apartment, Large Office, and Hospital. The High-rise Apartment water-loop heat pump heat rejection system fan is close to 5 hp, so it will be affected. However, the Hospital and Large Office prototypes have cooling tower fans that are much greater than 7.5 hp; therefore, they are not impacted. These large cooling towers were established as variable speed by standard practice in the 2004 prototypes, so there was no change made for removing the exception in climate zones 1 and 2. For the High-rise Apartment, the evaporative fluid cooler type in the EnergyPlus model was changed from “SingleSpeed” in the 90.1-2013 baseline to “TwoSpeed” for 90.1-2016.

B.1.2.7 Addendum *ce*: Raises Minimum Energy Recovery Threshold

Addendum Description. Addendum *ce* raises the minimum threshold for energy recovery ventilation (ERV) from zero cfm to a reasonable amount based on minimum equipment sizes that are readily available. The addendum revises Tables 6.5.6.1-1 and 6.5.6.1-2. Generally, the base (≥80% outside air) threshold in the highest heat recovery climate zones is set at 40 cfm of outside air with operating hours ≥8000 hr/yr and 80 cfm with operating hours <8000 hr/yr. This base value is then adjusted in proportion to percent outside air or other table values to eliminate the zero values. Overall this will have the impact of reducing the requirement for ERV is certain climates where small size units were not readily available.

Modeling Strategy. The inclusion of an ERV in a system in the prototype model depends on the climate zone, system air flow and the design outdoor air fraction. An initial design simulation is performed, and based on the system supply and outdoor air flow rates, a script automatically inserts the ERV into the system where required. The requirement in addendum *ce* impacts systems with small supply and outdoor air flow rates, such as those found in the Mid- and High-rise Apartment prototypes. There was no change in ERV selection between the 2013 and 2016 models because there none of the models had systems meeting the lower thresholds in 90.1-2013, and thus, the higher threshold in addendum *ce* did not cause a change to the models. After including all addenda to 90.1-2016, the 2016 models do show a few instances where ERVs were added where they were not required in the 2013 models. This is because of a reduction in loads caused by other addenda, which increases the outdoor air fraction and triggers the ERV requirements.

B.1.2.8 Addendum *dd*: Modified Threshold for VSD Pumps

Addendum Description. Addendum *dd* changes the threshold for requiring variable speed drive (VSD) pump control from >5 hp to a threshold that varies by climate zone as shown in Table B.6. Where formerly only chilled water pumps were covered, large heating water pumps are now included. The requirements are revisions to Section 6.5.4.2.

Table B.6. Addendum dd Modified Thresholds for VSD Pumps

Motor Nameplate Horsepower	Chilled Water Pumps in These Climate Zones	Heating Water Pumps in These Climate Zones
≥2 hp	0A, 0B, 1A, 1B, 2B	NR
≥3 hp	2A, 3B	NR
≥5 hp	3A, 3C, 4A, 4B	7, 8
≥7.5 hp	4C, 5A, 5B, 5C, 6A, 6B	3C, 5A, 5C, 6A, 6B
≥10 hp		4A, 4C, 5B
≥15 hp	7, 8	4B
≥25 hp		2A, 2B, 3A, 3B
≥100 hp		1B
≥200 hp		0A, 0B, 1A

Modeling Strategy. This addendum potentially impacts the following prototypes with hydronic heating or cooling systems: Large Hotel, Large Office, Secondary School, Primary School, Outpatient Health Care, and Hospital. The baseline was modified to include a pump motor sizing factor of 1.25 times the required brake horsepower. Heating pumps did not require VSD in the baseline, so pumps are assumed to vary flow by "riding the pump curve." For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table B.6. For cooling pumps, the baseline was a VSD when the pump nameplate hp was greater than 5 hp, otherwise riding the pump curve. For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table B.6.

B.1.3 Lighting

B.1.3.1 Addendum *ah*: Egress Lighting Control

Addendum Description. Addendum *ah* modifies Sections 9.4.1.1(h) and (j) and requires lighting connected to emergency circuits to be turned off in spaces that comply with the automatic full off or scheduled off requirements when there are no occupants. The addendum provides an exception to the automatic full off and scheduled off requirements for egress lighting by allowing 0.02 W/ft^2 or less lighting power to remain on during the unoccupied period. The addendum targets the common practice of allowing emergency lighting circuits to run continuously throughout the unoccupied period. By allowing a specific exemption for egress lighting, the addendum clarifies that all other lighting must be turned off.

Modeling Strategy. The addendum is not applicable to prototypes with 24-hour operation (High-rise Apartment, Mid-rise Apartment, Small Hotel, and Large Hotel), or where safety and security could be a concern (Hospital, and Outpatient Health Care). Thus, the prototypes where the addendum was applied are: Large Office, Medium Office, Small Office, Quick Service Restaurant, Full Service Restaurant, Stand-alone Retail, Strip Mall, Primary School, Secondary School, and Warehouse.

All the applicable prototypes are required to have building sweep controls (scheduled off). To implement the addendum, the lighting power would have to be turned down to 0.02 W/ft^2 during the night when there are no occupants and if the lighting power is greater than 0.02 W/ft^2. The Energy Management System (EMS) within EnergyPlus was used to implement the strategy. The zone lighting power, occupancy, and area are sensed and, if the occupancy is zero and the lighting power density is greater than 0.02 W/ft^2, then it was reduced to 0.02 W/ft^2. One set of sensors, actuators, and the EMS code are required per zone. The EMS code was included in the EnergyPlus input file only for the 90.1-2016 cases.

During implementation, several cases were discovered that required special treatment. For the Strip Mall prototype, there is additional lighting power allowance for display lighting, which is modeled using a separate lighting power object. Two EMS actuators are required in this case to deal with the two lighting power objects in each zone. The display lighting is reduced to zero and the general lighting is set to 0.02 W/ft^2. For the corridor space, which is found in schools and other prototypes, the occupancy is always zero, and therefore building level occupancy data is used as a surrogate in the EMS program. For the data center in the basement of the Large Office prototype, the addendum is not implemented because the space operates continuously.

B.1.3.2 Addendum *as*: Parking Area Luminaire Control

Addendum Description. Addendum "*as"* modifies Section 9.4.1.4 and adds two requirements:

- Previously, exterior lighting not specified as facade or landscape lighting, including advertising signage, was required to be automatically reduced to 30% of its peak power between midnight or within 1 hour of business closing, whichever is later, and until 6 am or business opening, whichever is earlier. Addendum "*as"* states that the reduction in peak power must equal at least 50%.
- Activity sensing controls are now required for pole-mounted lighting in parking lots with mounting heights lower than 24 feet and with lighting power greater than 78 W. The controls must reduce lighting power of the pole-mounted luminaire by at least 50% after no activity is sensed for 15 minutes in the area illuminated by the luminaire. A group of luminaires can be controlled together as long as the total power is less than 1,500 W. This requirement, unlike exterior lighting control requirements in 90.1-2013, will produce savings during hours when parking lot lighting is expected to be on.

Modeling Strategy. Prototypes with 24/7 operation, including the High-rise and Mid-rise Apartments, Small and Large Hotels, and the Hospital and Outpatient Health Care prototypes, are considered exempt from the requirements of addendum "*as*." For the remaining prototypes, the following steps were followed to implement addendum as:

1. Previously, exterior lighting power was modeled using two exterior lighting objects in EnergyPlus: one for façade lighting and another for entrance and parking lot lighting because of the different lighting control requirements for those exterior lighting categories. For addendum "*as*," the lighting power for entrance and parking lots was separated into two objects, one for entrances and another for parking lots. Thus there are now three exterior lighting objects for the 90.1-2016 cases.

2. For entrance door exterior lighting, the automatic reduction was changed from 30% to 50% per the requirements of addendum "*as*." This change was implemented simply by changing the lighting schedule value from 0.7 to 0.5 for the applicable hours for the entrance door exterior lighting object.

3. For the parking lot lighting, *Parking Generation* 4th ed. (McCourt and Hooper 2010) was used to determine the fraction of lights that would be off for each hour for each prototype. Using this data, a lighting schedule was formulated that reduced the peak lighting power for the parking lot exterior lighting object.

B.1.3.3 Addendum *cg*: Exterior Lighting Power

Addendum Description. Addendum *cg* reduces the exterior lighting power allowances for all categories and:

1. Clarifies that the scope includes all lighting served through the building's electrical service.

2. Exempts public art display lighting.

3. Revises the exterior lighting power allowance table as follows:
    a. Adds allowances for exterior dining areas.

b. Combines the categories of "Main Entries" and "Other Doors" into a single category of "Pedestrian and Vehicular Entrances and Exits."

c. Clarifies that the allowance for building facades is applicable for the entire area of the wall being lit.

d. Clarifies that the allowance for building entrances is also applicable to "Uncovered Entrances."

e. Clarifies that the allowance for loading docks is also applicable to "Uncovered loading docks."

The addendum modifies Sections 9.1.1, 9.1.2, 9.4.2, and Table 9.4.2-2. The exterior lighting allowance in 90.1-2013 and those in addendum *cg* are summarized in Table B.7. Where more than one lighting zone is shown in Table B.7, the allowances of the listed lighting zones have been averaged.

Table B.7. Exterior Lighting Power Allowances for 90.1-2013 and 90.1-2016

Lighting Zone	Parking Lots (W/ft²)		Building Façade (W/ft²)		Doors (W/ft)			
					90.1-2013		90.1-2016	
	90.1-2013	90.1-2016	90.1-2013	90.1-2016	Main Doors	Other Doors	Main Doors	Other Doors
0	0	0	0	0	0	0	0	0
1	0.04	0.03	0	0	20	20	14	14
2	0.06	0.04	0.1	0.1	20	20	14	14
3	0.1	0.06	0.15	0.15	30	20	21	21
4	0.13	0.08	0.2	0.2	30	20	21	21
2,3	0.08	0.05	0.125	0.125	25	20	17.5	17.5
3,4	0.115	0.07	0.175	0.175	30	20	21	21
2,3,4	0.0967	0.06	0.15	0.15	26.67	20	18.67	18.67

Modeling Strategy. The requirements in addendum *cg* are applicable to all prototypes.

Table B.8 shows exterior lighting zones selected for each prototype. Where more than one lighting zone is selected, an average of the requirements for the multiple zones is used.

Table B.8. Exterior Lighting Zones for Prototypes

Prototype	Exterior Lighting Zone
Quick Service Restaurant	2,3,4
Full Service Restaurant	2,3,4
Strip Mall	2,3
Large Office	4
Outpatient Health Care	2,3
Warehouse	2,3
Stand-alone Retail	2,3
Small Office	2,3
Medium Office	2,3
Primary School	2
Secondary School	2,3
Hospital	3,4
Small Hotel	3
Large Hotel	3,4
Mid-rise Apartment	2,3
High-rise Apartment	3,4

The development of assumptions for exterior lighting in prototypes has been described in Thornton et al. (2011). Using the exterior lighting power allowances in addendum *cg*, the total exterior lighting power was calculated for parking lots, building facades, and building entrances for all prototypes. Table B.9 summarizes the total exterior lighting power for each prototype for 90.1-2013 and for 90.1-2016. The implementation of addendum *cg* was straightforward. The calculated exterior lighting power is assigned to the three exterior lighting objects in EnergyPlus models as described previously in Section B.1.3.2.

Table B.9. Exterior Lighting Power in Prototypes for 90.1-2013 and 90.1-2016

	Parking Lot		Building Entrances		Building Façade	
Prototype	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)
Small Office	713	446	149	115	51	51
Medium Office	6,947	4,342	456	376	519	519
Large Office	42,265	26,027	1,037	968	12,979	12,979
Stand-alone Retail	2,800	1,751	1,528	1,304	316	316
Strip Mall	3,390	2,120	3,285	2,498	418	418
Primary School	881	584	2,351	1,646	151	151
Secondary School	4,745	2,974	3,807	2,995	442	442
Outpatient Health Care	6,634	4,148	1,664	1,402	174	174
Hospital	8,905	5,432	1,669	1,499	2,932	2,932
Small Hotel	3,368	2,022	247	225	573	573
Large Hotel	10,182	6,192	487	444	4,997	4,997
Warehouse	1,604	1,005	4,594	3,955	114	114
Quick Service Restaurant	979	608	55	42	123	123
Full Service Restaurant	2,154	1,337	143	123	154	154
Mid-rise Apartment	2,286	1,429	0	0	222	222
High-rise Apartment	8,227	5,011	0	0	2,493	2,493

B.1.3.4 Addendum *ch*: Interior Lighting Power

Addendum Description. Addendum *ch* modifies the lighting power density (LPD) allowance for both building area and space-by-space methods. Tables 9.5.1 and 9.6.1 are modified by this addendum.

Modeling Strategy. The addendum affects all prototypes. The following describes how the appropriate LPD allowance is chosen for the prototype buildings:

1. The Large Office, Medium Office, and Small Office prototypes use the office building LPD allowance from the building area method (Table 9.5.1). Similarly, the basement zone in the Large Hotel, Hospital, and the office zone in the Warehouse use the LPD allowance from the building area method.
2. Most other zones in the prototypes are mapped to a single space-by-space category and the LPD allowance from that category is used directly.
3. A few zones in the prototypes (for example, the Back Space zone in the Stand-alone Retail prototype) are considered a mix of two or more space types; in such cases, the NC^3 database (Richman et al. 2008) is used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single LPD allowance for those spaces.
4. A room cavity ratio adjustment has been applied to a few spaces such as corridors, and exercise rooms.

Using these rules and the values in addendum *ch*, the LPD allowances for all prototypes and zones were determined. The implementation in EnergyPlus is straightforward and involved using the design LPD allowance as the input to the zone general lighting object.

B.1.3.5 Addendum *do*: Dwelling Unit Lighting Efficacy

Addendum Description. Addendum "*do*" adds a new section, Section 9.4.4, that requires at least 75% of permanently installed lighting fixtures in dwelling units to have a lamp with an efficacy of at least 55 lumens/W, or have a luminaire efficacy of at least 45 lumens/W. Lighting controlled with dimmers or automatic control devices is exempted from the requirement. The addendum also eliminates the exception that exempted dwelling units from lighting power and control requirements.

Modeling Strategy. Prior to addendum "*do*," lighting in dwelling units, i.e., the Mid-rise Apartment and High-rise Apartment prototypes, was based on a Building America Research Index Report[7] from 2005. Since then, a number of other studies have been published with more recent data on typical lighting usage in multi-family buildings. A study by Gifford et al. (2012) was used to update the baseline lighting usage in the two apartment prototypes. The baseline LPD and the mix of lamp types was calculated from the report using the following data:

1. From Table 4.2 of the referenced report, the average daily consumption for a typical multi-family dwelling unit in the U.S. was found to be 1,803 Wh and the total number of lamps equaled 24.8.
2. From Table 4.4, 21% of lamps in multifamily dwelling units are compact fluorescent (CFL), 62% are incandescent and the rest fall into the "other" category.
3. From Table 4.3, the average power of a CFL lamp is 15.13 W, an incandescent lamp is 58.31 W, and other lamps is 79.82 W.

Thus, the total lighting power is equal to 1,270 W (sum of number of lamps of each type times the average power for each lamp) and the average number of hours all the lamps are on is 1.42 hours per day (1,803 Wh divided by 1,269.6 W).

For addendum "*do*," 75% of the lamps must have an efficacy of 55 lumens/W. 21% of lamps in the baseline already meet this requirement. The rest were met by reducing the proportion of incandescent lamps and changing that proportion to CFLs, keeping the proportion of "other" lamps in the total the same. For 90.1-2016, the proportion of lamps was as follows: incandescent lamps 8%, CFLs 75%, and other lamps 17%. The lighting power was calculated to 568 W per dwelling unit. The hours lamps were energized remained the same between baseline and advanced cases. Implementation in EnergyPlus models is straightforward and is accomplished by inputting the lighting power and applying the schedule to each zone. Hourly values for the existing lighting schedule for apartment zones was scaled to ensure that the total operating hours per day were equal to 1.42.

B.1.3.6 Addendum *dq*: Display Lighting Adder

Addendum Description. Addendum *dq* reduces the allowance for retail display lighting found in Section 9.6.2. Table B.10 shows the retail display allowance for each of four sales area categories both before and after addendum dq.

Table B.10. Retail Display Lighting Adder

Retail Display Area	Area Function	90.1-2013 Display Adder	90.1-2016 Display Adder
1	Other areas not listed below	0.6 W/ft^2	0.45 W/ft^2
2	Sale of vehicles, sporting goods, and small electronics	0.6 W/ft^2	0.45 W/ft^2

[7] https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/44816.pdf.

3	Sale of furniture, clothing, cosmetics, and artwork	1.4 W/ft^2	1.05 W/ft^2
4	sale of jewelry, crystal, and china	2.5 W/ft^2	1.88 W/ft^2

Modeling Strategy. The Strip Mall prototype is the only prototype with display lighting. Each zone in the Strip Mall prototype is a separate retail store, and Table B.11 shows the classification for each store for the purpose of determining display lighting power.

In addition to the display lighting allowance for different types of merchandise, a base 1,000 W adder is provided for display lighting in Standard 90.1-2013 and remains in addendum *dq*. To implement addendum *dq*, the base display lighting adder of 1,000 W was combined with the reduced display lighting allowance to determine the total LPD for display lighting in each zone. Table B.12 shows the calculations for display LPD for 90.1-2013 and 90.1-2016. Implementation of display lighting was completed through the lighting object in EnergyPlus.

Table B.11. Strip Mall Store Classification for Display Lighting

Strip Mall Zone Name	Area (ft^2)	Retail Area Type for Display Lighting
LGstore 1	3,749	3
SMstore 1	1,874	
SMstore 2	1,874	2
SMstore 3	1,874	
SMstore 4	1,874	
LGstore 2	3,749	No Display Lighting
SMstore 5	1,874	
SMstore 6	1,874	
SMstore 7	1,874	
SMstore 8	1,874	

Table B.12. Display LPD for 90.1-2013 and 90.1-2016

			90.1-2013			90.1-2016		
Strip Mall Zone	Area (ft^2)	Area assumed for Display Lighting	Display Allowance (W/ft^2)	Display Adder (W)	Display LPD (W/ft^2)	Display Allowance (W/ ft^2)	Display Adder (W)	Display LPD (W/ft^2)
LGstore 1	3,749	25%	1.4	1000	0.617	1.05	1000	0.529
SMstore 1	1,874	25%	1.4	1000	0.884	1.05	1000	0.796
SMstore 2	1,874	25%	0.6	1000	0.684	0.45	1000	0.646
SMstore 3	1,874	25%	0.6	1000	0.684	0.45	1000	0.646
SMstore 4	1,874	25%	0.6	1000	0.684	0.45	1000	0.646

B.1.4 Service Hot Water Addenda

B.1.4.1 Addendum *by*: Require first 8 feet of SHW piping runout to be insulated

Addendum Description. Addendum "*by*" requires insulation of the first 8' of branch piping from recirculating SWH systems. The requirement was added to Section 7.4.3 as item c. The purpose of this addendum is to reduce heat loss from run-out piping between the recirculation piping and the fixture. As a result, less water will need to be dumped at the fixture before hot water arrives when there is a moderate time lag between hot water uses.

Modeling Strategy. This addendum impacts the following prototypes with recirculating service hot water systems: Large and Medium Office, Large and Small Hotel, Primary and Secondary School, Outpatient Health Care, Hospital, High-rise Apartment, and Full Service Restaurant. The baseline was changed to add the heat loss from runout piping not previously included. The total pipe loss heating use was modified in the EnergyPlus model as shown in Table B.13.

Table B.13. Addendum "by" Service Hot Water Runout Insulation

Prototype/Zone	Total (Main Loop + Branches with the new method) New Total Pipe Heat Loss for 90.1-2004, 2007 (W)	New Total Pipe Heat Loss for 90.1-2010, 2013 (W)	New Total Pipe Heat Loss for 90.1-2016 (W)	Estimated Saving of Addendum *by*, comparing to 90.1-2013 (%)
High-rise Apartment	9,465	9,260	8,167	11.8
Hospital	20,291	20,036	17,147	14.4
Large Hotel	18,667	18,467	15,908	13.9
Large Office	8,376	8,146	7,280	10.6
Medium Office	2,109	2,003	1,886	5.8
Outpatient Health Care	7,639	7,514	6,496	13.6
Primary School	1,065	1,006	970	3.6
Secondary School	1,332	1,268	1,205	5.0
Full Service Restaurant	1,053	993	947	4.6
Small Hotel	8,432	8,296	7,231	12.8

B.2 References

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