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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ANSI/ASHRAE/IES Standard 90.1-2022: Energy Savings Analysis

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Acknowledgments

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Nomenclature or List of Acronyms

AEO	Annual Energy Outlook
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu	British thermal unit(s)
CBECS	Commercial Building Energy Consumption Survey
COP	coefficient of performance
CRAC	computer room air conditioner
DCV	demand controlled ventilation
DDC	direct digital control
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
ECB	Energy Cost Budget
ECI	energy cost intensity
ECPA	Energy Conservation and Production Act
ERR	enthalpy recovery ratio
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERV	energy recovery ventilator
EUI	energy use intensity
ft^2	square foot (feet)
GWP	Global Warming Potential
HRV	heat recovery ventilator
HVAC	heating, ventilating, and air conditioning
IAM	integrated assessment model
IECC	International Energy Conservation Code
IEER	integrated energy efficiency ratio
IES	Illuminating Engineering Society

IESNA	Illuminating Engineering Society of North America
in wg	inches water gage
kft^2	thousand square feet
kWh	thousand Watt-hour
LPD	lighting power density
PBA	principal building activity
PCI	Performance Cost Index
PRM	Performance Rating Method
PNNL	Pacific Northwest National Laboratory
SAT	supply air temperature
SCOP	seasonal coefficient of performance
SC-CO_2	social cost of carbon
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
U.S.C.	United State Code
VAV	variable air volume
VRF	variable-refrigerant-flow
VT	visible transmittance
yr	year(s)

Executive Summary

Title III of the Energy Conservation and Production Act, as amended (ECPA), establishes requirements for DOE to review consensus-based building energy conservation standards. (42 U.S.C. 6831 et seq.) Section 304(b), as amended, of ECPA provides that whenever the ANSI/ASHRAE/IESNA[1] 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 a revision, whether the revised code would improve energy efficiency in commercial buildings, and must publish a notice of such determination in the *Federal Register*. (42 U.S.C. 6833(b)(2)(A))

Standard 90.1 is developed under ANSI-approved procedures[2], via a public review and consensus process through which any interested party can participate, 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.[3] Standard 90.1-2022 was published in January 2023, triggering the statutorily required DOE review process.

To meet the statutory requirement, DOE conducted a technical analysis to evaluate and quantify the expected energy savings associated with Standard 90.1-2022. This report documents the methodology, technical analysis, and findings supporting DOE's determination on Standard 90.1-2022.

Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analyses and determinations, is designed to evaluate the impact of the updated Standard on new construction across the U.S., 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 90.1-2022 and the previous 2019 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 16 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 90.1-2019, which serves as the baseline, and Standard 90.1-2022.

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

[2] See https://www.ansi.org/about_ansi/overview/

[3] More information on the development of ANSI/ASHRAE/IES Standard 90.1 is available at https://www.ashrae.org/technical-resources/bookstore/standard-90-1

Results

In creating Standard 90.1-2022, ASHRAE published 89 addenda in total, of which:

- 39 are expected to *decrease* energy use (i.e., increased energy savings);
- none are expected to *increase* energy use (i.e., decreased energy savings), and;
- 50 are expected to have *no direct impact* on energy savings (such as administrative changes, clarifications or changes to alternative compliance paths).[4]

New commercial buildings meeting the requirements of Standard 90.1-2022 that were analyzed in the quantitative analysis exhibit national average savings[5] from energy efficiency improvements (compared to Standard 90.1-2019) of approximately the following:

- 9.8 percent *site* energy savings;
- 9.4 percent *source* energy savings;
- 8.9 percent *energy cost* savings, and;
- 9.3 percent carbon emissions.

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 that 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 75 percent of the total square footage of new commercial construction (Lei et al. 2020).

Figure ES.1 and Tables ES.1, ES.2, and ES.3 provide **gross** energy performance results, which exclude the impact of on-site energy generation such as renewable energy systems. Site and source EUIs, energy cost indices (ECIs), and carbon emissions, are provided for Standard 90.1-2019 and Standard 90.1-2022, respectively, as well as percentage savings between the two editions. Figure ES.2 and Tables ES.4, ES.5, and ES.6 provide **net** energy performance results, in the same format as the above tables, but including the impact of on-site energy generation.

Results presented below are aggregated at the national level for each prototype, and as an average across prototypes. Analogous tables aggregated by climate zone are included in Section 4.2.

[4] Addenda characterized as having *no direct impact* on energy savings are detailed in Appendix A.
[5] Savings based on the impacts of increased energy efficiency in accordance with DOE's directive under 42 USC 6833.

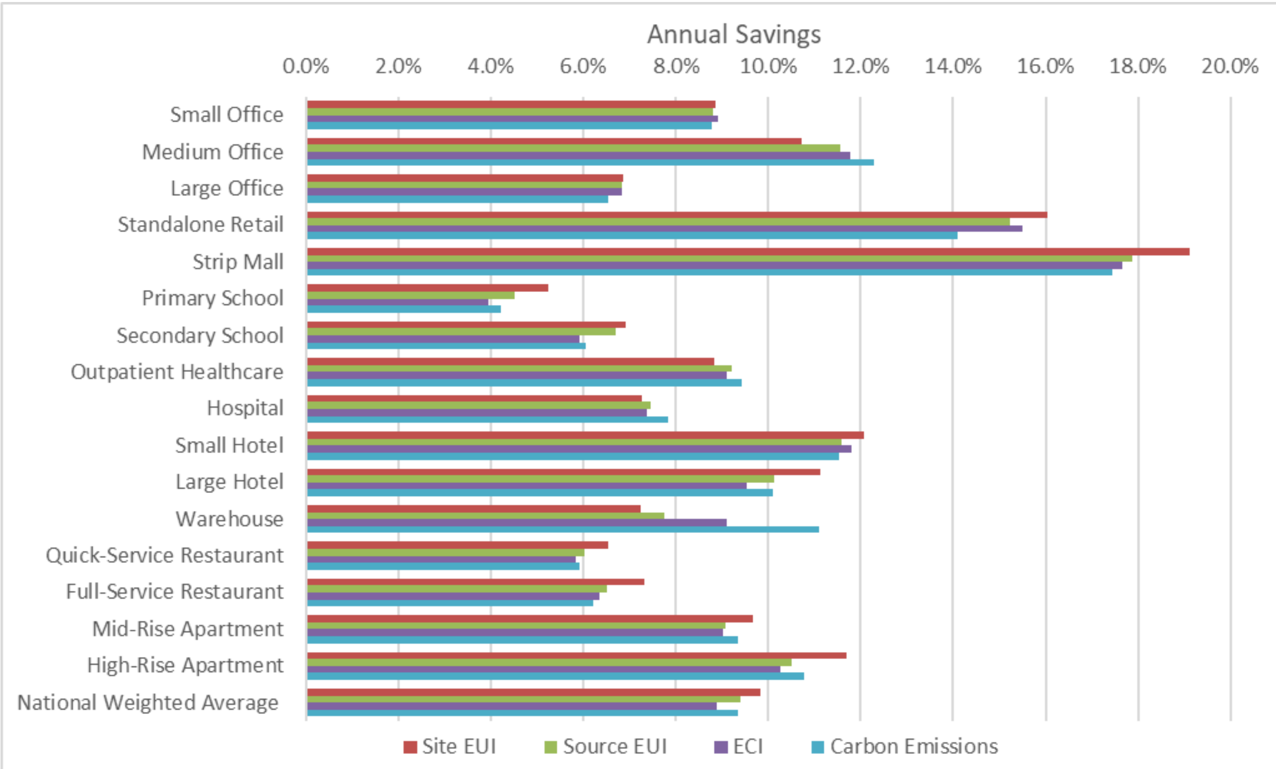

Figure ES.1. Percentage Gross Savings by Building Type from 90.1-2019 to 90.1-2022 (excluding the impact of on-site energy generation)

Table ES.1. Estimated Gross Energy Use Intensity by Building Type – Standard 90.1-2019 (excluding the impact of on-site energy generation)

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
Office	Small Office	3.8%	28.2	78.3	$1.01	5.7
	Medium Office	5.0%	30.8	79.6	$1.02	5.7
	Large Office	3.9%	53.9	147.6	$1.90	10.7
Retail	Standalone Retail	10.9%	46.8	103.7	$1.29	7.1
	Strip Mall	3.7%	50.2	121.4	$1.53	8.6
Education	Primary School	4.8%	43.9	101.6	$1.27	7.1
	Secondary School	10.9%	39.1	94.0	$1.18	6.6
Healthcare	Outpatient Healthcare	3.4%	99.6	228.9	$2.86	15.9
	Hospital	4.5%	100.4	236.7	$2.97	16.6
Lodging	Small Hotel	1.6%	61.3	119.0	$1.44	7.8
	Large Hotel	4.2%	84.4	164.8	$1.99	10.9
Warehouse	Warehouse	18.6%	13.8	27.1	$0.33	1.8
Food Service	Quick-Service Restaurant	0.3%	502.2	860.8	$10.09	54.1
	Full-Service Restaurant	1.0%	341.5	641.8	$7.70	41.8
Apartment	Mid-Rise Apartment	13.7%	39.3	103.6	$1.33	7.5
	High-Rise Apartment	9.6%	45.3	95.3	$1.17	6.5
National Weighted Average		**100%**	**47.8**	**108.5**	**$1.35**	**7.5**

Table ES.2. Estimated Gross Energy Use Intensity by Building Type – Standard 90.1-2022 (excluding the impact of on-site energy generation)

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft2-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
Office	Small Office	3.8%	25.7	71.4	$0.92	5.2
	Medium Office	5.0%	27.5	70.4	$0.90	5.0
	Large Office	3.9%	50.2	137.5	$1.77	10.0
Retail	Standalone Retail	10.9%	39.3	87.9	$1.09	6.1
	Strip Mall	3.7%	40.6	99.7	$1.26	7.1
Education	Primary School	4.8%	41.6	97.0	$1.22	6.8
	Secondary School	10.9%	36.4	87.7	$1.11	6.2
Healthcare	Outpatient Healthcare	3.4%	90.8	207.8	$2.60	14.4
	Hospital	4.5%	93.0	218.9	$2.75	15.3
Lodging	Small Hotel	1.6%	53.9	105.2	$1.27	6.9
	Large Hotel	4.2%	75.0	148.1	$1.80	9.8
Warehouse	Warehouse	18.6%	12.8	25.0	$0.30	1.6
Food Service	Quick-Service Restaurant	0.3%	469.4	808.9	$9.50	50.9
	Full-Service Restaurant	1.0%	316.5	600.0	$7.21	39.2
Apartment	Mid-Rise Apartment	13.7%	35.5	94.2	$1.21	6.8
	High-Rise Apartment	9.6%	40.0	85.3	$1.05	5.8
National Weighted Average		**100%**	**43.1**	**98.3**	**$1.23**	**6.8**

Table ES.3. Estimated Percent Gross Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Building Type (excluding the impact of on-site energy generation)

Building Type	Prototype Building	Savings				
		Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
Office	Small Office	3.8%	8.9%	8.8%	8.9%	8.8%
	Medium Office	5.0%	10.7%	11.6%	11.8%	12.3%
	Large Office	3.9%	6.9%	6.8%	6.8%	6.5%
Retail	Standalone Retail	10.9%	16.0%	15.2%	15.5%	14.1%
	Strip Mall	3.7%	19.1%	17.9%	17.6%	17.4%
Education	Primary School	4.8%	5.2%	4.5%	3.9%	4.2%
	Secondary School	10.9%	6.9%	6.7%	5.9%	6.1%
Healthcare	Outpatient Healthcare	3.4%	8.8%	9.2%	9.1%	9.4%
	Hospital	4.5%	7.4%	7.5%	7.4%	7.8%
Lodging	Small Hotel	1.6%	12.1%	11.6%	11.8%	11.5%
	Large Hotel	4.2%	11.1%	10.1%	9.5%	10.1%
Warehouse	Warehouse	18.6%	7.2%	7.7%	9.1%	11.1%
Food Service	Quick-Service Restaurant	0.3%	6.5%	6.0%	5.8%	5.9%
	Full-Service Restaurant	1.0%	7.3%	6.5%	6.4%	6.2%
Apartment	Mid-Rise Apartment	13.7%	9.7%	9.1%	9.0%	9.3%
	High-Rise Apartment	9.6%	11.7%	10.5%	10.3%	10.8%
National Weighted Average		**100%**	**9.8%**	**9.4%**	**8.9%**	**9.3%**

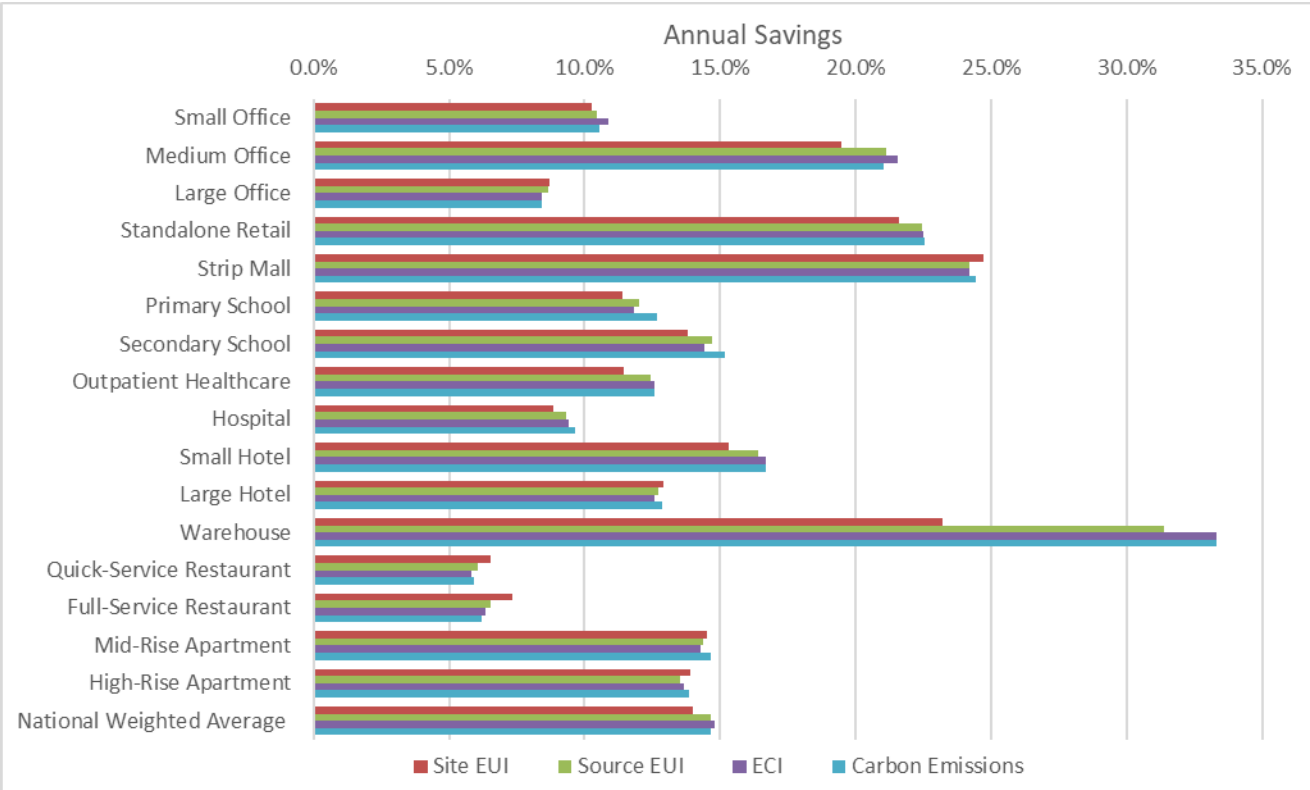

Figure ES.2. Percentage Net Savings by Building Type from 90.1-2019 to 90.1-2022 (including the impact of on-site energy generation)

Table ES.4. Estimated Net Energy Use Intensity by Building Type – Standard 90.1-2019 (including the impact of on-site energy generation)

Building Type	Building Prototype	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon (tons/kft²-yr)
Office	Small Office	3.8%	28.2	78.3	$1.01	5.7
	Medium Office	5.0%	30.8	79.6	$1.02	5.7
	Large Office	3.9%	53.7	147.6	$1.89	10.7
Retail	Standalone Retail	10.9%	46.8	103.7	$1.29	7.1
	Strip Mall	3.7%	50.2	121.4	$1.53	8.6
Education	Primary School	4.8%	43.9	101.6	$1.27	7.1
	Secondary School	10.9%	39.1	94.0	$1.18	6.6
Healthcare	Outpatient Healthcare	3.4%	99.6	228.9	$2.86	15.9
	Hospital	4.5%	100.4	236.7	$2.97	16.6
Lodging	Small Hotel	1.6%	61.3	119.0	$1.44	7.8
	Large Hotel	4.2%	84.4	164.8	$1.99	10.9
Warehouse	Warehouse	18.6%	13.8	27.1	$0.33	1.8
Food Service	Quick-Service Restaurant	0.3%	502.2	860.9	$10.09	54.1
	Full-Service Restaurant	1.0%	341.5	641.8	$7.70	41.8
Apartment	Mid-Rise Apartment	13.7%	39.3	103.6	$1.33	7.5
	High-Rise Apartment	9.6%	45.3	95.3	$1.17	6.5
National Weighted Average		**100%**	**47.8**	**108.5**	**$1.35**	**7.5**

Table ES.5. Estimated Net Energy Use Intensity by Building Type – Standard 90.1-2022 (including the impact of on-site energy generation)

Building Type	Building Prototype	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft2-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon (tons/kft²-yr)
Office	Small Office	3.8%	25.3	70.1	$0.90	5.1
	Medium Office	5.0%	24.8	62.8	$0.80	4.5
	Large Office	3.9%	49.2	134.8	$1.74	9.8
Retail	Standalone Retail	10.9%	36.7	80.4	$1.00	5.5
	Strip Mall	3.7%	37.8	92.0	$1.16	6.5
Education	Primary School	4.8%	38.9	89.4	$1.12	6.2
	Secondary School	10.9%	33.7	80.2	$1.01	5.6
Healthcare	Outpatient Healthcare	3.4%	88.2	200.4	$2.50	13.9
	Hospital	4.5%	91.5	214.6	$2.69	15.0
Lodging	Small Hotel	1.6%	51.9	99.5	$1.20	6.5
	Large Hotel	4.2%	73.5	143.8	$1.74	9.5
Warehouse	Warehouse	18.6%	10.6	18.6	$0.22	1.2
Food Service	Quick-Service Restaurant	0.3%	469.4	808.9	$9.50	50.9
	Full-Service Restaurant	1.0%	316.5	600.0	$7.21	39.2
Apartment	Mid-Rise Apartment	13.7%	33.6	88.7	$1.14	6.4
	High-Rise Apartment	9.6%	39.0	82.4	$1.01	5.6
National Weighted Average		**100%**	**41.1**	**92.5**	**$1.15**	**6.4**

Table ES.6. Estimated Percent Net Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Building Type (including the impact of on-site energy generation)

		Savings				
		Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
Office	Small Office	3.8%	10.3%	10.5%	10.9%	10.5%
	Medium Office	5.0%	19.5%	21.1%	21.6%	21.1%
	Large Office	3.9%	8.7%	8.7%	8.4%	8.4%
Retail	Standalone Retail	10.9%	21.6%	22.5%	22.5%	22.5%
	Strip Mall	3.7%	24.7%	24.2%	24.2%	24.4%
Education	Primary School	4.8%	11.4%	12.0%	11.8%	12.7%
	Secondary School	10.9%	13.8%	14.7%	14.4%	15.2%
Healthcare	Outpatient Healthcare	3.4%	11.4%	12.5%	12.6%	12.6%
	Hospital	4.5%	8.9%	9.3%	9.4%	9.6%
Lodging	Small Hotel	1.6%	15.3%	16.4%	16.7%	16.7%
	Large Hotel	4.2%	12.9%	12.7%	12.6%	12.8%
Warehouse	Warehouse	18.6%	23.2%	31.4%	33.3%	33.3%
Food Service	Quick-Service Restaurant	0.3%	6.5%	6.0%	5.8%	5.9%
	Full-Service Restaurant	1.0%	7.3%	6.5%	6.4%	6.2%
Apartment	Mid-Rise Apartment	13.7%	14.5%	14.4%	14.3%	14.7%
	High-Rise Apartment	9.6%	13.9%	13.5%	13.7%	13.8%
National Weighted Average		**100%**	**14.0%**	**14.7%**	**14.8%**	**14.7%**

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1 Introduction

ANSI/ASHRAE/IES[6] Standard 90.1 is recognized by the U.S. Congress as the national model energy code for commercial buildings under the Energy Conservation and Production Act (ECPA), as amended. (42 U.S.C 6833) With each new edition of Standard 90.1, Section 304(b) of ECPA directs the Secretary of Energy (Secretary) to make a *determination* as to whether the update would improve energy efficiency in commercial buildings. Standard 90.1 is developed under ANSI-approved consensus procedures[7] 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.[8] Standard 90.1-2022 (ASHRAE 2022), the most recent edition, was published in January 2023, triggering the statutorily required U.S. Department of Energy (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 July 28, 2021, DOE issued an affirmative determination of energy savings for Standard 90.1-2019 (DOE 2021), which concluded that it would achieve greater overall energy efficiency in commercial buildings required to meet the Standard than the previous edition, Standard 90.1-2016 (86 FR 40543). Through this determination, Standard 90.1-2019 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 90.1-2022. 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 (IECC), which includes the option to comply with Standard 90.1 by reference (ICC 2021). Separately, the DOE Building Energy Codes Program also provides technical assistance supporting states implementing building energy codes, including analysis to quantify state code impacts, tracking the status of state code adoption, and developing a suite of tools to assist states, local governments, and industry stakeholders in demonstrating compliance with their codes (BECP 2023).

To fulfill its statutory directive, DOE analyzes Standard 90.1-2022 to understand its overall impact on energy efficiency in commercial buildings required to meet the Standard. Section 2 of this report summarizes specific changes (known as 'addenda') made between Standard 90.1-2022 and the previous 2019 edition; Section 3 documents the qualitative and quantitative analysis methodology; and Section 4 presents the analysis results. Appendix A identifies addenda not included in the quantitative analysis. Appendix B details the modeling strategies for individual addenda included in the quantitative analysis.

1.1 Compliance with Standard 90.1

Standard 90.1-2022 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 heating, ventilating, and air conditioning (HVAC) systems. Some of

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

[7] See ANSI Essential Requirements (updated January 2020) at https://share.ansi.org/Shared%20Documents/Standards%20Activities/American%20National%20Standards/Procedures,%20Guides,%20and%20Forms/2020_ANSI_Essential_Requirements.pdf

[8] More information on the development of ANSI/ASHRAE/IES Standard 90.1 is available at http://sspc901.ashraepcs.org/index.php

those requirements are considered “mandatory” and must be met even when one of the other optional paths is utilized (e.g., performance path). The 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 90.1-2022 includes a second performance approach, the *Performance Rating Method* (PRM), often referred to by its location in the Standard, Appendix G. PRM is similar to ECB except that it uses a stable baseline that does not increase in stringency with each new edition of the Standard, target building performance factors which must be achieved on a whole-building basis to demonstrate compliance, and it allows credit for design features not credited in ECB. Each performance path is generally updated based on changes in the prescriptive path, and intended to yield building energy performance which meets or exceeds that required under the prescriptive path. The qualitative assessment in this analysis includes addenda impacting all three paths, and the quantitative analyzes the prescriptive path only. More details are provided in Section 3.

2 Summary of Addenda Included in Standard 90.1-2022

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 2022 edition, ASHRAE published 89 addenda in total (listed in Appendix M of Standard 90.1-2022). Table 1 shows the number of addenda included in Standard 90.1-2022 grouped into the primary sections of the Standard they impact. When an addendum impacts multiple sections, it is counted only once in this table towards the section that receives the most substantial impacts.

Table 1. Number of Addenda affecting Various Sections in Standard 90.1-2022

Section of 90.1-2022	Number of Addenda
5. Building Envelope	7
6. Heating, Ventilating, and Air Conditioning	26
7. Service Water Heating	2
8. Power	2
9. Lighting	13
10. Other Equipment	3
11. Additional Efficiency Requirements	1
Performance Compliance (including Sections 4.2.1.1, 12, and Appendices L and G)	29
Others	6
Total	89

More broadly, DOE characterized the individual addenda into three categories to help guide the analysis:

1. Clarifications, administrative revisions, or updates to references to other documents.
2. Modifications to the prescriptive and mandatory design and construction requirements for the building envelope, HVAC, service water heating (SWH), power, lighting, and other equipment sections of the Standard.

3. Modifications to the performance path options for compliance (e.g., the ECB, building envelope trade-off option, and PRM sections of Standard 90.1).

Although, DOE reviews all addenda from a given code cycle, performing a qualitative review to characterize the expected impacts of each, category #2 above—changes that affect the mandatory and prescriptive provisions of the code—represents the subset of addenda which ultimately become the primary focal point of the energy savings analysis. The methodology applied in the energy savings analysis is discussed in the following section.

3 Methodology

The methodology applied in this analysis is consistent with that utilized for previous DOE building energy codes analyses and determinations, evaluates the expected impact of the updated Standard on new construction, and is based on a combination of qualitative and quantitative assessments.

3.1 Overview

The *qualitative* phase of the analysis made initial assessments as to whether an individual addendum 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 is applicable to the *prescriptive* or *mandatory* requirements of Standard 90.1-2022.

2. Determine whether each addendum that is 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:

1. Of the addenda that directly impact energy use, determine those that can be reasonably quantified through energy modeling and simulation analysis.

2. Calculate whole-building results and quantify the national impact based on energy use of the addenda in step 1 of the Quantitative Analysis.

Additional detail on each phase of the analysis is provided in subsections 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 deemed to not directly impact energy use (within the context of this analysis). Addenda were excluded if they met either of the following criteria:

1. The addenda are not applicable to the *prescriptive* and *mandatory* requirements of the Standard, meaning they only applied to the performance paths in Standard 90.1: Section 12 (Energy Cost Budget Method), Appendix C (Methodology for Building Envelope Trade-off Option), Appendix G (Performance Rating Method), and Appendix L (Mechanical System Performance Rating Method). The performance paths represent optional alternatives to the prescriptive path and are generally intended to align with the prescriptive path. As the stringency of the prescriptive path is increased, the performance path rules and targets are typically updated to mirror those changes. Therefore, the use of the prescriptive and

mandatory requirements effectively represents changes to the entire Standard. Additionally, the purpose of the optional performance paths is to provide design flexibility, which occurs by allowing an almost limitless number of trade-off combinations that comply with the Standard. Analytically, it is not practical or possible to model all these combinations in a manner which can be aggregated to align with the purpose of a national energy savings determination.

2. The addenda affect the prescriptive path but have no impact on energy use, have an undetermined impact within the scope of the analysis, or cannot be reasonably quantified through established and accepted methods of energy modeling and simulation analysis. Addenda with no impact include administrative changes or clarifications, changes to rating methods or categorization of equipment (as opposed to required efficiency levels), changes to optional alternatives, exceptions, updates of references to other documents, and text changes that are intended to improve the general usability of Standard 90.1. Addenda with undetermined impact include those related to commissioning and functional testing requirements, and to those whose impact on energy is dependent on site-specific conditions (such as shading from trees or its neighboring buildings). Changes with impacts, which do not become effective within three years from the publication of Standard 90.1-2022 (i.e., until a cutoff date of December 31, 2025), are also considered as having no impact (within the context of this analysis).

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 carried 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 quantitative analysis builds on established methods 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 90.1-2019 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 Standard 90.1-2022. Additional details of the implementation into the prototype building models for each of the 16 addenda are provided in Appendix B.

The models were simulated using *EnergyPlus Version 22.1.0* (DOE 2022). Those addenda that were not captured through the quantitative analysis were filtered out and are labeled as such in Table 4. Addenda were not included in the quantitative analysis when they met one of the following criteria:

1. The addenda impact features are not representative of typical building designs. As explained in Section 3.3.1, the purpose of the prototype models is to represent common design features found in each building type in the United States. Therefore, there are less common features that are not incorporated in the prototypes; examples include: series energy recovery, large diameter ceiling fans, compressed air systems, and parking garages. Addenda affecting these features of buildings were not captured via the prototypes in order to preserve representation of the typical building stock.

2. The addenda adopt known standard practices. The systems and their configuration in the prototype models are based on standard practice that has been widely adopted in the United States. When an addendum is to fix a loophole for an uncommon design practice, the uncommon design is not modeled in the prototypes and thus, has no affect within the quantitative analysis.

3. The addenda relate 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.

4. The addenda incorporate federal minimum equipment standards. These addenda mirror update to federal equipment standards and will improve efficiency even in the absence of their replication in Standard 90.1-2022, 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 16 prototype buildings (DOE and PNNL 2020) 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 that are not included in CBECS but are covered by Standard 90.1 if more than three stories tall. Consequently, mid-rise and high-rise multi-family prototype buildings were added to the 14 prototype buildings identified through the review of CBECS (Thornton et al. 2011).

Table 2 lists the broad building categories, the prototype building names, floor areas of the prototype buildings, and construction weights relative to the other building types. These include 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 16 prototype buildings are representative of the characteristics of new construction in the United States. 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 75% 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 (Lei et al. 2020).

Table 2. Commercial Prototype Building Models

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

3.3.2 Climate Zones

Building models were analyzed in standardized climate zones described in ASHRAE Standard 169-2013 (ASHRAE 2013). Standard 169-2013 includes nine thermal zones and three moisture regimes. The U.S. 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 United States. These are also consistent with representative cities approved by the SSPC 90.1 for setting the criteria for Standard 90.1-2022.

The 16 cities used in the current analysis are as follows:

- 1A: Miami, Florida (very hot, humid)
- 2A: Tampa, Florida (hot, humid)
- 2B: Tucson, Arizona (hot, dry)
- 3A: Atlanta, Georgia (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Diego, California (warm, marine)
- 4A: New York, New York (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Seattle, Washington (mixed, marine)
- 5A: Buffalo, 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/arctic)

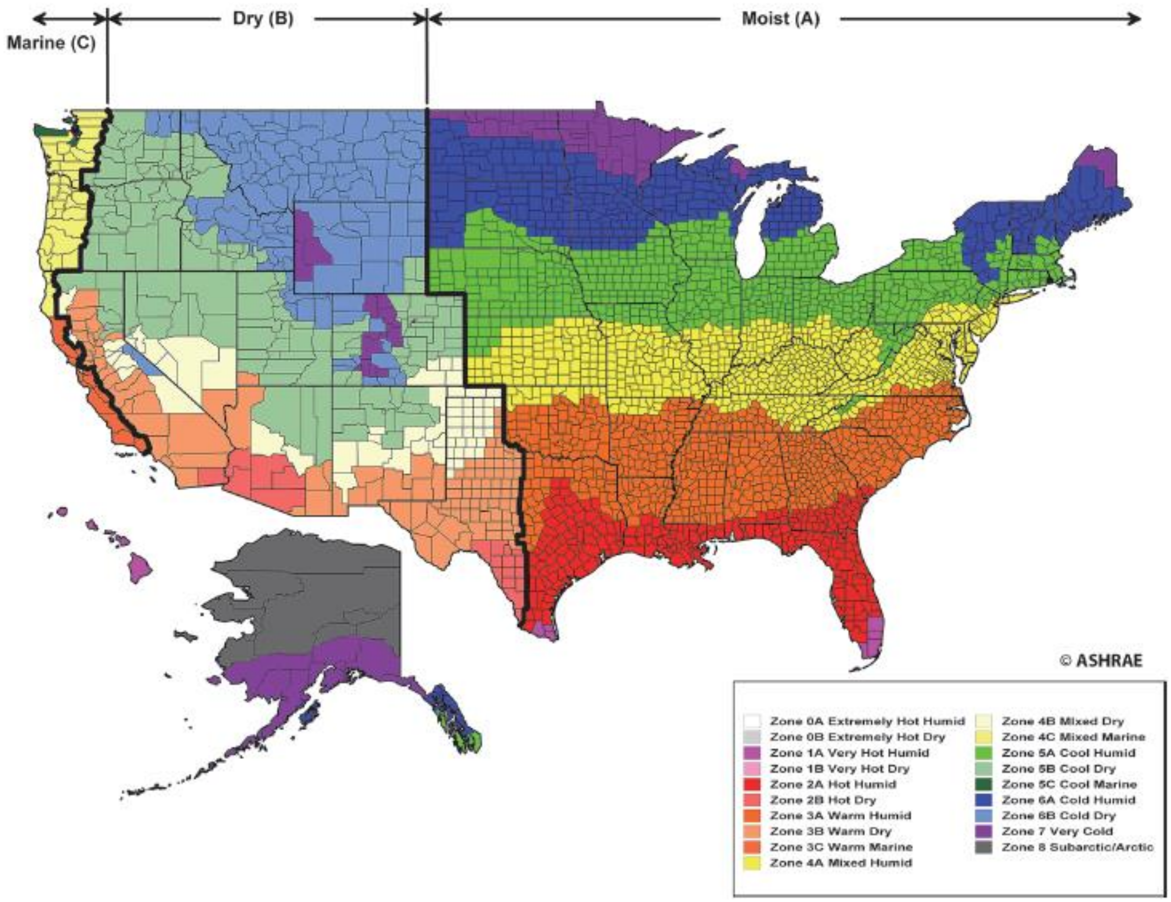

Figure 1. United States Climate Zone Map

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. Details of the development are further discussed in a PNNL report (Lei et al. 2020). New construction weights were determined for each building type in each climate zone based on the county-climate zone mapping from ASHRAE Standard 169-2013. Table 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 each prototype building and within the 16 climate zones.

Using the energy use intensity (EUI) statistics from each building simulation and the corresponding relative fractions of new construction floor space, PNNL developed floor-space-weighted national EUI statistics by energy type for each building type and standard edition. PNNL then summed these energy type-specific EUI estimates to obtain the national site energy EUI by building type and standard edition. PNNL also applied national data for average energy prices, average source energy conversion rates to the energy type-specific EUI data, average carbon emission factors, and social cost of carbon (SC-CO_2) to obtain estimates of national source energy EUI, national energy cost intensity (ECI), national carbon emissions, and national SC-CO_2, 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. 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. In the quantitative analysis, this was accomplished by assuming current minimum federal equipment efficiencies (i.e., as published in Standard 90.1-2022 with an effective date no later than December 31, 2025) in both the 2019 and 2022 prototype building models (with offsetting effects), which is consistent with historical DOE determination analyses. Note that the excluded addenda relate to minimum equipment efficiency levels set through the federal appliance and equipment standards rulemaking process, and not revised efficiency levels standards originating in ASHRAE Standard 90.1-2022. If the efficiency improvement is due to a change initiated in Standard 90.1, even those which may subsequently trigger an update in federal regulations, then those addenda are included in the determination savings.

3.3.5 Impacts of Renewable Energy Systems

Standard 90.1-2022 added prescriptive requirements for on-site energy generation in certain building types and climate zones which is to be achieved through the use of renewable energy systems. This is the first time requirements for renewable energy systems have been incorporated into the prescriptive requirements of the model energy codes and follows a trend exhibited by states and local governments (e.g., California Title 24). Historically, the model energy codes, and therefore DOE's energy code determinations, have focused on the impacts of energy efficiency. Consistent with ECPA, DOE's technical analysis of Standard 90.1-2022 and determination remain focused on increases in energy efficiency in commercial buildings. However, as building energy codes incorporate new technologies and construction practices, such as those pertaining to renewable energy systems, states, local governments, and industry stakeholders have requested a comprehensive analysis, and can benefit from understanding the impacts of more traditional energy efficiency measures compared to net reductions in building energy use achieved through on-site energy generation with renewable energy systems. DOE is therefore evaluating the impacts of renewable energy systems in terms of energy use and savings, but reporting such impacts separately, delineating the "gross" impacts (which *exclude* the impacts of on-site energy generation) from "net" impacts (which *include* the impacts of on-site energy generation). This approach is consistent with the reporting methods adopted by the national model energy code development bodies—for both Standard 90.1 and the IECC—and provides insight on the separate and combined effects of energy efficiency and renewable energy systems.

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

3.4 Comments on Methodology

The goal of this analysis was to determine if the 2022 edition of Standard 90.1 is more energy-efficient relative to the 2019 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 1), 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 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 39 of the 89 addenda had a direct impact on energy use as defined in Section 3.2 — all 39 of the addenda listed decrease energy use in commercial buildings. The 50 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.

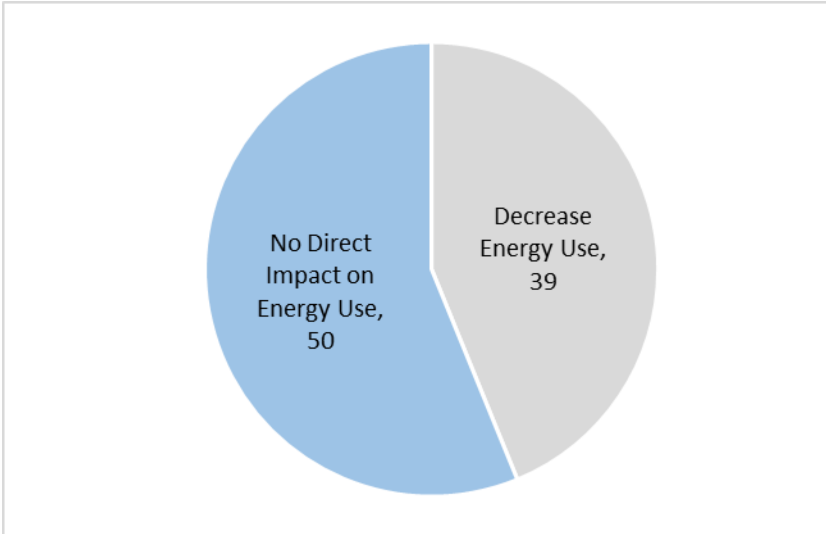

Figure 2. Categorization of Addenda

The 39 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 addendum designation assigned by ASHRAE.
2. **Code Section(s)**: a list of the section numbers in Standard 90.1-2019 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).

Addenda characterized as having *no direct impact* on energy savings are detailed in Appendix A.

Table 4. Addenda Determined to Directly Save Energy by the Qualitative Analysis of Standard 90.1-2022

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
a	6.5.3.7, 6.5.3.8, 13	Establishes minimum fan efficacy requirements for low-power ventilation fans; establishes Standard 62.2 as the reference for determining the minimum ventilation rates for non-transient dwelling units, in accordance with the scope of 62.2 and 62.1.	Yes	Yes	Reduces energy for exhaust and ERV fans in apartment dwelling units.
b	6.4.3.8	Replaces single threshold parameters for when demand controlled ventilation (DCV) is required with a table where the floor area threshold requirement is based on climate zone and occupant outside airflow rates per 1,000 sq. ft. determined through ASHRAE Standard 62.1.	Yes	Yes	DCV now required for some zones with moderate occupant density, such as retail, and also includes some zones that have ERV, such as classrooms.
c	6.3.2 6.4.3.3	Programmable thermostat for residential units.	Yes	Yes	Reduces energy for apartments by setting thermostats during daytime.
d	6.4.3.4.5	Adds new term to define *parking garage section* so that fan requirements can be refined for different configurations. Requires fans with the ability to modulate airflow and power as specified.	Yes	No	Excluded from quantitative analysis because parking garages are not included in the prototypes.
m	6.4.3.4.1	Adds a requirement for motorized dampers on shaft vents used for temperature control; reduces stringency and costs in mild climates and short buildings by allowing nonmotorized dampers in lieu of motorized dampers, mirroring Exception 1 to Section 6.4.3.4.2.	Yes	No	Excluded from quantitative analysis because shaft vents are not characterized in the prototypes.
n	6.5.2.6	Adds an exception for series energy recovery to the simultaneous heating and cooling limitation requirements on ventilation air heating control.	Yes	No	Excluded from quantitative analysis because series energy recovery not included in the prototypes.
o	9.4.1.1	Reduces the minimum connected load that triggers daylighting responsive controls.	Yes	No	Because LPD requirements are also more stringent, the reduction in load threshold tends to reflect the same floor area as previously required.
p	9.1.2 9.1.4	Closes loopholes that allow alteration projects to comply without meeting all the requirements of Chapter 9.	Yes	No	Excluded from quantitative analysis because analysis only considers the impacts on new construction.

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
s	5.5.3.2.2	Removes the use of solar reflectance index (SRI) for walls and replaces it with the more accurate and relevant term--solar reflectance (SRI is still used when referring to roofs); also adds requirements for south-, east-, and west-facing walls to have a minimum solar reflectance of 0.30 in climate zone 0.	Yes	No	Only affects Climate Zone 0 which is not present in the United States, so not reflected in determination results.
t	3.2, 5.4.3,5.7.2, 5.9.1.2, 6.5.1, Table 12.5.1 (5), 12.5.3, 13, C1.5, C3.5.5.3, C3.6, C3.1.1.4, Table G3.1 (5), Table H-3	Adds requirement to perform whole-building air leakage testing and measurement on buildings less than 10,000 ft^2.	Yes	Yes	Reduces infiltration loads for Small Office and Restaurant prototypes.
z	9.1.4	Reduces limit for track lighting power.	Yes	No	Excluded from quantitative analysis because there is no track lighting in the prototypes.
ac	3.2, 9.4.1.2, Table 9.2.3.1, Table 9.6.1, Appendix E	Updates interior lighting power and minimum control requirements: adds a power exception for the germicidal function in luminaires and sources, removes exceptions for casinos and parking garage daylight transition zone lighting.	Yes	No	Affects functions and space types not included in the prototypes.
ah	7.5.3	Increases required efficiency of large service water-heating systems.	Yes	Yes	Reduces SWH energy for Large Hotel.
am	9.2.3.2, Table 9.2.3.2, 9.4.1.4, 9.4.2, Table 9.4.2-1, Table 9.4.2-2	Modifies exterior lighting power and control requirements.	Yes	Yes	Significant reductions in all exterior lighting categories that are included in the prototypes.
ap	3.2, 3.3, 4.2.1, 4.2.2, 9.9.1, 12.2, 13, Section 11	Introduces a new section to Standard 90.1 for the use of energy credits to achieve additional energy savings over general prescriptive requirements.	Yes	Yes	Unique energy credit selections are applied to each prototype to achieve significant energy savings.

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
aq	6.8.3 7.4.3	Reorganizes Section 6.8.3 - Piping Insulation Tables, and adds new Table 7-4 for SWH piping insulation.	Yes	No	Excluded from quantitative analysis because the change is only applicable to SWH piping with fluid temperature greater than 140F, which is not present in the prototypes.
ar	3.2, Table 9.2.3.1, 9.4.4, Appendix E	Adds requirements for indoor horticultural lighting based on a new metric, photosynthetic photon efficacy (PPE).	Yes	No	Excluded from quantitative analysis because there are no indoor plant zones in the prototypes.
av	5.5.5	Adds requirements to address the impacts of thermal bridges in the building envelope.	Yes	Yes	Unmitigated thermal breaks are added to Standard 90.1-2019 prototype models where applicable, so mitigation savings can be determined for Standard 90.1-2022.
aw	Table 6.8.1-21	Adds efficiency requirements for large diameter ceiling fans (LDCF).	Yes	No	Excluded from quantitative analysis because there are no large diameter ceiling fans in the prototypes.
ay	Tables 6.8.1-8 and 6.8.1-9	Modifies Tables 6.8.1-8 and 6.8.1-9 for variable refrigerant flow (VRF) equipment based on the new AHRI 1230-2021 test procedure which required an adjustment to EER and IEER values.	Yes	No	Excluded from quantitative analysis because there are no VRF systems in the prototypes.
az	3.2, 10.4.6	Introduces compressed air system requirements with measures for reducing common sources of energy waste.	Yes	No	Excluded from quantitative analysis because there are no compressed air systems in the prototypes.
ba	9.4.1.1, Table 9.5.2.1, Table G3.7-1, Table G3.7-2	Updates lighting power density values for space-by-space method.	Yes	Yes	Reduces lighting power for most space types.
bb	9.5.1	Updates the lighting power density values for the Building Area Method compliance path.	Yes	No	Excluded from quantitative analysis because the Building Area Method is not used in the prototypes.

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
bc	6.5.4.8	Requires condensing boilers for new construction to achieve condensing-level efficiency (i.e., 90% Et) for large boiler systems (i.e., between 1 and 10 million Btu/h) and, to ensure condensing occurs, requires boiler entering water to be in the prescribed limits for temperature or flow rate.	Yes	Yes	Reduces heating energy through improved boiler efficiency.
bf	9.5.2.2	Changes to additional lighting power allowances.	Yes	Yes	Reduces lighting energy in Strip Mall prototype.
bk	6.4.3.3.2 6.4.3.3.5.1	Adopts Standard 62.1-2019 to change dehumidification from relative humidity to dew point setpoint with lower humidity setpoints for both occupied and unoccupied time for moisture control.	Yes	No	Excluded from quantitative analysis because prototypes with dehumidification have 24/7 operation.
bm	6.5.3.8.1	Requires shutting off ventilation air to standby zones.	Yes	No	No new savings for this measure, since it was already included in the Standard 90.1-2019 models.
br	9.4.3	Increases the efficacy threshold for lamps and luminaires in dwelling units and specifies requirements for interior and exterior lighting controls.	Yes	Yes	Decreases lighting energy in apartment prototypes.
bs	9.3.1, 9.3.2	Reduced the lighting power density values in 9.3.1, Simplified Building Method Compliance Path, to maintain alignment with the established method.	Yes	No	Excluded from quantitative analysis because the prototypes use the space-by-space approach.
bx	Table 6.8.1-5	Large furnace (>= 225k) efficiency increases from 80% to 81% on 1/1/23.	Yes	No	Excluded from quantitative analysis because the impacted furnaces are federally-regulated.
by, cc	10.5	Adds minimum prescriptive requirement for on-site renewable energy for buildings at least 10,000 ft^2.	Yes	Yes	Reduces net site energy for all prototypes except Small Office and Restaurants.
cb	1.1, 2.1, 2.2, 2.3, 3.2, 4.1.1.6, 4.2.1.4, 4.1.2.5, 10.4.6, Table G3.1	Revises the Standard 90.1 Purpose and Scope to apply to areas outside of the physical building that qualify under the new definition for “site”.	Yes	No	Excluded from quantitative analysis because the prototypes only include building grounds.

Addendum	Code Sections	Description of Change	Impact on Energy Use	Included in Quantitative Analysis	Discussion
cd	6.5.6.1	Clarifies the requirement on bypass or controls of energy recovery systems during air economizer mode, eliminates energy exchange in economizing mode that reduces the effectiveness of economizing, and reduces the pressure drop through the energy recovery system in economizing mode.	Yes	No	Excluded from quantitative analysis because the correct controls were already assumed to be included in the prototypes.
cf	10.4	Introduces provisions that improve elevator fan, lighting, and movement efficiency.	Yes	Yes	Reduces energy use for lights and lift motors.
cg	5.5.3.1.2	Adds a definition for insulated metal panels (IMPs) and a new section to explain how the U-factor of a given IMP is determined.	Yes	No	Excluded from quantitative analysis because there are no insulated panels in the prototypes.
ci	Table 6.5.1-1	Lowers the threshold for economizer from 54 kBtuh to 33 kBtuh for fan cooling units located outside the building (e.g. packaged rooftops); not applicable to interior systems such as water source heat pump terminals.	Yes	Yes	Reduces cooling energy for smaller packaged systems in several prototypes.
cj	Table 6.8.1-16	Corrections to chiller efficiency table; only full load value that changes is for Path A centrifugal, 150 to 300 tons.	Yes	No	Excluded from quantitative analysis because a Path A centrifugal chiller in this size range is not used in any of the prototypes.
cu	6.5.6.3	Change from requiring condenser heat recovery to heat pump chiller that uses the cooling system return water as the heat source.	Yes	No	Excluded from quantitative analysis because a Path A centrifugal chiller in this size range is not used in any of the prototypes.

4.2 Quantitative 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 "Direct Impact & Not Quantified" includes those addenda that were determined to have a direct impact on energy use but are not included in the quantitative analysis. Appendix B describes the implementation of addenda into the prototype models.

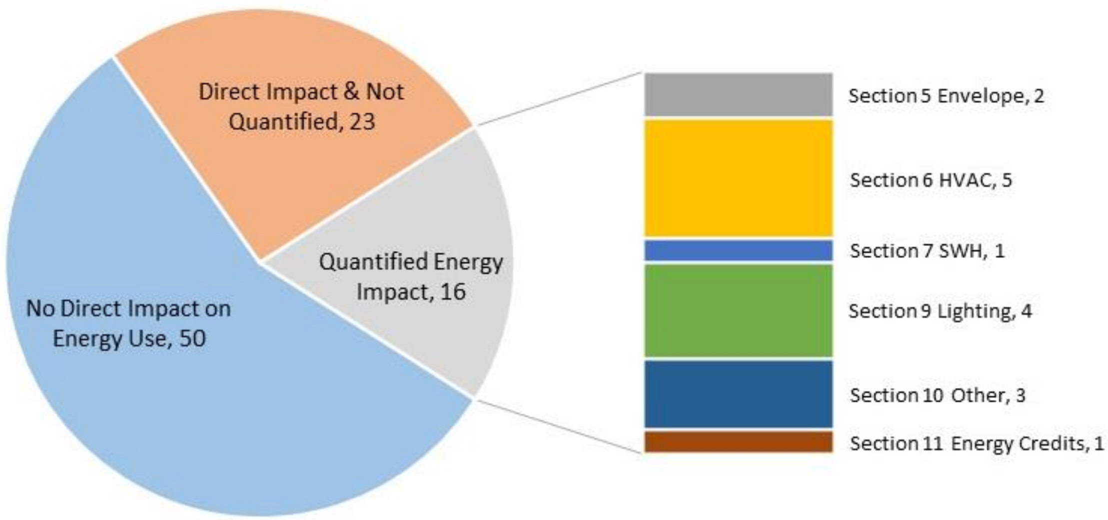

Figure 3. Categorization of Quantified Addenda

A summary of the quantitative analysis results showing national weighted averages for several result metrics is provided in Table 5. Gross energy refers to the total energy consumed by end uses in the building and on the building site. Net energy refers to the energy provided to the building by the grid and is calculated as the difference between the gross energy and the on-site renewable energy generation. Requirements for renewable energy systems are a new addition in Standard 90.1-2022, and the reporting scheme included in this report—separating net vs. gross impacts—is intended to mimic that utilized by SSPC 90.1 in developing the Standard. The results were aggregated on a national basis for each Standard, based on the weighting factors discussed in Section 3.3.3.

Table 5. Weighted National Average Simulation Summary Results

	Gross Energy Savings			Net Energy Savings (including renewable energy)		
Annual Result Metric	90.1-2019	90.1-2022	2022 vs 2019	90.1-2019	90.1-2022	2022 vs 2019
Site Energy [kBtu/ft2-yr]	47.8	43.1	9.8%	47.8	41.1	14.0%
Source Energy [kBtu/ft2-yr]	108.5	98.3	9.4%	108.5	92.5	14.7%
Energy Cost [$/ft^2-yr]	$1.35	$1.23	8.9%	$1.35	$1.15	14.8%
Emissions [tons/kft2-yr]	7.5	6.8	9.3%	7.5	6.4	14.7%

More detailed quantitative analysis results are provided in several tables and figures on the following pages. The first group of results, which includes Table 7 through Table 12 and Figure 4 and Figure 5, presents gross energy results, while the second group, which includes Table 13 through Table 18 and Figure 6 and Figure 4.7, presents net energy results. The data are aggregated in these tables and charts either by building type or by climate zone.

In the results tables site energy refers to the energy consumed at the building site, and 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. The development of these conversion factors is explained below.

The electric energy source conversion factor of 9,667 Btu/kWh was calculated from EIA's Annual Energy Outlook (AEO) 2023 (EIA 2023) Table 2[9] as follows:

- Delivered commercial electricity, 2022: 4.59 quads
- Commercial electricity related losses, 2022: 8.42 quads
- Total commercial electric energy use, 2022: 13.01 quads
- Commercial electric source ratio, U.S. 2022: 2.83
- Source electric energy factor (3413 Btu/kWh site) [10] 9,667 Btu/kWh

Natural gas EUIs in the prototype buildings were converted to source energy using a factor of 1.099 Btu of source energy per Btu of site natural gas use, based on the 2022 national energy use estimate shown in Table 2 of the AEO 2022 as follows:

- Delivered total natural gas, 2022: 29.89 quads
- Natural gas used in well, field, and pipeline: 2.96 quads
- Total gross natural gas use, 2022: 32.85 quads
- Total natural gas source ratio, U.S. 2022: 1.099 Btu source/Btu site
- Source natural gas energy factor (100,000 Btu/therm site): 109,900 Btu/therm

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

- $0.1251/kWh of electricity
- $11.39 per 1000 cubic feet ($1.099/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.

Carbon emissions in the quantitative analysis are based on the source energy consumption on a national scale. Carbon emission metrics are provided by the U.S. Environmental Protection Agency (EPA) Greenhouse Gas Equivalencies Calculator[11]. This calculator reports the national marginal carbon emission conversion factor for electricity at 7.07×10^{-4} metric tons carbon dioxide (CO_2)/kWh. For natural gas, the carbon emission conversion factor is 0.0053 metric tons CO_2/therm. Table 6 summarizes the carbon emission factors.

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

[10] The final conversion value is calculated using the full seven-digit values available in Table 2 of AEO 2023. Other values shown in the text are rounded.

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

Table 6. Carbon Emission Factors by Fuel Type

Fuel Source	Carbon Emission Factor
Electricity	7.07×10^{-4} metric tons CO_2/kWh
Natural Gas	0.0053 metric tons CO_2/therm

Overall, the analysis indicates that Standard 90.1-2022 will result in increased energy efficiency in commercial buildings. On a weighted national average basis, Standard 90.1-2022 will result in gross savings of 9.8% site energy, 9.4% source energy, 8.9% energy cost, and 9.3% carbon emissions. When renewable energy is factored into the results, the net savings increase to 14.0% site energy, 14.7% source energy, 14.8% energy cost, and 14.7% carbon emissions.

Table 7. Estimated Gross Energy Use Intensity by Building Type – Standard 90.1-2019

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft^2-yr)	Source EUI (kBtu/ft^2-yr)	ECI ($/ft^2-yr)	Carbon Emissions (tons/kft^2-yr)
Office	Small Office	3.8%	28.2	78.3	$1.01	5.7
	Medium Office	5.0%	30.8	79.6	$1.02	5.7
	Large Office	3.9%	53.9	147.6	$1.90	10.7
Retail	Standalone Retail	10.9%	46.8	103.7	$1.29	7.1
	Strip Mall	3.7%	50.2	121.4	$1.53	8.6
Education	Primary School	4.8%	43.9	101.6	$1.27	7.1
	Secondary School	10.9%	39.1	94.0	$1.18	6.6
Healthcare	Outpatient Healthcare	3.4%	99.6	228.9	$2.86	15.9
	Hospital	4.5%	100.4	236.7	$2.97	16.6
Lodging	Small Hotel	1.6%	61.3	119.0	$1.44	7.8
	Large Hotel	4.2%	84.4	164.8	$1.99	10.9
Warehouse	Warehouse	18.6%	13.8	27.1	$0.33	1.8
Food Service	Quick-Service Restaurant	0.3%	502.2	860.8	$10.09	54.1
	Full-Service Restaurant	1.0%	341.5	641.8	$7.70	41.8
Apartment	Mid-Rise Apartment	13.7%	39.3	103.6	$1.33	7.5
	High-Rise Apartment	9.6%	45.3	95.3	$1.17	6.5
National Weighted Average		**100%**	**47.8**	**108.5**	**$1.35**	**7.5**

Table 8. Estimated Gross Energy Use Intensity by Building Type – Standard 90.1-2022

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft2-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
Office	Small Office	3.8%	25.7	71.4	$0.92	5.2
	Medium Office	5.0%	27.5	70.4	$0.90	5.0
	Large Office	3.9%	50.2	137.5	$1.77	10.0
Retail	Standalone Retail	10.9%	39.3	87.9	$1.09	6.1
	Strip Mall	3.7%	40.6	99.7	$1.26	7.1
Education	Primary School	4.8%	41.6	97.0	$1.22	6.8
	Secondary School	10.9%	36.4	87.7	$1.11	6.2
Healthcare	Outpatient Healthcare	3.4%	90.8	207.8	$2.60	14.4
	Hospital	4.5%	93.0	218.9	$2.75	15.3
Lodging	Small Hotel	1.6%	53.9	105.2	$1.27	6.9
	Large Hotel	4.2%	75.0	148.1	$1.80	9.8
Warehouse	Warehouse	18.6%	12.8	25.0	$0.30	1.6
Food Service	Quick-Service Restaurant	0.3%	469.4	808.9	$9.50	50.9
	Full-Service Restaurant	1.0%	316.5	600.0	$7.21	39.2
Apartment	Mid-Rise Apartment	13.7%	35.5	94.2	$1.21	6.8
	High-Rise Apartment	9.6%	40.0	85.3	$1.05	5.8
National Weighted Average		**100%**	**43.1**	**98.3**	**$1.23**	**6.8**

Table 9. Estimated Gross Energy Use Intensity by Climate Zone – Standard 90.1-2019

Climate Zone	Floor Area Weight	Whole Building Energy Metrics			
		Site EUI (kBtu/ft2-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
1A	0.04	46.5	115.6	$1.47	8.2
2A	0.17	45.3	113.1	$1.43	8.0
2B	0.03	41.2	103.6	$1.32	7.4
3A	0.15	45.8	107.4	$1.35	7.5
3B	0.09	39.4	95.3	$1.20	6.7
3C	0.02	39.0	96.9	$1.23	6.9
4A	0.21	48.2	106.2	$1.32	7.3
4B	0.00	49.4	113.0	$1.41	7.8
4C	0.03	41.0	93.5	$1.17	6.5
5A	0.18	55.0	113.0	$1.38	7.6
5B	0.05	48.8	107.8	$1.34	7.4
5C	0.00	54.4	116.9	$1.44	8.0
6A	0.03	64.8	129.5	$1.57	8.6
6B	0.01	60.5	123.5	$1.51	8.3
7	0.00	70.2	137.5	$1.67	9.1
8	0.00	87.5	156.4	$1.85	10.0
National	**1.00**	**47.8**	**108.5**	**$1.35**	**7.5**

Table 10. Estimated Gross Energy Use Intensity by Climate Zone – Standard 90.1-2022

Climate Zone	Floor Area Weight	Whole Building Energy Metrics			
		Site EUI (kBtu/ft2-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
1A	0.04	42.5	105.5	$1.34	7.5
2A	0.17	41.4	103.1	$1.31	7.3
2B	0.03	37.7	94.6	$1.20	6.7
3A	0.15	41.8	97.8	$1.23	6.8
3B	0.09	36.0	87.2	$1.10	6.1
3C	0.02	35.5	87.9	$1.11	6.2
4A	0.21	43.2	95.8	$1.19	6.6
4B	0.00	44.8	103.0	$1.29	7.2
4C	0.03	36.9	84.6	$1.06	5.9
5A	0.18	48.9	101.4	$1.24	6.8
5B	0.05	43.8	97.6	$1.21	6.7
5C	0.00	48.5	105.9	$1.31	7.2
6A	0.03	57.2	115.5	$1.41	7.7
6B	0.01	53.6	111.2	$1.36	7.5
7	0.00	62.5	123.8	$1.50	8.2
8	0.00	77.1	140.0	$1.67	9.0
National	**1.00**	**43.1**	**98.3**	**$1.23**	**6.8**

Table 11. Estimated Percent Gross Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Building Type

Building Type	Prototype Building	Savings				
		Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
Office	Small Office	3.8%	8.9%	8.8%	8.9%	8.8%
	Medium Office	5.0%	10.7%	11.6%	11.8%	12.3%
	Large Office	3.9%	6.9%	6.8%	6.8%	6.5%
Retail	Standalone Retail	10.9%	16.0%	15.2%	15.5%	14.1%
	Strip Mall	3.7%	19.1%	17.9%	17.6%	17.4%
Education	Primary School	4.8%	5.2%	4.5%	3.9%	4.2%
	Secondary School	10.9%	6.9%	6.7%	5.9%	6.1%
Healthcare	Outpatient Healthcare	3.4%	8.8%	9.2%	9.1%	9.4%
	Hospital	4.5%	7.4%	7.5%	7.4%	7.8%
Lodging	Small Hotel	1.6%	12.1%	11.6%	11.8%	11.5%
	Large Hotel	4.2%	11.1%	10.1%	9.5%	10.1%
Warehouse	Warehouse	18.6%	7.2%	7.7%	9.1%	11.1%
Food Service	Quick-Service Restaurant	0.3%	6.5%	6.0%	5.8%	5.9%
	Full-Service Restaurant	1.0%	7.3%	6.5%	6.4%	6.2%
Apartment	Mid-Rise Apartment	13.7%	9.7%	9.1%	9.0%	9.3%
	High-Rise Apartment	9.6%	11.7%	10.5%	10.3%	10.8%
National Weighted Average		**100%**	**9.8%**	**9.4%**	**8.9%**	**9.3%**

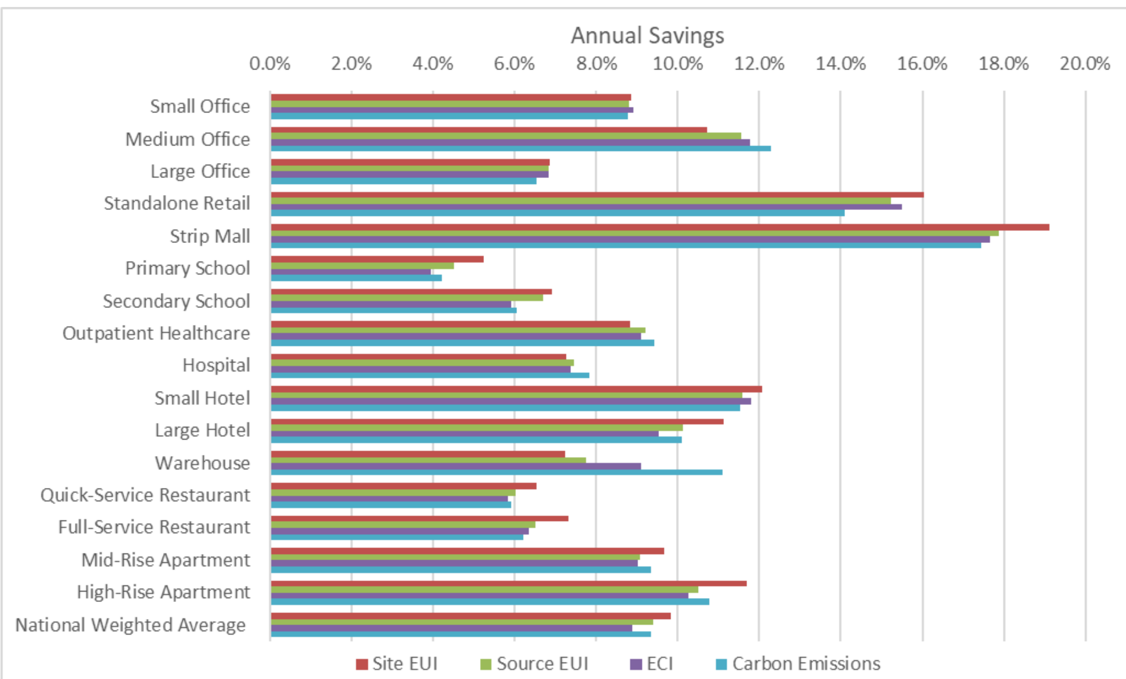

Figure 4. Percentage Gross Savings by Building Type from Standard 90.1-2019 to 90.1-2022

Table 12. Estimated Percent Gross Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Climate Zone

		Savings			
Climate Zone	Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
1A	0.04	8.6%	8.7%	8.8%	8.5%
2A	0.17	8.6%	8.8%	8.4%	8.8%
2B	0.03	8.5%	8.7%	9.1%	9.5%
3A	0.15	8.7%	8.9%	8.9%	9.3%
3B	0.09	8.6%	8.5%	8.3%	9.0%
3C	0.02	9.0%	9.3%	9.8%	10.1%
4A	0.21	10.4%	9.8%	9.8%	9.6%
4B	0.00	9.3%	8.8%	8.5%	7.7%
4C	0.03	10.0%	9.5%	9.4%	9.2%
5A	0.18	11.1%	10.3%	10.1%	10.5%
5B	0.05	10.2%	9.5%	9.7%	9.5%
5C	0.00	10.8%	9.4%	9.0%	10.0%
6A	0.03	11.7%	10.8%	10.2%	10.5%
6B	0.01	11.4%	10.0%	9.9%	9.6%
7	0.00	11.0%	10.0%	10.2%	9.9%
8	0.00	11.9%	10.5%	9.7%	10.0%
National	**1.00**	**9.8%**	**9.4%**	**8.9%**	**9.3%**

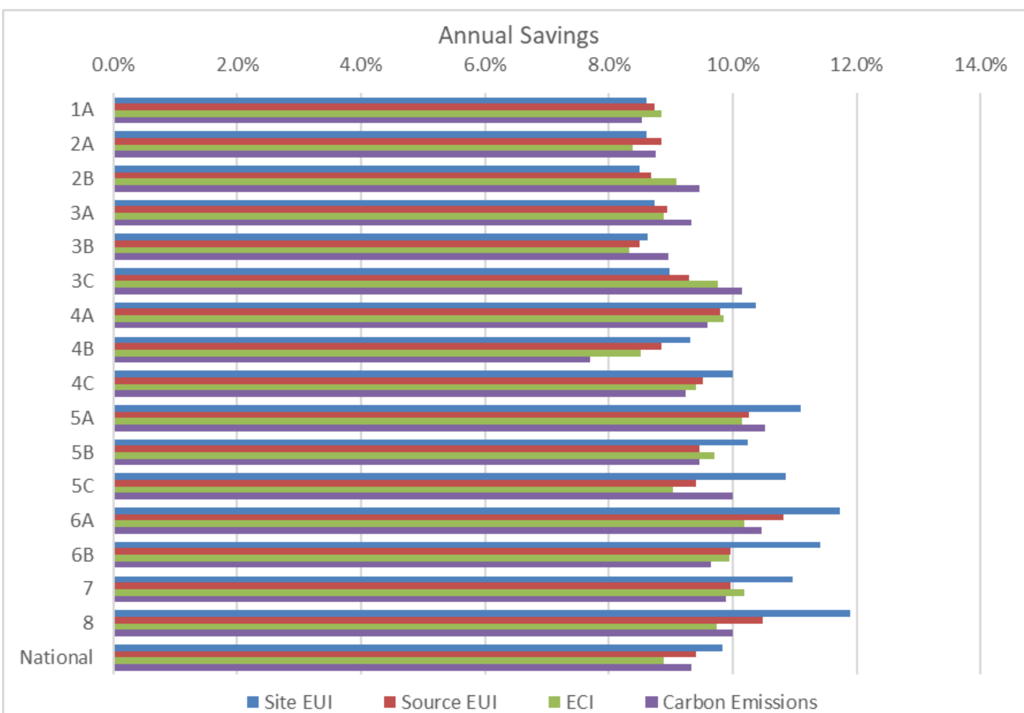

Figure 5. Percentage Gross Savings by Climate Zone from Standard 90.1-2019 to 90.1-2022

Table 13. Estimated Net Energy Use Intensity by Building Type – Standard 90.1-2019

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
Office	Small Office	3.8%	28.2	78.3	$1.01	5.7
	Medium Office	5.0%	30.8	79.6	$1.02	5.7
	Large Office	3.9%	53.9	147.6	$1.90	10.7
Retail	Standalone Retail	10.9%	46.8	103.7	$1.29	7.1
	Strip Mall	3.7%	50.2	121.4	$1.53	8.6
Education	Primary School	4.8%	43.9	101.6	$1.27	7.1
	Secondary School	10.9%	39.1	94.0	$1.18	6.6
Healthcare	Outpatient Healthcare	3.4%	99.6	228.9	$2.86	15.9
	Hospital	4.5%	100.4	236.7	$2.97	16.6
Lodging	Small Hotel	1.6%	61.3	119.0	$1.44	7.8
	Large Hotel	4.2%	84.4	164.8	$1.99	10.9
Warehouse	Warehouse	18.6%	13.8	27.1	$0.33	1.8
Food Service	Quick-Service Restaurant	0.3%	502.2	860.8	$10.09	54.1
	Full-Service Restaurant	1.0%	341.5	641.8	$7.70	41.8
Apartment	Mid-Rise Apartment	13.7%	39.3	103.6	$1.33	7.5
	High-Rise Apartment	9.6%	45.3	95.3	$1.17	6.5
National Weighted Average		**100%**	**47.8**	**108.5**	**$1.35**	**7.5**

Table 14. Estimated Net Energy Use Intensity by Building Type – Standard 90.1-2022

Building Type	Prototype Building	Whole Building Energy Metrics				
		Floor Area Weight	Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
Office	Small Office	3.8%	25.3	70.1	$0.90	5.1
	Medium Office	5.0%	24.8	62.8	$0.80	4.5
	Large Office	3.9%	49.2	134.8	$1.74	9.8
Retail	Standalone Retail	10.9%	36.7	80.4	$1.00	5.5
	Strip Mall	3.7%	37.8	92.0	$1.16	6.5
Education	Primary School	4.8%	38.9	89.4	$1.12	6.2
	Secondary School	10.9%	33.7	80.2	$1.01	5.6
Healthcare	Outpatient Healthcare	3.4%	88.2	200.4	$2.50	13.9
	Hospital	4.5%	91.5	214.6	$2.69	15.0
Lodging	Small Hotel	1.6%	51.9	99.5	$1.20	6.5
	Large Hotel	4.2%	73.5	143.8	$1.74	9.5
Warehouse	Warehouse	18.6%	10.6	18.6	$0.22	1.2
Food Service	Quick-Service Restaurant	0.3%	469.4	808.9	$9.50	50.9
	Full-Service Restaurant	1.0%	316.5	600.0	$7.21	39.2
Apartment	Mid-Rise Apartment	13.7%	33.6	88.7	$1.14	6.4
	High-Rise Apartment	9.6%	39.0	82.4	$1.01	5.6
National Weighted Average		100%	41.1	92.5	$1.15	6.4

Table 15. Estimated Net Energy Use Intensity by Climate Zone – Standard 90.1-2019

Climate Zone	Floor Area Weight	Whole Building Energy Metrics			
		Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
1A	0.04	46.5	115.6	$1.47	8.2
2A	0.17	45.3	113.1	$1.43	8.0
2B	0.03	41.2	103.6	$1.32	7.4
3A	0.15	45.8	107.4	$1.35	7.5
3B	0.09	39.4	95.3	$1.20	6.7
3C	0.02	39.0	96.9	$1.23	6.9
4A	0.21	48.2	106.2	$1.32	7.3
4B	0.00	49.4	113.0	$1.41	7.8
4C	0.03	41.0	93.5	$1.17	6.5
5A	0.18	55.0	113.0	$1.38	7.6
5B	0.05	48.8	107.8	$1.34	7.4
5C	0.00	54.4	116.9	$1.44	8.0
6A	0.03	64.8	129.5	$1.57	8.6
6B	0.01	60.5	123.5	$1.51	8.3
7	0.00	70.2	137.5	$1.67	9.1
8	0.00	87.5	156.4	$1.85	10.0
National	**1.00**	**47.8**	**108.5**	**$1.35**	**7.5**

Table 16. Estimated Net Energy Use Intensity by Climate Zone – Standard 90.1-2022

Climate Zone	Floor Area Weight	Whole Building Energy Metrics			
		Site EUI (kBtu/ft²-yr)	Source EUI (kBtu/ft²-yr)	ECI ($/ft²-yr)	Carbon Emissions (tons/kft²-yr)
1A	0.04	40.6	100.2	$1.27	7.1
2A	0.17	39.2	96.8	$1.23	6.9
2B	0.03	35.2	87.5	$1.11	6.2
3A	0.15	39.6	91.6	$1.15	6.4
3B	0.09	33.4	79.9	$1.01	5.6
3C	0.02	33.3	81.6	$1.03	5.8
4A	0.21	41.4	90.8	$1.13	6.2
4B	0.00	42.1	95.5	$1.19	6.6
4C	0.03	35.4	80.4	$1.00	5.6
5A	0.18	47.1	96.3	$1.18	6.5
5B	0.05	41.7	91.5	$1.13	6.3
5C	0.00	46.7	100.9	$1.25	6.9
6A	0.03	55.4	110.2	$1.34	7.3
6B	0.01	51.7	105.6	$1.29	7.1
7	0.00	60.7	118.8	$1.44	7.8
8	0.00	75.7	136.0	$1.61	8.7
National	**1.00**	**41.1**	**92.5**	**$1.15**	**6.4**

Table 17. Estimated Percent Net Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Building Type

			Savings			
		Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
Office	Small Office	3.8%	10.3%	10.5%	10.9%	10.5%
	Medium Office	5.0%	19.5%	21.1%	21.6%	21.1%
	Large Office	3.9%	8.7%	8.7%	8.4%	8.4%
Retail	Standalone Retail	10.9%	21.6%	22.5%	22.5%	22.5%
	Strip Mall	3.7%	24.7%	24.2%	24.2%	24.4%
Education	Primary School	4.8%	11.4%	12.0%	11.8%	12.7%
	Secondary School	10.9%	13.8%	14.7%	14.4%	15.2%
Healthcare	Outpatient Healthcare	3.4%	11.4%	12.5%	12.6%	12.6%
	Hospital	4.5%	8.9%	9.3%	9.4%	9.6%
Lodging	Small Hotel	1.6%	15.3%	16.4%	16.7%	16.7%
	Large Hotel	4.2%	12.9%	12.7%	12.6%	12.8%
Warehouse	Warehouse	18.6%	23.2%	31.4%	33.3%	33.3%
Food Service	Quick-Service Restaurant	0.3%	6.5%	6.0%	5.8%	5.9%
	Full-Service Restaurant	1.0%	7.3%	6.5%	6.4%	6.2%
Apartment	Mid-Rise Apartment	13.7%	14.5%	14.4%	14.3%	14.7%
	High-Rise Apartment	9.6%	13.9%	13.5%	13.7%	13.8%
National Weighted Average		100%	14.0%	14.7%	14.8%	14.7%

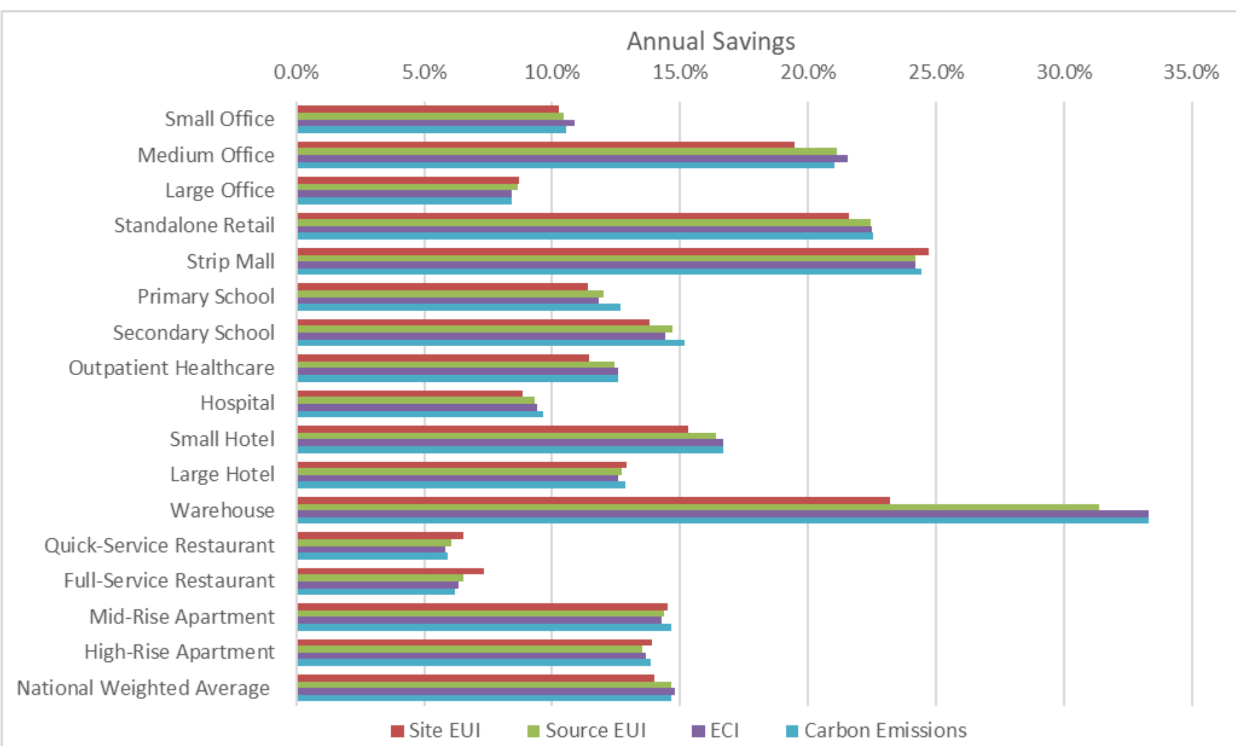

Figure 6. Percentage Net Savings by Building Type from Standard 90.1-2019 to 90.1-2022

Table 18. Estimated Percent Net Energy Savings between 2019 and 2022 Editions of Standard 90.1 – by Climate Zone

		Savings			
Climate Zone	Floor Area Weight	Site EUI	Source EUI	ECI	Carbon Emissions
1A	0.04	12.7%	13.3%	13.6%	13.4%
2A	0.17	13.5%	14.4%	14.0%	13.8%
2B	0.03	14.6%	15.5%	15.9%	16.2%
3A	0.15	13.5%	14.7%	14.8%	14.7%
3B	0.09	15.2%	16.2%	15.8%	16.4%
3C	0.02	14.6%	15.8%	16.3%	15.9%
4A	0.21	14.1%	14.5%	14.4%	15.1%
4B	0.00	14.8%	15.5%	15.6%	15.4%
4C	0.03	13.7%	14.0%	14.5%	13.8%
5A	0.18	14.4%	14.8%	14.5%	14.5%
5B	0.05	14.5%	15.1%	15.7%	14.9%
5C	0.00	14.2%	13.7%	13.2%	13.8%
6A	0.03	14.5%	14.9%	14.6%	15.1%
6B	0.01	14.5%	14.5%	14.6%	14.5%
7	0.00	13.5%	13.6%	13.8%	13.3%
8	0.00	13.5%	13.0%	13.0%	13.0%
National	**1.00**	**14.0%**	**14.7%**	**14.8%**	**14.7%**

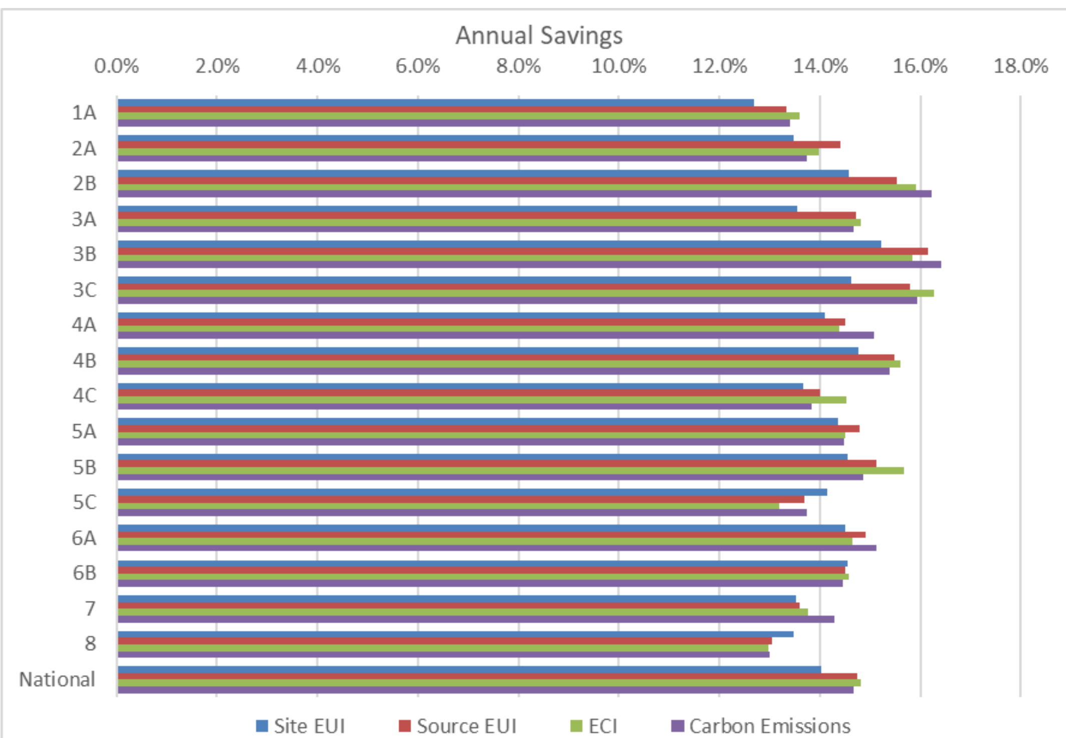

Figure 7. Percentage Net Savings by Climate Zone from Standard 90.1-2019 to 90.1-2022

5 Monetized GHG & Energy Savings Benefits from Adoption of Improved Model Energy Codes

DOE's Building Energy Codes Program (BECP) periodically evaluates national and state-level impacts associated with the IECC and Standard 90.1, the national model energy codes for residential and commercial buildings, respectively. A comprehensive evaluation is undertaken following the publication of the updated model codes and published by the DOE Building Energy Codes Program[12]. However, because Standard 90.1 and the IECC are published by independent organizations and not at the same time, the comprehensive results and full impact analysis is not available at the time that DOE conducts its model energy codes determinations.

However, as states, local governments and other stakeholders wish to understand the impacts of updated codes, DOE conducts a preliminary assessment of such impacts that can be referenced at the time of the determination. Therefore, DOE conducted this preliminary assessment of the impacts of adopting Standard 90.1-2022 compared to 90.1-2019. Although these results are not yet published elsewhere, the analysis methodology is described in prior reports.[13]

5.1 Methodology

As part of the development of this determination, for the purpose of complying with the requirements of Executive Order 12866, DOE considered the estimated monetary benefits from the reduced emissions of Carbon dioxide (CO_2), methane (CH_4), and Nitrous Oxide (N_2O) that are expected to result from adoption of new energy codes.

Monetization of Greenhouse Gas Emissions

DOE estimates the monetized benefits of the reductions in emissions of CO_2, CH_4, and N_2O by using a measure of the social cost (SC) of each pollutant (e.g., SC-CO_2). These estimates represent the monetary value of the net harm to society associated with a marginal increase in emissions of these pollutants in a given year, or the benefit of avoiding that increase. These estimates are intended to include (but are not limited to) climate-change-related changes in net agricultural productivity, human health, property damages from increased flood risk, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. DOE exercises its own judgment in presenting monetized climate benefits as recommended by applicable Executive orders, and DOE would reach the same conclusion presented in this determination in the absence of the social cost of greenhouse gases. That is, the social costs of greenhouse gases, whether measured using the February 2021 interim estimates presented by the Interagency Working Group on the Social Cost of Greenhouse Gases or by another means, did not affect the determination ultimately adopted by DOE.

DOE estimated the global social benefits of CO_2, CH_4, and N_2O reductions using SC-GHG values that were based on the interim values presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*, published in February 2021 by the IWG ("February 2021 SC-GHG TSD"). The SC-GHG is the monetary value of the net harm to society associated with a marginal increase in emissions in a given year, or the benefit of avoiding that increase. In principle, the SC-GHG includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG therefore, reflects the societal value of reducing emissions of the gas in question by one metric ton. The SC-GHG is the theoretically appropriate value to use in conducting benefit-cost analyses of

[12] https://www.energycodes.gov/impact-analysis
[13] https://www.energycodes.gov/impact-analysis

policies that affect CO_2, N_2O and CH_4 emissions. As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, DOE agrees that the interim SC-GHG estimates represent the most appropriate estimate of the SC-GHG until revised estimates have been developed reflecting the latest, peer-reviewed science.

The SC-GHG estimates presented here were developed over many years, using transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. Specifically, in 2009, the IWG, that included the DOE and other executive branch agencies and offices was established to ensure that agencies were using the best available science and to promote consistency in the social cost of carbon (SC-CO_2) values used across agencies. The IWG published SC-CO_2 estimates in 2010 that were developed from an ensemble of three widely cited integrated assessment models (IAMs) that estimate global climate damages using highly aggregated representations of climate processes and the global economy combined into a single modeling framework. The three IAMs were run using a common set of input assumptions in each model for future population, economic, and CO_2 emissions growth, as well as equilibrium climate sensitivity – a measure of the globally averaged temperature response to increased atmospheric CO_2 concentrations. These estimates were updated in 2013 based on new versions of each IAM. In August 2016 the IWG published estimates of the social cost of methane (SC-CH_4) and nitrous oxide (SC-N_2O) using methodologies that are consistent with the methodology underlying the SC-CO_2 estimates. The modeling approach that extends the IWG SC-CO_2 methodology to non-CO_2 GHGs has undergone multiple stages of peer review. The SC-CH_4 and SC-N_2O estimates were developed by Marten *et al*. (2015) and underwent a standard double-blind peer review process prior to journal publication.

In 2015, as part of the response to public comments received to a 2013 solicitation for comments on the SC-CO_2 estimates, the IWG announced a National Academies of Sciences, Engineering, and Medicine review of the SC-CO_2 estimates to offer advice on how to approach future updates to ensure that the estimates continue to reflect the best available science and methodologies. In January 2017, the National Academies released their final report, Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide, and recommended specific criteria for future updates to the SC-CO_2 estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process. (National Academies 2017) Shortly thereafter, in March 2017, President Trump issued Executive Order 13783, which disbanded the IWG, withdrew the previous TSDs, and directed agencies to ensure SC-CO_2 estimates used in regulatory analyses are consistent with the guidance contained in OMB's Circular A-4, "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (EO 13783, Section 5(c)). Benefit-cost analyses following E.O. 13783 used SC-GHG estimates that attempted to focus on the U.S.-specific share of climate change damages as estimated by the models and were calculated using two discount rates recommended by Circular A-4, 3 percent and 7 percent. All other methodological decisions and model versions used in SC-GHG calculations remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued Executive Order 13990, which re-established the IWG and directed it to ensure that the U.S. Government's estimates of the social cost of carbon and other greenhouse gases reflect the best available science and the recommendations in the National Academies 2017 report. The IWG was tasked with first reviewing the SC-GHG estimates currently used in Federal analyses and publishing interim estimates within 30 days of the E.O. that reflect the full impact of GHG emissions, including by taking global damages into account. The interim SC-GHG estimates published in February 2021 are used here to estimate the climate benefits for this determination. The E.O. instructs the IWG to undertake a fuller update of the SC-GHG estimates that takes into consideration the advice in the National Academies 2017 report and other recent scientific literature.

The February 2021 SC-GHG TSD provides a complete discussion of the IWG's initial review conducted under E.O. 13990. In particular, the IWG found that the SC-GHG estimates used under E.O. 13783 fail to reflect the full impact of GHG emissions in multiple ways. First, the IWG found that the SC-GHG estimates used under E.O. 13783 fail to fully capture many climate impacts that affect the welfare of U.S. citizens and residents, and those impacts are better reflected by global measures of the SC-GHG. Examples of omitted effects from the E.O. 13783 estimates include direct effects on U.S. citizens, assets, and investments located abroad, supply chains, U.S. military assets and interests abroad, and tourism, and spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns. In addition, assessing the benefits of U.S. GHG mitigation activities requires consideration of how those actions may affect mitigation activities by other countries, as those international mitigation actions will provide a benefit to U.S. citizens and residents by mitigating climate impacts that affect U.S. citizens and residents. A wide range of scientific and economic experts have emphasized the issue of reciprocity as support for considering global damages of GHG emissions. If the United States does not consider impacts on other countries, it is difficult to convince other countries to consider the impacts of their emissions on the United States. The only way to achieve an efficient allocation of resources for emissions reduction on a global basis—and so benefit the U.S. and its citizens—is for all countries to base their policies on global estimates of damages. As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, DOE agrees with this assessment and, therefore, in this determination DOE centers attention on a global measure of SC-GHG. This approach is the same as that taken in DOE regulatory analyses from 2012 through 2016. A robust estimate of climate damages that accrue only to U.S. citizens and residents does not currently exist in the literature. As explained in the February 2021 SC-GHG TSD, existing estimates are both incomplete and an underestimate of total damages that accrue to the citizens and residents of the U.S. because they do not fully capture the regional interactions and spillovers discussed above, nor do they include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature. As noted in the February 2021 SC-GHG TSD, the IWG will continue to review developments in the literature, including more robust methodologies for estimating a U.S.-specific SC–GHG value, and explore ways to better inform the public of the full range of carbon impacts. As a member of the IWG, DOE will continue to follow developments in the literature pertaining to this issue.

Second, the IWG found that the use of the social rate of return on capital (7 percent under current OMB Circular A-4 guidance) to discount the future benefits of reducing GHG emissions inappropriately underestimates the impacts of climate change for the purposes of estimating the SC-GHG. Consistent with the findings of the National Academies (2017) and the economic literature, the IWG continued to conclude that the consumption rate of interest is the theoretically appropriate discount rate in an intergenerational context and recommended that discount rate uncertainty and relevant aspects of intergenerational ethical considerations be accounted for in selecting future discount rates. (IWG 2010, 2013, 2016a, 2016b) Furthermore, the damage estimates developed for use in the SC-GHG are estimated in consumption-equivalent terms, and so an application of OMB Circular A-4's guidance for regulatory analysis would then use the consumption discount rate to calculate the SC-GHG. DOE agrees with this assessment and will continue to follow developments in the literature pertaining to this issue. DOE also notes that while OMB Circular A-4, as published in 2003, recommends using 3% and 7% discount rates as "default" values, Circular A-4 also reminds agencies that "different regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues and the sensitivity of the benefit and cost estimates to the key assumptions." On discounting, Circular A-4 recognizes that "special ethical considerations arise when comparing benefits and costs across generations," and Circular A-4 acknowledges that analyses may appropriately "discount future costs and consumption benefits…at a lower rate than for intragenerational analysis." In the 2015 Response to Comments on the Social Cost of Carbon for Regulatory Impact Analysis, OMB, DOE, and the other IWG members recognized that "Circular A-4 is a living document" and "the use of 7 percent is not considered appropriate for intergenerational discounting. There is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself." Thus, DOE concludes that a 7% discount rate is not appropriate to apply to value the social cost of greenhouse gases in the analysis presented in this analysis. In this analysis, to calculate the present and annualized values of climate benefits, DOE uses the same discount rate as the rate used to discount the value of damages from future GHG emissions, for internal consistency. That approach to discounting follows the same approach that the February 2021 TSD recommends "to ensure internal consistency—i.e., future damages from climate change using the SC-GHG at 2.5 percent should be discounted to the base year of the analysis using the same 2.5 percent rate." DOE has also consulted the National Academies' 2017 recommendations on how SC-GHG estimates can "be combined in RIAs with other cost and benefits estimates that may use different discount rates." The National Academies reviewed "several options," including "presenting all discount rate combinations of other costs and benefits with [SC-GHG] estimates."

As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, DOE agrees with the above assessment and will continue to follow developments in the literature pertaining to this issue.

While the IWG works to assess how best to incorporate the latest, peer reviewed science to develop an updated set of SC-GHG estimates, it set the interim estimates to be the most recent estimates developed by the IWG prior to the group being disbanded in 2017. The estimates rely on the same models and harmonized inputs and are calculated using a range of discount rates. As explained in the February 2021 SC-GHG TSD, the IWG has recommended that agencies revert to the same set of four values drawn from the SC-GHG distributions based on three discount rates as were used in regulatory analyses between 2010 and 2016 and were subject to public comment. For each discount rate, the IWG combined the distributions across models and socioeconomic emissions scenarios (applying equal weight to each) and then selected a set of four values recommended for use in benefit-cost analyses: an average value resulting from the model runs for each of three discount rates (2.5 percent, 3 percent, and 5 percent), plus a fourth value, selected as the 95th percentile of estimates based on a 3 percent discount rate. The fourth value was included to provide information on potentially higher-than-expected economic impacts from climate change. As explained in the February 2021 SC-GHG TSD, and DOE agrees, this update reflects the immediate need to have an operational SC-GHG for use in regulatory benefit-cost analyses and other applications that was developed using a transparent process, peer-reviewed methodologies, and the science available at the time of that process. Those estimates were subject to public comment in the context of dozens of proposed rulemakings as well as in a dedicated public comment period in 2013.

There are a number of limitations and uncertainties associated with the SC-GHG estimates. First, the current scientific and economic understanding of discounting approaches suggests discount rates appropriate for intergenerational analysis in the context of climate change are likely to be less than 3 percent, near 2 percent or lower. (IWG 2021) Second, the IAMs used to produce these interim estimates do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature and the science underlying their “damage functions” – i.e., the core parts of the IAMs that map global mean temperature changes and other physical impacts of climate change into economic (both market and nonmarket) damages – lags behind the most recent research. For example, limitations include the incomplete treatment of catastrophic and non-catastrophic impacts in the integrated assessment models, their incomplete treatment of adaptation and technological change, the incomplete way in which inter-regional and intersectoral linkages are modeled, uncertainty in the extrapolation of damages to high temperatures, and inadequate representation of the relationship between the discount rate and uncertainty in economic growth over long time horizons. Likewise, the socioeconomic and emissions scenarios used as inputs to the models do not reflect new information from the last decade of scenario generation or the full range of projections. The modeling limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates. However, as discussed in the February 2021 SC-GHG TSD, the IWG has recommended that, taken together, the limitations suggest that the interim SC-GHG estimates used in this determination likely underestimate the damages from GHG emissions. DOE concurs with this assessment.

Monetization of Greenhouse Gas Emissions

The SC-CO_2 values used for this determination were based on the values developed for the February 2021 SC-GHG TSD, which are shown in Table 19 in five-year increments from 2020 to 2050. Values after 2050 are based on modeling conducted by EPA using the same methods, assumptions, and parameters as were used in developing the 2020-2050 estimates published by the IWG. [14]

Table 19. Annual SC-CO_2 Values from 2021 Interagency Update, 2020–2050 (2020$ per Metric Ton CO_2)

Year	Discount Rate and Statistic			
	5%	3%	2.5%	3%
	Average	Average	Average	95th percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

DOE multiplied the CO_2 emissions reduction estimated for each year by the SC-CO_2 value for that year in each of the four cases. DOE adjusted the values to 2022$ using the implicit price deflator for gross domestic product ("GDP") from the Bureau of Economic Analysis. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SC-CO_2 values in each case.

Social Cost of Methane and Nitrous Oxide

The SC-CH_4 and SC-N_2O values used for this determination were based on the values developed for the February 2021 SC-GHG TSD. Table 20 shows the updated sets of SC-CH_4 and SC- N_2O estimates from the latest interagency update in 5-year increments from 2020 to 2050. To capture the uncertainties involved in regulatory impact analysis, DOE has determined it is appropriate to include all four sets of SC-CH_4 and SC-N_2O values, as recommended by the IWG.

Table 20. Annual SC-CH_4 and SC-N_2O Values from 2021 Interagency Update, 2020–2050 (2020$ per Metric Ton)

Year	SC-CH_4				SC-N_2O			
	Discount Rate and Statistic				Discount Rate and Statistic			
	5%	3%	2.5%	3%	5%	3%	2.5 %	3%
	Average	Average	Average	95th percentile	Average	Average	Average	95th percentile
2020	670	1500	2000	3900	5800	18000	27000	48000
2025	800	1700	2200	4500	6800	21000	30000	54000
2030	940	2000	2500	5200	7800	23000	33000	60000
2035	1100	2200	2800	6000	9000	25000	36000	67000
2040	1300	2500	3100	6700	10000	28000	39000	74000
2045	1500	2800	3500	7500	12000	30000	42000	81000
2050	1700	3100	3800	8200	13000	33000	45000	88000

DOE multiplied the CH_4 and N_2O emissions reduction estimated for each year by the SC-CH_4 and SC-N_2O estimates for that year in each of the cases. DOE adjusted the values to 2022$ using the implicit price deflator for gross domestic product ("GDP") from the Bureau of Economic Analysis. To calculate a present value of

[14] See "Revised 2023 and Later Model Year Light-Duty Vehicle GHG Emissions Standards: Regulatory Impact Analysis," published by EPA in December 2021. Available at: www.epa.gov/system/files/documents/2021-12/420r21028.pdf.

the stream of monetary values, DOE discounted the values in each of the cases using the specific discount rate that had been used to obtain the SC-CH_4 and SC-N_2O estimates in each case.

5.2 Results

Table 21 provides estimates of the GHG emissions expected to result from commercial model code adoption of Standard 90.1-2022 compared to 90.1-2019. Table 22 provides estimates of the monetized GHG emissions expected to result from commercial model code adoption using all four SC-GHG estimate scenarios. Table 23 provides estimates of the monetized energy cost savings expected to result from commercial model code adoption using a 3-percent, 5-percent, and 7-percent discount rate. All these results are based on gross savings and improvements in energy efficiency, which exclude the impact of on-site energy generation through renewable energy systems.

Table 21. Cumulative Emissions Reduction from Standard 90.1-2022

Analysis Time Frame	CO_2 Reduction (million metric tons)	CH_4 Reduction (thousand short tons)	N_2O Reduction (thousand short tons)
Cumulative 2024-2053	134.8	1,106	1.225

Table 22. Present Value of Emissions Reduction from Standard 90.1-2022, (2022$ billions)

	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
Annual (2030)				
SC-CO_2	48	178	265	535
SC-CH_4	20	47	62	125
SC-N_2O	0.123	0.411	0.61	1.09
Annual (2040)				
SC-CO_2	104	421	645	1,290
SC-CH_4	8	129	176	347
SC-N_2O	0.248	0.926	1.41	2.47
Cumulative 2024-2053				
SC-CO_2	2,480	10,440	16,180	32,000
SC-CH_4	1,133	3,268	4,523	8,724
SC-N_2O	5.799	22.54	34.69	60.08

Table 23. Energy Cost Savings from Standard 90.1-2022 (2022$ billions)

Analysis Time Frame	Monetized Consumer Energy Savings		
	3% Discount Rate	5% Discount Rate	7% Discount Rate
Annual (2030)	0.79	0.69	0.60
Annual (2040)	2.32	1.30	0.74
Cumulative 2024-2053	45.43	31.59	22.56

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Appendix A – Addenda Not Quantified in Energy Savings Analysis

Addendum	Sections Affected	Description of Change	Discussion
f	Table 6.5.1-2	Clarifies the efficiency improvement required in order to eliminate an economizer.	Clarification only.
g	6.5.1.1.5	Clarifies requirements on relieving excess outdoor air during air economizer operation.	Clarification only.
h	4.2.1.1	Clarifies that the gross floor area should be used when calculating the area-weighted building performance factor (BPF).	Clarification only.
i	G3.1.2.10	Corrects a mistake and exempts large laboratory exhaust (>15,000 cfm) to be modeled with energy recovery in the baseline.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
k	12.5.2	Adjusts the budget building fan power to avoid a fan power credit for cases where the proposed building includes heat recovery and the budget building does not include heat recovery.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
l	Table G3.1	Describes the methodology that must be used by projects where the baseline vertical fenestration area that must be allocated to a certain building face exceeds the gross above grade wall area of that building face.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
q	Table G3.7	Removes the duplicate lighting requirement for laboratory classrooms.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
r	6.4.3.3.3	Clarifies residential spaces are exempted from optimal start control requirements.	Clarification only.
u	12.5.2	Modifies budget HVAC systems economizer requirements and requirements for determining budget HVAC equipment capacities when thermal zones are combined.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
v	12.7.2, G1.3.2	Clarifies documentation that must be submitted to the rating authority or jurisdiction by projects following Section 11 and Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
w	G3.1.3.7 Table G3.1.3.7	Clarifies that baseline building design chillers should be sized based on the total peak coincident cooling load of baseline HVAC systems of type 7, 8, 11, 12 and 13.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
x	6.4.1.2	Changes cooling efficiency adjustment for centrifugal chillers and exempts chillers employing freeze-protection fluids.	Clarification only.
y	Table 6.8.1-16	Clarifies efficiency requirements for heat pump and heat recovery water-chiller packages.	Clarification only.
aa	G3.1.2.9 (SI Units) Table G3.1(16) (SI Units) Table G3.1(18) (SI Units)	Corrects the SI version fan power values in Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ab	G3.1.1	Clarifies the process of selecting baseline HVAC systems when using Appendix G Performance Rating Method.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ad	10	Reorganizes Chapter 9.	Clarification only.
ae	8.4.4	Specifies the use of linear interpolation for low-voltage dry-type transformer efficiency.	Clarification only.
af	Table G3.1 Table G3.6	Modifies lighting modeling requirements in Appendix G with more specific guidance on determining lighting power in the baseline vs. proposed building.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ag	3.2, 3.3, 6.2.26.6, Appendix K	Introduces an optional Mechanical System Performance Path that allows HVAC system efficiency trade-offs based on a new metric—total system performance ratio (TSPR).	Introduces an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
aj	Table G3.1	Updates Appendix G Table G3.1 to determine the baseline performance of transformers not listed through linear interpolation.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ak	G3.1.1	Update the process to isolate an HVAC zone attached to a multizone system in the baseline building that may prevent the system from operating in an efficient way.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
an	Table G3.1	Clarifies baseline HVAC fan schedule requirements for projects that rely on ventilation via operable windows that are manually opened by the occupants.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ao	5.4.3.3.3 6.4.3.9 10.4.5	Clarifies the installation and commissioning requirements for air curtains.	Clarification only.
as	4.2.4, 5.9, 6.9, 7.9, 8.9, 9.9, 10.9	Rearranges envelope inspection requirements and improves commissioning language throughout.	Clarification only.
at	3.2, 4, 5, 6, 7, 8, 10	Establishes a consistent numbering system for each section of the standard and revises the definition for alteration.	Clarification only.
au	6.3.2	Clarifies the HVAC simplified path to require verification of equipment efficiencies.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bd	12.5.2, Table 12.5.1, G3.1.2, Table G3.1, Table G3.5.3, Appendix L	Provides part load performance curves for modeling chillers in budget (Section 12) and baseline designs (Appendix G) as well as default performance curves that can be used for chillers in proposed designs.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
be	12.4.1.4, 12, C3.1.4, G2.2.4	Updates the reference year for ASHRAE Standard 140.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
bg	3.2, 8.1, 8.7.3.2, 9.1.1, 9.4.1, 9.6.3, 10.1.1, Table 12.5.1 (12), G1.2.2, Table G3.1	Updates Sections 8, 9, 10, 12 and Appendix G to reflect the new purpose and scope (Addendum cb), utilizing the new definition of site.	Clarification only.
bh	Table 12.5.1	Modifies the on-site photovoltaic system parameters for modeling inputs.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bi	3.2, 5.1.3, 5.5.3.1	Creates specific provisions to distinguish roof replacements from other types of alterations.	Clarification only.
bj	5.5.3, A1, A9, Appendix E	Reformats and clarifies Normative Appendix A requirements for thermal performance calculations to demonstrate compliance with Section 5.5.	Clarification only.
bp	9.4.1.3	Remove exception to lighting control where card key controls are used.	Clarification only.
bq	8.4.3	Adds refrigeration systems to requirement for end-use metering of building energy.	No direct energy savings from metering.
bt	G3.1.3	Clarification: Pumps should be off when there is no load.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bv	Table 4.2.1.1	Updates the building performance factor table used for compliance with Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
bw	6.5.3.1.3	Clarifies that the fan efficiency metric is to be applied at the highest design airflow rate.	Clarification only.
bz	6.5.6.1	Add language to state that energy recovery can be sensible-only if space is not humidified and system requires only sensible heating energy recovery.	Clarification only.

Addendum	Sections Affected	Description of Change	Discussion
ce	A2.5, A3.3	Adds new reference and clarifies requirements for steel-framed walls aligned with ANSI/AISI S250, which provides additional options for wall framing and insulation placement.	Clarification only.
ck	Table 12.5.1	Adds language to Section 12 to specify modeling rules for on-site renewable energy systems and provide a method of trade off against other prescriptive requirements.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cm	13	Updates the normative references used in the standard to the latest applicable versions.	Reference update only.
co	4.2.1.1, 4.2.1.3, G3.1, G3.2, G3.3	Relaxes building performance factors for alterations using Appendix G.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cp	4.2.1.1, G2.2, Table G3.1	Adds language to Appendix G to specify modeling rules for on-site renewable energy systems and follows 5% renewable energy cap introduced in Addendum s to adjust the Performance Cost Index Target.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cq	G3.1.2.1, Table G3.1 (10), Table G3.1.3.7, Table G3.5.3	Change from water chiller to liquid chiller. Remove some obsolete references.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cr	12.2, G1.2.1	Adds language to limit the extent that envelope trade-offs can be used for compliance with Section 12 and Appendix G based on the amount that a proposed envelope performance factor is permitted to exceed the base value (i.e., envelope “backstop”).	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
cs	12.5.2	Clarifies efficiency requirements for HVAC and service water-heating equipment in the Section 12 budget building design.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
ct	Table G3.1 (5)	Provides additional details about the envelope modeling requirements for Appendix G baseline buildings.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Addendum	Sections Affected	Description of Change	Discussion
cy	Section 12	Change normative reference to include all addenda.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
da	G1.3.2, G2.2, G2.3, G2.4.2, G2.5, Table G3.1	Aligns Appendix G requirements for documentation, simulation programs, climactic data, and exceptions with the corresponding portions of Section 12.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.
db	Table G3.1 5 Table G3.4-9	Clarifies how to establish the Normative Appendix G baseline space conditioning categories that must be used in conjunction with Tables G3.4-1 through G3.4-8 so that the baseline envelope will remain consistent should Section 3 undergo changes.	Change applies to an alternative compliance path and does not affect the prescriptive or mandatory requirements.

Appendix B – Modeling of Individual Addenda

This appendix details the modeling of the 16 addenda to Standard 90.1-2019 simulated for the quantitative analysis. They are a subset of the addenda listed in Table 4 and marked as "Included in Quantitative Analysis". In the cases where multiple individual addenda modify the same section of Standard 90.1, these addenda are discussed together. The procedures for implementing the addenda into the Standard 90.1-2019 and 90.1-2022 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 90.1-2019 and the advanced case is Standard 90.1-2022. In some instances, a new addendum to Standard 90.1-2019 identifies the need for a change to baseline 2019 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 the simulation of the 2022 Standard, thermal breaks in the building envelope were assumed to be included in the overall prescriptive U-values. With the introduction of new thermal break mitigation requirements in Addendum av, methods have been developed to account for unmitigated thermal breaks in older code versions, and mitigated breaks in Standard 90.1-2022.

Building Envelope Addenda

Addendum *t*: Infiltration Testing

Addendum Description. Addendum *t* revises the air leakage requirements in Standard 90.1 such that air leakage testing is no longer optional for buildings less than 10,000 ft^2. Prior to addendum t, the air leakage testing was not required as long as specific design and construction practices were followed.

Modeling Strategy. Three prototypes have conditioned floor area less than 10,000 ft^2 and are thus subject to the new air leakage testing requirement: Small Office, Quick Service Restaurant, and Sit-Down Restaurant. For these prototypes, the infiltration rate was set based on the Addendum *t* test requirement of 0.35 cfm/ft^2 of building envelope at 0.3 inches of water column instead of 1.0 cfm/ft^2 which was assumed for buildings that did not undergo testing. This requirement is applicable to all climate zones. The test condition values were converted to natural conditions for the models using the methods described by Gowri et al. (2009).

Addendum *av*: Thermal Break Mitigation

Addendum Description. While Standard 90.1-2019 defines thermal performance requirements for a building envelope, it does not include separate considerations for thermal bridging other than those for framing members. Addendum *av* establishes a new set of prescriptive envelope requirements for thermal bridges in commercial buildings. Addendum *av* characterizes the new thermal bridging requirements using sets of "psi-" and "chi-" factors to represent the thermal transmittance of linear and point thermal bridges in a building envelope. Data sets to represent un-mitigated thermal bridges and data sets for cases where the impact of thermal bridging is mitigated are included in the addendum.

Modeling Strategy. The analysis only considered the impact of linear thermal bridges and did not include the impact of any point thermal bridges. To estimate the impact of these new requirements, the U-factors modeled in the prototype commercial building models were de-rated according to equation (1).

$$U_{derated} = \frac{\sum \psi_i L_i + \sum \chi_j n_j}{A} + U_{clear\ field} \qquad (1)$$

Where:

1. $U_{derated}$ is the overall thermal transmittance that includes the effect of thermal bridging in Btu/(h-ft^2-°F)
2. $U_{clear\ field}$ is the clear field thermal transmittance of the construction assembly as determined in Section 5 of Standard 90.1 in Btu/(h-ft^2-°F)
3. A is the total opaque surface area of the construction assembly, in ft^2
4. Ψ is the psi-factor, or thermal transmittance of a linear thermal bridge, in Btu/(h-ft-°F)
5. X is the chi-factor, or thermal transmittance of a point thermal bridge, in Btu/(h-°F)
6. L is the length of each linear thermal bridge, in ft
7. n is the quantity of each type of point thermal bridge

The length and number of linear thermal bridges for all prototype models were identified by conducting detailed take-off assessments of geometry parameters to characterize five types of thermal breaks:

1. Parapet
2. Cladding support
3. Wall to vertical fenestration intersection
4. Intermediate floor balcony or overhang intersection with opaque wall
5. Intermediate floor balcony in contact with vertical fenestration

For implementation in the prototypes, overall average de-rated thermal transmittance values were determined on a floor-by-floor basis. For multi-story prototypes, the linear thermal bridge impacts were evaluated for up to three floor categories: ground floor, middle floor (for buildings over 2 stories), and top floor.

Mitigated psi-factors were used to represent prototype building models compliant with Standard 90.1-2022 and unmitigated psi-factors were used for the 90.1-2019 baseline prototypes. Mitigation of thermal bridging is only required for climate zone 4 through 8, so for prototype building models in all other climate zones thermal bridging was modeled as being unmitigated proposed and baseline cases. The mitigated and unmitigated psi factors selected for the analysis are based on the defaults in addendum av and the wall assembly type assumed for each prototype.

Thermal bridges for cladding supports for buildings with masonry veneer constructions were applied to the prototype models based on assumptions of how prevalent this construction type is in the building population. The assumptions for which prototypes are affected, and the percentage of wall area that would be affected across all buildings are listed in Table B.1.

Table B.1. Prevalence of Thermal Bridges Associated with Masonry Veneer Construction

Prototype	Percent of buildings with feature		
	Idealized Wall	Shelf Angle (brick masonry veneer)	Girts
Medium Office	0.8	0.2	0
Large Office	0.9	0.1	0
Secondary School	0.8	0.2	0
Hospital	0.9	0.1	0
Outpatient	0.8	0.2	0
Large Hotel	0.9	0.1	0
Small Hotel	0.9	0.1	0
Midrise Multifamily	0.8	0.2	0
Highrise Multifamily	0.8	0.2	0

Assumptions for modeling of thermal bridges caused by wall-to-window intersections in the prototypes are summarized in Table B.2. For some prototype models, the window objects are abstracted as ribbon windows, even though more typical constructions would use punched openings. In those cases the number of windows was calculated based on a typical window width assumption as listed in the table.

Table B.2. Thermal Bridging Parameters for Window-to-Wall Intersections

Prototype	Typical Punched Window Width, ft	Ground Floor				Middle Floors				Top Floor			
		Window Area, ft²	Avg. Window Height, ft	Number of Windows	Window/Wall Intersection, ft	Window Area, ft²	Avg. Window Height, ft	Number of Windows	Window/Wall Intersection, ft	Window Area, ft²	Avg. Window Height, ft	Number of Windows	Window/Wall Intersection, ft
Medium Office	NA	2,342	4.3	4	1,126	2,342	4.3	4	1,126	2,342	4.3	4	1,126
Large Office	NA	4,158	5.2	16	1,766	4,158	5.2	4	1,641	4,158	5.2	4	1,641
Small Office	6.0	601	5.0	20	440								
Primary School	NA	9,344	4.5	15	4,288								
Secondary School	NA	13,627	4.5	16	6,200					8,859	4.5	16	4,081
Full-Service Restaurant	NA	508	3.0	3	357								
Quick-Service Restaurant	NA	280	3.0	3	205								
Hospital	7.2	1,033	4.0	36	805	2,189	4.0	68	1,639	1,402	4.0	44	1,053
Outpatient Healthcare	NA	1,172	4.6	36	820	939	4.4	27	660	1,207	5.0	31	790
Warehouse	NA	190	5.0	2	96								
Standalone Retail	NA	820	3.7	2	453								
Strip Mall	7.0	837	5.0	24	576								
Large Hotel	10.0	1,773	8.5	3	468	2,244	4.0	56	1,570	1,638	4.0	35	1,099
Small Hotel	3.6	462	5.0	22	405	473	5.0	26	449	473	5.0	26	449
Mid-Rise Apartment	8.0	808	5.0	20	523	820	5.0	20	528	820	5.0	20	528
High-Rise Apartment	7.	1,224	5.5	32	797	1,236	5.5	32	801	1,236	5.5	32	801

Based on a previous prototype evaluation of sliding doors (Halverson, 2014), the occurrence of balconies on intermediate floors for thermal bridging was assumed to be 9.6% for Large Hotel, 11.6% for Midrise Apartment, and 36.5% for Highrise Apartment. None of the other prototypes were modeled with balconies. The length of each balcony was assumed to be 9 ft, and two thirds of the length was assumed to be in contact with vertical fenestration.

Heating, Refrigerating, and Air-Conditioning Addenda

Addendum *a*: Small Fan Efficacy

Code Change Description. Addendum *a* sets efficacy requirements for low capacity ventilation system fans with motors less than 1/12 hp (0.062 kW).

Modeling Strategy. ERV and bathroom exhaust fans in the Mid-Rise Apartments and High-Rise Apartments are affected by Addendum *a*. The minimum efficacy is 1.2 cfm/W for ERV fans with no airflow constraints and 2.8 cfm/W for bathroom fans when airflow is within the range of 10 to 90 CFM. The fan power used in the prototypes prior to the new requirements was based on a survey of data for products available in the marketplace. The fan static in the models was established at 0.25 in wc, and the fan power was selected from the manufacturer data corresponding to that pressure. The fan power values specified in Addendum *a* are required to be determined at a rated static pressure of at least 0.2 in wc for ERV fans and 0.1 in wc for bathroom exhaust fans. To convert these rated values to the installed pressure of 0.25 in wc, additional manufacturer data at varying installed pressure conditions were evaluated to determine the pressure-power relationship as shown in Table B.3. The ratios calculated for the product data columns in Table B.3 were applied to the 90.1-2022 columns to determine the typical installed efficacy for the prototype models.

Table B.3. Conversion of Low-Capacity Ventilation Fan Power from Code Spec Condition to Typical Installed Condition

Condition	Bathroom Fans			ERV Fans		
	Static in wc	Product data cfm/W	90.1-2022 cfm/W	Static in wc	Product data cfm/W	90.1-2022 cfm/W
Code Specification	0.1	1.4	2.8	0.2	1.14	1.20
Typical Installed	0.25	1.24	2.48	0.25	1.07	1.13
	Ratio	88.6%	88.6%	Ratio	93.9%	93.9%

Addendum *b*: Demand Controlled Ventilation

Addendum Description. Standard 90.1-2019 already has requirements for demand control ventilation (DCV) for spaces based on occupant density. Addendum *b* changes that criteria from a fixed occupant density threshold to a floor area threshold that depends on climate zone and the occupant component of outside air requirement. Moreover, there was an exception in Standard 90.1-2019 for systems with exhaust air energy recovery (ERV). This exception has been removed for Addendum *b,* but the area threshold to require DCV is higher for spaces served by systems with ERV than for those without ERV.

Modeling Strategy. Implementation in the prototypes is accomplished using a lookup table that gives DCV requirement for each zone in each prototype based on climate zone and whether the zone is served by a system with ERV. The lookup of DCV requirement is done after sizing runs have determined energy recovery requirements. Prototypes that have new DCV requirements due to Addendum *b* include both hotels, both retail buildings, both schools, and Outpatient Healthcare.

Addendum *c*: Small Unit Setback Control

Addendum Description. Section 6.4.3.3 in Standard 90.1-2019 includes an exception (Exception 2) for off-hour controls for HVAC systems having a design heating and cooling capacities less than 15,000 Btu/h that are equipped with readily accessible manual on/off controls. The exception means small HVAC systems serving multifamily units are not required to use the following controls as specified in Sections 6.4.3.3.1 through 6.4.3.3.4: automatic shutdown, setback controls, optimum start controls, zone isolation, and automatic control of HVAC in hotel/motel guest rooms. Some of the controls are not applicable to the small units for multifamily units but the energy savings from setback controls, typically through a programmable thermostat, are an opportunity that is not captured in Standard 90.1-2019.

Addendum *c* modifies Exception 2 as follows:

- No longer allow the exception for HVAC systems serving residential spaces
- Reduce the thresholds of the exception to systems not serving residential spaces and having a design heating and cooling capacities less than 7,000 Btu/h (2.1 kW) that are equipped with a readily accessible manual on/off control.

Similar provisions to the simplified systems in Section 6.3.2 are adjusted to make them consistent with the description of unoccupied setback controls elsewhere in the standard. The addendum saves HVAC energy in multifamily units by installing programmable thermostats.

Modeling Strategy. Midrise and Highrise Apartment prototypes are affected by Addendum c. They are not required to have programmable thermostats for Standard 90.1-2019, and therefore they are modeled with constant heating and cooling thermostat setpoint temperatures throughout the day and night.

In order to reasonably evaluate the energy impacts at the national level, we need to make estimations about how many families in the two prototypes would use their programmable thermostats to schedule setbacks during their unoccupied periods. There are some research papers on the impacts of occupancy behavior on energy use through energy simulation and they often need to define typical occupancy schedules too. We took a conservative approach to estimate half of the apartment units in each of the two apartment prototypes are families with working schedules and would use their programmable thermostats. We assumed a set back of 10°F for heating and 5°F for cooling on weekdays during mid-day based on Section 6.4.3.3.2.

Addendum *ci*: Economizer Threshold

Addendum Description. Standard 90.1-2019 requires economizers in Climate Zone 2 and colder for fan-cooling units with capacities at least 54,000 Btu/h. Addendum ci reduces that threshold to 33,000 Btu/h for systems where the fan-cooling units are located outside the building.

Modeling Strategy. Addendum *ci* is implemented in the prototypes by a sizing script that applies the new threshold for prototypes that have single zone systems that would be located outside of the building. This includes the Small Office, the retail buildings, the schools, the restaurants, and the Warehouse. The packaged systems in the small office are always less than 33,000 Btu/h, so the economizer is not triggered for that prototype. The systems in Standalone Retail and the restaurants are above the 54,000 Btu/h threshold of Standard 90.1-2019, so there was no new economizer requirement for those prototypes under Addendum *ci*.

Addendum *bc*: Boiler Efficiency

Addendum Description. Addendum *bc* adds a new section that requires a minimum thermal efficiency of 90% for boiler systems with input capacity of at least 1,000,000 Btu/h but not more than 10,000,000 Btu/h. There are several exceptions to this new requirement including individual gas boilers with input capacity less than 300,000 Btu/h.

Modeling Strategy. Addendum *bc* is implemented in the prototypes by a sizing script that applies 90% thermal efficiency for cases where the total heating input capacity falls within the target range. This occurs for some climates in the Large Office, Primary School, Secondary School, Hospital, Large Hotel, and High-Rise Apartment prototypes.

Since this level of efficiency indicates a condensing boiler, some additional changes are implemented into the models. To take full advantage of condensing in the system, the boiler supply temperature is reduced relative to typical operation for a conventional boiler. When the prototypes are equipped with conventional boilers, the supply temperature is set to 180°F, whereas a prototype with condensing boilers is operated with a supply temperature of 140°F.

Another change to the model to account for condensing boiler performance is the boiler efficiency curve, which accounts for the effects of both part load ratio (PLR) and entering water temperature (EWT) on the efficiency of the boiler during the simulation. The curve is based on published data for a specific manufacturer, and the resulting curve coefficients are listed in Table B.4.

Table B.4. Normalized Efficiency Curve for Condensing Boilers

Curve Input	Curve Variables	Value
Coefficient1	Constant	0.946581
Coefficient2	PLR	0.022541
Coefficient3	PLR**2	-3.10E-15
Coefficient4	EWT	0.00904
Coefficient5	EWT**2	-0.00029
Coefficient6	PLR*EWT	-0.00176
Coefficient7	PLR**3	-0.03203
Coefficient8	EWT**3	2.15E-06
Coefficient9	PLR**2*EWT	0.000827
Coefficient10	PLR*EWT**2	1.40E-05

Service Water Heating Addenda

Addendum *ah*: Large Capacity Service Water Heater

Code Change Description. Standard 90.1-2019 Section 7.5.3 includes a requirement for 90% thermal efficiency for individual systems with total installed water heating input capacity of 1,000,000 Btu/h or greater. Addendum *ah* changes the requirement to be based on the total installed input capacity in the building instead of considering individual systems in isolation. Under the new language the increased thermal efficiency is required if the total building water heating capacity is at least 1,000,000 Btu/h and individual storage water heaters are greater than 105,000 Btu/h.

Modeling Strategy. The only prototype that meets the criteria of 1,000,000 Btu/h water heating capacity is the Large Hotel. Addendum *ah* is implemented in the Large Hotel by increasing the thermal efficiency of both the general water heater that serves the hotel rooms and the laundry water heater. Since the Large Hotel prototype also has the Efficient Gas Water Heater additional efficiency measure (W03) selected for the analysis (see Section 0), the model thermal efficiency is set to 95%.

Lighting Addenda

Addenda *ba*: LPD Values

Addendum Description. Addendum *ba* modifies the lighting power density (LPD) values using the space-by-space method. This addendum results in changes in Table 9.5.2.1 (formerly Table 9.6.1, the table was renumbered in a different addendum). Most space types have reduced LPD values under Addendum *ba*, with significant reductions in some common space types, such as storage (8%), dining (10%), office (8%), conference (9%), and retail sales area (19%). A few common space types also have increased LPD values, including restrooms (17%), kitchen (9%), and corridor (7%). Although electrical/mechanical appeared to increase (65%), the addendum eliminated a footnote with an additional LPD value that allowed the aggregated power to be higher, thus electrical/mechanical rooms were s a net reduction.

Modeling Strategy. All the prototypes use the space-by-space method as the basis for lighting power. The following describes how the appropriate LPD values are incorporated into the prototype building models:

- For the Large Office, Medium Office, and Small Office prototypes all zones are considered as a mix of multiple space types. For each of these, the NC3 database (Richman et al. 2008) was partially used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single lighting power allowance for each of the office prototypes.

- Most zones in the other prototypes are mapped to a single space-by-space category and the LPD value from that category is used directly.
- 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. Again, the NC3 database (Richman et al. 2008) was partially used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single lighting power allowance for those spaces.
- A room cavity ratio adjustment has been applied to a few spaces such as corridors, and exercise rooms based on the requirements of Section 9.5.2.4. The room cavity ratio adjustments used in the prototypes were established by Thornton et al. (2010).
- Using these rules and the values in Addendum *ba*, the LPD values for all prototypes and zones were determined. The design lighting power is modeled in EnergyPlus as a direct input to the zone general lighting object.

Addendum *bf*: Additional Lighting Power Allowance

Addendum Description. Addendum *bf* reduces the lighting power values for “additional lighting power” for decorative and retail sales categories. The addendum also adds another category for video conferencing. All subcategories of the retail allowance are significantly reduced under this addendum.

Modeling Strategy. Addendum bf only affects the Strip Mall retail prototype, because that is the only one that incorporates the additional lighting power allowances. Table B.5 shows the additional lighting power values for each zone of the Strip Mall for both the area-based portion of the allowance and the fixed portion of the allowance.

Table B.5. Additional Lighting Power Allowance by Zone for Strip Mall for Standard 90.1 Code Versions from 2004 to 2022

Zone Name	Area Based Category	Percent of Total Building Area	Zone Area Percent for Area Based Allowance	Area Based LPD, W/ft2							Fixed Allowance, W	
				2004	2007	2010	2013	2016	2019	2022	2004 to 2019	2022
LGstore1	Type 3	25%	25%	3.9	2.6	1.4	1.4	1.05	1.05	0.7	1000	750
SMstore1												
SMstore2	Type 2	25%	25%	1.60	1.70	0.60	0.60	0.45	0.45	0.40	1000	750
SMstore3												
SMstore4												
LGstore2	none	50%	0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SMstore5												
SMstore6												
SMstore7												
SMstore8												

Addendum *br*: Dwelling Unit Lighting Efficacy and Control

Addendum Description. Under Addendum *br*, the required lamp efficacy for dwelling units increases from 55 to 75 lm/W, and luminaire efficacy increases from 45 to 50 lm/W. The addendum also adds interior lighting control requirements for dwelling units. It states that 50% of interior luminaires shall be controlled with either manual dimming devices or automatic occupant-based control.

Modeling Strategy. Addendum *br* only affects the apartment prototypes, since they are the only ones that include dwelling units as defined by 90.1. To accommodate the new efficacy and control requirements, the apartment lighting was refactored. For each version of Standard 90.1 a lighting design was established with specific combinations of lamps and fixtures that are currently available in the marketplace, and that meet but do not exceed the requirements of that code version. For 90.1-2019 and 2022 the resulting lighting power and efficacy for each space in a typical apartment are shown in Table B.6 along with the assumptions for control. Lighting in dwelling units is assumed to be provided by a mix of hard-wired and plug-in fixtures. The resulting LPD for hard-wired fixtures is 0.42 W/ft^2 for 90.1-2019 and 0.20 W/ft^2 for 90.1-2022. The plug-in fixtures are not regulated by the standard, so all vintages are based on current common practice, which is estimated to be 80% LED technology and 20% incandescent, and results in an LPD of 0.09 W/ft^2.

Table B.6. Lighting Design and Control for Apartment Prototypes

			90.1-2019			90.1-2022		
Space	Area ft^2	Type	Watts	lm/Watt	Control	Watts	lm/Watt	Control
Bedroom 1, fixture 1	168	Plug-in	43.0	15	Switch	16.4	49	Switch
Bedroom 1, fixture 2	168	Hard-wire	12.0	100	Switch	12.0	100	Occupancy
Kitchen, fixture 1	149	Hard-wire	62.8	108	Switch	62.8	108	Occupancy
Kitchen, fixture 2	149	Hard-wire	12.0	100	Switch	12.0	100	Occupancy
Bathroom, fixture 1	96	Hard-wire	46.0	70	Switch	14.0	71	Dimmer
Bathroom, fixture 2	96	Hard-wire	80.0	8	Switch	20.0	59	Dimmer
1/2 Bath	30	Hard-wire	46.0	70	Switch	14.0	71	Dimmer
Living Room	234	Plug-in	32.7	15	Switch	32.7	49	Switch
Bedroom 2, fixture 1	132	Plug-in	32.7	15	Switch	32.7	49	Switch
Bedroom 2, fixture 2	132	Hard-wire	12.0	100	Switch	12.0	100	Occupancy
Corridor	60	Hard-wire	92.0	70	Switch	28.0	71	Switch
Dining	81	Hard-wire	39.0	69	Switch	18.0	80	Dimmer

Addendum *am*: Exterior Lighting Power

Addendum Description. Addendum *am* reduces the maximum allowed exterior lighting power based on improvements in technology and revised lighting practices related to light loss factors.

Modeling Strategy. For past evaluations of Standard 90.1, exterior lighting in the prototypes was modeled with three categories: parking lot, building entrances, and building facade (DOE, 2010 and 2017), under the assumption that these categories represent the majority of exterior lighting energy. One category that should have been included in the previous evaluations is the base site allowance, which is applicable to all buildings. For this update, the base site allowance for each code version has been added to the analysis and allocated to each of the three exterior lighting categories in proportion to the basic allowance of each category. The resulting exterior lighting power values for Standard 90.1-2019 and 2022 are summarized in Table B.7.

Table B.7. Exterior Lighting Power with Base Site Allowance

	90.1-2019 Watts Allowed				90.1-2022 Watts Allowed				Savings
Prototype	Parking Lot	Doors	Façade	Total	Parking Lot	Doors	Façade	Total	Total
Small Office	773	200	88	1,062	515	144	88	747	30%
Medium Office	4,715	408	564	5,686	3,002	280	542	3,825	33%
Large Office	26,595	989	13,272	40,856	17,216	920	12,953	31,089	24%
Stand-Alone Retail	1,984	1,478	359	3,821	1,266	1,019	346	2,631	31%
Strip Mall	2,307	2,744	456	5,507	1,466	1,883	438	3,787	31%
Primary School	686	1,922	176	2,783	445	1,344	172	1,961	30%
Secondary School	3,174	3,204	473	6,851	2,015	2,196	454	4,665	32%
Outpatient Health Care	4,472	1,512	187	6,172	2,850	1,040	181	4,071	34%
Hospital	5,806	1,605	3,141	10,552	3,668	1,276	2,996	7,940	25%
Small Hotel	2,379	265	674	3,319	1,500	217	644	2,361	29%
Large Hotel	6,570	471	5,297	12,338	4,148	374	5,050	9,572	22%
Non-Refrigerated Warehouse	1,091	4,306	124	5,521	694	2,956	119	3,769	32%
Quick Service Restaurant	1,079	75	218	1,372	685	58	209	952	31%
Full-Service Restaurant	1,833	169	211	2,214	1,174	131	205	1,510	32%
Mid-Rise Apartment	1,818	NA	283	2,101	1,176	NA	276	1,452	31%
High-Rise Apartment	5,475	NA	2,726	8,201	3,457	NA	2,600	6,057	26%

Other Equipment Addenda

Addendum *by* and *cc*: Renewable Energy

Addendum Description. Addenda *by and cc* add a new prescriptive requirement for on-site renewable energy. The basic requirement is for a rated renewable energy system capacity of not less than 0.5 W/ft^2 (1.7 Btu/ft^2) multiplied by the gross conditioned floor area for all floors up to the three largest floors. There are several exceptions, including buildings where the applicable floor area is less than 10,000 ft^2.

Modeling Strategy. The requirement for on-site renewable energy is applicable to all prototypes except the Small Office and the restaurants, which have total floor area below 10,000 ft^2. The on-site renewable capacity was implemented as a photovoltaic (PV) electric system in the prototype models. For all prototypes, the hourly on-site renewable generation is never greater than the hourly gross power consumption, so there is never a situation where power is provided by the on-site renewable to the grid. Table B.8 lists the minimum required renewable capacity (PV Capacity) for each prototype along with the conditioned floor area up to the three largest floors, which was the basis for the calculated values.

Table B.8. Prescriptive On-site Renewable Requirement for Standard 90.1-2022

Prototypes	Total Floor Area (ft²)	Sum of Gross Conditioned Floor Area Up to the Three Largest Floors (ft²)	Minimum Required PV Capacity (W)
Small Office	5,503	5,503	Exempt
Medium Office	53,633	53,633	26,817
Large Office	498,600	115,070	57,535
Stand-Alone Retail	24,692	24,692	12,346
Strip Mall	22,500	22,500	11,250
Primary School	73,966	73,966	36,983
Secondary School	210,907	210,907	105,454
Outpatient Health Care	40,946	40,946	20,473
Hospital	241,410	120,705	60,353
Small Hotel	43,200	30,866	15,433
Large Hotel	122,132	58,504	29,252
Non-Refrigerated Warehouse	52,050	52,050	26,025
Quick Service Restaurant	2,500	2,500	Exempt
Full Service Restaurant	5,502	5,502	Exempt
Mid-Rise Apartment	84,360	22,800	11,400
High-Rise Apartment	33,700	22,800	11,400

The PVWatts feature of EnergyPlus was used to model the system performance in the prototypes. The following additional design parameters assumed for the simulation are based on requirements in Addendum *ck* to ASHRAE 90.1-2019:

- Module Type: Crystalline Silicon Panel with a glass cover, 19.1% nominal efficiency and temperature coefficient of -0.47%/°C. Performance shall be based on a reference temperature of 77°F (25°C) and irradiance of 317 Btu/ft^2-hr (1,000 W/m^2)
- Array Type: Rack mounted array with installed nominal operating cell temperature (INOCT) of 103°F (45°C).
- Total System losses (DC output to AC output): 11.3%
- Tilt: 0-degrees (mounted horizontally)
- Azimuth:180 degrees.

Addendum *cf*: Elevator Lights, Fans, and Lift Motors

Addendum Description. Addendum *cf* increases the efficacy of elevator cab lighting and ventilation fans. The addendum also introduces a requirement for elevator lift energy performance, with a requirement of Efficiency Class E or better based on ISO 25745-2 (ISO 2015).

Modeling Strategy. A list of prototypes affected by Addendum *cf* is provided in Table B.9, along with key parameters to characterize the energy performance.

Table B.9. Key Parameters for Elevators in the Prototypes

Prototype	Usage Category (cat)[a]	Operating days/yr (d)[a]	Number of elevators (n_e)	Number of floors (n_f)	flr-flr height m (h)	speed m/s (v)[a]	Trips Per Day (n_d)[a]	Percent of avg travel dist (s_{pct})[b]
High-Rise Apartment	4	360	1	10	3.05	2.5	750	44%
Mid-Rise Apartment	3	360	1	4	3.05	1.6	300	49%
Hospital	4	360	8	5	4.27	2.5	750	44%
Large Hotel	4	360	6	6	3.05	2.5	750	44%
Small Hotel	3	360	2	4	3.05	1.6	300	49%
Large Office	4	260	12	12	3.96	2.5	750	44%
Medium Office	2	260	2	3	3.96	1	125	67%
Outpatient Health Care	3	360	3	3	3.05	1.6	300	67%
Secondary School	2	260	2	2	3.96	1	125	100%

[a] From Table A.1 of ISO 25745-2

[b] From Table 2 of ISO 25745-2

Lighting efficacy in elevators under Addendum *cf* increases from 35 lm/W to 50 lm/W. The effect of this change on total lighting power per elevator is shown in Table B.10. This wattage is applied to the total number of elevators listed in Table B.9.

Table B.10. Elevator Lighting Parameters

Code Version	Total light level * lm/ft²	Elevator car size ft²	Type 1 (70%)		Type 2 (30%)		Total W/ft²	W/ elevator
			lm/W	W/ft²	lm/W	W/ft²		
90.1-2004 to 2007	40	28.305	10	4.00	35	1.14	3.14	88
90.1-2010 to 2019	40	28.305	35	1.14	35	1.14	1.14	32
90.1-2022	40	28.305	50	0.80	50	0.80	0.80	22

Note: * lumen/ft² may also be footcandles (fc). This table combines the total initial light level lm/ft² and efficacy lm/W to determine the power in the elevator.

Elevator ventilation fan efficacy under Addendum *cf* increases from 3 cfm/W to 4 cfm/W. However, the previous implementation of addendum aj (fractional horsepower motor efficiency) in 90.1-2013 resulted in fan efficacy of 7.4 cfm/W, so it was deemed that the increase in fan efficacy requirement in Addendum cf would not result in any new energy savings.

The new requirement for the energy performance of the elevator lift was implemented in the prototypes using equations from Table 7 of ISO 25745-2 for energy consumption per day by efficiency class. Since Addendum *cf* states that the efficiency class shall be E or better, class F is assumed for previous versions of Standard 90.1.

$$E = (C1 * Q * n_d * S_{av} / 1000 + C2 * t_{nr}) * d$$

where:

E	= annual energy consumption of the elevator
C1	= 3.65 for class E and 5.47 for class F
C2	= 800 for Class E and 1,600 for class F
Q	= rated load of elevator, assumed to be 1,361 kg for all prototypes
n_d	= number of trips per day (given in Table B.9)
S_{av}	= Averate distance per trip, m
	= $nf * h * S_{pct}$ (all given in Table B.9
t_{nr}	= time not running per day
	= $24 - n_d * t_{av}$
d	= days per year (given in Table B.9)
t_{av}	= average trip time, seconds
	= $S_{av}/v + v/a + a/j + t_d$
v	= lift speed (given in Table B.9)
a	= acceleration = 1 m/s^2, based on Annex B of ISO 25745-2
j	= jerk = 1.25 m/s^3, based on Annex B of ISO 25745-2
t_d	= door time = 8 s, based on Annex B of ISO 25745-2

The application of the methodology of ISO 25745-2 represents an enhancement to the elevator modeling calculations. The new methods include usage categories that can be aligned with the prototypes, and which identify key parameters, such as number of trips per day and elevator lift speed. The equations above are used to calculate annual energy for an elevator, and the term $C2 * t_{nr}$ can be used to calculate the energy during idle and standby modes. This, in turn allows estimation of instantaneous power during both elevator operation and idle/standby modes. Before the enhancement, the elevator use schedules in the prototype models during off-hours were typically 0 to 5% as shown in Table B.11. With the enhancement, the minimum off-hour power was set to 12%, resulting in increases in Equivalent Full Load Hours (EFLH) for most prototypes. The effective installed power for each prototype was then calculated by dividing the annual energy calculated according to ISO 25745-2 by EFLH.

Table B.11. Effective Power and EFLH Before and After Elevator Enhancement

	Before Enhancement			After Enhancement			
	Off-hour power	EFLH	2004 to 2019 Watts	Off-hour power	EFLH	2004 to 2019 Watts	90.1-2022 Watts
High-Rise Apartment	5%	2,148	20,370	12%	2,264	17,212	10,597
Mid-Rise Apartment	5%	2,148	16,055	12%	2,264	8,012	4,361
Hospital	20%	4,314	162,963	20%	4,314	57,630	34,668
Large Hotel	5%	2,154	122,222	12%	2,264	75,383	44,861
Small Hotel	5%	2,148	32,110	12%	2,264	16,024	8,722
Large Office	5%	2,148	244,444	12%	2,264	226,204	140,025
Medium Office	0%	1,470	32,110	12%	1,917	16,363	8,518
Outpatient Health Care	5%	3,737	48,165	20%	4,006	13,673	7,453
Secondary School	0%	585	32,110	12%	1,384	22,659	11,793

Additional Efficiency Requirements

Addendum *ap*: Energy Credits – General Description

Addendum Description. Addendum *ap* creates a new section in Standard 90.1 that includes a list of energy credit measures that are incorporated into a flexible prescriptive requirement that achieves energy savings relative to the prescriptive requirements of Sections 5 through 10. Energy credit points are assigned to each measure based on expected savings for each combination of building type and climate zone. The building design team must implement a group of measures that collectively satisfy a minimum target for number of points as listed in Addendum *ap* according to building type and climate.

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

1. Begin with the cost-effective package of credits identified by Hart (2022).
2. Remove measures that are difficult to incorporate into the prototype simulations (e.g.: Fault Detection, Point-of-Use Water Heaters, Load Management).
3. Remove measures that underperformed[15] in the prototype analysis (Envelope Performance).
4. Remove measures that overperformed in the prototype analysis (Heat Pump Water Heaters).
5. Add replacement measures that are likely to be cost-effective and commonly installed (e.g.: HVAC Efficiency, lighting control).

Final selections for each building type and climate zone are listed in Table B.12 through Table B.20. For most building types, the selected measures result in point totals that are a few points above the targets. A few cases fall one or two points short of the total; for these, the difference is assumed to be met by one of the un-modeled

[15] Measured under or overperforming relative to their assigned points in the prototype analysis relative to their assigned points may indicate a need to reevaluate assigned points for the next edition of Standard 90.1.

measures, such as Fault Detection. Table B.21 provides a rollup of all measures selected by building type, with a count of applicable climate zones for each.

Table B.12. Multifamily Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
H02	Heating efficiency										5	2	2	6	4	6	9
H03	Cooling efficiency	14	11	9				4			3						
W08	SHW distribution sizing	13	16	16	20	19	24	22	22	25	23	23	27	23	24	24	24
L05	Residential light control	10	10	10	9	10	11	9	9	10	7	9	10	7	8	8	6
L06	Light power reduction	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
R01	Renewable energy	15	15	18	16	19	21	13	19	14	11	17	13	12	14	11	9
	Target	50	50	50	46	50	50	48	50	46	50	50	49	50	50	50	50
	Total Selected	54	54	55	47	50	58	50	52	51	51	53	54	50	52	50	49

Table B.13. Health Care Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
E01	Envelope performance	12	15	13	20	18	27	26	24	33	24	24	43	23	27	28	28
H02	Heating efficiency										4	3	4	6	5	7	9
H03	Cooling efficiency	30	28	20	18	16	8	7	6		5	5		5			
W03	Efficient gas water heater	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
L02	Lighting dimming & tuning										6	7		6	6	5	5
L03	Lighting occupancy sensor	1	1	2	2	1	2	2	1	2	2	1	2	1			
L06	Light power reduction	8	8	8	9	9	10	8	9	10	8	9	9	7	8	7	6
R01	Renewable energy	5	5	7	6	7	7	5	7	5	4	6	5	5	5	4	3
	Target	47	47	45	49	47	50	46	46	50	50	50	50	50	50	50	50
	Total Selected	57	58	51	56	52	55	49	48	51	54	56	64	54	52	52	52

Table B.14. Small Hotel Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
E01	Envelope performance	8	10	9	12	12	15	14	14	12	12	14	13	13	13	15	16
H02	Heating efficiency											1		3	1	3	5
H03	Cooling efficiency	19	15	12													
W03	Efficient gas water heater	5	6	6	8	7	8	9	8	10	10	9	10	10	10	10	10
W08	SHW distribution sizing				7	6	7	8	7	9	8	8	9	9	9	9	9
L02	Lighting dimming & tuning		1			2					2		2			2	
L03	Lighting occupancy sensor	4	4	5	5	4	5	4	4	5	4	4	5	4	4	4	3
L06	Light power reduction	2	4	4	4	4	3	4	6	6	4	4	6	4	4	4	4
R01	Renewable energy	9	9	12	10	13	13	9	13	10	8	12	9	9	10	8	7
	Target	47	49	48	46	47	50	48	50	50	47	46	47	49	46	50	50
	Total Selected	47	49	48	46	48	51	48	52	52	48	52	54	52	51	55	54

Table B.15. Large Hotel Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
E01	Envelope performance	8	10	9	12	12	15	14	14	12	12	14	13	13	13	15	16
H02	Heating efficiency										2	1		3	1	3	5
H03	Cooling efficiency	19	15	12	10	10	7	7	7	3	5			5		4	
W03	Efficient gas water heater	2	2	2	2	2	2	3	2	3	3	3	3	3	3	3	3
W08	SHW distribution sizing	4	5	6	7	6	7	8	7	9	8	8	9	9	9	9	9
L02	Lighting dimming & tuning	2	1							2	2	2	2	2	2	2	2
L03	Lighting occupancy sensor	4	4	5	5	4	5	4	4	5	4	4	5	4	4	4	3
L06	Light power reduction	2	4	4	2	2	3	4	3	6	4	4	6	2	4	4	4
R01	Renewable energy	9	9	12	10	13	13	9	13	10	8	12	9	9	10	8	7
	Target	47	49	48	46	47	50	48	50	50	47	46	47	49	46	50	50
	Total Selected	50	50	50	48	49	52	49	50	50	48	48	47	50	46	52	49

Table B.16. Office Building Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
H02	Heating efficiency							2	1	2	5	3	2	7	5	7	10
H03	Cooling efficiency	15	12	10	8	8	7	6		3	8	4	2	8	2	3	
L02	Lighting dimming & tuning		6		6	7		6	7	7	6	6	7	5	6	5	5
L03	Lighting occupancy sensor	6	7	6	6		8	6	6	7	6	6	7	6	6	5	5
L06	Light power reduction	16	16	18	16	16	18	16	18	18	16	16	18	14	16	14	12
R01	Renewable energy	14	14	16	15	18	19	13	18	14	11	16	13	12	14	16	18
	Target	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Total Selected	51	55	50	51	49	52	49	50	51	52	51	49	52	49	50	50

Table B.17. Restaurant Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
H02	Heating efficiency							5	3	4	8	5	5	10	8	13	17
H03	Cooling efficiency	15	13	10	8	7											
W03	Efficient gas water heater	8	9	10	11	11	14	13	13	14	13	13	15	13	13	13	12
L06	Light power reduction	8	8	8	8	8	8	8	8	6	6	8	6	6	6	6	4
Q02	Efficient kitchen equipment	24	24	26	26	27	31	27	28	30	26	27	30	24	26	23	22
	Target	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Total Selected	55	54	54	53	53	53	53	52	54	53	53	56	53	53	55	55

Table B.18. Retail Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
E01	Envelope performance		6	6	7	7	7	8	8	8	9	9	9				10
H02	Heating efficiency							14	4	10	20	12	12	24	18	18	26
H03	Cooling efficiency	21	18	15	11	11			7	2	4	5	1			3	
L02	Lighting dimming & tuning	6	6	6	5	6	6	4	5	5	3	4	4	3	3	2	2
L03	Lighting occupancy sensor				5		6	4		5				3	4	2	
L06	Light power reduction	12	12	12	11	12	14	10	11	9	8	8	9	8	8	7	6
R01	Renewable energy	11	13	16	14	18	19	12	17	13	10	15	12	10	12	10	7
	Target	50	50	50	50	50	50	50	50	50	49	50	47	48	45	42	46
	Total Selected	50	55	55	53	54	52	52	52	52	54	53	47	48	45	42	51

Table B.19. Education Building Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
H02	Heating efficiency								2		3		2	5	4	7	11
H03	Cooling efficiency	19	18	15	12	12	10	9	9		6			6		5	2
L02	Lighting dimming & tuning	6	6		6		8			8	7	7	7	6	6	6	5
L03	Lighting occupancy sensor	5	6		6	7		7		6	6	6	7	5	6	5	4
L06	Light power reduction	8	8	18	9	10	11	18	18	20	18	18	20	16	18	16	14
R01	Renewable energy	13	14	18	16	20	21	15	21	16	13	19	15	14	16	13	10
	Target	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	46
	Total Selected	51	52	51	49	49	50	49	50	50	53	50	51	52	50	52	46

Table B.20. Warehouse Energy Credit Selections

		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
H02	Heating efficiency				5			21	9	12	21	20	11	24	18	23	29
H03	Cooling efficiency	9	11	9	6	8	2	1	4		2	1					
L03	Lighting occupancy sensor	7	7	7	7	7	9	6	7	7	5	6	8	5	6	5	4
L06	Light power reduction	34	34	34	32	36	38	26	32	34	22	28	34	22	28	22	20
	Target	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Total Selected	50	52	50	50	51	49	54	52	53	50	55	53	51	52	50	53

Table B.21. Rollup of Energy Credit Selections

ID	Measure Name	Number of Climate Zones Selected for the Measure								
		Apartment	HealthCare	Small Hotel	Large Hotel	Office	Restaurant	Retail	School	Warehouse
E01	Envelope performance	0	19	19	19	0	0	12	0	0
W03	Efficient gas water heater	0	19	19	11	0	19	0	0	0
W08	SHW distribution sizing	19	0	14	19	0	0	0	0	0
H03	Cooling efficiency	8	14	6	15	17	8	14	15	4
H02	Heating efficiency	7	7	5	6	10	10	10	7	8
L05	Residential light control	19	0	0	0	0	0	0	0	0
L03	Increase occupancy sensor	0	16	19	19	17	0	7	16	6
L02	Lighting dimming & tuning	0	6	5	12	16	0	19	15	0
L06	Light power reduction	19	19	19	19	18	19	19	19	3
R01	Renewable energy	19	19	19	19	19	0	19	19	19
Q02	Efficient kitchen equipment	0	0	0	0	0	19	0	0	0

Envelope Performance (E01)

Addendum Description. Energy credits for the envelope performance measure are calculated from the envelope performance factors in accordance with Normative Appendix C (Envelope Trade-off Option) of Standard 90.1.

Modeling Strategy. In practice, the envelope performance energy credit is highly flexible, allowing for improvements to any of the envelope characteristics that are included in Normative Appendix C. The values included in the energy credit tables of Addendum *ap* are based on specific window improvements, as listed in Table B.22. Since the energy credit tables were used as the basis for measure selections for the prototype analysis, those same window improvements were applied to the models.

Table B.22. Proposed Envelope Values for Envelope Performance Energy Credits

Climate Zones	U	SHGC	VT
1 to 5	0.248	0.21	0.29
6 to 8	0.240	0.29	0.5

Heating and Cooling Efficiency Energy Credits (H02 and H03)

Addendum Description. Energy credits for heating and cooling efficiency measures can be selected for efficiencies up to 20% better than the prescriptive requirements.

Modeling Strategy. The heating and cooling efficiency credits were applied to all prototypes, with selections corresponding to 5 to 10% efficiency improvements. The measure was implemented in the prototype models by multiplying the prescriptive efficiency by 1.05 or 1.10, accordingly.

Efficient Gas Water Heater Energy Credits (W03)

Addendum Description. Energy credits for the efficient gas storage water heater are based on a thermal efficiency of 95%. Addendum ap states that if the SWH systems in a building are subject to the high efficiency SWH requirements of Section 7.5.3, then the points available for the measure are adjusted by a factor of 0.296 to account for the higher baseline efficiency before the measure is applied.

Modeling Strategy. The efficient gas storage water heater measure is incorporated into the prototypes by increasing the modeled thermal efficiency from the prescriptive efficiency value to 95%. The measure was selected for the hotels, the restaurants, and the health care prototypes. For the Large Hotel, the baseline prescriptive requirement of Section 7.5.2 is applicable due to the large system size, and the points are reduced by the 0.296 adjustment factor. For all the other prototypes, the full points are available.

SWH Distribution Sizing (W08)

Addendum Description. The SWH Distribution Sizing measure in Addendum *ap* includes two design requirements: (1) sizing of piping system using “IAPMO/ANSI WE Stand Appendix C” and (2) selection of low flow fixtures in specified applications.

Modeling Strategy. After Addendum *ap* was approved for publication in Standard 90.1-2022, a modeling error was corrected which resulted in a reduction in savings for the pipe sizing portion of the measure to near-zero. Thus, the implementation of the measure into the prototype models is based only on the low flow fixture requirements. To be consistent with the modeling assumptions in the updated SWH Distribution Sizing measure, the prototype was modeled with a 10.8% reduction in water use compared to the base case and no savings due to re-sizing of the piping.

Lighting | Continuous Dimming and High-End Trim (L02)

Addendum Description. Measure L02 requires the installation of dimming lighting systems with central and zonal controls configured for continuous dimming with either high-trim; lumen maintenance control; or a combination of the two in at least 75% of the gross lighted floor area. The measure saves energy by tuning the light levels in different spaces more specifically to the needed task. This reduces the initial maximum light output to best match the space task visual need. Additionally, lighting is often designed for higher initial lighting levels to compensate for luminaire output depreciation over time. The capability to manually or automatically tune lighting output over time to maintain task level illumination allows the added depreciation compensation power to be saved. The measure is not applicable to apartments, hotel guest rooms, or specialty lighting.

Modeling Strategy. Measure L02 was incorporated into the prototype models by reducing 75% of the space lighting by 7.5% compared to the baseline (total reduction factor of 0.94375). This reflects an operating scenario where there is initially a 15% reduction in power due to the adjusted light output, and the reduction is slowly reduced over time. . For the hotel prototypes, the hotel guest rooms were excluded, and for the Strip Mall prototype, the specialty lighting was excluded.

Increase Occupancy Sensor (L03)

Addendum Description. Measure L03 requires that occupancy sensor control is installed for all space types where it is not required by Section 9.4.1.1(f) except stairwells.

Modeling Strategy. This measure was implemented into the prototypes as an adjustment to the lighting operation schedule. The adjustment was calculated for each space type based on the occupancy sensor reduction values listed in Table G3.7-2 of Standard 90.1-2022.

Residential Lighting Control (L05)

Addendum Description. Measure L05 requires the installation of a centralized master switch near the apartment main entrance that can turn off the entire lighting in the unit with one or two switch operations. There is an additional requirement that there be two clearly identified switched receptacles in each room connected to the unit entrance control. It is anticipated these receptacles would be used for floor lamps or other task lighting. As a master switch, this does not require three-way or four-way switching. The measure can be implemented with traditional wiring or with wireless remote-control methods. The measure also incorporates occupancy-based controls in all common areas where they are not already required by Section 9.4.1.1(f).

Modeling Strategy. This measure only affects the dwelling units of the apartment prototypes, since the common areas already have occupancy control based on the requirements of Section 9. The measure was implemented in the prototypes as a 10% reduction in the lighting use schedules for both hard-wired and plug-in fixtures.

Lighting Power Reduction (L06)

Addendum Description. Measure L06 requires that the installed lighting system power is at least 5% lower than the prescriptive lighting power allowance. This can be achieved through selection of higher efficacy luminaires or a better match of design fixture layout to space lighting requirements. The measure does not apply to dwelling units in apartment buildings, hotel guest rooms, or the additional lighting power allowances from Section 9.5.2.2.

Modeling Strategy. The measure was applied to all prototypes by applying a lighting power reduction ranging from 5% to 10%. Exceptions were applied where applicable.

Renewable Energy (R01)

Addendum Description. Measure R01 requires the installation of on-site renewable energy systems to meet a portion of the energy requirements of the building. The values listed in the energy credit point tables are based on a nominal rated system capacity of 0.10 W/ft^2 of gross building floor area, which is also the minimum allowable capacity. Higher levels of points can be achieved for the measure by installing more capacity. Capacity that is credited for R01 must be in excess of any renewable capacity required by Section 10.5.1.1.

Modeling Strategy. Measure R01 was selected for all prototypes except the Restaurants, and the minimum capacity of 0.1 W/ft^2 was selected in most cases. The renewable measure was not selected for the Warehouse prototype because the points were well above the target points for most climates, and we did not want the overall savings to reflect more savings than would be achieved by just meeting the targets. The modeling methodology was the same as for the basic renewable requirement (see Section 0), except the area basis for the energy credit measure is gross floor area instead of the gross conditioned area of the largest three floors. The electrical energy generation from the additional 0.1W/sq.ft. of on-site renewable energy when combined with the electricity generated by the prescriptive renewable requirement still results in 100% self-utilization across each of the prototypes.

Efficient Kitchen Equipment (Q02)

Addendum Description. Measure Q02 requires the installation of higher efficiency cooking and dishwashing equipment meeting efficiency targets that are specified in the standard.

Modeling Strategy. The efficient commercial kitchen measure is calculated based on a more efficient fryer replacing a standard fryer. Following the methods used for the energy credit point determinations (Hart et al. 2022), the high efficiency fryer is estimated to reduce the total cooking energy end use by 5.4%. The savings factor is applied to both gas and electric cooking equipment in the model.

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