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PNNL-34100

National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2022

January 2025

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program provides technical assistance supporting the development and implementation of building energy codes and standards (42 USC 6833), which set minimum requirements for energy-efficient design and construction of new and renovated buildings, and impact energy use and environmental impacts over the life of buildings. Continuous improvement of building energy efficiency is achieved by periodically updating national model energy codes through consensus-based code development processes, such as those administered by ASHRAE[1] and the International Code Council (ICC). DOE provides technical analysis of potential code revisions and amendments, supporting technologically feasible and economically justified energy efficiency measures during the national model code development process, as well as their implementation across U.S. states and municipalities. Evaluating the expected impacts of the updated model energy codes, including their cost-effectiveness, helps ensure that code changes are economically justifiable and encourages adoption of the latest building codes. Pacific Northwest National Laboratory (PNNL) prepared this analysis to support DOE in evaluating the economic impacts associated with updated codes in commercial buildings.

The purpose of this analysis is to examine the cost-effectiveness of the 2022 edition of ANSI/ASHRAE/IES[2] Standard 90.1 (Standard 90.1-2022),[3] which is developed by the ASHRAE Standard Standing Project Committee (SSPC) 90.1, and is the model energy standard for all commercial buildings and multifamily residential buildings over three floors.[4] PNNL analyzed the cost-effectiveness of changes in Standard 90.1-2022, compared to the previous 90.1-2019 edition, as applied in commercial buildings across the United States. In reviewing proposed changes to Standard 90.1, the SSPC considers the cost-effectiveness of individual changes (addenda). Due to the continuous nature of the development process, however, ASHRAE does not evaluate the entire package of addenda from one edition of the standard to the next, which is of particular interest to adopting state and local governments. Providing states with an analysis of cost-effectiveness facilitates a more comprehensive understanding of the impacts associated with updated model energy codes, informs the state decision-making process and its authorities, and ultimately encourages greater adoption of updated energy codes. This information also informs the development of future editions of Standard 90.1.

To establish the cost-effectiveness of Standard 90.1-2022, three main tasks were addressed:

- Identification of building elements impacted by the updated standard
- Allocation of associated costs (e.g., installation, maintenance, and replacement costs)
- Cost-effectiveness analysis of changes.

Various costs were needed to determine cost-effectiveness including installation, maintenance, and replacement costs, in addition to energy cost differences, which are the costs of the energy impacts associated with individual changes and efficiency measures. The energy costs for each

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[1] ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
[2] ANSI – American National Standards Institute; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America.
[3] ASHRAE. 2022. *ANSI/ASHRAE/IES 90.1-2022, Energy Standard for Buildings Except Low-Rise Residential Buildings*. ASHRAE, Atlanta, GA.
[4] 42 USC 6833. ECPA, Public Law 94-385, as amended. Available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

edition of Standard 90.1 were determined previously under the development of Standard 90.1-2022, as described below.

This cost-effectiveness analysis builds on the PNNL analysis (as outlined in Section 5.2) of the energy use and energy cost saving impacts of Standard 90.1-2022. The overall energy savings analysis used a suite of 16 prototype EnergyPlus[1] building models[2] simulated across all 16 U.S. climate zones. The detailed methodology and overall energy saving results are documented in the technical report titled *ANSI/ASHRAE/IES Standard 90.1-2022: Energy Savings Analysis* (Maddox et al. 2024).

The cost-effectiveness analysis presented in this report uses the following approach. Researchers selected a subset of prototype models and climate locations, covering most of the changes to Standard 90.1-2019 that affect energy usage and construction costs. The individual changes included in the analysis are detailed in Section 3.0. The following prototype buildings (six total) and climate locations (five total) were selected for the analysis using the rationale described in Section 2.1:

Prototype Buildings	**Climate Locations**
Small Office	2A Tampa, Florida (hot, humid)
Large Office	3A Atlanta, Georgia (warm, humid)
Standalone Retail	3B El Paso, Texas (hot, dry)
Primary School	4A New York, New York (mixed, humid)
Small Hotel	5A Buffalo, New York (cool, humid)
Mid-rise Apartment	

These selected prototypes represent the energy impact of five of the eight commercial principal building activities (see Table 2.1) and account for 72% of new construction by floor area covered by the full suite of 16 prototypes. The five climate locations are from the set of representative cities approved by the SSPC 90.1 for establishing criteria for 90.1-2022. Each of the six selected prototype buildings was analyzed in the five selected climate locations for a total of 30 individual cost-effectiveness assessments.

DOE relies upon an established methodology for assessing the energy impacts and cost-effectiveness of building energy codes.[3] Consistent with the methodology, three economic metrics are used: life-cycle cost analysis (LCCA), SSPC 90.1 Scalar Method, and simple payback period.

Although multiple metrics are employed in the analysis, LCCA is the primary metric by which DOE determines the cost-effectiveness of building energy codes. In addition, DOE often provides analysis based on additional metrics for informational purposes and to support the variety of perspectives employed by adopting states and other interested entities.

Table ES.1 summarizes the cost-effectiveness of Standard 90.1-2022. Findings demonstrate that the 2022 edition is cost-effective overall relative to the 2019 edition under the LCCA and

[1] Available at https://energyplus.net
[2] Download from http://www.energycodes.gov/development/commercial/90.1_models
[3] Hart, R, and B. Liu. 2015. “Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.” DOE Building Energy Codes Program. http://www.energycodes.gov/development/commercial/methodology.

SSPC 90.1 Scalar Method for all representative prototypes and climate locations. The results are aggregated across building types and climate zones using weighting factors based on new-building permit data as described in Section 2.4.

Table ES.1. Summary of Cost-Effectiveness Analysis

Prototype Model	Climate Zone and Location					
Life-Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$1.23	$1.13	$1.17	$0.95	$0.96	$1.09
Large Office	$0.94	$1.61	$1.72	$1.44	$1.49	$1.41
Standalone Retail	$3.54	$3.33	$3.03	$3.46	$3.68	$3.47
Primary School	$1.36	$1.09	$1.20	$0.98	$1.08	$1.14
Small Hotel	$2.17	$1.87	$2.07	$2.31	$2.49	$2.20
Mid-rise Apartment	$3.10	$2.76	$3.27	$3.33	$3.30	$3.17
Weighted Total	$2.53	$2.33	$2.59	$2.61	$2.79	$2.58
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	6.2	6.4	6.4	9.0	9.2	7.5
Large Office	10.8	7.6	7.2	8.3	8.0	8.5
Standalone Retail	4.6	4.8	5.0	4.8	4.2	4.6
Primary School	8.3	9.3	8.8	10.2	9.9	9.3
Small Hotel	7.4	7.9	7.4	7.6	7.2	7.5
Mid-rise Apartment	5.2	5.7	4.6	4.6	4.8	5.0
Weighted Total	6.2	6.3	5.7	6.3	5.9	6.1
Scalar Ratio, Limit = 22.24[(a)]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	5.14	5.30	5.29	7.68	8.51	6.44
Large Office	12.10	7.37	6.85	8.08	7.88	8.55
Standalone Retail	8.88	4.89	(0.06)	4.85	4.14	5.01
Primary School	7.87	10.16	9.34	10.20	9.90	9.47
Small Hotel	8.14	8.68	8.12	7.51	7.20	7.90
Mid-rise Apartment	1.97	2.10	0.67	(0.47)	(0.02)	0.72
Weighted Total	6.19	5.33	2.69	4.18	4.26	4.72

(a) Scalar ratio limit for an analysis period of 40 years.
Note: A negative scalar ratio indicates that the cost is negative. This occurs, for example, when there are net decreases in costs either from reductions in HVAC capacity, or reductions in installed lighting due to lower lighting power densities (LPDs), or reduction in replacement costs such as that which occurs with a switch to LED lighting.

Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank Jeremy Williams and Christopher Perry at DOE for providing programmatic direction and oversight. This work was truly a team effort, and the authors would like to express their deep appreciation to everyone from the PNNL codes team who contributed to its completion.

Matt Tyler, PE
Pacific Northwest National Laboratory

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
Btu	British thermal units
Btu/h	British thermal units per hour
CAV	constant air volume
CFM	cubic feet per minute
DOE	U.S. Department of Energy
DX	direct expansion
EIA	Energy Information Administration
ERV	energy recovery ventilator
ESC	Envelope Subcommittee (90.1 SSPC)
Et	thermal efficiency
FEMP	Federal Energy Management Program
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
inch WC	inches of water column
LCCA	life-cycle cost analysis
lm	lumens
LPD	lighting power density
LSC	Lighting Subcommittee (SSPC 90.1)
MEP	mechanical, electrical and plumbing
NC3	National Commercial Construction Characteristics
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
PTAC	packaged terminal air conditioner
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
VAV	variable air volume

Contents

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1.0 Introduction

This study was conducted by Pacific Northwest National Laboratory (PNNL) in support of the U.S. Department of Energy (DOE) Building Energy Codes Program (BECP). BECP was founded in 1993 in response to the *Energy Policy Act of 1992*, which mandated that DOE participate in the development process for national model building energy codes and that DOE help states adopt and implement progressive energy codes. DOE has supported the development and implementation of building energy codes since the 1970s, with BECP being the only DOE program assigned specific mandates with regard to energy codes.

Building energy codes set minimum energy efficiency requirements and additional energy efficiency building design provisions for new and renovated buildings, and impact energy use and associated emissions for the life of the buildings. Energy codes are part of the greater collection of regulations that govern the design, construction, and operation of buildings for the health and life safety of occupants. Effective building energy codes represent one of the largest opportunities to ensure consistent, cost-effective, and long-lasting energy efficiency impacts.

This report centers on *ANSI/ASHRAE/IES 90.1-2022, Energy Standard for Buildings Except Low-Rise Residential Buildings*, the national model energy standard for commercial buildings.[1] The 2019 and 2022 editions of Standard 90.1 are the primary focus of this report (ASHRAE 2019, 2022). These standards are referred to as 90.1-2019 and 90.1-2022 respectively, or as Standard 90.1 when referring to multiple editions of the standard.

DOE provides technical assistance and supports the incremental updating of the model energy codes and states' adoption and implementation of updated codes. DOE takes an active role by participating in the industry code maintenance and revision processes, as administered by ASHRAE and the International Code Council (ICC), seeking adoption of technologically feasible and economically justified energy efficiency measures, per the Department's statutory direction.

PNNL supports DOE in its code-improvement efforts and is closely involved in the updating of the model codes. Specifically, PNNL provides significant technical assistance to the ASHRAE Standing Standard Project Committee for 90.1 (SSPC 90.1), which is responsible for developing the Standard. This assistance ranges from conducting technical analysis on revised codes and proposed changes, to serving on related technical committees, to developing change proposals (addenda) for consideration by the deliberating code review bodies. PNNL also conducts analyses on the energy-savings impacts of published codes in support of DOE energy savings determinations, which assess whether each updated edition of the model codes will improve energy efficiency in residential and commercial buildings.[2]

The Standard 90.1 process relied upon by ASHRAE considers cost-effectiveness of individual proposed changes, known as addenda, to the Standard. However, the process does not include an analysis of the total combined changes from one edition to the next, which is of particular interest to adopting states and localities, as well as to inform the SSPC in developing the next edition of Standard 90.1. Therefore, DOE requested that PNNL analyze the cost-effectiveness

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[1] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers (until 2012, then just ASHRAE); IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)

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

of 90.1-2022 as a whole compared to the previous edition, based on the established life-cycle cost analysis (LCCA) methodology. Through this action, DOE seeks to provide states with cost-effectiveness information to aid in adopting updated editions of commercial energy codes based on Standard 90.1 and for use in the development of future editions of the Standard. The cost-effectiveness analysis of Standard 90.1-2022, compared to the previous 2019 edition, is the subject of this current analysis and report.

1.1 Supporting State Energy Code Adoption

DOE is statutorily directed to provide technical assistance to assist states in reviewing and updating their energy codes, as well as to support state code implementation (e.g., compliance, enforcement, and workforce training activities). The cost-effectiveness analysis covered in this report is an instrumental part of DOE's technical assistance effort to encourage states to adopt the newest edition of Standard 90.1 (or its equivalent). States are increasingly adopting Standard 90.1-2019 with the adoption of 90.1-2022 expected to follow based on historical trends. Figure 1.1 shows the current—as of December 2024—applicable energy standard or code that most closely matches the state's regulation (DOE 2024a).

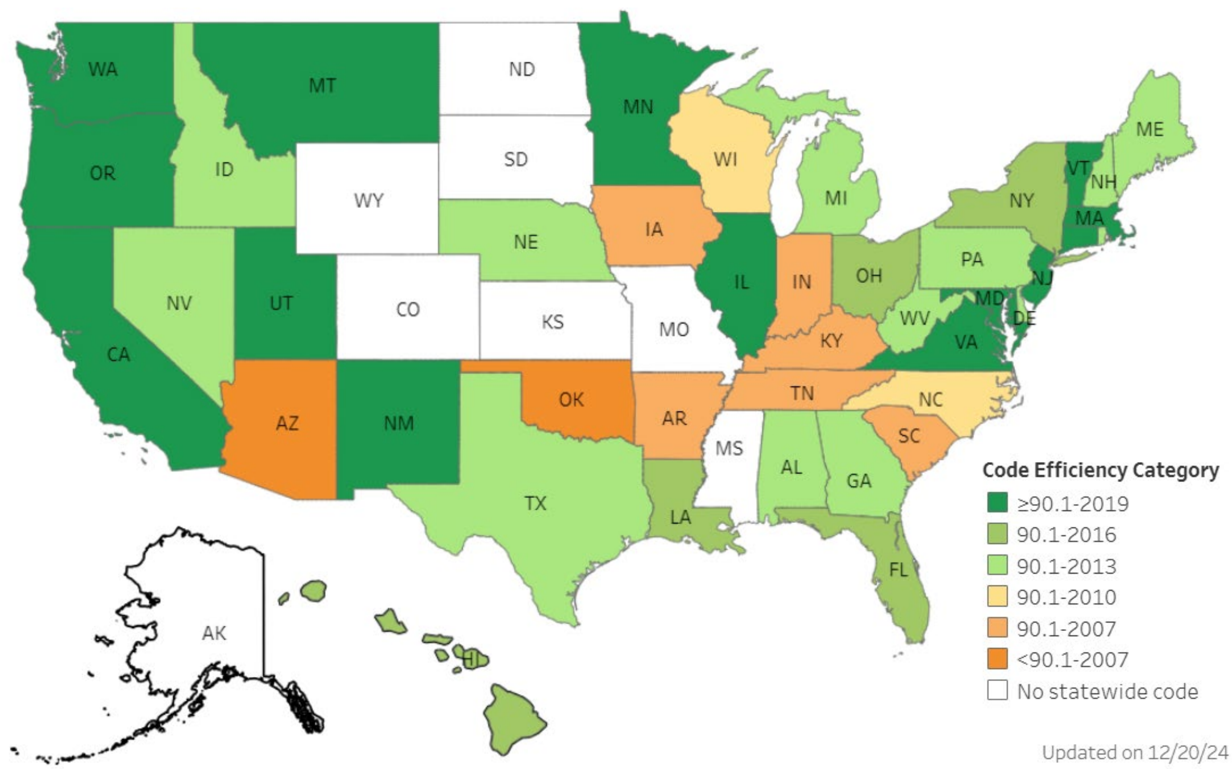

Figure 1.1. Commercial Building Energy Code Adoption Status (December 2024)

1.2 Contents of the Report

This report documents the approach and results for PNNL's analysis of the cost-effectiveness of 90.1-2022 compared to 90.1-2019. Much of the work builds on the previously completed cost-effectiveness comparison between 90.1-2007 and 90.1-2010 along with updates made for 90.1-

2013, 90.1-2016, and 90.1-2019 (Thornton et al. 2013; Hart et al. 2015, 2020; and Tyler et al. 2021). The cost-effectiveness analysis began with the energy savings analysis for development of 90.1-2022, which included energy performance simulation for 16 prototype models in 16 climate locations and is discussed further in Section 5.2. The energy savings analysis was expanded to include addenda related to federally regulated equipment efficiency improvements that were excluded from the determination analysis.

Development of the prototypes and simulation structure was originally completed during the energy savings analysis of 90.1-2010 compared to 90.1-2004 (ASHRAE 2004) and 90.1-2007 (ASHRAE 2007). The technical analysis process, model descriptions, and results were presented in PNNL's technical report titled *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010, referred to in this report as Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011). The prototype models used in the analysis, their development, and the climate locations are described in detail in the quantitative determination and are available for download[1] (DOE 2024b, Maddox et al. 2024).

Six prototypes and five climate locations were chosen from those used for the energy savings analysis simulation models to represent the building construction, energy, and maintenance cost impacts of the changes from 90.1-2019 to 90.1-2022. Section 2.0 provides an overview of the selected prototypes and climate locations utilized for this analysis. Section 3.0 describes the included addenda.

Costs were developed for each of the addenda items included in the cost-effectiveness analysis. The cost estimate methodology and cost items are described in Section 4.0, with a summary of the incremental costs provided. An expanded summary of the incremental costs is also included in Appendix A of this report. The complete cost estimates are available in a spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2022* (PNNL 2024). The cost-effectiveness analysis methodology and results are presented in Section 5.0.

The report has two appendices. Appendix A includes a summary of incremental cost estimate data. Appendix B includes the energy analysis results.

[1] Download from https://www.energycodes.gov/prototype-building-models

2.0 Building Prototypes and Climate Locations

As part of its technical support to SSPC 90.1, PNNL quantified the energy savings of 90.1-2022 compared to 90.1-2019. The analysis used 16 prototype building models that were simulated in 16 climate locations present in the United States. These prototype models, their development, and the climate locations are described in detail in the quantitative determination and are available for download (Maddox et al. 2024). PNNL selected six of the prototype buildings and developed cost estimates for these in five climate locations. The resulting cost-effectiveness analysis represents most of the energy and cost impacts of the changes in Standard 90.1. The results are presented in Section 5.0 and Appendix B.

2.1 Selection of Prototype Buildings

The 6 of 16 prototype models selected for the cost-effectiveness analysis are shown in bold font in Table 2.1. These six prototypes were chosen because they do the following:

- Provide a good representation of the overall code cost-effectiveness, without requiring simulation of all 16 prototype models
- Represent most of the energy and cost impacts of the changes in Standard 90.1
- Include all of the lighting systems and most of the heating, ventilating, and air conditioning (HVAC) systems represented in the prototypes, as shown in Table 2.1
- Capture 19 of the 22 addenda with quantifiable energy savings. The remaining three addenda affect building types not included in the six prototypes or were not applicable to the prototypes as modeled
- Represent the energy impact of five of the eight commercial principal building activities that account for 72% of the new construction by floor area covered by the full suite of 16 prototypes.

Table 2.1. Prototype Buildings

Principal Building Activity	Building Prototype	Included in Current Analysis
Office	**Small Office**	**Yes**
	Medium Office	No
	Large Office	**Yes**
Mercantile	**Standalone Retail**	**Yes**
	Strip Mall	No
Education	**Primary School**	**Yes**
	Secondary School	No
Healthcare	*Outpatient Healthcare*	No
	Hospital	No
Lodging	**Small Hotel**	**Yes**
	Large Hotel	No
Warehouse	*Warehouse (non-refrigerated)*	No
Food Service	*Quick-service Restaurant*	No
	Full-service Restaurant	No
Apartment	**Mid-rise Apartment**	**Yes**

Principal Building Activity	Building Prototype	Included in Current Analysis
	High-rise Apartment	No

2.2 Selection of Climate Locations

As energy usage varies with climate, there are multiple climate zones[1] used by ASHRAE for residential and commercial standards. These climate zones cover the entire United States, as shown in Figure 2.1 (ASHRAE 2013b).

For analysis of the Standard 90.1 energy impact in the United States, 16 specific climate locations (cities) selected by SSPC 90.1 represent characteristics of each climate zone. Representative cities for zones 0A, 0B, and 1B are also listed, even though these zones only represent areas outside the United States.

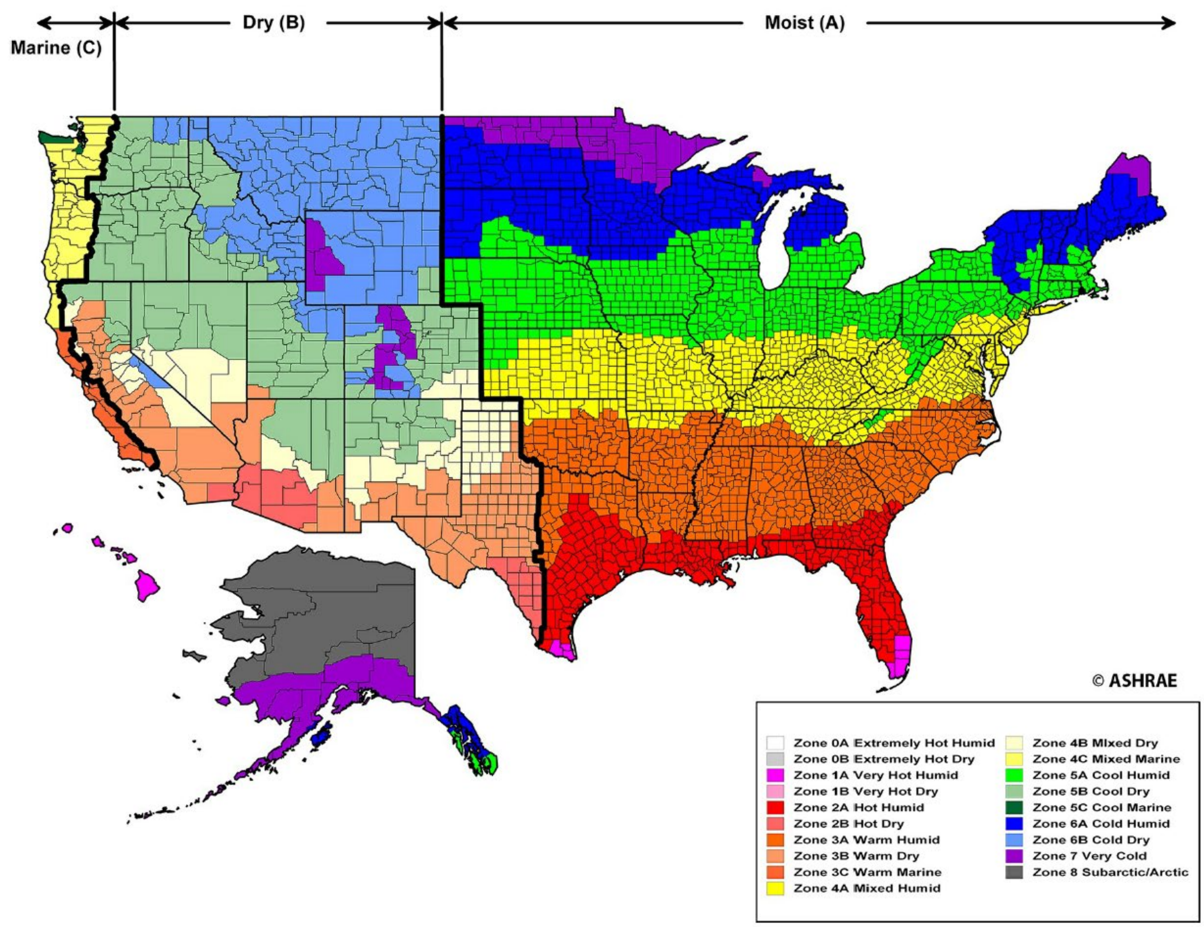

Figure 2.1. United States Climate Zone Map

The cities representing climate zones are listed in Table 2.2 with the five selected for the cost-effectiveness analysis shown in bold font. The selected zones cover most of the high population regions of the United States and include 79% of new construction by floor area (Thornton et al.

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[1] Thermal climate zones are numbered from 0 to 8, from hottest to coldest categorized by cooling and heating degree days. Letters designate moisture characteristics: (A) moist, (B) dry, and (C) marine.

2011). The full climate location list was approved by the SSPC 90.1 for setting the criteria for 90.1-2016 and are different from those used in analyses prior to 90.1-2016. These new climate locations are also consistent with those used in the determination of energy savings of Standard 90.1-2022 (Maddox et al. 2024).

Table 2.2. Climate Locations by Climate Subzones

Climate Zone	Climate Zone Type	Representative City	Included in Current Analysis
0A	Extremely Hot, Humid	Tan Son Hoa (Ho Chi Minh City/Saigon), Vietnam	No
0B	Extremely Hot, Dry	Dubai International Airport, United Arab Emirates	No
1A	Very Hot, Humid	Miami, Florida	No
1B	Very Hot, Dry	New Delhi, India	No
2A	**Hot, Humid**	**Tampa Florida**	**Yes**
2B	Hot, Dry	Tucson, Arizona	No
3A	**Warm, Humid**	**Atlanta, Georgia**	**Yes**
3B	**Warm, Dry**	**El Paso, Texas**	**Yes**
3C	Warm, Marine	San Diego, California	No
4A	**Mixed, Humid**	**New York, New York**	**Yes**
4B	Mixed, Dry	Albuquerque, New Mexico	No
4C	Mixed, Marine	Seattle, Washington	No
5A	**Cool, Humid**	**Buffalo, New York**	**Yes**
5B	Cool, Dry	Denver, Colorado	No
5C	Cool, Marine	Port Angeles, Washington	No
6A	Cool, Humid	Rochester, Minnesota	No
6B	Cold, Dry	Great Falls, Montana	No
7	Very Cold	International Falls, Minnesota	No
8	Subarctic	Fairbanks, Alaska	No

2.3 Description of Selected Prototypes

Table 2.3 provides a brief overview of the six prototypes selected for this cost-effectiveness analysis. *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* provides further information (Thornton et al. 2011). The EnergyPlus input files and detailed modeling information for all the prototypes are available for download.[1] Information from the prototype profiles (also referred to as "scorecards") are also available at the same website. The scorecards include information on the overview tab for each prototype. References such as "See under Outdoor Air" or "See under Schedules" are to other tabs on the full profile spreadsheets.

[1] Download from http://www.energycodes.gov/development/commercial/prototype_models

Table 2.3. Overview of Six Selected Prototypes

Building Prototype	Floor area (ft²)	Number of Floors	HVAC Systems Heating	Cooling	Main System
Small Office	5,502	1	Heat pump	Unitary direct expansion (DX)	Packaged constant air volume (CAV)
Large Office	498,588	12[a]	Boiler	Chiller, cooling tower	Variable air volume (VAV) with hydronic reheat
Standalone Retail	24,692	1	Gas furnace	Unitary DX	Packaged CAV[a]
Primary School	73,959	1	Boiler/Gas furnace	Unitary DX	Packaged VAV with hydronic reheat
Small Hotel	43,202	4	Electricity	DX	Packaged terminal air conditioner (PTAC)
Mid-rise Apartment	33,741	4	Gas furnace	DX	Split DX system

(a) Systems with a cooling capacity > 65,000 Btuh include two speed fans.

2.4 Construction Weighting

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. These data represent all new buildings, as well as additions to existing facilities, over a period of 16 years (2003–2018) and are based on a set of 1,085,104 individual records of commercial building construction across the United States covering a total of 23.2 billion square feet. Details of their 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 90.1-2022. These construction weights were applied to both the baseline and advanced cases. The new full weighting table for all prototypes and U.S. climate zones is included in Lei et al. (2020). For this analysis, the weightings for the selected prototypes and climate zones were normalized to the weightings shown in Table 2.4.

Table 2.4. Construction Weights by Building Type and Climate Zone

Climate Zone	Small Office	Large Office	Stand-alone Retail	Primary School	Small Hotel	Mid-rise Apartment	All Building Types
2A	2.5%	1.8%	5.9%	3.2%	1.0%	7.4%	21.9%
3A	2.3%	1.8%	5.9%	3.1%	0.9%	5.9%	19.8%
3B	0.9%	0.8%	2.8%	1.2%	0.4%	3.9%	10.0%
4A	1.9%	3.7%	6.3%	2.9%	1.0%	10.0%	25.9%
5A	2.2%	1.6%	7.8%	2.6%	0.9%	7.3%	22.4%
U.S. Average	9.9%	9.8%	28.8%	13.0%	4.1%	34.5%	100.0%

Using the energy saving results from each building simulation, the incremental costs, and the corresponding relative fractions of new construction floor space, PNNL developed floor-space-weighted national energy savings results by energy type for each building type and climate zone. Life-cycle cost was completed for each building type. The individual building type and climate zone results were weighted to find a national cost-effectiveness result in Section 5.0.

3.0 Cost Estimate Items from 90.1-2019 Addenda

Of the 89 addenda included in 90.1-2022, 39 have a direct energy impact. Of those 39 addenda, the energy savings of 24 of them were not captured as they are already accounted for in the prototypes, or they do not affect the prototypes or climate zones chosen for this analysis. The remaining 15 addenda are included in the 90.1-2022 savings analysis used as the basis for this report.

This list is slightly different than those included in the 90.1-2022 determination quantitative analysis (Maddox et al. 2024) as the determination analysis includes all prototypes and climate zones and excludes federal appliance standards regulations. Addenda based on federal appliance standards regulations are included in this cost-effectiveness analysis because they have the potential to impact cost. They are also included in order to provide a clearer picture of the incremental costs and savings that can be expected by adopting states, municipalities, and commercial building owners.

3.1 Addenda Included in Cost-Effectiveness Analysis

As described in Section 2.1, the cost-effectiveness analysis uses a subset of six representative prototypes to quantify savings and costs. Fifteen addenda with quantified savings were modeled in the six prototypes and five climate zones used for the cost-effectiveness analysis. These are listed in Table 3.1. Figure 3.1 shows the breakdown of addenda captured in the cost estimate by chapter of the standard.

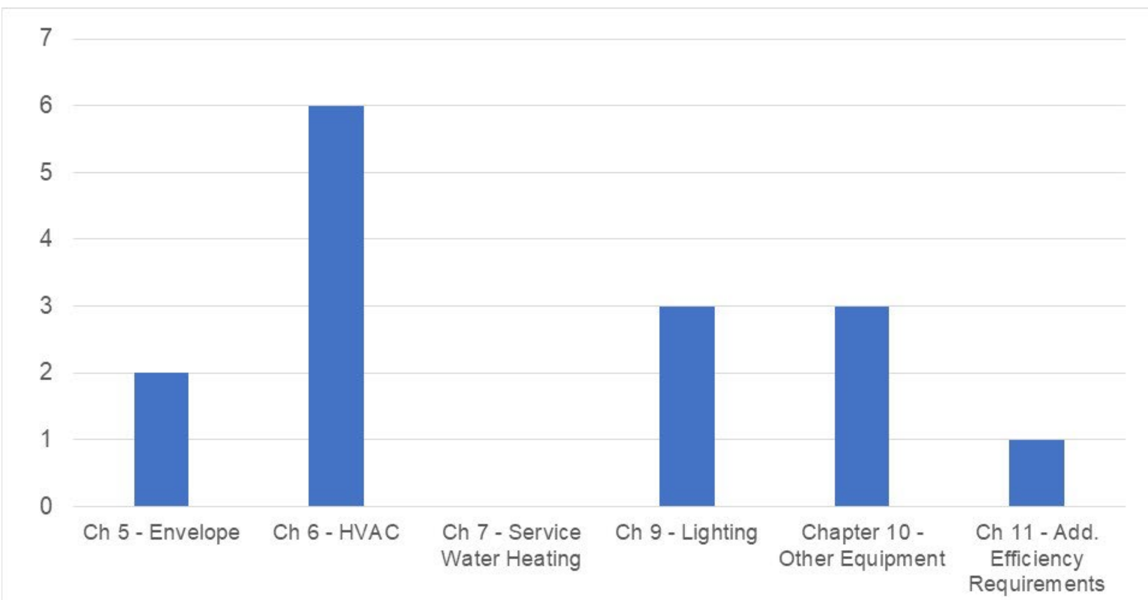

Figure 3.1. Quantity of Addenda Included in Analysis by Standard 90.1 Chapter

Table 3.1 provides a listing and a brief description of all the addenda modeled in this analysis and the prototypes to which they apply. The changes due to these addenda are described in Chapter 4.0 of this report. Material and labor costs were separated out for HVAC systems because there are adjustments in HVAC system capacities due to the other changes in the models, particularly reduced heat gains from lighting power reductions.

Throughout this report, each addendum is named according to a convention that begins with 90.1-19, followed by the letter identifier of the addendum (e.g., 90.1-19am). In text it may be referred to by just the letter designation: *am*.

Table 3.1. Addenda Included in Cost-Effectiveness Analysis

90.1 Addenda	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apt.
Standard 90.1 Chapter 5 – Envelope							
90.1-19t	Infiltration testing	X					
90.1-19av	Thermal bridging	X	X	X	X	X	X
Standard 90.1 Chapter 6 – Heating, Ventilating, and Air Conditioning							
90.1-19a	Small fan efficacy						X
90.1-19b	DCV			X	X	X	
90.1-19c	Small unit setback controls						X
90.1-19bc	Boiler efficiencies		X		X		
90.1-19bx	Furnace efficiency			X	X		
90.1-19ci	Lowers economizer threshold			X		X	
Standard 90.1 Chapter 9 – Lighting							
90.1-19am	Exterior Lighting	X	X	X	X	X	X
90.1-19ba	Lighting tables - space type method	X	X	X	X	X	X
90.1-19br	Dwelling unit lighting efficacy						X
Standard 90.1 Chapter 10 – Other Equipment							
90.1-19by, cc	Renewable energy prescriptive requirements		X	X	X	X	X
90.1-19cf	Elevator performance		X			X	X
Standard 90.1 Chapter 11 – Additional Efficiency Requirements							
90.1-19ap	Energy Credits	X	X	X	X	X	X

3.2 Addenda Not Included in Cost-Effectiveness Analysis

The following addenda with quantifiable energy savings affect prototypes and/or climate zones not included in those selected for the cost-effectiveness analysis or not applicable to the subset of prototypes/climate zones modeled. These are listed in Table 3.2 along with the reason for exclusion.

Table 3.2. Addenda Not Included in Cost-Effectiveness Analysis

90.1 Addenda	Description	Reason
90.1-19s	Adds a new requirement for minimum solar reflectance in climate zone 0	Does not apply to any of the modeled climate zones
90.1-19ah	Increased efficiency of large capacity service water heaters	Does not apply to any of the six modeled prototypes
90.1-19bf	Additional lighting power allowance	Does not apply to any of the six modeled prototypes

4.0 Incremental Cost Estimates

This chapter describes the approach used for developing the incremental construction cost estimates, a description of each, and a summary of the results. The incremental cost estimates were developed for the sole purpose of evaluating the cost-effectiveness of the changes between 90.1-2019 and 90.1-2022. They should not be applied to actual building projects or used for any other purpose as these are aggregated estimates designed to represent the average building stock. Estimates rely on specific prototype designs and assembly cost surveys developed for the purpose of cost estimates for prior cycles, current estimates based on *RS Means* handbooks, and surveys of product costs. All costs are intended to approximately represent the 2023 time frame, and earlier estimates are adjusted with equipment-specific inflation factors. Costs are for national average construction, and these represent total cost to building owners, including contractor overhead and profit.

4.1 Incremental Cost Estimate Approach

The first step in developing the incremental cost estimates was to define the items to be estimated, such as specific pieces of equipment and their installation. Part of the cost item information was extracted from the prototype building energy model inputs and outputs, and from addenda descriptions in the determination quantitative analysis report (Maddox et al. 2024). In some cases, the prototype models did not include sufficient design detail to provide the basis for cost estimates—requiring additional details to be developed to support the cost estimating effort. These are described in Section 4.2 of this report along with the costs. A summary of the incremental costs is included in Appendix A of this report. The cost estimates are available in the spreadsheet *Cost-effectiveness of ASHRAE Standard 90.1-2022* (PNNL 2024).

The second step in the cost estimating process began by defining the types of costs to be collected including material, labor, construction equipment, commissioning, maintenance, and overhead and profit. These were estimated for both initial construction as well as for replacing equipment or components at the end of the useful life.

The third step was to compile the unit and assembly costs needed for the cost estimates. PNNL worked with a cost estimating consulting firm and with a mechanical, electrical, and plumbing (MEP) consulting engineering firm, and utilized its own expertise to develop detailed design-based cost information during the development of the cost-effectiveness comparison between 90.1-2010 and 90.1-2007 (Thornton et al. 2013). For this report, PNNL limited its efforts to updating the prior developed costs where appropriate and completing in-house estimates where needed. *RS Means* cost handbooks were used extensively and provided nearly all of the labor costs (*RS Means* 2023a,b,c). Comparison with *RS Means* cost handbooks from 2012 and 2014 provided specific technology inflation factors where the costs developed in 2012 or 2014 were used (*RS Means* 2012a,b,c, 2014a,b,c). While specific references are included in the cost estimate spreadsheet, in this report the *RS Means* cost handbooks are referred to as *RS Means 2023*, *RS Means 2014*, and *RS Means 2012*, and the specific handbook used can be inferred from the type of cost item being discussed. Cost estimates for new work and later replacements were developed to approximate what a general contractor typically submits to the developer or owner, and these include subcontractor and contractor costs and markups. Maintenance costs were intended to reflect what a maintenance firm would charge, rather than in-house maintenance labor. Once initial costs were developed, a technical review was conducted by PNNL internal sources.

4.1.1 Source of Cost Estimates

Many of the general HVAC costs were originally developed while analyzing the cost-effectiveness of 90.1-2010 compared to 90.1-2007. Table 4.1 includes a description of all sources of cost estimates by category of costs. HVAC cost items were developed primarily by two consulting firms during prior analysis (Thornton et al. 2013). The cost estimating firm provided the cost for HVAC systems including packaged DX and chilled and hot water systems as well as central plant equipment. The engineering consulting firm provided most of the ductwork and piping costs, and most of the control items. These earlier cost estimates from 2012 and 2014 have been adjusted to 2023 values by applying inflation factors developed using RS Means cost handbooks from 2012, 2014, and 2023 (*RS Means* 2012a,b,c; 2014a,b,c; 2023a,b,c).

For lighting and some HVAC items, PNNL developed new cost estimates. Online sources were used together with input from the 90.1 SSPC Lighting Subcommittee (LSC). For envelope items, national costs collected for the prior analysis by a cost estimating contractor were updated, including some input developed by the 90.1 SSPC Envelope Subcommittee (ESC). In addition to these summary tables, specific sources, such as the name of product suppliers, are included in the cost estimate spreadsheet (PNNL 2024).

Bare costs are the costs of materials and labor that the installation contractor pays. They do not include any markups for profit and overhead.

Table 4.1. Sources of Cost Estimates by Cost Category

Cost Category	Source
HVAC Motors included in this category	Cost estimator and PNNL staff used quotes from suppliers and manufacturers, online sources, and their own experience.[a]
HVAC Ductwork, piping, selected controls items	MEP consulting engineers provided ductwork and plumbing costs based on one-line diagrams they created; the model outputs, including system airflows, capacity, and other factors; and detailed costs by duct and piping components using *RS Means 2012*. The MEP consulting engineers also provided costs for several control items.[a] Additional items were costed using *RS Means 2023*.
HVAC Selected items	PNNL provided using staff expertise and experience supplemented with online sources.[a]
Lighting Interior lighting power allowance and daylighting controls	PNNL provided using staff with oversight from a member of 90.1 LSC. Product catalogs were used for consistency with some other online sources where needed.
Envelope Fenestration	Costs dataset developed by specialist cost estimator with additional input from the 90.1 ESC.[a]
Commissioning	Cost estimator, RS Means, MEP consulting engineers, or PNNL staff expertise.
Labor	*RS Means 2023* and the MEP consulting engineers for commissioning rate.
Replacement life	Lighting equipment including lamps and ballasts from product catalogs. Mechanical from 90.1 Mechanical Subcommittee protocol for cost analysis.

Cost Category	Source
Maintenance	Available from the originator of the other costs for the affected items, or PNNL staff expertise.

(a) Detailed costs developed in 2012 or 2014 were updated to 2023 using equipment-specific inflation factors developed from RS Means handbooks.

4.1.2 Cost Parameters

Several general parameters were applied to all the bare cost estimates. These parameters are part of the general construction costs and represent profit and overhead items typical in the construction industry. These items included new construction material and labor cost adjustments, a replacement labor hour adjustment, replacement material and labor cost adjustments, and a project cost adjustment. These parameters are based on work by the cost estimating firm in the prior analysis and are described in Table 4.2.

Costs were not adjusted for climate locations, as this is intended to be a national analysis. The climate location results were intended to represent an entire climate subzone even though climate data for a particular city are used for modeling purposes. Even within a climate zone, costs will vary significantly between a range of urban, suburban, and rural areas. The five selected climate locations cross multiple states. Due to this variation, for this national analysis, average national U.S. construction costs are used. For those interested in a more local analysis, costs could be adjusted for specific cities based on city cost index adjustments from *RS Means 2023* or other sources.

Table 4.2. Cost Estimate Adjustment Parameters

Cost Items	Value[(a)]	Description[(b)]
New construction labor cost adjustment	52.6%	Labor costs used are base wages with fringe benefits. Added to this is 19%: 16% for payroll, taxes, and insurance including worker's comp, FICA, unemployment compensation, and contractor's liability and 3% for small tools. The labor cost plus 19% is multiplied by 25%: 15% for home office overhead and 10% for profit. A contingency of 2.56% is added as an allowance to cover wage increases resulting from new labor agreements.
New construction material cost adjustment	15.0% to 26.5%	Material costs are adjusted for a waste allowance set at 10% in most cases for building envelope materials. For other materials such as HVAC equipment, 0% waste is the basis. The material costs plus any waste allowance are multiplied by the sum of 10% profit on materials. An average value for sales taxes of 5% is applied.
Replacement - additional labor allowance	65.0%	Added labor hours for replacement to cover demolition, protection, logistics, cleanup, and lost productivity relative to new construction. Added prior to calculating replacement labor cost adjustment.
Replacement labor cost adjustment	62.3%	The replacement labor cost adjustment is used instead of the new construction labor cost adjustment for replacement costs. The adjustment is the same except for subcontractor (home office) overhead, which is 23% instead of 15% to support small repair and replacement jobs.
Replacement material cost adjustment	26.5% to 38.0%	The replacement material cost adjustment is used instead of the new construction material cost adjustment for replacement costs. The adjustment is for purchase of smaller lots and replacement parts. 10% is added and then is adjusted for profit and sales taxes.

Cost Items	Value[a]	Description[b]
Project cost adjustment	28.8%	The combined labor, material, and any incremental commissioning or construction costs are added together and adjusted for subcontractor general conditions and for general contractor overhead and profit. Subcontractor general conditions add 12% and include project management, job-site expenses, equipment rental, and other items. A general contractor markup of 10% and a 5% contingency is added to the subcontractor subtotal as an alternative to calculating detailed general contractor costs (*RS Means* 2023c).

(a) Values shown and used are rounded to first decimal place.
(b) Values provided by the cost estimator except where noted.

4.1.3 Cost Estimate Spreadsheet Workbook

The cost estimate spreadsheet (PNNL 2024) that supports cost estimates in this report is organized in the following sections, some with multiple worksheets, each highlighted with a different colored tab described in the introduction to the spreadsheet:

1. Introduction
2. HVAC cost estimates
3. Lighting cost estimates
4. Envelope cost estimates
5. Cost estimate summaries and cost-effectiveness analysis results

4.2 Modeling of Individual Addenda

This section details the simulation modeling of the applicable addenda. The procedures for implementing the addenda into the Standard 90.1-2019 and 90.1-2022 prototype models include identifying the changes to the models required by each addendum, developing model inputs to simulate those changes, applying those changes to the models, running the simulations, and extracting and post-processing the results.

This section also 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” or “target” 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 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 improve 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.

4.2.1 Building Envelope

Building envelope addenda included infiltration testing and improvements to reduce thermal bridging heat loss and heat gain.

4.2.1.1 Addendum t: Infiltration Testing

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 if specific design and construction practices were followed. Addendum *t* only applies to small offices out of the six prototypes included in this cost-effectiveness analysis.

Energy Modeling Strategy

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).

Incremental Cost Impact

Costs for infiltration testing are reported in *Envelope Air Tightness for Commercial Buildings* (Hart et al. 2018). This addendum only applies to small offices out of the six prototypes included in this cost-effectiveness analysis.

4.2.1.2 Addendum av: Thermal Bridging

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. Addendum *av* applies to all the six prototypes included in this cost-effectiveness analysis.

Energy 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 support 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 4.3.

Table 4.3. Prevalence of Thermal Bridges Associated with Masonry Veneer Construction

	Percent of buildings with feature		
Prototype	Idealized Wall	Shelf Angle (brick masonry veneer)	Girts
Large Office	0.9	0.1	0
Small Hotel	0.9	0.1	0
Mid-rise 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 4.4. 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 4.4. 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
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								
Standalone Retail	NA	820	3.7	2	453								
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

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 11.6% for mid-rise 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.

Incremental Cost Impact

Costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Envelope Subcommittee. The economic analysis appears reasonable; thus, these costs are used in this analysis.

4.2.2 Heating, Ventilating, and Air-Conditioning

A substantial part of the HVAC system cost estimate was tied to changes in system and plant equipment capacity between 90.1-2019 and 90.1-2022. Costs for these capacity changes are described together in Section 4.2.2.1 of this report. Other cost estimates were tied to specific addenda. In some cases there was a net decrease in HVAC costs due to reductions in system capacity, airflow, and water flow offsetting increased costs from other addenda.

Many of the HVAC items for which costs were determined remained the same in the current analysis as they were in a prior cost-effectiveness analysis. For example, the change in equipment capacity requires costs for various equipment sizes, which were obtained during a previous analysis. For this round of analysis, costs for HVAC items from previous analyses were brought forward to 2023 costs by applying inflation adjustment factors that were calculated by comparing corresponding items in prior versions of *RS Means* to *RS Means 2023*.

4.2.2.1 HVAC System and Plant Equipment Capacity Changes

Costs were estimated to address changes in HVAC system and plant equipment capacity between the 90.1-2019 and 90.1-2022 prototype models. HVAC equipment capacity changes result from reductions in heating and cooling loads due to changes in fenestration U-factor and SHGC requirements and lighting power, for example. In some cases there may be a heating load increase as a result of reduced internal gains. The change in capacity is taken from the building simulations as an interactive effect of the other code changes implemented.

The HVAC capacity changes are a substantial part of the HVAC cost differences. The costs are developed for a range of equipment sizes corresponding to the prototype models. In most cases, equipment costs from two manufacturers were obtained and the average was used. These costs were originally developed for the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For capacity changes going from 90.1-2019 to 90.1-2022, the same costs were used but were brought forward to 2023 by multiplying them by an adjustment factor. The inflation adjustment factors inflate the material costs and are calculated by comparing corresponding equipment costs in *RS Means 2012* and *RS Means 2014* with those in *RS Means 2023*. Labor costs were updated by using current labor crew rates from *RS Means 2023*.

Many of the HVAC capacity-related equipment costs in the component cost worksheet are the same for 90.1-2019 and 90.1-2022 for the same capacity equipment. The costs differ in the prototype-specific cost worksheets when there is a change in equipment capacity, based on data extracted from the simulation models. Changes in capacity often result in changes in efficiency, and those too are reflected in the costs. Ductwork and piping cost results were calculated separately because a total cost for each combination of prototype and climate location and the values for 90.1-2019 and 90.1-2022 are different, relative to system airflow or water flow.

Piping and ductwork costs were developed for a previous analysis by MEP consulting engineers. This effort included developing schematic-level single-line representative layouts of the ductwork and piping for each prototype. Detailed costs were previously developed at the level of duct and pipe size and length, and all fittings based on the component-by-component costs from *RS Means 2012*. These costs are brought forward to 2023 by applying an inflation factor. Most of the incremental differences from 90.1-2019 to 90.1-2022 are based on changes in heating load, cooling load, and airflow; thus, the cost estimates from the previous analysis are relevant. For some systems like PTACs in the small hotel prototype, the differences in capacity do not impact size selection, so those costs are not adjusted for actual capacity requirements.

An example of the process for developing piping and ductwork costs is shown below. Figure 4.1 provides an exterior view of the Small Office prototype model and an image of the air distribution layout provided by the MEP consulting engineers. Table 4.4 shows an example of the level of ductwork detail developed. Costs for each air distribution element were estimated (primarily from *RS Means 2012*) and then summed. For example, for the Buffalo climate location, the 90.1-2007 material cost is $5,561 and the 90.1-2010 cost is $5,573 before adjusting to 2023 costs. More detailed costs are shown in the associated spreadsheet (PNNL 2024). Based on cost data from all the estimates, a curve fit was developed relating costs to airflow. Then, the resulting airflow for each climate location, prototype, and code edition was used to generate specific air distribution material and labor costs. These costs were then brought forward to 2023 with separate inflation factors for material and labor.

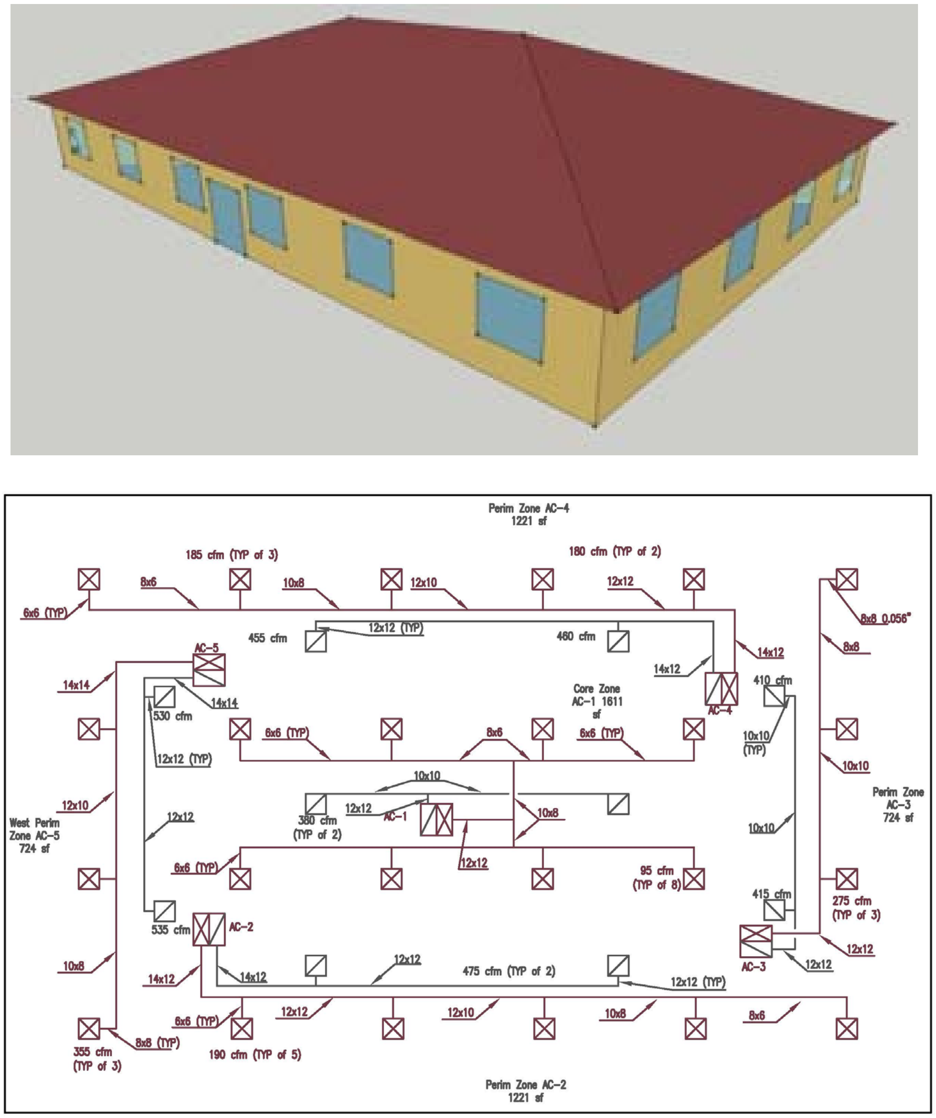

Figure 4.1. Small Office Air Distribution System

Table 4.5. Small Office Duct Details for One HVAC System

Description	Multiplier	Depth (in.)	Width (in.)	Area (ft²)	Duct Length (ft)	Depth + Width	Duct Weight (lb)	Item Qty
Supply Side								
12×12 Duct	1	12	12	1.00	6	24	34.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	1	10	8	0.56		18		17.3
10×8 Duct	2	10	8	0.56	4	18	34.7	
SR5-14 Dovetail WYE	1	8	6	0.33		14		20.9
8×6 Duct	4	8	6	0.33	7	14	85.5	
SR5-13 Tee, 45 degrees (Qs)	4	6	6	0.25		12		15.2
SR5-13 Tee, 45 degrees (Qb)	1	6	6	0.25		12		
6×6 Duct	4	6	6	0.25	20	12	182.4	
CR3-14 Elbow (1.5" Vane Spc)	4	6	6	0.25		12		4.0
6x6 Duct	8	6	6	0.25	2	12	36.5	
Damper Ɵ = 0°, 6x6	8							8.0
Diffuser, 6x6	8							8.0
Return Side								
12x12 Duct	8	12	12	1.00	2	24	92.8	
SR5-14 Dovetail WYE	1	12	10	0.83		22		32.9
ER4-2, Transition, Pyramidal	2	10	10	0.69		20		38.7
10×10 Duct	2	10	10	0.69	15	20	145.2	
CR3-14 Elbow (1.5" Vane Spc)	2	10	10	0.69		20		2.0
10×10 Duct	2	10	10	0.69	2	20	19.4	
Damper Ɵ = 0°, 10x10	2							2.0
Grille, NC 30 10"x10"	2							2.0
						Duct Weight	631.26	

4.2.2.2 Addendum a: Small Fan Efficacy

Addendum *a* sets efficacy requirements for low-capacity ventilation system fans with motors less than 1/12 hp (0.062 kW). Addendum *a* only applies to mid-rise apartments out of the six prototypes included in this cost-effectiveness analysis.

Energy Modeling Strategy

ERV and bathroom exhaust fans in the mid-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 inches of water column (inch 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 inch WC for ERV fans and 0.1 inch WC for bathroom exhaust fans. To convert these rated values to the installed pressure of 0.25 inch WC, additional manufacturer data at varying installed pressure conditions were evaluated to determine the pressure-power relationship as shown in Table 4.6. The ratios calculated for the product data columns in Table 4.6 were applied to the 90.1-2022 columns to determine the typical installed efficacy for the prototype models.

Table 4.6. Conversion of Low-Capacity Ventilation Fan Power from Code Spec Condition to Typical Installed Condition

Condition	Bathroom Fans			ERV Fans		
	Static inch WC	Product data cfm/W	90.1-2022 cfm/W	Static inch 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%

Incremental Cost Impact

Material costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. The economic analysis presented in the addendum appears reasonable. It states, "In some cases, fans complying with the proposed efficacy levels can be obtained for less than fans that do not comply. A comparison of entry-level and compliant exhaust fans for major manufacturers shows that this proposal can result in no incremental first costs or short simple paybacks where incremental costs are incurred." Thus, no incremental material cost is included in this analysis. There is also no incremental labor cost to implement this addendum.

4.2.2.3 Addendum b: DCV

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.

Energy 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 small hotel, standalone retail, and primary school.

Incremental Cost Impact

Costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. The economic analysis presented in the addendum appears reasonable. It states, "Since an economizer or motorized dampers are already required as part of the charging language of this section, the cost to add a sensor and wiring is expected to be $300 or less per unit. A present value allowance of $63 is added to the cost to allow for replacement of up to 50% of sensor elements halfway through the measure life."

4.2.2.4 Addenda c: Small Unit Setback Controls

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.

Energy Modeling Strategy

Addendum c only applies to mid-rise apartments out of the six prototypes included in this cost-effectiveness analysis. 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.

To reasonably evaluate the energy impacts at the national level, we need to make estimations about how many families in the prototype 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. We took a conservative approach to estimate half of the apartment units in the prototype are families with working schedules and would use their programmable thermostats. We assumed a setback of 10°F for heating and 5°F for cooling on weekdays during mid-day based on Section 6.4.3.3.2.

Incremental Cost Impact

Material costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. The economic analysis presented in the addendum appears reasonable. It states, "A review of thermostats available in the market shows that going from one with no scheduling capability to one with weekday/weekend schedule capability adds between $0 and $13 per thermostat." The midpoint of $6.50 was used in this analysis as the incremental material cost. There is no incremental labor cost to implement this addendum.

4.2.2.5 Addendum bc: Boiler Efficiencies

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.

Energy 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 and primary school 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 model change to account for condensing boiler performance is the boiler efficiency curve. This accounts for the effects of part load ratio (PLR) and entering water temperature (EWT) on the boiler efficiency during the simulation. The curve is based on published data for a specific manufacturer and the resulting curve coefficients are listed in Table 4.7.

Table 4.7. 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

Incremental Cost Impact

Costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. The economic analysis presented in the addendum appears reasonable. It states, "First cost was determined from the *2012 GSA Condensing Boiler Study*, which estimates $38.50/MBtu for non-condensing and $42.60/MBtu for condensing boilers. In addition, the study estimates an additional average annual maintenance cost of $400 for condensing boilers." Costs were adjusted to 2023 dollars using inflation factors from RS Means.

4.2.2.6 Addendum bx: Furnace Efficiency

Warm-air gas furnaces with an input heating capacity of 225,000 Btu/h and larger improve from 80% to 81% minimum thermal efficiency as of January 1, 2023. This applies to standalone retail and primary school of the six prototypes included in this cost-effectiveness analysis.

Energy Modeling Strategy

Where efficiency is dependent on system capacity, sizing simulations were conducted, and the results of those simulations were used to select the appropriate efficiency values.

Incremental Cost Impact

Material costs at different efficiency levels were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2023 dollars using inflation factors from RS Means. Labor costs are from RS Means.

4.2.2.7 Addendum ci: Lowers Economizer Threshold

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.

Energy 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, standalone retail, small hotel, and primary school of the six prototypes included in this cost-effectiveness analysis. However, 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 primary school are above the 54,000 Btu/h threshold of Standard 90.1-2019, so there was no new economizer requirement for that prototypes under Addendum *ci*.

Incremental Cost Impact

Addendum *ci* only applies to standalone retail and small hotel out of the six prototypes included in this analysis. The cost-effectiveness analysis model already includes economizer costs from prior code cycles. This is because the economizer size and cost change in proportion to outdoor airflow, which has changed in prior code cycles. Costs were adjusted to 2023 dollars using inflation factors from RS Means.

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[1] https://www.regulations.gov/docket/EERE-2013-BT-STD-0021

4.2.3 Service Water Heating

Standard 90.1-2022 incorporates no addenda that reduces service water heating energy usage for the building types and/or climate zones included in this cost-effectiveness analysis.

4.2.4 Lighting

Standard 90.1-2022 incorporates three addenda that reduce lighting energy usage. One addendum reduces exterior lighting power, another affects interior lighting power, and another affects dwelling unit lighting efficacy and control.

4.2.4.1 Addendum am: Exterior Lighting

Addendum *am* modifies the LPD values for exterior lighting. The changes in LPD are the result of improving lighting technology. The addendum saves energy by reducing the allowed installed lighting power for exterior applications. Addendum *am* applies to all the six prototypes included in this cost-effectiveness analysis.

Energy 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 most of the 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 4.8.

Table 4.8. 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%
Large Office	26,595	989	13,272	40,856	17,216	920	12,953	31,089	24%
Standalone Retail	1,984	1,478	359	3,821	1,266	1,019	346	2,631	31%
Primary School	686	1,922	176	2,783	445	1,344	172	1,961	30%
Small Hotel	2,379	265	674	3,319	1,500	217	644	2,361	29%
Mid-Rise Apartment	1,818	NA	283	2,101	1,176	NA	276	1,452	31%

Incremental Cost Impact

The economic analysis presented in the addendum states, “Prices were supplied by a third party and have remained relatively flat relative to the 2016 options (last time the values were modified), while efficacy improved.” This does not have an incremental cost because it just reflects the fact that most lighting technology became more efficient.

4.2.4.2 Addendum ba: Lighting Tables – Space Type Method

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.

Energy Modeling Strategy

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 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 standalone 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.

Incremental Cost Impact

This does not have a cost because it just reflects the fact that most lighting technology became more efficient.

4.2.4.3 Addendum br: Dwelling Unit Lighting Efficacy and Control

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. The change in efficacy is driven by a change in lamp efficacy as well as the recognition that fewer lighting fixtures use lamps and instead have dedicated LEDs. The lighting controls are to turn off or reduce the lighting in the space. The addendum saves energy by potentially reducing the connected load of the lighting as well as requiring lighting controls to save additional energy.

Energy 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 4.9 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 4.9. Lighting Design and Control for Apartment Prototypes

Space	Area ft^2	Type	90.1-2019			90.1-2022		
			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

Incremental Cost Impact

PNNL staff with lighting expertise developed costs using the spreadsheet cost tool that the 90.1 lighting subcommittee dwelling working group used to develop Addendum *br*.

4.2.5 Other Equipment

4.2.5.1 Addenda by and cc: Renewable Energy Prescriptive Requirements

Addenda *by and cc* add a new prescriptive requirement for onsite 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.

Energy Modeling Strategy

The requirement for onsite renewable energy is applicable to all prototypes except the small office, which has 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 4.10 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 4.10. Prescriptive Onsite Renewable Requirement for Standard 90.1-2022

Prototypes	Total Floor Area (ft$^{2)}$	Sum of Gross Conditioned Floor Area Up to the Three Largest Floors (ft^2)	Minimum Required PV Capacity (W)
Small Office	5,503	5,503	Exempt
Large Office	498,600	115,070	57,535
Standalone Retail	24,692	24,692	12,346
Primary School	73,966	73,966	36,983
Small Hotel	43,200	30,866	15,433
Mid-Rise Apartment	84,360	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.

Incremental Cost Impact

Costs for these addenda are from the National Renewable Energy Laboratory (Ramasamy et al. 2022). The commercial tax credit of 30% is included as described by DOE's Solar Energy Technologies Office.[1]

4.2.5.2 Addendum cf: Elevator Performance

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).

Energy Modeling Strategy

A list of prototypes affected by Addendum *cf* is provided in Table 4.11, along with key parameters to characterize the energy performance.

Table 4.11. 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]
Mid-rise Apartment	3	360	1	4	3.05	1.6	300	49%
Small Hotel	3	360	2	4	3.05	1.6	300	49%
Large Office	4	260	12	12	3.96	2.5	750	44%

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-8. This wattage is applied to the total number of elevators listed in Table 4.12.

Table 4.12. 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)

[1] https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses

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-7)
- S_{av} = Average distance per trip, m
  $= nf * h * S_{pct}$ (all given in Table B-7
- t_{nr} = time not running per day
  $= 24 – n_d * t_{av}$
- d = days per year (given in Table B-7)
- t_{av} = average trip time, seconds
  $= S_{av}/v + v/a + a/j + t_d$
- v = lift speed (given in Table B-7)
- 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 4.13. 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 4.13. 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

Incremental Cost Impact

Material costs are from RS Means 2023c using the base elevator cost and applying a 10% markup for the higher efficiency upgrade. This is a conservative estimate as the requirement is a relatively low hurdle, so almost all standard practice will likely meet it. This addendum applies to three of the six prototypes included in this cost-effectiveness analysis. The analysis accounts for two elevators in the small hotel, one elevator in the mid-rise apartment, and 12 elevators in the large office.

4.2.6 Additional Efficiency Requirements

4.2.6.1 Addendum ap: Energy Credits – General 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. Addendum *ap* applies to all the six prototypes included in this cost-effectiveness analysis.

Modeling Strategy. For each prototype and climate location many possible measure combinations are available to achieve the target number of points. To make selections of energy credit categories for the prototype models in this analysis, PNNL 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[1] 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 4.14 through Table 4.18. 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 measures, such as Fault Detection.

Table 4.14. Multifamily Energy Credit Selections

		2A	3A	3B	4A	5A
H02	Heating efficiency					5
H03	Cooling efficiency	11			4	3
W08	SHW distribution sizing	16	20	19	22	23
L05	Residential light control	10	9	10	9	7
L06	Light power reduction	2	2	2	2	2
R01	Renewable energy	15	16	19	13	11
	Target	50	46	50	48	50
	Total Selected	54	47	50	50	51

Table 4.15. Small Hotel Energy Credit Selections

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

[1] 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.

Table 4.16. Office Building Energy Credit Selections

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

Table 4.17. Retail Energy Credit Selections

		2A	3A	3B	4A	5A
E01	Envelope performance	6	7	7	8	9
H02	Heating efficiency				14	20
H03	Cooling efficiency	18	11	11		4
L02	Lighting dimming & tuning	6	5	6	4	3
L03	Lighting occupancy sensor		5		4	
L06	Light power reduction	12	11	12	10	8
R01	Renewable energy	13	14	18	12	10
	Target	50	50	50	50	49
	Total Selected	55	53	54	52	54

Table 4.18. Education Building Energy Credit Selections

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

Incremental Cost Impact

Costs for this addendum are based on prior work as documented in *90.1 Energy Credits Analysis Documentation* (Hart et al. 2022).

4.2.6.2 Energy Credits – Envelope Performance (E01)

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 *ab* are based on specific window improvements, as listed in Table 4.19. 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 4.19. 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

4.2.6.3 Heating and Cooling Efficiency Energy Credits (H02 and H03)

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.

4.2.6.4 Efficient Gas Water Heater Energy Credits (W03)

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%.

4.2.6.5 SWH Distribution Sizing (W08)

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, PNNL discovered an error in the pipe sizing analysis that was the basis for the measure. Correction of this error 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.

4.2.6.6 Lighting – Continuous Dimming and High-End Trim (L02)

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 prototype, the hotel guest rooms were excluded.

4.2.6.7 Increase Occupancy Sensor (L03)

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.

4.2.6.8 Residential Lighting Control (L05)

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.

4.2.6.9 Lighting Power Reduction (L06)

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.

4.2.6.10 Renewable Energy (R01)

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 in this analysis, and the minimum capacity of 0.1 W/ft^2 was selected in most cases. The modeling methodology was the same as for the basic renewable requirement, 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 0.1 W/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.

4.3 Cost Estimate Results

The cost estimates result in incremental costs for new construction and replacement material, labor, any construction equipment, overhead and profit, as well as maintenance and commissioning. Appendix A includes incremental cost summaries for first cost, maintenance cost, replacement costs for years 1 to 29, and residual value of items with useful lives extending beyond the 30-year analysis period. Residual values are discussed in Section 5.1.1, and are used in the Life-Cycle Cost Analysis in Section 5.1.1.

The associated cost estimate spreadsheet (PNNL 2024) includes a worksheet with details of the summaries in Appendix A and a similar worksheet extending the analysis period to 40 years. The cost is a negative value if there was a replacement cost for 90.1-2019 that was greater than the replacement cost for 90.1-2022. The useful lives of corresponding items such as lamps and ballasts may not be the same for the 90.1-2019 and 90.1-2022 cases; therefore, replacement cost values can be positive or negative throughout the 30-year analysis period.

Table 4.20 includes total incremental first costs for each prototype and climate combination in units of total cost and cost per ft^2. Table 4.21 includes estimated total building costs per ft^2 from *RS Means 2023* for each prototype, and a rough indicator of the percentage increase due to the incremental costs (based on the RS Means costs being representative of buildings that meet 90.1-2019). As described in Section 4.1, these costs were not adjusted for climate location. In all cases moving from 90.1-2019 to 90.1-2022 resulted in an incremental increase in first cost, shown as a positive value. This contrasts with the prior analysis, which in most cases moving from 90.1-2016 to 90.1-2019 resulted in an incremental decrease in first cost, shown as a negative value. That was due to larger reductions in HVAC equipment capacity, as well as for reductions in lighting costs in some cases. While 90.1-2022 represents an initial cost increase, in many cases it is comparable to 90.1-2016 levels due to the initial cost reduction from the 90.1-2019 standard.

Table 4.20. Incremental Initial Construction Costs

Prototype	Value	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	First Cost	$3,232	$3,114	$3,190	$4,556	$5,069
	$/ft^2	$0.59	$0.57	$0.58	$0.83	$0.92
Large Office	First Cost	$841,279	$566,392	$552,616	$589,405	$584,902
	$/ft^2	$1.69	$1.14	$1.11	$1.18	$1.17
Standalone Retail	First Cost	$29,256	$31,003	$30,128	$31,743	$28,287
	$/ft^2	$1.18	$1.26	$1.22	$1.29	$1.15
Primary School	First Cost	$98,390	$99,798	$94,692	$101,162	$102,326
	$/ft^2	$1.33	$1.35	$1.28	$1.37	$1.38
Small Hotel	First Cost	$72,137	$69,400	$68,448	$68,614	$68,661
	$/ft^2	$1.67	$1.61	$1.58	$1.59	$1.59
Mid-rise Apartment	First Cost	$32,597	$32,283	$28,183	$26,953	$28,339
	$/ft^2	$0.97	$0.96	$0.84	$0.80	$0.84

Table 4.21. Comparison of Total Building Cost and Incremental Cost (per ft^2 and percentage)

Prototype	Building First Cost ($/ft^2)	Incremental Cost for 90.1-2022				
		2A Tampa $/ft^2)	3A Atlanta ($/ft^2)	3B El Paso ($/ft^2)	4A New York ($/ft^2)	5A Buffalo ($/ft^2)
Small Office	$220	$0.59 0.27%	$0.57 0.26%	$0.58 0.26%	$0.83 0.38%	$0.92 0.42%
Large Office	$180	$1.69 0.94%	$1.14 0.63%	$1.11 0.62%	$1.18 0.66%	$1.17 0.65%
Standalone Retail	$116	$1.18 1.02%	$1.26 1.08%	$1.22 1.05%	$1.29 1.11%	$1.15 0.99%
Primary School	$225	$1.33 0.59%	$1.35 0.60%	$1.28 0.57%	$1.37 0.61%	$1.38 0.61%
Small Hotel	$197	$1.67 0.85%	$1.61 0.82%	$1.58 0.80%	$1.59 0.81%	$1.59 0.81%
Mid-rise Apartment	$218	$0.97 0.44%	$0.96 0.44%	$0.84 0.38%	$0.80 0.37%	$0.84 0.39%

5.0 Cost-Effectiveness Analysis

The purpose of this analysis is to determine the overall cost-effectiveness of Standard 90.1-2022 compared to the 90.1-2019 edition. Cost-effectiveness was analyzed using the incremental cost information presented in Section 4.0 and the energy cost information presented in this section. Three economic metrics are presented:

- Net present value life-cycle cost savings
- The SSPC 90.1 Scalar Method
- Simple payback

Annual energy costs, a necessary part of the cost-effectiveness analysis, are presented in Section 5.2, with additional detail provided in Appendix B.

5.1 Cost-Effectiveness Analysis Methodology

The methodology for cost-effectiveness assessments has been established for analysis of prior editions of Standard 90.1 (Tyler et al. 2024). This report presents a cost-effectiveness assessment using an LCCA and the SSPC 90.1 Scalar Method for the combined changes in Standard 90.1-2019 to 2022 for each of the 30 combinations of prototype and climate evaluated.[1] The commonly used metric of simple payback period is also included for informational purposes.

5.1.1 Life-Cycle Cost Analysis

The LCCA perspective compared the present value of incremental costs, replacement costs, maintenance, and energy savings for each prototype building and climate location. The degree of borrowing and the impact of taxes vary considerably for different building projects, creating many possible cost scenarios. The LCCA analysis was based on a fixed scenario representative of public sector funding. Thus, these varying costs were not included in the LCCA. Private sector discounting and funding costs were included indirectly with the 90.1 Scalar Method as described in Section 5.1.3.

The LCCA approach is based on the LCCA method used by the Federal Energy Management Program (FEMP), a method required for federal projects and used by other organizations in both the public and private sectors (NIST 1995). The LCCA method consists of identifying costs (and revenues, if any) and the year in which they occur and determining their value in present dollars (known as the net present value). This method uses fundamental engineering economics relationships about the time value of money. For example, the value of money in hand today is normally worth more than money tomorrow, which is why we pay interest on a loan and earn interest on savings. Future costs were discounted to the present based on a discount rate. The discount rate may reflect what interest rate can be earned on other conventional investments with similar risk, or in some cases, the interest rate at which money can be borrowed for projects with the same level of risk.

[1] LCCA is the primary perspective by which DOE determines cost effectiveness for building energy codes

The following calculation method can be used to account for the present value of costs or revenues:

Present Value = Future Value / $(1+ i)^n$

"i" is the discount rate (or interest rate in some analyses)

"n" is the number of years in the future the cost occurs.

The present value of any cost that occurs at the beginning of year one of an analysis period is equal to that initial cost. For this analysis, initial construction costs occur at the beginning of year one, and all subsequent costs occur at the end of the future year identified.

In the LCCA, the present value of the incremental costs for new construction, replacement, maintenance, and energy of the 2022 edition of Standard 90.1 is analyzed and compared to similar results for the 2019 edition. If the present value cost of the 2022 edition is less than the present value cost of the 2019 edition, there is positive net present value savings and Standard 90.1-2022 is cost-effective.

The LCCA depends on the number of years into the future that costs and revenues are considered, known as the study period. The FEMP method uses 25 years; this analysis used 30 years. This is the same study period used for the cost-effectiveness analysis of the residential energy code conducted by PNNL (Salcido et al. 2022) and is the same period used in the previous commercial cost-effectiveness analyses, for example between 90.1-2016 and 90.1-2019 (Tyler et al. 2021). The 30-year study period is also widely used for LCCA in government and industry. The study period is also a balance between capturing the impact of future replacement costs, inflation, and energy escalation with understanding the increasing uncertainty of these costs as they are projected into the future.

Several factors go into choosing the length of the study period and the residual value of equipment beyond the period of analysis. Sometimes the useful life of equipment or materials extends beyond the study period. In this case, the longest useful life defined is 40 years for all envelope cost items, such as wall assemblies, as recommended by the 90.1 SSPC ESC. Forty years is longer than the typical 25- or 30-year study period for LCCA. A residual value of the unused life of a cost item is calculated at the last year of the study period for components with longer lives than the study period, or for items whose replacement life does not fit neatly into the study period, (e.g., a chiller with a 23-year useful life). The residual value is not a salvage value, but rather a measure of the available additional years of service not yet used. The FEMP LCCA method includes a simplified approach for determining the residual value. The residual value is the proportion of the initial cost equal to the remaining years of service divided by the initial cost. For example, the residual value of a wall assembly in year 30 is (40-30)/40 or 25% of the initial cost. The present value of the residual values applied in year 30 is included in the total present value.

The LCCA requires an estimate about the value of money today relative to the value of money in the future. Also required is an estimate of how values of the cost items will change over time, such as the cost of energy and HVAC equipment. These values are determined by the analyst depending on the purpose of the analysis. In the case of the FEMP LCCA method, the National Institute of Standards and Technology (NIST) periodically publishes an update of economic factors. The values published by NIST in May 2022 (Lavappa and Kneifel 2022) were used in this analysis.

The nominal discount rate is based on long-term Treasury bond rates averaged over the 12 months prior to publication of the NIST report. The nominal rate is converted to a real rate to correspond with the constant-dollar analysis approach for this analysis. The method for calculating the real discount rate from the nominal discount rate uses the projected rate of general inflation published in the most recent *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the NIST 2022 annual supplement without citation; Lavappa and Kneifel 2022). The mandated procedure would result in a discount rate for 2022 lower than the 3.0% floor prescribed in federal regulations (10 CFR 431.306). Thus, the 3.0% floor is used as the real discount rate for FEMP analyses in 2022. The implied long-term average rate of inflation was calculated as 0.1% (Lavappa and Kneifel 2022). Table 5.1 summarizes the analysis assumptions used.

Table 5.1. Life-Cycle Cost Analysis Parameters – Public Funded Scenario

Economic Parameter	Value	Source
Nominal Discount Rate[(a) (d)]	2.0%	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2022*, NIST annual update (Lavappa and Kneifel 2022).
Real Discount Rate[(b) (d)]	3.0%	
Inflation Rate[(c) (d)]	-1.0%	
Electricity and Gas Price	$0.1099/kWh, $0.983/therm	SSPC-90.1 for 90.1-2022 scalar
Energy Price Escalation	Uniform present value factors Electricity 18.30 Natural gas 19.43	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2022*, NIST annual update (Lavappa and Kneifel 2022). The NIST uniform present value factors are multiplied by the first year annual energy cost to determine the present value of 30 years of energy costs and are based on a series of different annual real escalation rates for 30 years.

(a) Nominal discount rate is like a quoted interest rate and takes into account expectations about the impact of inflation on future values. Higher nominal rates imply higher expectations of inflation.
(b) Real discount rate excludes inflation so that future amounts can be defined in today's dollars in the calculations. This is not a quoted interest rate. If inflation is zero, real and nominal discount rates are the same. Inflation is captured in the process of using constant dollar costs and the modified discount rate.
(c) General inflation is the background level of price increases for all costs other than energy. This is indirectly applied to replacement and maintenance costs through the real discount rate.
(d) Note that only the real discount rate is needed for the Scenario 1 LCCA calculation. The implied nominal discount rate and inflation rate are shown for comparison to other methods.

5.1.2 Simple Payback

Simple payback, or simple payback period, is a more basic metric often used to assess the reasonableness of an energy efficiency investment. It is based on the number of years required for the sum of the annual return on an investment to equal the original investment. In this case, simple payback is the total incremental first cost (described in Section 4.0) divided by the annual savings, where the annual savings is the annual energy cost savings less any incremental annual maintenance cost. This method does not consider any costs or savings after the year in which payback is reached, does not consider the time value of money, and does not consider any replacement costs, even those that occur prior to the year simple payback is reached. The method also does not have a defined threshold for determining whether an alternative's payback is cost-effective. Decision makers generally set their own threshold for a maximum allowable payback. The simple payback perspective is reported for informational purposes only, not as a basis for concluding that 90.1-2022 is cost-effective.

5.1.3 SSPC 90.1 Scalar Method

The SSPC 90.1 does not consider cost-effectiveness when evaluating the entire set of changes for an update to the whole Standard 90.1. Instead, cost-effectiveness is considered when evaluating a specific addendum to Standard 90.1. The Scalar Method was developed by SSPC 90.1 to evaluate the cost-effectiveness of proposed changes (McBride 1995). The Scalar Method is an alternative life-cycle cost approach for individual energy efficiency changes with a defined useful life, taking into account first costs, annual energy cost savings, annual maintenance, inflation, energy escalation, and financing impacts. So, the scalar method addresses the major drawback of the simple payback method: identifying a target or threshold that indicates cost-effectiveness. The Scalar Method allows a discounted payback threshold (scalar ratio limit) to be calculated based on the measure life. For example, the scalar threshold for an electricity saving measure with a 40-year life is 22.1 years. As this method is designed to be used with a single measure with one value for useful life, it does not account for replacement costs. A measure is considered cost-effective if the simple payback (scalar ratio) is less than the scalar threshold or limit. For example, a measure that saves cooling or electricity and has a 40-year life is considered cost-effective if the simple payback is less than 22.1 years.

Table 5.2 shows the economic parameters used for the 90.1-2022 analysis for this study. These parameters were adopted by the SSPC 90.1 in an ANSI consensus process. The parameters are constant for all measure lives. Given a certain measure life—40 years is used in the table example (typical for building envelope measures, and the life used in this analysis with replacement costs included)—a scalar limit can be determined. Due to differences in energy price escalation, different scalar ratio limits are provided by measure life for heating or natural gas and cooling or electricity. When there is a mix of savings, the two scalar limits are weighted by savings to arrive at a project scalar limit.

Table 5.2. Scalar Ratio Method Economic Parameters and Scalar Ratio Limit

Input Economic Variables – Linked	Heating (Natural Gas)	Cooling (Electricity)
Constant Parameters:		
Down Payment - $	0.00	0.00
Energy Escalation Rate - %[(a)]	2.90[(a)]	2.25[(a)]
Nominal Discount Rate - %[(b)]	8.1	8.1
Loan Interest Rate - %	5.0	5.0
Heating – Natural Gas Price, $/therm	$0.983	
Cooling - Electricity Price $/kWh		$0.1099
Measure Life Example:		
Economic Life - Years	40	40
Scalar Ratio Limit (Weighted: 22.24)	**25.1**	**22.0**

(a) The energy escalation rate used in the scalar calculation for 90.1-2022 includes inflation, so it is a nominal rather than a real escalation rate. For the first 30 years, it is based on NIST reported parameters sourced from EIA nominal price projections and is assumed to be the general rate of inflation beyond 30 years.

PNNL extended the Scalar Method to allow for the evaluation of multiple measures with different useful lives. This extension is necessary to evaluate a complete code edition, since the 90.1 Scalar Method was developed to only evaluate single measures with individual lives. This extended method takes into account the replacement of different components in the total package of 90.1-2022 changes, allowing the net present value of the replacement costs to be calculated over 40 years. The SSPC 90.1 ESC uses a 40-year replacement life for envelope components, and most other cost component useful lives in the cost estimate are less than that. For example, an item with a 20-year life would be replaced once during the study period. The residual value of any items with useful lives that do not fit evenly within the 40-year period is calculated using the method described in Section 5.1.1. Using this approach, an adjusted payback is compared to the scalar limit rather than using a simple payback. The adjusted payback is calculated as the sum of the first costs and present value (PV) of the replacement costs less the PV of residual costs, divided by the difference of the energy cost savings and incremental maintenance cost, as shown in this formula:

$$\mathit{Adjusted\ Payback} = \frac{[\mathit{Initial\ Incremental\ Construction\ Cost}] + [\mathit{PV\ of\ Replacement\ Costs}] - [\mathit{PV\ Residual\ Costs}]}{[\mathit{Annual\ Energy\ Cost\ Savings}] - [\mathit{Increased\ Annual\ Maintenance\ Costs}]}$$

The result is compared to the weighted scalar ratio limit for the 40-year period, 22.08, as shown in Table 5.2. This limit or threshold is determined as follows:

- Due to differing escalation rates for different energy types, the scalar threshold is determined separately for heating (primarily gas) and cooling (primarily electricity).
- To develop one scalar threshold that can be used across building types, the gas and electric savings per floor area from each building type and climate zone are weighted by expected construction share.
- Then the distinct gas and electric scalar ratio thresholds are weighted by that savings share.

- Since the total national savings in this cycle are primarily electric, the weighted scalar threshold is quite close to the lower threshold for electricity.
- The packages of changes for each combination of prototype and climate location were considered cost-effective under the scalar ratio method if the corresponding scalar ratio was less than the scalar ratio limit.

When the adjusted payback is less than the scalar ratio limit, the measure or group of measures is determined to be cost-effective. Therefore, the 90.1 scalar ratio method accounts for the discounted value of future energy savings, by assigning a 40-year measure life a threshold of 22.24 years that it has to meet. If the future savings were not discounted, a 40-year simple payback would be allowed for a 40-year measure life. Reducing that threshold to 22.24 years accounts for the fact that energy savings received in the future are less valuable than savings received immediately today.

5.2 Energy Cost Savings

Annual energy costs are a necessary part of the cost-effectiveness analysis. Annual energy costs were lower for all of the selected 90.1-2022 models compared to the corresponding 90.1-2019 models. The energy costs for each edition of Standard 90.1 were based primarily on DOE's determination of energy savings of 90.1-2022. Detailed methodology and overall energy savings results from Standard 90.1-2022 are documented in the technical report titled *ANSI/ASHRAE/IES Standard 90.1-2022: Energy Savings Analysis* (Maddox et al. 2024).

The current savings analysis builds on the 90.1-2022 determination analysis by including savings from equipment efficiency upgrades that are specifically excluded[1] from the determination analysis. Table 5.3 shows the resulting annual energy cost savings (total and cost/ft^2). Appendix B includes the energy simulation results and additional details of these energy cost savings.

Energy rates used to calculate the energy costs from the modeled energy usage were $0.983/therm for fossil fuel[2] and $0.1099/kWh for electricity. These rates were used for the 90.1-2022 energy analysis and derived from the U.S. DOE Energy Information Administration (EIA) data. These were the values approved by the SSPC 90.1 for cost-effectiveness for the evaluation of individual addenda during the development of 90.1-2022.

[1] The determination only includes savings originating uniquely in the ASHRAE 90.1 Standard and excludes savings from federally mandated appliance efficiency improvements. These savings are included here, as this analysis considers the cost-effectiveness of Standard 90.1 in its entirety.

[2] The fossil fuel rate is a blended heating rate and includes proportional (relative to national heating fuel use) costs for natural gas, propane, heating oil, and electric heat. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas equipment, but in practice, natural gas equipment may be operated using propane or boilers that are modeled because natural gas may use oil in some regions.

Table 5.3. Annual Energy Cost Savings, 90.1-2022 Compared to 90.1-2019

Prototype		Climate Zone and Location				
		2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	Total	$521	$486	$502	$508	$549
	$/ft²	$0.09	$0.09	$0.09	$0.09	$0.10
Large Office	Total	$77,396	$74,449	$76,421	$70,968	$72,265
	$/ft²	$0.16	$0.15	$0.15	$0.14	$0.14
Standalone Retail	Total	$6,330	$6,356	$5,898	$6,499	$6,546
	$/ft²	$0.26	$0.26	$0.24	$0.26	$0.27
Primary School	Total	$11,387	$10,322	$10,367	$9,499	$9,938
	$/ft²	$0.15	$0.14	$0.14	$0.13	$0.13
Small Hotel	Total	$9,441	$8,561	$9,081	$9,081	$9,509
	$/ft²	$0.22	$0.20	$0.21	$0.21	$0.22
Mid-rise Apartment	Total	$6,315	$5,644	$6,147	$5,844	$5,916
	$/ft²	$0.19	$0.17	$0.18	$0.17	$0.18

5.3 Cost-Effectiveness Analysis Results

Table 5.4 shows the results of the analysis from all three methods: LCCA, simple payback, and scalar ratio. This analysis demonstrates that 90.1-2022 is cost-effective relative to 90.1-2019 for all the analyzed prototypes in each climate location for all three methods. Although multiple metrics are employed in the analysis, LCCA is the primary metric by which DOE determines the cost-effectiveness of building energy codes, as discussed in the DOE cost-effectiveness methodology (Tyler et al. 2024). In addition, DOE often provides analysis based on additional metrics for informational purposes and to support the variety of perspectives employed by adopting states and other interested entities. For the two life-cycle cost and simple payback metrics shown in Table 5.4, cost-effectiveness is determined as follows:

- The life-cycle cost net savings is greater than zero. The life-cycle cost net savings is the present value of energy savings for a building built under 90.1-2022 compared to 90.1-2019, less the incremental cost difference, less the present value of the replacement and residual cost difference. The national net savings, weighted across climate zones and building types, is $2.56 per square foot. A positive number indicates cost-effectiveness. Note that the life-cycle net savings is positive for all analyzed building types in all climate zones.
- The simple payback period (years) is the first cost divided by first year energy savings. It does not include discounted future energy savings or replacement costs. The national simple payback, weighted across climate zones and building types, is immediate. This indicates cost-effectiveness.
- The scalar ratio is less than the scalar limit for the analysis. The scalar ratio is calculated using the 90.1 methodology and is similar to a discounted payback. The national scalar ratio, weighted across climate zones and building types, is negative, indicating cost-effectiveness.
- The national weighted values use weighting factors discussed in Section 2.4.

Table 5.4. Cost-Effectiveness Analysis Results

Prototype Model	Climate Zone and Location					
Life-Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$1.23	$1.13	$1.17	$0.95	$0.96	$1.09
Large Office	$0.94	$1.61	$1.72	$1.44	$1.49	$1.41
Standalone Retail	$3.54	$3.33	$3.03	$3.46	$3.68	$3.47
Primary School	$1.36	$1.09	$1.20	$0.98	$1.08	$1.14
Small Hotel	$2.17	$1.87	$2.07	$2.31	$2.49	$2.20
Mid-rise Apartment	$3.10	$2.76	$3.27	$3.33	$3.30	$3.17
Weighted Total	$2.53	$2.33	$2.59	$2.61	$2.79	$2.58
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	6.2	6.4	6.4	9.0	9.2	7.5
Large Office	10.8	7.6	7.2	8.3	8.0	8.5
Standalone Retail	4.6	4.8	5.0	4.8	4.2	4.6
Primary School	8.3	9.3	8.8	10.2	9.9	9.3
Small Hotel	7.4	7.9	7.4	7.6	7.2	7.5
Mid-rise Apartment	5.2	5.7	4.6	4.6	4.8	5.0
Weighted Total	6.2	6.3	5.7	6.3	5.9	6.1
Scalar Ratio, Limit = 22.24[(a)]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	5.14	5.30	5.29	7.68	8.51	6.44
Large Office	12.10	7.37	6.85	8.08	7.88	8.55
Standalone Retail	8.88	4.89	(0.06)	4.85	4.14	5.01
Primary School	7.87	10.16	9.34	10.20	9.90	9.47
Small Hotel	8.14	8.68	8.12	7.51	7.20	7.90
Mid-rise Apartment	1.97	2.10	0.67	(0.47)	(0.02)	0.72
Weighted Total	6.19	5.33	2.69	4.18	4.26	4.72

(a) Scalar ratio limit for an analysis period of 40 years.
Note: A negative scalar ratio indicates that the cost is negative. This occurs, for example, when there are net decreases in costs either from reductions in HVAC capacity or reductions in installed lighting due to lower LPDs, or reduction in replacement costs such as that which occurs with a switch to LED lighting.

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Appendix A – Incremental Cost Estimate Summary

This appendix includes summary cost data used in the cost-effectiveness analysis. Cost tables for each building prototype show cost data grouped by HVAC, Lighting, Envelope and Power, and Total. Cost data includes the incremental cost of implementing 90.1-2022 compared to 90.1-2019. Incremental costs include New Construction or initial cost, annual maintenance cost, replacement costs for years 1 through 29, and residual costs in year 30.

A.1 Small Office Cost Summary

Small Office			HVAC					Lighting		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$1,156	-$1,274	-$1,198	-$1,592	-$1,079	$0	$0	$0	$0	$0
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$769	-$664	-$696	-$799	-$433	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$1,621	-$1,857	-$1,719	-$2,333	-$1,626	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$824	$1,017	$914	$1,289	$940	$0	$0	$0	$0	$0

Small Office	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$4,388	$4,388	$4,388	$6,148	$6,148	$3,232.2	$3,114	$3,190	$4,556	$5,069
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$769	-$664	-$696	-$799	-$433
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$1,621	-$1,857	-$1,719	-$2,333	-$1,626
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$824	$1,017	$914	$1,289	$940

A.2 Large Office Cost Summary

Large Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$240,685	-$34,202	-$47,978	-$39,447	-$43,950	$0	$0	$0	$0	$0
Maintenance	$400	$400	$400	$400	$400					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$11,812	-$12,351	-$18,373	-$6,912	-$3,752	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$317,443	-$12,207	-$11,798	-$13,052	-$13,218	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	-$1,296	-$1,300	-$1,296	-$1,371	-$1,355	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$81,022	-$84,518	-$158,303	-$93,635	-$98,350	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	-$273	-$393	-$400	-$3,822	-$7,011	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$50,649	$52,904	$100,092	$63,753	$70,679	$0	$0	$0	$0	$0

Large Office	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$600,594	$600,594	$600,594	$628,852	$628,852	$841,279	$566,392	$552,616	$589,405	$584,902
Maintenance	$0	$0	$0	$0	$0	$400	$400	$400	$400	$400
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$11,812	-$12,351	-$18,373	-$6,912	-$3,752
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$317,443	-$12,207	-$11,798	-$13,052	-$13,218
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	-$1,296	-$1,300	-$1,296	-$1,371	-$1,355
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$81,022	-$84,518	-$158,303	-$93,635	-$98,350
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	-$273	-$393	-$400	-$3,822	-$7,011
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$50,649	$52,904	$100,092	$63,753	$70,679

A.3 Standalone Retail Cost Summary

Standalone Retail			HVAC					Lighting		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$6,332	-$4,585	-$5,460	-$6,948	-$10,404	$0	$0	$0	$0	$0
Maintenance	$0	$135	$135	$135	$135					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$1,060	$1,270	$991	$349	-$458	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$7,879	-$5,891	-$6,965	-$8,743	-$12,960	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$259,497	$0	-$265,381	$5,945	$8,488	$0	$0	$0	$0	$0

Standalone Retail	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$35,588	$35,588	$35,588	$38,691	$38,691	$29,256	$31,003	$30,128	$31,743	$28,287
Maintenance	$0	$0	$0	$0	$0	$0	$135	$135	$135	$135
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$1,060	$1,270	$991	$349	-$458
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$7,879	-$5,891	-$6,965	-$8,743	-$12,960
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$259,497	$0	-$265,381	$5,945	$8,488

A.4 Primary School Cost Summary

Primary School			HVAC					Lighting		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$3,894	$5,302	$196	-$16,127	-$14,963	$0	$0	$0	$0	$0
Maintenance	$398	$398	$399	$390	$390					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$2,565	$2,492	-$1,888	-$9,188	-$8,455	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	-$227	-$269	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$110,472	-$1,494	-$6,141	-$31,277	-$30,271	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	-$19	-$56	-$57	-$1,470	-$1,738	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$74,520	$1,875	$3,513	$19,049	$18,852	$0	$0	$0	$0	$0

Primary School	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$94,496	$94,496	$94,496	$117,289	$117,289	$98,390	$99,798	$94,692	$101,162	$102,326
Maintenance	$0	$0	$0	$0	$0	$398	$398	$399	$390	$390
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	$2,565	$2,492	-$1,888	-$9,188	-$8,455
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	-$227	-$269
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$110,472	-$1,494	-$6,141	-$31,277	-$30,271
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	-$19	-$56	-$57	-$1,470	-$1,738
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$74,520	$1,875	$3,513	$19,049	$18,852

A.5 Small Hotel Cost Summary

Small Hotel			HVAC					Lighting		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$2,418	$2,842	$1,890	-$2,101	-$2,054	$0	$0	$0	$0	$0
Maintenance	$268	$268	$267	-$2	-$3					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$4,919	$4,943	$4,971	$227	$542	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$1,305	$1,986	$372	-$4,043	-$4,057	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$769	$324	$1,409	$2,771	$2,885	$0	$0	$0	$0	$0

Small Hotel	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$69,719	$66,558	$66,558	$70,715	$70,715	$72,137	$69,400	$68,448	$68,614	$68,661
Maintenance	$0	$0	$0	$0	$0	$268	$268	$267	-$2	-$3
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	$4,919	$4,943	$4,971	$227	$542
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	$1,305	$1,986	$372	-$4,043	-$4,057
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$769	$324	$1,409	$2,771	$2,885

A.6 Mid-rise Apartment Cost Summary

Mid-rise Apartment			HVAC					Lighting		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$22,666	-$22,980	-$27,080	-$33,365	-$31,979	$9,858	$9,858	$9,858	$9,858	$9,858
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	-$33,924	-$34,380	-$40,497	-$49,888	-$47,787	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$33,924	-$34,380	-$40,497	-$49,888	-$47,787	$0	$0	$0	$0	$0
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$11,308	$11,460	$13,499	$16,629	$15,929	$0	$0	$0	$0	$0

Mid-rise Apartment	Envelope, Power and Other							Total		
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$45,405	$45,405	$45,405	$50,460	$50,460	$32,597	$32,283	$28,183	$26,953	$28,339
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)						$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
15	$0	$0	$0	$0	$0	-$33,924	-$34,380	-$40,497	-$49,888	-$47,787
16	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$33,924	-$34,380	-$40,497	-$49,888	-$47,787
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$11,308	$11,460	$13,499	$16,629	$15,929

Appendix B – Energy Cost and Use

This appendix includes summary energy use, cost, and savings data used in the cost-effectiveness analysis.

Energy cost savings tables show the total building energy cost in dollars per square foot for each prototype in each climate zone analyzed. Annual energy cost for each edition of Standard 90.1 is shown with the cost savings and percentage savings.

Energy use savings tables show the total building site energy use cost in kilowatt-hours, therms, and thousand British thermal units per square foot per year for each prototype in each climate zone analyzed. Annual energy use for each edition of Standard 90.1 is shown with the use, savings, and percentage savings.

Energy end use tables show the end use breakdown of annual electric and gas use per square foot for each prototype in each climate zone analyzed. Results are shown for 90.1-2019 and 90.1-2022.

B.1 Energy Cost and Savings Summary, 90.1-2019 and 90.1-2022

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings	
Small Office												
Electricity	$0.922	$0.828	$0.095	10.3%	$0.857	$0.769	$0.088	10.3%	$0.869	$0.778	$0.091	10.5%
Gas	$0.000	$0.000	$0.000	-	$0.003	$0.003	$0.000	0.0%	$0.000	$0.000	$0.000	-
Totals	$0.922	$0.828	$0.095	10.3%	$0.860	$0.772	$0.088	10.2%	$0.869	$0.778	$0.091	10.5%
Large Office												
Electricity	$1.759	$1.604	$0.155	8.8%	$1.663	$1.514	$0.149	9.0%	$1.748	$1.595	$0.152	8.7%
Gas	$0.013	$0.013	$0.000	0.0%	$0.021	$0.021	$0.001	4.8%	$0.020	$0.019	$0.001	5.0%
Totals	$1.772	$1.617	$0.155	8.7%	$1.684	$1.535	$0.149	8.8%	$1.768	$1.615	$0.153	8.7%
Stand-Alone Retail												
Electricity	$1.165	$0.911	$0.254	21.8%	$0.972	$0.729	$0.243	25.0%	$0.996	$0.767	$0.230	23.1%
Gas	$0.039	$0.037	$0.003	7.7%	$0.109	$0.094	$0.015	13.8%	$0.062	$0.053	$0.009	14.5%
Totals	$1.204	$0.948	$0.256	21.3%	$1.080	$0.823	$0.257	23.8%	$1.059	$0.820	$0.239	22.6%
Primary School												
Electricity	$1.207	$1.052	$0.154	12.8%	$0.999	$0.866	$0.134	13.4%	$0.973	$0.836	$0.138	14.2%
Gas	$0.075	$0.075	-$0.001	-1.3%	$0.123	$0.117	$0.006	4.9%	$0.083	$0.081	$0.003	3.6%
Totals	$1.281	$1.128	$0.154	12.0%	$1.122	$0.982	$0.140	12.5%	$1.057	$0.916	$0.140	13.2%
Small Hotel												
Electricity	$1.025	$0.836	$0.189	18.4%	$0.933	$0.771	$0.162	17.4%	$0.940	$0.764	$0.175	18.6%
Gas	$0.277	$0.248	$0.029	10.5%	$0.298	$0.262	$0.036	12.1%	$0.291	$0.258	$0.033	11.3%
Totals	$1.303	$1.084	$0.219	16.8%	$1.231	$1.033	$0.198	16.1%	$1.230	$1.022	$0.208	16.9%
Mid-Rise Apartment												
Electricity	$1.210	$1.022	$0.187	15.5%	$1.124	$0.956	$0.168	14.9%	$1.144	$0.962	$0.182	15.9%
Gas	$0.001	$0.001	$0.000	0.0%	$0.021	$0.022	-$0.001	-4.8%	$0.007	$0.007	$0.000	0.0%
Totals	$1.211	$1.024	$0.187	15.4%	$1.145	$0.978	$0.167	14.6%	$1.151	$0.969	$0.182	15.8%

Energy Cost Saving Results for ASHRAE Standard 90.1, $ per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings	
Small Office								
Electricity	$0.857	$0.766	$0.091	10.6%	$0.869	$0.773	$0.097	11.2%
Gas	$0.005	$0.005	$0.001	20.0%	$0.024	$0.020	$0.003	12.5%
Totals	$0.862	$0.770	$0.092	10.7%	$0.893	$0.793	$0.100	11.2%
Large Office								
Electricity	$1.606	$1.467	$0.139	8.7%	$1.565	$1.425	$0.140	8.9%
Gas	$0.031	$0.028	$0.003	9.7%	$0.044	$0.039	$0.005	11.4%
Totals	$1.637	$1.495	$0.142	8.7%	$1.609	$1.464	$0.145	9.0%
Standalone Retail								
Electricity	$0.908	$0.686	$0.222	24.4%	$0.854	$0.651	$0.203	23.8%
Gas	$0.205	$0.164	$0.041	20.0%	$0.292	$0.230	$0.062	21.2%
Totals	$1.113	$0.849	$0.263	23.6%	$1.146	$0.881	$0.265	23.1%
Primary School								
Electricity	$0.919	$0.804	$0.114	12.4%	$0.846	$0.738	$0.108	12.8%
Gas	$0.139	$0.125	$0.014	10.1%	$0.190	$0.164	$0.026	13.7%
Totals	$1.058	$0.929	$0.128	12.1%	$1.037	$0.902	$0.134	12.9%
Small Hotel								
Electricity	$0.921	$0.756	$0.165	17.9%	$0.934	$0.764	$0.170	18.2%
Gas	$0.319	$0.274	$0.045	14.1%	$0.338	$0.288	$0.050	14.8%
Totals	$1.241	$1.030	$0.210	16.9%	$1.272	$1.052	$0.220	17.3%
Mid-Rise Apartment								
Electricity	$1.112	$0.948	$0.164	14.7%	$1.092	$0.935	$0.157	14.4%
Gas	$0.057	$0.048	$0.010	17.5%	$0.098	$0.080	$0.018	18.4%
Totals	$1.169	$0.996	$0.173	14.8%	$1.190	$1.015	$0.175	14.7%

B.2 Energy Use and Savings Summary, 90.1-2019 and 90.1-2022

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	2A				3A				3B			
Code:	90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings	
Small Office												
Electricity, kWh/ft^2	8.393	7.532	0.861	10.3%	7.801	6.998	0.804	10.3%	7.906	7.076	0.830	10.5%
Gas, therm/ft^2	0.000	0.000	0.000	-	0.003	0.003	0.000	0.0%	0.000	0.000	0.000	-
Totals, kBtu/ft^2	28.645	25.707	2.938	10.3%	26.911	24.158	2.753	10.2%	27.020	24.190	2.830	10.5%
Large Office												
Electricity, kWh/ft^2	16.005	14.594	1.411	8.8%	15.043	13.709	1.334	8.9%	15.810	14.427	1.384	8.8%
Gas, therm/ft^2	0.014	0.014	0.000	0.0%	0.022	0.021	0.001	4.5%	0.021	0.020	0.001	4.8%
Totals, kBtu/ft^2	55.994	51.161	4.834	8.6%	53.527	48.879	4.648	8.7%	56.028	51.200	4.829	8.6%
Stand-Alone Retail												
Electricity, kWh/ft^2	10.600	8.293	2.307	21.8%	8.840	6.632	2.207	25.0%	9.067	6.977	2.090	23.1%
Gas, therm/ft^2	0.040	0.037	0.003	7.5%	0.111	0.096	0.015	13.5%	0.064	0.054	0.009	14.1%
Totals, kBtu/ft^2	40.197	32.039	8.157	20.3%	41.230	32.188	9.042	21.9%	37.301	29.230	8.071	21.6%
Primary School												
Electricity, kWh/ft^2	10.983	9.577	1.406	12.8%	9.101	7.881	1.220	13.4%	8.826	7.571	1.255	14.2%
Gas, therm/ft^2	0.076	0.076	-0.001	-1.3%	0.125	0.117	0.008	6.4%	0.087	0.084	0.004	4.6%
Totals, kBtu/ft^2	45.066	40.319	4.747	10.5%	43.554	38.636	4.917	11.3%	38.867	34.196	4.671	12.0%
Small Hotel												
Electricity, kWh/ft^2	9.286	7.567	1.719	18.5%	8.480	7.004	1.475	17.4%	8.542	6.946	1.596	18.7%
Gas, therm/ft^2	0.282	0.252	0.030	10.6%	0.303	0.267	0.037	12.2%	0.296	0.262	0.034	11.5%
Totals, kBtu/ft^2	59.900	51.060	8.840	14.8%	59.283	50.558	8.725	14.7%	58.725	49.926	8.800	15.0%
Mid-Rise Apartment												
Electricity, kWh/ft^2	10.724	9.058	1.666	15.5%	10.035	8.529	1.505	15.0%	10.250	8.601	1.649	16.1%
Gas, therm/ft^2	0.001	0.001	0.000	0.0%	0.022	0.022	-0.001	-4.5%	0.007	0.007	0.000	0.0%
Totals, kBtu/ft^2	36.738	31.055	5.683	15.5%	36.413	31.340	5.073	13.9%	35.662	30.053	5.610	15.7%

Energy Use Saving Results for ASHRAE Standard 90.1, Energy Use per Square Foot per Year

Climate Zone:	4A				5A			
Code:	90.1-2019	90.1-2022	Savings		90.1-2019	90.1-2022	Savings	
Small Office								
Electricity, kWh/ft^2	7.798	6.966	0.832	10.7%	7.910	7.030	0.880	11.1%
Gas, therm/ft^2	0.005	0.005	0.001	20.0%	0.024	0.021	0.003	12.5%
Totals, kBtu/ft^2	27.161	24.238	2.923	10.8%	29.387	26.073	3.314	11.3%
Large Office								
Electricity, kWh/ft^2	14.548	13.290	1.258	8.6%	14.184	12.920	1.264	8.9%
Gas, therm/ft^2	0.031	0.028	0.004	12.9%	0.045	0.038	0.006	13.3%
Totals, kBtu/ft^2	52.799	48.128	4.670	8.8%	52.885	47.921	4.964	9.4%
Standalone Retail								
Electricity, kWh/ft^2	8.261	6.238	2.023	24.5%	7.767	5.921	1.845	23.8%
Gas, therm/ft^2	0.208	0.167	0.042	20.2%	0.297	0.234	0.063	21.2%
Totals, kBtu/ft^2	49.017	37.951	11.066	22.6%	56.232	43.599	12.634	22.5%
Primary School								
Electricity, kWh/ft^2	8.459	7.412	1.047	12.4%	7.820	6.817	1.003	12.8%
Gas, therm/ft^2	0.146	0.129	0.017	11.6%	0.201	0.169	0.032	15.9%
Totals, kBtu/ft^2	43.449	38.180	5.269	12.1%	46.778	40.195	6.583	14.1%
Small Hotel								
Electricity, kWh/ft^2	8.370	6.864	1.506	18.0%	8.493	6.948	1.545	18.2%
Gas, therm/ft^2	0.325	0.279	0.045	13.8%	0.344	0.293	0.051	14.8%
Totals, kBtu/ft^2	61.038	51.348	9.690	15.9%	63.408	53.009	10.400	16.4%
Mid-Rise Apartment								
Electricity, kWh/ft^2	9.935	8.477	1.457	14.7%	9.789	8.381	1.407	14.4%
Gas, therm/ft^2	0.059	0.049	0.010	16.9%	0.101	0.082	0.019	18.8%
Totals, kBtu/ft^2	39.778	33.834	5.945	14.9%	43.479	36.789	6.691	15.4%

B.3 Energy by Usage Category, 90.1-2019 and 90.1-2022

Annual Energy Usage for Buildings in Climate Zone 2A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr
ASHRAE 90.1-2019												
Heating, Humidification	0.015	0.000	0.189	0.001	0.000	0.007	0.000	0.014	0.050	0.001	0.000	0.001
Cooling	1.945	0.000	3.450	0.000	3.980	0.000	4.074	0.000	3.290	0.000	2.089	0.000
Fans, Pumps, Heat Recovery	0.970	0.000	1.562	0.000	1.421	0.000	1.185	0.000	1.651	0.000	0.912	0.000
Lighting, Interior & Exterior	1.843	0.000	1.564	0.000	3.014	0.000	1.169	0.000	1.469	0.000	0.873	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.240	0.000	2.186	0.000	4.458	0.046	2.827	0.092	3.722	0.000
Service Water Heating (SWH)	1.182	0.000	0.000	0.012	0.000	0.034	0.097	0.016	0.000	0.189	3.127	0.000
Total	8.393	0.000	16.005	0.014	10.600	0.040	10.983	0.076	9.286	0.282	10.724	0.001
ASHRAE 90.1-2022												
Heating, Humidification	0.014	0.000	0.189	0.001	0.000	0.004	0.000	0.014	0.047	0.000	0.000	0.001
Cooling	1.777	0.000	3.255	0.000	3.438	0.000	3.713	0.000	2.917	0.000	1.816	0.000
Fans, Pumps, Heat Recovery	0.936	0.000	1.518	0.000	1.329	0.000	1.182	0.000	1.583	0.000	0.863	0.000
Lighting, Interior & Exterior	1.330	0.000	1.101	0.000	2.220	0.000	1.006	0.000	1.248	0.000	0.659	0.000
Plugs, Refrigeration, Other	2.439	0.000	8.847	0.000	2.186	0.000	4.458	0.046	2.442	0.092	3.476	0.000
Service Water Heating (SWH)	1.182	0.000	0.000	0.012	0.000	0.034	0.097	0.016	0.000	0.160	2.886	0.000
Total	7.679	0.000	14.910	0.014	9.172	0.037	10.456	0.076	8.237	0.252	9.699	0.001
Total Savings	0.714	0.000	1.095	0.000	1.428	0.003	0.527	-0.001	1.049	0.030	1.024	0.000

Annual Energy Usage for Buildings in Climate Zone 3A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr
ASHRAE 90.1-2019												
Heating, Humidification	0.314	0.003	0.535	0.008	0.000	0.076	0.000	0.061	0.362	0.007	0.000	0.022
Cooling	1.041	0.000	2.260	0.000	2.192	0.000	2.327	0.000	2.195	0.000	1.214	0.000
Fans, Pumps, Heat Recovery	0.939	0.000	1.439	0.000	1.428	0.000	1.038	0.000	1.621	0.000	0.752	0.000
Lighting, Interior & Exterior	1.853	0.000	1.568	0.000	3.034	0.000	1.181	0.000	1.474	0.000	0.873	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.240	0.000	2.186	0.000	4.457	0.046	2.827	0.092	3.722	0.000
Service Water Heating (SWH)	1.217	0.000	0.000	0.013	0.000	0.035	0.097	0.018	0.000	0.204	3.474	0.000
Total	7.801		15.043	0.022	8.840	0.111	9.101	0.125	8.480	0.303	10.035	0.022
ASHRAE 90.1-2022												
Heating, Humidification	0.303		0.535	0.007	0.000	0.060	0.000	0.053	0.337	0.001	0.000	0.022
Cooling	0.945	0.000	2.129	0.000	1.872	0.000	2.132	0.000	2.027	0.000	1.104	0.000
Fans, Pumps, Heat Recovery	0.899	0.000	1.399	0.000	1.446	0.000	1.031	0.000	1.554	0.000	0.714	0.000
Lighting, Interior & Exterior	1.337	0.000	1.104	0.000	1.979	0.000	1.016	0.000	1.292	0.000	0.659	0.000
Plugs, Refrigeration, Other	2.439	0.000	8.847	0.000	2.186	0.000	4.457	0.046	2.442	0.092	3.476	0.000
Service Water Heating (SWH)	1.217	0.000	0.000	0.013	0.000	0.035	0.097	0.018	0.000	0.173	3.197	0.000
Total	7.139		14.014	0.021	7.483	0.096	8.732	0.117	7.653	0.267	9.150	0.022
Total Savings	0.662	0.000	1.029	0.001	1.357	0.015	0.369	0.008	0.827	0.037	0.885	-0.001

Annual Energy Usage for Buildings in Climate Zone 3B

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$	kWh/ $ft^2 \cdot yr$	therms/ $ft^2 \cdot yr$
ASHRAE 90.1-2019												
Heating, Humidification	0.128	0.000	0.996	0.008	0.000	0.029	0.000	0.024	0.146	0.003	0.000	0.007
Cooling	1.175	0.000	2.321	0.000	2.189	0.000	2.232	0.000	2.233	0.000	1.409	0.000
Fans, Pumps, Heat Recovery	1.109	0.000	1.689	0.000	1.575	0.000	0.845	0.000	1.860	0.000	0.861	0.000
Lighting, Interior & Exterior	1.848	0.000	1.564	0.000	3.117	0.000	1.195	0.000	1.476	0.000	0.873	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.240	0.000	2.186	0.000	4.456	0.046	2.827	0.092	3.722	0.000
Service Water Heating (SWH)	1.208	0.000	0.000	0.013	0.000	0.035	0.097	0.017	0.000	0.200	3.385	0.000
Total	7.906	0.000	15.810	0.021	9.067	0.064	8.826	0.087	8.542	0.296	10.250	0.007
ASHRAE 90.1-2022												
Heating, Humidification	0.128	0.000	0.996	0.006	0.000	0.019	0.000	0.020	0.134	0.000	0.000	0.007
Cooling	1.069	0.000	2.182	0.000	1.912	0.000	2.118	0.000	2.109	0.000	1.275	0.000
Fans, Pumps, Heat Recovery	1.064	0.000	1.638	0.000	1.607	0.000	0.846	0.000	1.787	0.000	0.820	0.000
Lighting, Interior & Exterior	1.339	0.000	1.131	0.000	2.295	0.000	1.077	0.000	1.253	0.000	0.659	0.000
Plugs, Refrigeration, Other	2.439	0.000	8.847	0.000	2.186	0.000	4.456	0.046	2.442	0.092	3.476	0.000
Service Water Heating (SWH)	1.208	0.000	0.000	0.013	0.000	0.035	0.097	0.017	0.000	0.170	3.117	0.000
Total	7.246	0.000	14.794	0.020	8.000	0.054	8.594	0.084	7.725	0.262	9.347	0.007
Total Savings	0.659	0.000	1.016	0.001	1.066	0.009	0.232	0.004	0.817	0.034	0.903	0.000

Annual Energy Usage for Buildings in Climate Zone 4A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr	Electric kWh/ ft²·yr	Gas therms/ ft²·yr
ASHRAE 90.1-2019												
Heating, Humidification	0.607	0.005	0.704	0.017	0.000	0.172	0.000	0.081	0.822	0.016	0.000	0.059
Cooling	0.780	0.000	1.659	0.000	1.470	0.000	1.642	0.000	1.683	0.000	0.886	0.000
Fans, Pumps, Heat Recovery	0.895	0.000	1.376	0.000	1.488	0.000	1.076	0.000	1.573	0.000	0.707	0.000
Lighting, Interior & Exterior	1.834	0.000	1.568	0.000	3.116	0.000	1.186	0.000	1.464	0.000	0.873	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.240	0.000	2.186	0.000	4.457	0.046	2.827	0.092	3.722	0.000
Service Water Heating (SWH)	1.244	0.000	0.000	0.014	0.000	0.036	0.097	0.019	0.000	0.217	3.747	0.000
Total	7.798	0.005	14.548	0.031	8.261	0.208	8.459	0.146	8.370	0.325	9.935	0.059
ASHRAE 90.1-2022												
Heating, Humidification	0.530	0.005	0.703	0.013	0.000	0.130	0.000	0.064	0.748	0.003	0.000	0.049
Cooling	0.710	0.000	1.559	0.000	1.282	0.000	1.496	0.000	1.487	0.000	0.778	0.000
Fans, Pumps, Heat Recovery	0.843	0.000	1.341	0.000	1.479	0.000	1.078	0.000	1.453	0.000	0.662	0.000
Lighting, Interior & Exterior	1.323	0.000	1.105	0.000	2.030	0.000	1.021	0.000	1.295	0.000	0.659	0.000
Plugs, Refrigeration, Other	2.439	0.000	8.847	0.000	2.186	0.000	4.457	0.046	2.442	0.092	3.476	0.000
Service Water Heating (SWH)	1.244	0.000	0.000	0.014	0.000	0.036	0.097	0.019	0.000	0.183	3.441	0.000
Total	7.089	0.005	13.555	0.028	6.976	0.167	8.149	0.129	7.426	0.279	9.016	0.049
Total Savings	0.709	0.001	0.993	0.004	1.285	0.042	0.309	0.017	0.944	0.045	0.919	0.010

Annual Energy Usage for Buildings in Climate Zone 5A

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr	kWh/ ft²·yr	therms/ ft²·yr
ASHRAE 90.1-2019												
Heating, Humidification	1.006	0.024	0.806	0.030	0.000	0.260	0.000	0.135	1.377	0.025	0.000	0.101
Cooling	0.465	0.000	1.225	0.000	0.823	0.000	1.020	0.000	1.272	0.000	0.547	0.000
Fans, Pumps, Heat Recovery	0.898	0.000	1.345	0.000	1.645	0.000	1.073	0.000	1.554	0.000	0.670	0.000
Lighting, Interior & Exterior	1.836	0.000	1.568	0.000	3.112	0.000	1.174	0.000	1.463	0.000	0.873	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.240	0.000	2.186	0.000	4.457	0.046	2.827	0.092	3.722	0.000
Service Water Heating (SWH)	1.267	0.000	0.000	0.015	0.000	0.037	0.097	0.020	0.000	0.227	3.977	0.000
Total	7.910	0.024	14.184	0.045	7.767	0.297	7.820	0.201	8.493	0.344	9.789	0.101
ASHRAE 90.1-2022												
Heating, Humidification	0.875	0.021	0.805	0.023	0.000	0.197	0.000	0.103	1.267	0.008	0.000	0.082
Cooling	0.403	0.000	1.107	0.000	0.703	0.000	0.943	0.000	1.097	0.000	0.492	0.000
Fans, Pumps, Heat Recovery	0.841	0.000	1.312	0.000	1.452	0.000	1.067	0.000	1.427	0.000	0.627	0.000
Lighting, Interior & Exterior	1.324	0.000	1.104	0.000	2.292	0.000	0.965	0.000	1.256	0.000	0.659	0.000
Plugs, Refrigeration, Other	2.439	0.000	8.847	0.000	2.186	0.000	4.457	0.046	2.442	0.092	3.476	0.000
Service Water Heating (SWH)	1.267	0.000	0.000	0.015	0.000	0.037	0.097	0.020	0.000	0.192	3.647	0.000
Total	7.148	0.021	13.175	0.038	6.632	0.234	7.528	0.169	7.489	0.293	8.900	0.082
Total Savings	0.761	0.003	1.009	0.006	1.135	0.063	0.292	0.032	1.004	0.051	0.889	0.019

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