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Pacific Northwest
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National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2019

July 2021

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U.S. DEPARTMENT OF ENERGY

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Richland, Washington 99352

Executive 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 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. It is important to ensure that model code changes are cost-effective because this encourages their adoption and implementation at the state and local levels. 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 2019 edition of ANSI/ASHRAE/IES[2] Standard 90.1 (Standard 90.1-2019)[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 90.1-2019, compared to the previous 90.1-2016 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 90.1-2019, 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 edition of Standard 90.1 were determined previously under the development of Standard 90.1-2019, 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 90.1-2019. The overall energy savings analysis

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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. 2019. *ANSI/ASHRAE/IES 90.1-2019, 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.

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 *Preliminary Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019*.[3]

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 90.1-2016 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 90.1-2019. 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.[4] Consistent with the methodology, three economic metrics are used:

- Life-cycle cost analysis (LCCA)
- SSPC 90.1 Scalar Method
- 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 90.1-2019. Findings demonstrate that the 2019 edition is cost-effective overall relative to the 2016 edition under the LCCA and 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.

[1] Available at https://energyplus.net
[2] Download from http://www.energycodes.gov/development/commercial/90.1_models
[3] DOE. 2020. "Preliminary Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2019." U.S. Department of Energy, Washington D.C. https://www.energycodes.gov/development/determinations.
[4] 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.

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	$4.20	$4.16	$4.23	$4.00	$3.98	$4.11
Large Office	$4.40	$4.39	$3.92	$4.29	$4.22	$4.29
Standalone Retail	$4.83	$4.56	$4.70	$4.34	$4.28	$4.50
Primary School	$5.43	$5.06	$5.45	$5.04	$5.10	$5.19
Small Hotel	$14.14	$14.04	$14.07	$13.86	$13.81	$13.97
Mid-rise Apartment	$2.65	$2.66	$2.19	$1.83	$1.80	$2.18
Weighted Total	$4.50	$4.44	$4.03	$3.79	$3.91	$4.12
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Large Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Standalone Retail	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	7.5	7.8	7.7	8.7	9.0	8.1
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Scalar Ratio, Limit = 22.08[(a)]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	(58)	(63)	(61)	(67)	(68)	(64)
Large Office	(40)	(39)	(44)	(50)	(46)	(45)
Standalone Retail	(17)	(27)	(34)	(31)	(33)	(28)
Primary School	(41)	(38)	(36)	(45)	(45)	(42)
Small Hotel	(97)	(103)	(101)	(115)	(121)	(108)
Mid-rise Apartment	(41)	(47)	(215)	(776)	(1,137)	(507)
Weighted Total	(39)	(43)	(110)	(328)	(403)	(203)

(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 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

AFUE	Annual Fuel Utilization Efficiency
AHRI	Air Conditioning, Heating and Refrigeration Institute
AHU	air handling unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASRAC	Appliance Standards and Rulemaking Federal Advisory Committee
BECP	Building Energy Codes Program
Btu	British thermal units
Btu/h	British thermal units per hour
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CFI	central fan integrated
CFM	cubic feet per minute
CHW	chilled water
COP	coefficient of performance
CRAC	computer room air conditioners
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
DX	direct expansion
EIA	Energy Information Administration
EMS	Energy Management System
ERR	enthalpy recovery ratio
ERV	energy recovery ventilator
ESC	Envelope Subcommittee (90.1 SSPC)
Et	thermal efficiency
FEMP	Federal Energy Management Program
GWP	Global Warming Potential
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
LCCA	life-cycle cost analysis
lm	lumens
LPD	lighting power density
LSC	Lighting Subcommittee (SSPC 90.1)
MEP	mechanical, electrical and plumbing

NC^3	National Commercial Construction Characteristics
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
PTAC	packaged terminal air conditioner
SAT	supply air temperature
SCOP	seasonal coefficient of performance
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
VAV	variable air volume
VSD	variable speed drive
VT	visible transmission
w.c.	water column
WSHP	water source heat pump
WWR	window-to-wall ratio

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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 baseline minimum requirements for energy-efficient design and construction 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 90.1-2019, Energy Standard for Buildings Except Low-Rise Residential Buildings*, the national model energy standard for commercial buildings.[1] The 2016 and 2019 editions of Standard 90.1 are the primary focus of this report (ASHRAE 2016, 2019). These standards are referred to as 90.1-2016 and 90.1-2019 respectively, or as Standard 90.1 when referring to multiple editions of the standard.

DOE provides technical assistance and supports the incremental upgrading of the model energy codes, and states' adoption and implementation of upgraded 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 upgrading 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 requests that PNNL analyze the cost-effectiveness of 90.1-2019 as a whole compared to

[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.

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 90.1-2019, compared to the previous 2016 edition, is the subject of this current analysis and report.

1.1 Supporting State Energy Code Adoption

DOE is 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 at various stages of incorporating the latest edition of Standard 90.1 or its equivalent into their building codes. Figure 1.1 shows the current—as of June 2020—applicable energy standard or code that most closely matches the state's regulation (DOE 2020a).

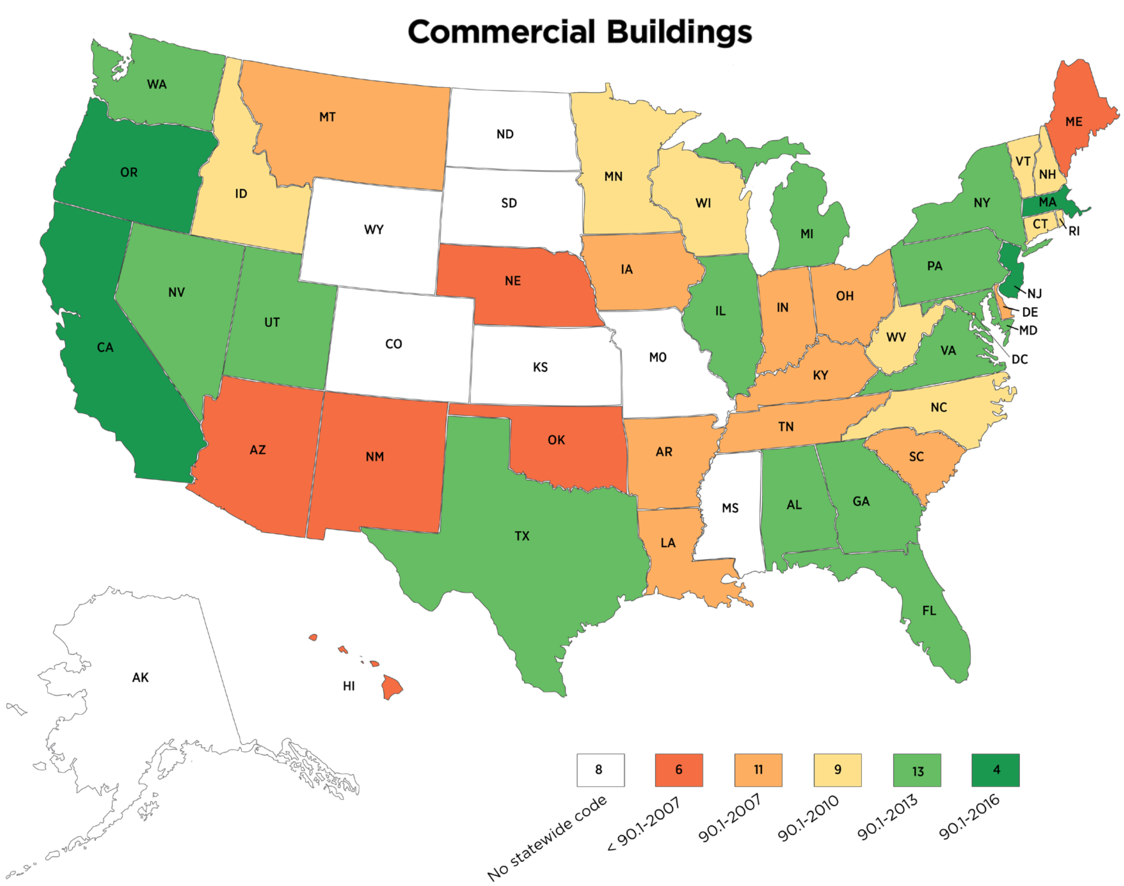


Figure 1.1. Commercial Building Energy Code Adoption Status (June 2020)

1.2 Contents of the Report

This report documents the approach and results for PNNL's analysis of the cost-effectiveness of 90.1-2019 compared to 90.1-2016. 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 and 90.1-2016 (Thornton et al. 2013; Hart et al. 2015, 2020). The cost-effectiveness analysis began with the energy savings analysis for development of 90.1-2019, 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 five 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. 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 2018, 2020).

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 90.1-2016 to 90.1-2019. 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 90.1-2019* (PNNL 2020). The cost-effectiveness analysis methodology and results are presented in Section 5.0.

The report has two appendixes. Appendix A includes a summary of incremental cost estimate data. Appendix B includes the energy analysis results for 90.1-2019 compared to 90.1-2016.

[1] Download from http://www.energycodes.gov/development/commercial/90.1_models.

2.0 Building Prototypes and Climate Locations

As part of its technical support to SSPC 90.1, PNNL quantified the energy savings of 90.1-2019 compared to 90.1-2016. 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 (DOE 2020b). 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 2.2
- 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**
	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.

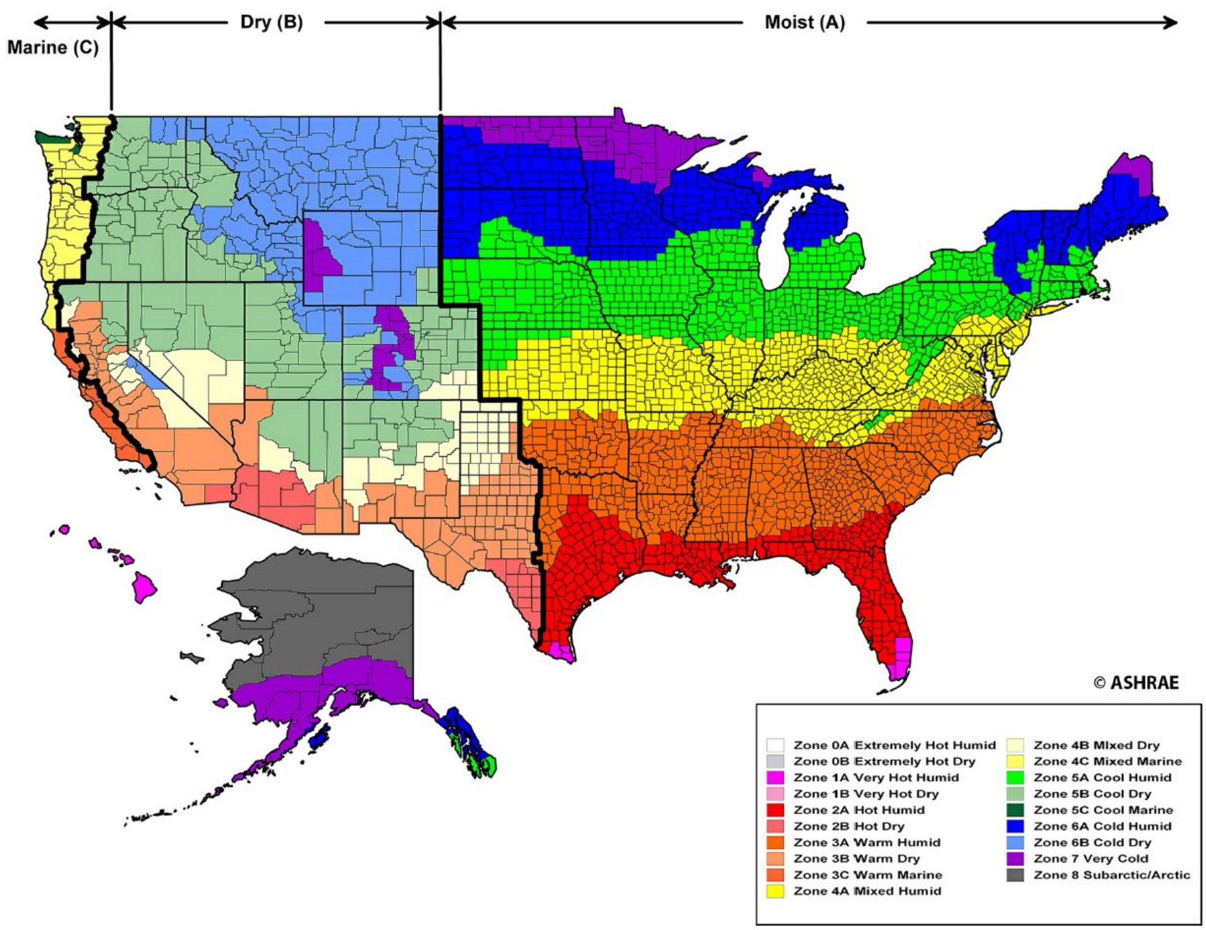


Figure 2.1. United States Climate Zone Map

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. 2011). The full climate location list was approved by the SSPC 90.1 for setting the criteria for 90.1-2016 and are different

[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.

from those used in previous analyses. These new climate locations are also consistent with those used in the determination of energy savings of Standard 90.1-2019 (DOE 2020b).

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	Honolulu, Hawaii	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.

Table 2.3. Overview of Six Selected Prototypes

			HVAC Systems		
Building Prototype	Floor area (ft²)	Number of Floors	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.

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

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 90.1-2019. 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 90.1-2016 Addenda

Of the 88 addenda included in 90.1-2019, 22 were considered to have quantifiable energy savings represented in the prototypes. Of those, 17 were modeled in DOE's 90.1-2019 determination and are described in more detail in the report documenting the determination quantitative analysis (DOE 2020b). The five that were not modeled for the determination analysis mirror federal appliance standards regulations. However, these five addenda and their associated savings are included in the cost-effectiveness analysis because they do have the potential to impact cost. The remaining 66 addenda do not have quantifiable savings, had no savings, do not directly affect building energy usage, or could not be quantified during the determination quantitative analysis.

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. Of the 22 addenda with quantified savings, 19 were modeled in the six prototypes being used for the cost estimate. 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.

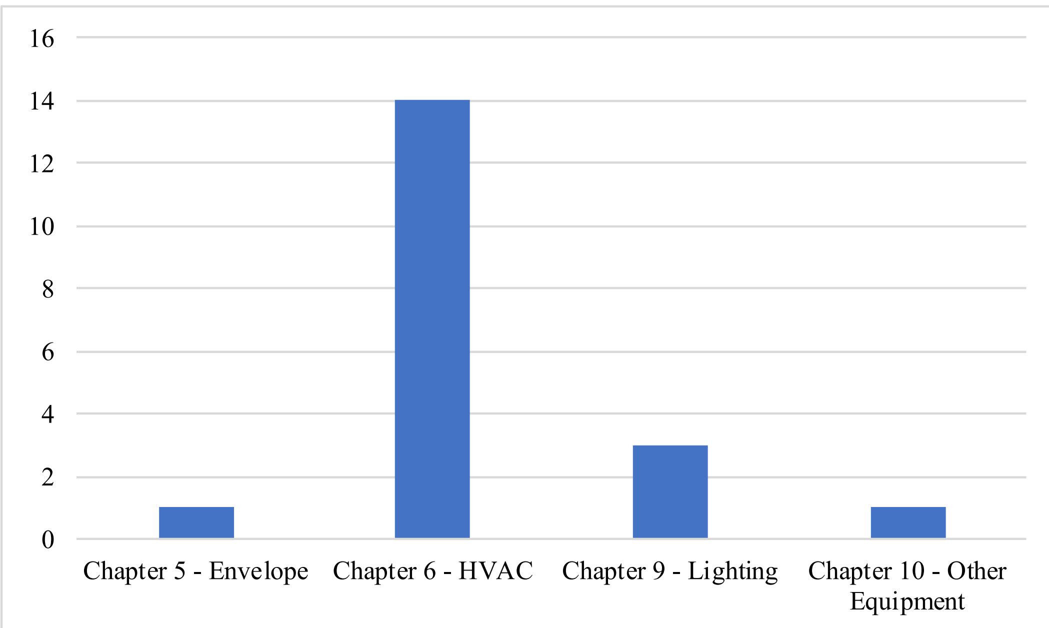


Figure 3.1. Quantity of Addenda Included in Analysis by Standard 90.1 Chapter

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 90.1-16, followed by the letter identifier of the addendum (e.g., 90.1-16bo). In text it may be referred to by just the letter designation: *bo*.

Table 3.1. Addenda Included in Cost-Effectiveness Analysis

90.1 Addenda and Other Cost Items	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
Standard 90.1 Chapter 5 - Envelope							
90.1-16aw	Revises prescriptive fenestration U and SHGC requirements and makes them material neutral	X	X	X	X	X	X
Standard 90.1 Chapter 6 – Heating, Ventilating, and Air Conditioning							
90.1-16a	Changes term "ventilation air" to "outdoor air" in multiple locations. Revises tables and footnotes. Clarifies requirements for economizer return dampers.			X		X	
90.1-16g	Provides definition of "occupied-standby mode" and adds new ventilation air requirements for zones serving rooms in occupied-standby mode	X	X		X	X	X
90.1-16h	Clarifies that exhaust air energy recovery systems should be sized to meet both heating and cooling design conditions unless one mode is not exempted by existing exceptions						X
90.1-16k	Revises definition of networked guest room control system and aligns HVAC and lighting time-out periods					X	
90.1-16ap	Revises supply air temperature reset controls		X		X		
90.1-16au,cm,co	Eliminates the requirement that zones with DDC have flow rates ≤ 20% of zone design peak flow rate. Allows Simplified Ventilation Procedure from Standard 62.1.		X		X		
90.1-16ay	Provides separate requirements for nontransient dwelling unit exhaust air energy recovery						X
90.1-16be	Revises computer room air conditioner (CRAC) requirements to clarify these are for floor mounted units and adds a new table for ceiling mounted units		X				
90.1-16bo	Adds definition of Standby Power Mode Consumption. Increases furnace efficiency requirements.	X		X	X	X	X
90.1-16bq	Adds dry cooler efficiency requirements and increases efficiency requirements for evaporative condensors		X				
90.1-16br	Combines commercial refrigerator and freezer table with refrigerated casework table. Better efficiency requirements.				X		
90.1-16cn	Cleans up outdated language regarding walk-in cooler and walk-in freezer requirements, and makes the requirements consistent with current and future federal regulations				X		
Standard 90.1 Chapter 9 - Lighting							
90.1-16bb	Changes interior lighting power density (LPD) requirements for many space types	X	X	X	X	X	X
90.1-16cg	Revises LPDs using the Building Area Method	X	X	X	X	X	X
90.1-16cw	Changes the daylight responsive requirements from continuous dimming or stepped control to continuous dimming required for all spaces	X	X	X	X	X	
Standard 90.1 Chapter 10 – Other Equipment							
90.1-16an	Implements 2020 federal clean water pump requirements		X		X		

3.2 Addenda Not Included in Cost-Effectiveness Analysis

The remaining addenda with quantifiable energy savings affect prototypes not included in those selected for the cost-effectiveness analysis or not applicable to the subset of prototypes modeled. These are listed in Table 3.2 along with the reason for non-inclusion.

Table 3.2. Addenda Not Included in Cost-Effectiveness Analysis

90.1 Addenda	Description	Reason
90.1-16v	Adds a new requirement for heat recovery for space conditioning for in-patient hospitals	Does not apply to any of the six modeled prototypes
90.1-16bd	Adds new chiller table for heat pump and heat recovery chillers	Does not apply to any of the six modeled prototypes
90.1-16bp	Adds a new table to specify DOE covered residential water boiler efficiency requirements. Adds standby mode and improves efficiency.	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 90.1-2016 and 90.1-2019. 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 be in the 2020 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 (DOE 2020b). 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 90.1-2019* (PNNL 2020).

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* 2020a,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 2020, RS Means 2018, 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 2020 values by applying inflation factors developed using RS Means cost handbooks from 2012, 2014, 2018, and 2020 (*RS Means* 2012a,b,c; 2014a,b,c; 2018a,b,c; 2020a,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 2020).

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 2020*.
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 2020* 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.
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 2020 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 2020* 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.
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* 2018c).

(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 2020) 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
   a. Interior lighting power density (LPD)
   b. Interior lighting controls
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 90.1-2016 and 90.1-2019 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 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 90.1-2016 and the advanced case is Standard 90.1-2019. In some instances, a new addendum identifies the need for a change to baseline 2016 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 improvements to reduce fenestration heat loss and heat gain.

4.2.1.1 Addendum *aw*: Fenestration U and SHGC

Addendum *aw* revises the prescriptive U-factor and solar heat gain coefficient (SHGC) requirements in Tables 5.5-0 through 5.5-8 for vertical fenestrations and skylights. It also modifies the vertical fenestration categories from “Nonmetal,” “Metal fixed,” “Metal operable,” and “Metal entrance door” to “Fixed,” “Operable,” and “Entrance Door.” The adjusted categorization is independent of frame material type, provides increased consistency with the International Energy Conservation Code (IECC), and helps facilitate alignment of 90.1 and IECC criteria. The revised SHGC values for operable and vertical fenestrations are slightly lower than those for fixed windows, which is to acknowledge the fact that operable ones have a larger frame-to-glass ratio and therefore lower SHGC values with the same glazing type. The addendum generally reduces U-factor for fixed metal framed windows; however; it also increases the U-factor for non-metal framed windows. Since the predominant framing is metal in commercial construction, the average U-factor is reduced, in turn reducing heat loss and gain for commercial buildings, which provides an overall reduction in both annual and peak heating and cooling loads. SHGC is slightly reduced overall, contributing further to a reduction in cooling load and energy use.

Energy Modeling Strategy

All the prototypes have vertical fenestration and two have skylights (Standalone Retail and Primary School). These are all modeled using U-factor and SHGC inputs to Window Material – Simple Glazing System objects in EnergyPlus. To capture the window requirements with different categorizations introduced by this addendum, weighting factors of different window categories as shown in Table 4.3 were used to calculate weighted U-factor and SHGC values for each prototype based on recent market data from Ducker.[1] The weighting factors are slightly updated from those used in the previous analyses (Thornton et al. 2011). Although the required minimum ratio of visible transmittance (VT) to SHGC (VT/SHGC) is not changed by the addendum, the new SHGC values resulted in different VT inputs in the prototypes.

Table 4.3. Weighting Factors of Different Windows Categorized in 90.1-2016 and 90.1-2019

	Vertical fenestration categories in 90.1-2016			Vertical fenestration categories in 90.1-2019	
Building Prototype	Nonmetal	Metal - Fixed	Metal - Operable	Fixed	Operable
Small Office	2.5%	95.7%	1.8%	96.9%	3.1%
Large Office	2.5%	95.7%	1.8%	96.9%	3.1%
Stand-alone Retail	2.6%	96.2%	1.2%	97.8%	2.2%
Primary School	7.5%	86.6%	5.8%	89.8%	10.2%
Small Hotel	5.8%	89.7%	4.5%	92.0%	8.0%
Mid-Rise Apartment	17.3%	68.7%	14.0%	75.4%	24.6%

Incremental Cost Impact

The incremental costs are the same as those used for the 90.1-2016 analysis, with costs brought forward to 2020 dollars. Industry stakeholders reviewed these costs with their members. Some of the general feedback was that these costs were still reasonable when used as incremental costs. For some of the newer technologies where one would expect costs to decrease with increasing volume and market penetration, those potential decreases were offset by increases in material and shipping costs. Thus, the workgroup decided to stay with the same incremental costs as the prior analysis. This addendum will generally result in a reduction in peak heating and cooling loads, reducing the overall size of heating and cooling systems. Therefore, the cost for this addendum includes incremental increases associated with reduced U-factors and SHGC along with incremental reductions in HVAC system sizing.

[1] Detailed market data from https://www.ducker.com/ were processed by SSPC 90.1 Envelope Subcommittee.

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 90.1-2016 and 90.1-2019. 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 2020 costs by applying inflation adjustment factors that were calculated by comparing corresponding items in prior versions of *RS Means* to *RS Means 2020*.

4.2.2.1 HVAC System and Plant Equipment Capacity Changes

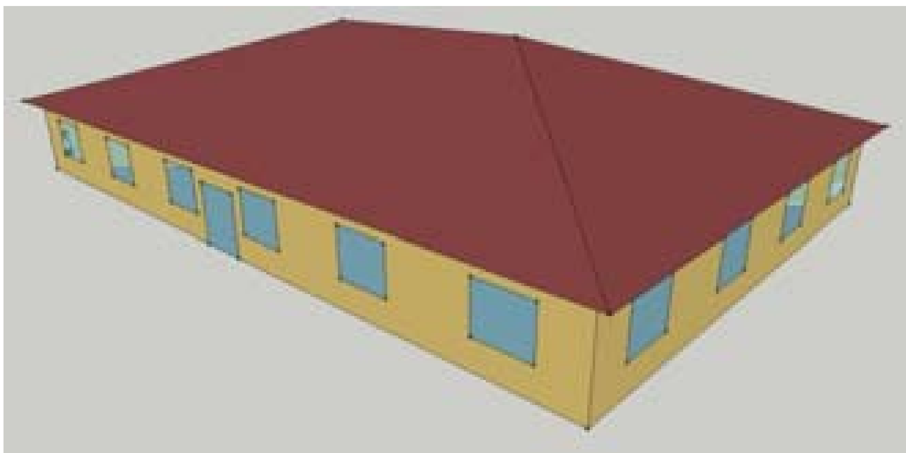
Costs were estimated to address changes in HVAC system and plant equipment capacity between the 90.1-2016 and 90.1-2019 prototype models. HVAC equipment capacity changes result from reductions in heating and cooling loads due to changes in fenestration U-factor and SHGC requirements and lighting power, 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 90.1-2016 to 90.1-2019, the same costs were used but were brought forward to 2020 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, RS Means 2014,* and *RS Means 2018* with those in *RS Means 2020*. Labor costs were updated by using current labor crew rates from *RS Means 2020*.

Many of the HVAC capacity-related equipment costs in the component cost worksheet are the same for 90.1-2016 and 90.1-2019 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 90.1-2016 and 90.1-2019 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 2020 by applying an inflation factor. Most of the incremental differences from 90.1-2016 to 90.1-2019 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 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 2020 costs. More detailed costs are shown in the associated spreadsheet (PNNL 2020). 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 2020 with separate inflation factors for material and labor.



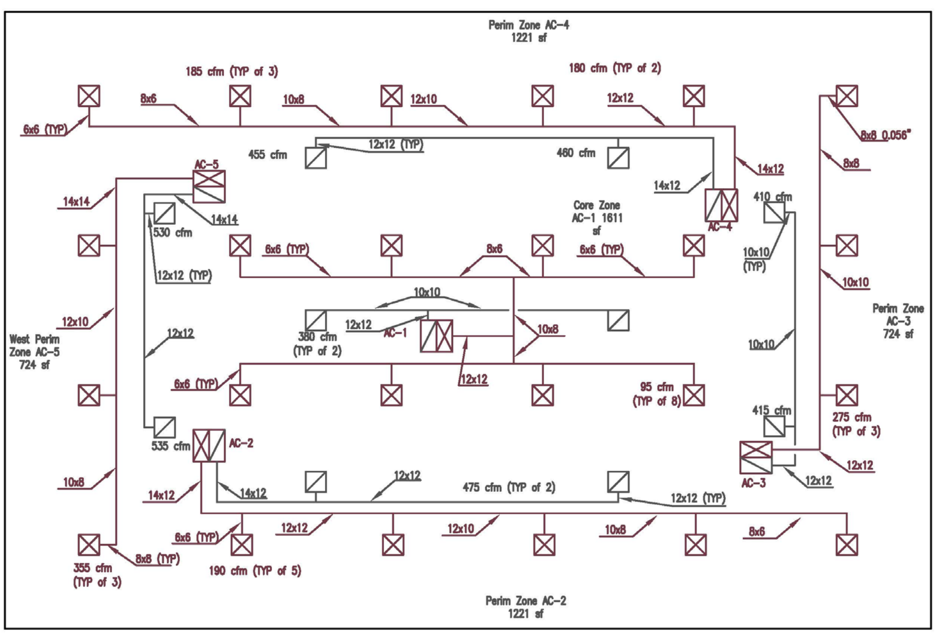


Figure 4.1. Small Office Air Distribution System

Table 4.4. Small Office Duct Details for One HVAC System

Description	Multiplier	Depth (in.)	Width (in.)	Area (ft^2)	Duct Length (ft)	Depth + Width	Duct Weight (lb)	Item Qty
Supply Side								
12x12 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
10x8 Duct	2	10	8	0.56	4	18	34.7	
SR5-14 Dovetail WYE	1	8	6	0.33		14		20.9
8x6 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		
6x6 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 Θ = 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
10x10 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
10x10 Duct	2	10	10	0.69	2	20	19.4	
Damper Θ = 0°, 10x10	2							2.0
Grille, NC 30 10"x10"	2							2.0
						Duct Weight	631.26	

4.2.2.2 Addendum *a*: Outdoor and Return Dampers

Addendum a makes a few clarifying changes such as modifying the term “ventilation air” to “outdoor air.” It also improves energy efficiency by requiring return dampers to meet Table 6.4.3.4.3, which means a lower leakage rate from return air to supply air than Standard 90.1-2016. This improves economizer operation by increasing the outside air entering the system during economizer mode, as leaky return air dampers result in mixing of some return air back into the mixed air, even when dampers are fully closed. In addition, an exception is added to Section 6.4.3.4.2. Without this exception, a system with continuous ventilation intake needs to have an outdoor air damper, which creates a pressure drop. With the exception, such a system without the outdoor air damper would have lower pressure drop and therefore less fan energy consumption.

Energy Modeling Strategy

When air-side economizers are modeled in single-zone unitary systems in the baseline prototypes, their maximum fraction of outdoor over design supply air is modeled to be 70% based on field measurements for unitary systems (Davis et al. 2002), which limits the maximum outdoor airflow during economizer operation. With the lower leakage damper required by the addendum, the improvement in economizer operation is modeled as an increase in the maximum outdoor air fraction from 70% to 75%, which is approximated based on the relationship between damper leakage rates and opening positions of sample products. The savings were only captured for single-zone systems with economizers. In some systems, the design outdoor airflow fraction is already higher than 70% due to zone exhaust or ventilation needs; therefore, the impacts of the addendum on these systems are not modeled. Similarly, for multiple-zone variable air volume (VAV) systems, the modeled maximum outdoor air fraction is already 100%; therefore, the impacts on these are not captured.

Incremental Cost Impact

Incremental material costs for low leakage return air dampers were obtained from a major damper manufacturer. Labor costs were obtained from *RS Means*.

4.2.2.3 Addendum *g*: Occupied Standby Controls

Standard 90.1-2016 Section 9.4.1.1 (see Table 9.6.1) already requires occupancy sensors for lighting control in certain spaces but some types of occupancy status are not required to control HVAC systems except for hotel/motel guest rooms (see Section 6.3.3.3.5). Standard 62.1-2016, referenced by Standard 90.1-2019, introduced a new definition for occupied-standby mode: when a zone is scheduled to be occupied and an occupant sensor indicates zero population within the zone. It now allows outside air ventilation to be shut off in occupied-standby mode for many occupancy categories including office and conference/meeting spaces (see Note H in Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone in Standard 62.1-2016). Addendum g requires zones, that already have occupancy sensors and qualify for the occupied-standby mode, to automatically enter an occupied standby mode, during which the zones should have a heating and cooling thermostat setback of 1°F and should completely shut off HVAC supply air within the deadband.

Addendum g provides energy savings for VAV systems by significantly reducing deadband airflow and thereby reducing fan, cooling, and reheat energy during the occupied-standby mode. Before this addendum, the full minimum amount of air was delivered to empty zones during the occupied-standby mode, resulting in excessive reheat to maintain temperature. Energy is saved by reducing reheat, primary air cooling, and fan use for unneeded airflow. Single-zone, dedicated outdoor air systems (DOAS) and other HVAC systems experience similar savings through shut off of airflow to temporarily unoccupied spaces unless there is a demand for thermal conditioning.

Energy Modeling Strategy

Prototype models were modified to include "occupied-standby" periods for some of the spaces as needed. Occupied-standby periods correspond to times during normal building occupancy when a space is unoccupied. This was achieved by modifying the space occupancy schedules. In general, around two of the normally occupied hours per day are now unoccupied as a result of the new occupied-standby schedule. The ventilation to the space completely shuts off during these periods along with a 1°F temperature setup/setback for the thermostat schedules. The fan operation for single-zone systems was changed from constant to cycling. There are similar changes to multi-zone systems. During occupied-standby periods, the fan operates only as needed to meet the heating and cooling loads. The minimum VAV box damper positions were modeled using hourly schedule fractions and the dampers were allowed to fully close when not heating or cooling.

Incremental Cost Impact

There is a labor cost but no incremental material cost to implement this addendum. The labor cost includes programming to interface the occupancy sensor to the HVAC system. Although once the programming becomes standard practice, the programing cost goes away. The labor is estimated at 15 minutes per conditioned zone and the labor cost is from *RS Means*.

4.2.2.4 Addenda *h* and *ay*: ERV Sizing Requirements + Residential Energy Recovery

Standard 90.1-2016 already has requirements for exhaust air energy recovery for ventilation systems based on the design supply fan airflow rate and the ratio of outdoor airflow rate to fan supply airflow rate at design conditions. Dwelling units are subject to the criteria in Table 6.5.6.1-2 Exhaust Air Energy Recovery Requirements for Ventilation Systems Operating Greater than or Equal to 8000 Hours per Year. There has been confusion as to whether heating or cooling design should be used for sizing an energy recovery ventilator (ERV).

Addendum h clarifies that the ERV equipment should meet the greater enthalpy recovery ratio (ERR) of either heating or cooling, unless one mode is specifically excluded for the climate zone by exception. This addendum is primarily a clarification.

Addendum *ay* provides new requirements for the nontransient dwelling unit (apartment) exhaust air energy recovery that are distinct from other commercial buildings. Dwelling unit energy recovery uses different equipment than general commercial spaces, and has a different cost-effectiveness, so the addenda resulted in energy recovery being required in more climate zones than under the commercial requirements. Based on the SSPC 90.1 analysis, climate zone 3C is completely exempt, while the energy recovery device selection is based on heating only in climate zones 4 through 8 and cooling only in climate zones 0 through 2. Climate zones 3A and 3B must meet both heating and cooling requirements. Smaller apartments, less than 500 square feet, are exempt in climate zones 0 through 3 and 4C and 5C.

Exhaust air energy recovery provides energy savings by pre-heating or pre-cooling incoming outside air for ventilation using the heat energy in the exhaust air stream. Pre-treatment of the outside air reduces the energy use by the heating and cooling systems. While there is some increase in fan energy use, this is partially offset by reduced exhaust fan operation for ventilation. Overall, in the climate zones where it is required, exhaust air energy recovery will save more heating and cooling energy than the fan energy increase. The addendum specifies an enthalpy recovery ratio of at least 50% at cooling design condition and at least 60% at heating design condition. There are several exceptions to these requirements. The addendum increases the number of climate zones and situations where exhaust air energy recovery is required in apartments, dormitories, and residential institutions.

Energy Modeling Strategy

While Addendum *ay* specifies the ERR requirements for ERVs, the energy simulations require inputs in terms of heat recovery effectiveness. In order to convert the ERR values to effectiveness, PNNL collected representative data from equipment manufacturers for which both ERR and effectiveness are available. One complication in the translation of the ERR requirements of Addendum *ay* to effectiveness values for simulation is that the standard specifies the ERR values at the local design condition rather than at an Air Conditioning, Heating and Refrigeration Institute (AHRI) standard rating condition. For a given design ERR, the required heat exchanger effectiveness will vary from one climate to another. In order to handle this climate variation requirement, the actual ERR delivered by the same equipment was calculated in heating and cooling across climate zones, and the corresponding rated ERR values were determined for use as the reference point for calculating the heat exchanger effectiveness values.

The typical fan power of the units is also needed to characterize the performance of the ERVs. A review of manufacturers' literature was conducted to determine an appropriate value for this parameter. This yielded data for 18 different systems of varying capacity. For the typical apartment ventilation rate of 55 cubic feet per minute (cfm) per apartment, the corresponding fan power would be 65 watts per unit.

Incremental Cost Impact

Material and labor costs were developed by the proponents of this addendum and reviewed by the SSPC 90.1 Mechanical Subcommittee. For the cost analysis, the base case is a central fan integrated (CFI) ventilation supply air system, which is a common low-cost supply ventilation system. The enhanced case is an ERV installed in each apartment with fan efficacy of 1.2 cfm/W (minimum setting in IECC for residential ERVs). This system displaces two bathroom exhaust fans, using the ERV exhaust fans for this function. There is no defrost, economizing, or bypass. An additional offset to the cost is an average reduction in heating and cooling unit sizing that reduces the cost of apartment heating and cooling units.

4.2.2.5 Addendum *k*: Hotel/Motel HVAC Guest Room Controls

Standard 90.1-2016 already requires hotel/motel guest rooms to have automatic setback thermostat setpoint and shut off ventilation for rooms that are either rented and unoccupied or unrented and unoccupied. Addendum *k* clarifies the language by calling out the two modes with the same intent and the clarification does not have quantifiable energy impacts. The addendum saves more energy by reducing the time-out period for unoccupied indication from 30 minutes to 20 minutes. Consequently, there will be 10 minutes more per cycle with reduced ventilation and setback heating and cooling, reducing energy use.

Energy Modeling Strategy

The baseline Small Hotel prototype was already modeled to meet the control requirements through thermostat and ventilation schedules. The schedules in their advanced models were slightly adjusted to capture the added savings from the reduced time-out period.

Incremental Cost Impact

No cost impact as no additional materials or labor are needed.

4.2.2.6 Addendum *ap*: SAT Reset

HVAC systems with simultaneous heating and cooling (typically multiple-zone VAV systems) were previously required to provide supply air temperature (SAT) reset except in climate zones 0A through 3A. In these climate zones, several approaches can successfully dehumidify the outside air while still providing SAT reset and reducing reheat energy use. Addendum *ap* extends the requirement for SAT reset to the warm and humid climate zones where it was previously excepted. The dehumidification requirements of addendum *ap* can be met with either a separate outside air cooling coil or alternative approaches, including bypassing return air around the cooling coil, a dedicated outside air system, or series heat recovery.

Units smaller than 3,000 cfm are excepted from SAT reset in climate zones 0A, 1A and 3A, with units smaller than 10,000 cfm excepted in 2A. There are also requirements that the system is designed to allow simultaneous SAT reset and dehumidification with one of the strategies discussed above.

Supply air temperature reset saves significant heating energy in VAV reheat systems that require minimum airflow for ventilation. That savings is higher in northern climate zones than in climate zones 0A through 3A, which were previously excepted because outside air dehumidification (typically performed with a low dewpoint on the supply air) is required much of the year. Dehumidification can be achieved more efficiently by separately dehumidifying the outside air, as it reduces the total volume of air that must be cooled, significantly reducing cooling energy use in all the warm and humid climate zones and allowing SAT reset that reduces reheat energy use.

Energy Modeling Strategy

For 90.1-2019, addendum *ap* requires SAT reset to be used in climate zones 0A, 1A, 2A, and 3A even if there is dehumidification control. Therefore, all air VAV multizone air handling units (AHUs) in the prototypes in these warm and humid climates should have SAT reset.

An informative note in addendum *ap* suggests having a return air bypass or separate outside air cooling coil controlled by the zone humidistat to dehumidify the outside air stream will meet the requirement that dehumidification and SAT reset be able to function simultaneously without depressing the dewpoint temperature of the full supply airstream to provide dehumidification. After reviewing the change of zone humidity levels from no SAT reset to standard SAT reset, PNNL found that for the prototypes impacted by this addendum the humidity level was within an acceptable range after applying the regular SAT reset and that appropriate energy savings are achieved in the model.

Incremental Cost Impact

Addendum *ap* requires that when both SAT reset and dehumidification are used, that provisions are made to focus the dehumidification on the outside air stream, either with a separate outside air coil for dehumidification or controlled bypass of return air around the cooling coil. Costs were based on the bypass approach. Material and labor costs were obtained from *RS Means* and include the following:

- pair of modulating volume dampers with damper actuators
- bypass ductwork for return air to reduce dehumidification cooling use
- ductwork insulation
- associated controls.

4.2.2.7 Addenda *au*, *cm*, and *co*: DDC VAV Minimum Damper

Addendum *co* reflects the periodic update of Standard 90.1 normative references. It updates many references with new effective dates and adds some new references. One of them (i.e., the Addendum *f* to Standard 62.1-2016, Ventilation for Acceptable Indoor Air Quality), in particular, creates a “Simplified Procedure” to determine system ventilation efficiency. Addenda *au* and *cm* take advantage of the changes in Standard 62.1 to reduce the minimum airflow required in VAV boxes and outdoor air intake of the AHUs; hence, these reduce energy used to condition outdoor air intake and reheat of cooled primary air.

Addenda *au* and *cm* refer to this new minimum primary airflow rate to replace the provision in Standard 90.1 that allows VAV box minimum setpoints to be 20% of the design supply air rate. Outdoor air rates for zones with moderate occupancy density, such as offices, are generally much lower than 20% of the design supply air rate, but designers often need a higher percentage or an oversized VAV box when they follow the system ventilation efficiency specified in Standard 62.1 and its Normative Appendix A Multiple-zone System Ventilation Efficiency. With these addenda, Appendix A in Standard 62.1 becomes an alternative to the Simplified Procedure, by which designers no longer need to calculate what minimum rates are required using the multiple spaces equations in Appendix A. They now can set the minimum primary airflow to be 1.5 times the ventilation zone airflow. The system ventilation efficiency from the Simplified Procedure is generally higher than that calculated using Appendix A, which means the outdoor air intake through the AHU is less. Moreover, using percentages to determine minimums is problematic because VAV boxes are almost always oversized due to conservative load assumptions for occupants, lights, plug loads, etc. It is not unusual for boxes to be sized three or more times larger than they need to be, as was found in ASHRAE RP-1515 "Thermal and air quality acceptability in buildings that reduce energy by reducing minimum airflow from overhead diffusers." (Arens et al. 2015) RP-1515 showed that even if the minimums were set to 20% instead of 30%, excess minimum air would have been supplied due to the oversized cooling maximum box sizing, wasting fan energy, reheat energy, and cooling energy.

In summary, Addenda *au* and *cm* save energy by 1) reducing outdoor air intake at the central system; and 2) reducing the actual airflow minimums in VAV boxes using the cfm-based approach rather than percentage-based minimums previously used in 90.1. When the minimum airflow in VAV boxes is reduced, less air volume needs to be reheated, saving both cooling and heating energy.

Energy Modeling Strategy

Two of the prototypes used in this analysis include multiple-zone VAV systems (i.e., Large Office and Primary School). Section 2.2.6 in the PNNL report *Enhancements to ASHRAE Standard 90.1 Prototype Building Models* (Goel et al. 2014) describes the modeling strategy used in the 2016 prototypes to calculate system ventilation efficiency using Appendix A of Standard 62.1-2013. Where the efficiency is lower than 0.6, VAV box minimums of the critical zones are adjusted from 20% to be higher values to reach a target efficiency of 0.6. Then, the design outdoor air intake is determined using this efficiency and can be dynamically reset during the operation using the dynamic efficiency reflecting the zone loads at each time step. For VAV systems serving low occupancy density zones, the VAV box minimums remain at 20%.

In the 2019 prototypes, the VAV box minimum, system ventilation efficiency, and design and operation outdoor air intake are based on different calculations as required by Addenda *au* and *cm* and the referenced Addendum f to Standard 62.1-2016. The VAV box minimum ($V_{pz\text{-}min}$) is changed to

$$V_{pz\text{-}min} = V_{oz} \times 1.5$$

Where,

$V_{pz\text{-}min}$ is minimum primary airflow, and

V_{oz} is ventilation zone airflow.

The Simplified Procedure allows the system ventilation efficiency and the corresponding outdoor air intake flow to be determined in accordance with the following equations

$$E_v = 0.88 * D + 0.22 \text{ for } D<0.60$$

$$E_v = 0.75 \text{ for } D \geqslant 0.60$$

$$V_{ot} = V_{ou} / E_v$$

Where,

E_v is the system ventilation efficiency, and

D is the occupancy diversity ratio,

V_{ot} is the design outdoor air intake flow

V_{ou} is the uncorrected outdoor air intake.

To simplify the calculation, we assumed D always to be greater than 0.6 for all VAV systems in the prototypes. The change in E_v from 0.6 to 0.75 results in a significant reduction in the design outdoor air intake flow. Although both editions require Multiple-Zone VAV System Ventilation Optimization Control, also known as dynamic ventilation reset, in Section 6.5.3.3 of Standard 90.1, the design outdoor air intake flow serves a maximum outdoor air, which leads to energy reduction. The dynamic ventilation reset can be modeled using native EnergyPlus controls, which are able to follow the Normative Appendix A Multiple-zone System Ventilation Efficiency in Standard 62.1-2016 during the operational hours. PNNL consulted with the SSPC 90.1 Mechanical Subcommittee experts and clarified that Appendix A is intended to be used during building operation for 90.1-2019. The reduced design outdoor air intake flow V_{ot} calculated with the Simplified Procedure should be used as the maximum outside airflow for the dynamic ventilation reset, except for economizer mode, and the maximum is implemented in the prototypes through an EnergyPlus energy management system program.

Incremental Cost Impact

This addendum is not expected to increase the cost of construction. The requirement is simply for existing VAV terminal boxes to be set with a different dead band primary air minimum for dual maximum boxes. In some cases, the new simplified minimum may be below the typical VAV box sensor accuracy; however, the addendum allows the maximum deadband airflow to be met on an average basis—in accordance with Standard 62.1, Section 6.2.6.2 Short-Term Conditions—by cycling between a closed damper and a higher minimum that can be sensed by a standard sensor. This means that a higher cost or more accurate sensor is not required, as the average approach allows low minimum airflows to be met with time-limited higher airflows within the sensing range of a standard sensor. However, there is a cost reduction as any required energy recovery units can be downsized due to the lower outdoor airflow.

4.2.2.8 Addendum *be*: CRAC Unit Efficiencies

Addendum *be* clarifies that the computer room air conditioners (CRAC) listed in Table 6.8.1-11 are floor mounted computer room units. Efficiency requirements were modified to align with current industry levels. The addendum also adds a new Table 6.8.1-19 that covers small ceiling mounted computer room units.

Energy Modeling Strategy

Computer rooms and IT closets were added to the Large Office prototype as part of an enhancement in 2014 (Goel et al. 2014). CRAC units were modeled as water source heat pumps (WSHP) to simulate a water cooled air conditioner during its debut into the prototypes and the modeled efficiency was based on Standard 90.1-2010 efficiency requirements. Seasonal coefficient of performance (SCOP) was converted to coefficient of performance (COP). The efficiency inputs were also adjusted to match the WSHP configurations used in EnergyPlus.

The CRAC unit efficiency requirements were introduced in 90.1-2010 and were updated in 2013 and 2016; however, these interim changes were not included in the prior analysis because there was pending federal rulemaking. The analysis of Addendum *be* includes the change to the 90.1-2019 efficiencies. The baseline and improved COP for the CRAC units in the basement computer rooms and IT closets are based on typical equipment sizes used in data centers, even though the EnergyPlus model thermal zoning grouped areas that would be served by multiple CRAC units into a large thermal zone and modeled them as one unit.

This addendum saves energy by reducing the compressor energy needed to transfer heat from the data center area and reject it outside. Because there is less compressor heat to reject, there is also a reduction in the fan use in the dry cooler that provides heat rejection for the water cooled CRAC units.

Table 4.5 shows the efficiency of the units by code year and location in the building.

Table 4.5. Efficiency of CRAC Units by Code Year and Location in Building

Location	Cooling Capacity	90.1-2016			90.1-2019		
		CRAC SCOP	WSHP EER	Eplus COP	CRAC SCOP	WSHP EER	Eplus COP
Datacenter Basement	20 tons	2.50	10.29	3.562	2.73	11.24	3.878
Datacenter All Other Floors	3.5 tons	2.60	10.71	3.702	2.82	11.62	4.005

Incremental Cost Impact

Material costs for different efficiency levels were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.9 Addendum *bo*: Table 6.8.1.5 Furnace Efficiency

Addendum *bo* increases efficiency requirements for commercial gas-fired and oil-fired furnaces. The addendum also increases efficiency requirements for residential (consumer) gas and oil furnaces to match DOE levels and adds a new Table F-4 in "Informative Appendix F for Residential Warm Air Furnace" requirements for products sold in the United States.

The following changes are included in this addendum:

1. The efficiency of >225,000 Btu/h gas-fired furnaces was increased from 80% thermal efficiency to 81% and for oil fired from 81% to 82%. The effective date for these changes is 1/1/2023.
2. The efficiency of <225,000 Btu/h gas-fired furnaces was increased from 78% AFUE to 80% AFUE for non-weatherized units and to 81% for weatherized units.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=31

3. The efficiency of <225,000 Btu/h oil-fired furnaces was increased from 78% AFUE to 83% AFUE for non-weatherized units and is unchanged for weatherized units.
4. Efficiency requirements were added for <225,000 Btu/h electric furnaces.
5. Requirements were added for <225,000 Btu/h standby power mode consumption and off mode power consumption.
6. To be consistent with other changes, the <225,000 Btu/hr single phase furnace requirements for U.S. applications will be moved to a new table F-4 in appendix F.

This addendum saves energy by increasing the useful heat delivered by oil and gas furnaces per unit of fuel input, thus reducing the fuel used to meet the same heating load.

Energy Modeling Strategy

Since the commercial product changes are not effective until more than three years after the publication of Standard 90.1-2019, only the residential sized furnace efficiency improvements will be accounted for in the analysis. This is a simple change of efficiency for small gas furnaces smaller than 225 kBtu/hr. This addendum increases AFUE from 78% to 81%.

Incremental Cost Impact

Material costs at different efficiency levels were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.10 Addendum *bq*: Table 6.8.1.7 Heat Rejection Efficiency

Addendum *bq* raises the minimum efficiencies for axial and centrifugal fan evaporative condensers due to a change in the rating fluid to R-448A from R-507A, with R-448A having a lower Global Warming Potential (GWP). The addendum also adds axial fan, air cooled fluid coolers (better known as dry coolers) to Table 6.8.1.7. The addendum saves energy for buildings with heat rejection equipment.

Energy Modeling Strategy

The minimum efficiency requirement for dry coolers introduced by this addendum impacts the Large Office prototype. The dry cooler in the Large Office prototype is modeled using the FluidCooler:TwoSpeed object. Since the dry cooler efficiency is not a direct EnergyPlus input, modeled efficiency must be calculated as:

Dry Cooler efficiency = pump (gpm) / fan (bhp), where

fan(bhp) = fan (hp at high speed) * 0.9.

The pump flow rate is dependent on the loads it serves, and the dry cooler serves the computer rooms and IT closets, in which the loads remain relatively constant across different climate zones. Per

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=59

recommendations from SSPC 90.1 Mechanical Subcommittee experts, the baseline efficiency is assumed to be 4.0 gpm/hp and that for the advanced model is 4.5 gpm/hp based on Addendum *be*.

Incremental Cost Impact

Material costs for the baseline case were obtained from *RS Means*. Incremental material costs were obtained from a major manufacturer of dry coolers, which estimated the baseline material cost is 4% less than the new requirement. Labor costs were obtained from *RS Means*.

4.2.2.11 Addendum *br*: Commercial Refrigeration

Addendum *br* implements new federal refrigeration minimum efficiency requirements that went into effect on March 27, 2017. This addendum updates the requirements for commercial refrigerators and freezers and commercial refrigeration and combines them into a single table. The addendum saves energy by reducing the energy allowed for refrigerators by 39% and freezers by 45%.

Energy Modeling Strategy

This addendum covers both commercial reach-in refrigerators and freezers with solid doors. These are modeled in the primary school prototype building, which includes a commercial kitchen. The equipment power associated with the energy use limits before and after the addendum is calculated. These calculated values, as shown in Table 4.6, are then implemented in the models.

Table 4.6. Calculated Power for Commercial Refrigeration

Standard	Equipment	Power (watts)
90.1-2016	Freezer	915.0
90.1-2019	Freezer	555.0
90.1-2016	Refrigerator	570.0
90.1-2019	Refrigerator	313.3

Incremental Cost Impact

Material costs were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.2.12 Addendum *cn*: Walk-In Coolers and Walk-In Freezers

This addendum mirrors increases in federal walk-in cooler and freezer efficiency manufacturing requirements. The addendum saves energy by increasing the efficiency required for walk-in coolers by 132% and walk-in freezers by 55%.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=28

Energy Modeling Strategy

The primary school prototype is impacted as it includes a commercial kitchen. The walk-in cooler and walk-in freezer are not connected to remote compressors and condensers. Therefore, any heat rejected from the walk-in refrigeration was rejected to the surrounding zone and not rejected outdoors. PNNL modeled the refrigeration system efficiency using an improved compressor COP for the walk-in cooler and walk-in freezer objects as shown in Table 4.7.

Table 4.7. Addendum cn Compressor Coefficients of Performance

Walk-in Freezer		Walk-in Cooler	
90.1-2016 COP	90.1-2019 COP	90.1-2016 COP	90.1-2019 COP
1.5	2.32	3.0	6.98

Incremental Cost Impact

Material costs were obtained from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

4.2.3 Lighting

Standard 90.1-2019 incorporates three addenda that reduce lighting energy usage. Two reduce interior lighting power and the third impacts daylighting controls.

4.2.3.1 Addenda *bb* and *cg*: LPD Values Space-by-Space and LPD Building Area Method

Addenda *bb* and *cg* modify the LPD allowance for space-by-space and building area methods, respectively. The changes in LPD are the result of improving lighting technology, changes in lighting baseline (model is 100% LED), changes to Illuminating Engineering Society (IES) recommended light levels, changes to space geometry assumptions, and additional room surface reflectance values. The addenda save energy in multiple ways. There is direct lighting power reduction. In addition, the reduced lighting power reduces the internal gains which reduces cooling loads and saves cooling energy. In some climate zones, the reduction in lighting power results in an increased need for heating during colder outside conditions, so there may be an increase in heating energy use. These three impacts are combined for a net savings of building energy.

Energy Modeling Strategy

These addenda affect all prototypes. The following describes how the appropriate LPD allowance is chosen for the prototype buildings:

1. The Large Office and Small Office prototypes use the office building LPD allowance from the building area method.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=56

2. Most zones in the other prototypes are mapped to a single space-by-space category and the LPD allowance from that category is used directly.
3. A few zones in the other prototypes (for example, the Back Space zone in the Standalone Retail prototype) are considered a mix of two or more space types; in such cases, the NC^3 database (Richman et al. 2008) is used to determine the mix of spaces and their proportion. This weighting is then applied to determine a single LPD allowance for those spaces.

Using these rules and the values in Addenda *bb* and *cg*, the LPD allowances for all prototypes and zones were determined. The design LPD allowance is modeled in EnergyPlus as a direct input to the zone general lighting object.

Incremental Cost Impact

Material and labor costs were estimated for each fixture type and lamp type. These costs were applied to the lighting design assumptions to calculate a cost per square foot for each space type or building area type.

In the few cases where the SSPC 90.1 Lighting Subcommittee incorporated a significant shift in lighting design philosophy from 2016 to 2019, which resulted in a change to lighting technology unrelated to a change in LPD, one of the designs was selected and adjustments were made in the quantity of fixtures installed while maintaining similar fixture types.

Fixture costs were determined using Grainger and Goodmart online catalogs (Grainger 2018; Goodmart 2018). *RS Means 2020* was used for labor costs and for a few lighting equipment items not available in the other sources (RS Means 2020b). Besides cost, light source life and complete connected luminaire wattage per fixture were recorded. Fixture cost per watt ($/W) was calculated by dividing the total cost by the fixture wattage.

The total cost per space type, $\$/ft^2$, was determined by combining the costs per fixture per square foot in proportion to the percentage of total illumination provided by each fixture described above. The cost per space type was multiplied by the area of each space type represented in each prototype to determine the total interior lighting power cost for each prototype. Virtually all spaces in 2016 and 2019 assume LED fixtures.

Replacement cost for LED fixtures was assumed to be 75% of the first cost of the LED fixture and replaced at the end of the operational life of the light fixture.

4.2.3.2 Addendum *cw*: Continuous Daylighting Control

Addendum *cw* changes daylight responsive requirements from either continuous dimming or stepped control to continuous dimming required for all spaces. It also adds a definition of continuous dimming. This measure saves energy because a stepped control cannot switch to the next lower power level until enough daylight is available to maintain the desired light level. This results in a period between steps where more than the required light level is maintained, resulting in a higher average power level that would be achieved with continuous dimming that adjusts the power smoothly to maintain just the needed lighting level. There is also a modest impact on HVAC energy use similar to the LPD reduction addenda.

Energy Modeling Strategy

This addendum affects all prototypes with daylighting control, which includes all the prototypes in this analysis. The EnergyPlus object Daylighting:Controls was changed from “Stepped” to “Continuous” to implement this change. Several of the prototype models that include stepped daylighting control for either top lighting or side lighting are impacted. These include Small and Large Offices, Stand-alone Retail, and School. The control type in the EnergyPlus model was changed from three steps (i.e., power fraction of 0.66, 0.33, and 0) to ContinuousOff (proportionally reduces the lighting power as the daylight increases until a minimum power fraction of 0.2). The lights will be completely off when sufficient daylight is available.

Incremental Cost Impact

The daylighting requirement already existed, so there is no cost increase for the daylight sensor and continuous dimming capability is standard for LED fixtures. Therefore, there is no increase in cost for this addendum.

4.2.4 Other Equipment

4.2.4.1 Addendum *an*: Pump Efficiency

Addendum *an* implements new federal standards for commercial and industrial clean water pumps which went into effect on January 27, 2020. This addendum adds a new table with the new efficiency requirements for these pumps. It defines “Clean-Water Pump” as a pump that is designed for use in pumping water with a maximum nonabsorbent free solid content of 0.016 lb/ft^3 and with a maximum dissolved solid content of 3.1 lb/ft^3, provided that the total gas content of the water does not exceed the saturation volume, and disregarding any additives necessary to prevent the water from freezing at a minimum of 14°F.

This addendum saves energy by reducing the pumping power required to move water in hydronic systems, either through pump or motor efficiency improvements. In addition, for chilled water systems, there is less heat transferred to the chilled water from the pumping process, so there is a small reduction in chiller energy use. For heating water systems, the increase in pump efficiency shifts some heating energy use from pump electricity to whatever the heating source is.

Energy Modeling Strategy

The federal appliance standards rulemaking reports show about 4.3% of average efficiency improvement, and after considering 25% of the market, about 1.1% of the final average efficiency improvement is estimated. For the Addendum *an* update, PNNL assumed that 1% of efficiency improvement can be applied to the HVAC pump variable (motor efficiency) in the current baseline prototypes based on this information.

The affected pumps in the large office prototype are the heating hot water pump, chilled water primary and secondary pumps, and cooling tower pump. The affected pump in the primary school prototype is the heating hot water pump.

Incremental Cost Impact

Material costs were obtained for different efficiency levels from the federal appliance standards rulemaking documentation.[1] Costs were adjusted to 2020 dollars using inflation factors from *RS Means*. Labor costs are from *RS Means*.

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 2020) includes a worksheet with details of the summaries in Appendix A and a similar worksheet extending the analysis period to 40 years. The cost in a given year in these tables is a negative value if there was a replacement cost for 90.1-2016 that was greater than the replacement cost for 90.1-2019. The useful lives of corresponding items such as lamps and ballasts may not be the same for the 90.1-2016 and 90.1-2019 cases; therefore, replacement cost values can be positive or negative throughout the 30-year analysis period.

Table 4.8 includes total incremental first costs for each prototype and climate combination in units of total cost and cost per ft^2. Table 4.9 includes estimated total building costs per ft^2 from *RS Means 2020* 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 90.1-2016). As described in Section 4.1, these costs were not adjusted for climate location. In most cases moving from 90.1-2016 to 90.1-2019 resulted in an incremental reduction in first cost, shown as a negative value. This is due to reductions in HVAC equipment capacity, as well as for reductions in lighting costs in some cases.

[1] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=41

Table 4.8. Incremental Initial Construction Costs

Prototype	Value	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	First Cost	-$9,897	-$10,155	-$10,262	-$9,881	-$9,919
	$/ft^2	-$1.80	-$1.85	-$1.87	-$1.80	-$1.80
Large Office	First Cost	-$1,026,974	-$1,012,495	-$964,619	-$1,076,405	-$1,034,993
	$/ft^2	-$2.06	-$2.03	-$1.93	-$2.16	-$2.08
Standalone Retail	First Cost	-$33,265	-$33,727	-$34,252	-$34,054	-$34,679
	$/ft^2	-$1.35	-$1.37	-$1.39	-$1.38	-$1.40
Primary School	First Cost	-$160,141	-$144,443	-$157,341	-$153,557	-$155,314
	$/ft^2	-$2.17	-$1.95	-$2.13	-$2.08	-$2.10
Small Hotel	First Cost	$29,862	$29,271	$29,394	$29,143	$28,680
	$/ft^2	$0.69	$0.68	$0.68	$0.67	$0.66
Mid-rise Apartment	First Cost	-$11,992	-$12,389	-$13,661	-$9,966	-$9,674
	$/ft2	-$0.36	-$0.37	-$0.40	-$0.30	-$0.29

Table 4.9. Comparison of Total Building Cost and Incremental Cost (per ft^2 and percentage)

Prototype	Building First Cost ($/ft^2)	Incremental Cost for 90.1-2019				
		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	-$1.80 -0.82%	-$1.85 -0.84%	-$1.87 -0.85%	-$1.80 -0.82%	-$1.80 -0.82%
Large Office	$180	-$2.06 -1.14%	-$2.03 -1.13%	-$1.93 -1.07%	-$2.16 -1.20%	-$2.08 -1.15%
Standalone Retail	$116	-$1.35 -1.16%	-$1.37 -1.18%	-$1.39 -1.20%	-$1.38 -1.19%	-$1.40 -1.21%
Primary School	$225	-$2.17 -0.96%	-$1.95 -0.87%	-$2.13 -0.95%	-$2.08 -0.92%	-$2.10 -0.93%
Small Hotel	$197	$0.69 0.35%	$0.68 0.34%	$0.68 0.35%	$0.67 0.34%	$0.66 0.34%
Mid-rise Apartment	$218	-$0.36 -0.16%	-$0.37 -0.17%	-$0.40 -0.19%	-$0.30 -0.14%	-$0.29 -0.13%

5.0 Cost-Effectiveness Analysis

The purpose of this analysis is to determine the overall cost-effectiveness of Standard 90.1-2019 compared to the 90.1-2016 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 ratio
- 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 (Hart and Liu 2015). This report presents a cost-effectiveness assessment using an LCCA and the SSPC 90.1 Scalar Method for the combined changes in Standard 90.1-2016 to 2019 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 2019 edition of Standard 90.1 is analyzed and compared to similar results for the 2016 edition. If the present value cost of the 2019 edition is less than the present value cost of the 2016 edition, there is positive net present value savings and Standard 90.1-2019 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 DOE and PNNL (DOE 2015) and is the same period used in the previous cost-effectiveness comparisons, for example between 90.1-2013 and 90.1-2016 (Hart et al. 2020). 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 March 2019 (Lavappa and Kneifel 2019) were used in this analysis.

The DOE 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 2019 annual supplement without citation; Lavappa and Kneifel 2019). The mandated procedure would result in a discount rate for 2019 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 2019. The implied long-term average rate of inflation was calculated as 0.1% (Lavappa and Kneifel 2019). Table 5.1 summarizes the analysis assumptions used.

Table 5.1. Life-Cycle Cost Analysis Parameters

Economic Parameter	Commercial State Cost-Effectiveness Scenario 1 without Loans or Taxes	
	Value	Source
Nominal Discount Rate[a] [d]	3.1%	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2019*, NIST annual update (Lavappa and Kneifel 2019).
Real Discount Rate[b] [d]	3.0%	
Inflation Rate[c] [d]	0.1%	
Electricity and Gas Price	$0.1063/kWh, $0.98/therm	SSPC-90.1 for 90.1-2019 scalar
Energy Price Escalation	Uniform present value factors Electricity 19.17 Natural gas 23.45	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2019*, NIST annual update (Lavappa and Kneifel 2019). 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 and common 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 take into account any costs or savings after the year in which payback is reached, does not consider the time value of money, and does not take into account 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 90.1-2019 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 90.1-2019 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)]	2.73[(a)]	2.07[(a)]
Nominal Discount Rate - %[(b)]	8.5	8.5
Loan Interest Rate - %	5.0	5.0
Heating – Natural Gas Price, $/therm	$0.98	
Cooling - Electricity Price $/kWh		$0.1063
Measure Life Example:		
Economic Life - Years	40	40
Scalar Ratio Limit (Weighted: 22.08)	**25.2**	**22.1**

(a) The energy escalation rate used in the scalar calculation for 90.1-2019 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 90.1-2019 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 22.08 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 22.08 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 90.1-2019 models compared to the corresponding 90.1-2016 models. The energy costs for each edition of Standard 90.1 were based primarily on DOE's determination of energy savings of 90.1-2019. Detailed methodology and overall energy savings results from Standard 90.1-2019 are documented in the DOE technical report titled *Preliminary Energy Savings Analysis ANSI/ASHRAE/IES Standard 90.1-2019* (DOE 2020b).

The current savings analysis builds on the 90.1-2019 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 $0.98/therm for fossil fuel[2] and $0.1063/kWh for electricity. These rates were used for the 90.1-2019 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 90.1-2019.

Table 5.3. Annual Energy Cost Savings, 90.1-2019 Compared to 90.1-2016

		Climate Zone and Location				
Prototype		2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	Total	$278	$259	$271	$237	$235
	$/ft²	$0.05	$0.05	$0.05	$0.04	$0.04
Large Office	Total	$36,020	$36,525	$29,947	$29,898	$31,038
	$/ft²	$0.07	$0.07	$0.06	$0.06	$0.06
Standalone Retail	Total	$2,674	$2,309	$2,395	$2,035	$1,927
	$/ft²	$0.11	$0.09	$0.10	$0.08	$0.08
Primary School	Total	$6,320	$6,085	$6,945	$5,411	$5,439
	$/ft²	$0.09	$0.08	$0.09	$0.07	$0.07
Small Hotel	Total	$4,002	$3,754	$3,833	$3,364	$3,203
	$/ft²	$0.09	$0.09	$0.09	$0.08	$0.07
Mid-rise Apartment	Total	$1,747	$1,581	$732	$542	$522
	$/ft²	$0.05	$0.05	$0.02	$0.02	$0.02

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 90.1-2019 is cost-effective relative to 90.1-2016 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 (Hart and Liu 2015). 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:

[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.

- 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 90.1-2019 compared to 90.1-2016, 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 $4.12 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	$4.20	$4.16	$4.23	$4.00	$3.98	$4.11
Large Office	$4.40	$4.39	$3.92	$4.29	$4.22	$4.29
Standalone Retail	$4.83	$4.56	$4.70	$4.34	$4.28	$4.50
Primary School	$5.43	$5.06	$5.45	$5.04	$5.10	$5.19
Small Hotel	$14.14	$14.04	$14.07	$13.86	$13.81	$13.97
Mid-rise Apartment	$2.65	$2.66	$2.19	$1.83	$1.80	$2.18
Weighted Total	$4.50	$4.44	$4.03	$3.79	$3.91	$4.12
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Large Office	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Standalone Retail	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	7.5	7.8	7.7	8.7	9.0	8.1
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Scalar Ratio, Limit = 22.08[(a)]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	(58)	(63)	(61)	(67)	(68)	(64)
Large Office	(40)	(39)	(44)	(50)	(46)	(45)
Standalone Retail	(17)	(27)	(34)	(31)	(33)	(28)
Primary School	(41)	(38)	(36)	(45)	(45)	(42)
Small Hotel	(97)	(103)	(101)	(115)	(121)	(108)
Mid-rise Apartment	(41)	(47)	(215)	(776)	(1,137)	(507)
Weighted Total	(39)	(43)	(110)	(328)	(403)	(203)

(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.

6.0 References

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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 90.1-2019 compared to 90.1-2016. 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	-$412	-$322	-$429	$22	-$16	-$10,042	-$10,042	-$10,042	-$10,042	-$10,042
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	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
15	-$722	-$607	-$734	-$407	-$242	$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	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$1,907	-$1,792	-$1,919	-$1,296	-$1,428	$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	$1,031	$992	$1,035	$728	$871	$1,394	$1,394	$1,394	$1,394	$1,394

Small Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$557	$209	$209	$139	$139	-$9,897.3	-$10,155	-$10,262	-$9,881	-$9,919
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	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
15	$0	$0	$0	$0	$0	-$722	-$607	-$734	-$407	-$242
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	-$9,758	-$9,758	-$9,758	-$9,758	-$9,758
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$1,907	-$1,792	-$1,919	-$1,296	-$1,428
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	$2,425	$2,386	$2,429	$2,122	$2,265

A.2 Large Office Cost Summary

Large Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$159,886	-$118,371	-$70,495	-$176,848	-$135,437	-$910,359	-$910,359	-$910,359	-$910,359	-$910,359
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	-$111,828	-$112,316	-$30,465	-$103,170	-$103,449	$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	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$82,035	$91,420	$62,416	$20,172	$55,597	$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	-$35,522	-$10,666	-$3,941	-$12,114	-$5,025	$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	-$266,879	-$252,629	-$242,490	-$261,838	-$244,112	$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	-$7,955	-$10,638	-$9,442	-$12,183	-$14,457	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
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	$156,729	$142,881	$160,626	$153,772	$141,961	$713,604	$713,604	$713,604	$713,604	$713,604

Large Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$43,271	$16,234	$16,234	$10,802	$10,802	-$1,026,974	-$1,012,495	-$964,619	-$1,076,405	-$1,034,993
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	-$111,828	-$112,316	-$30,465	-$103,170	-$103,449
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	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$82,035	$91,420	$62,416	$20,172	$55,597
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	-$35,522	-$10,666	-$3,941	-$12,114	-$5,025
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	-$266,879	-$252,629	-$242,490	-$261,838	-$244,112
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	-$7,955	-$10,638	-$9,442	-$12,183	-$14,457
36	$0	$0	$0	$0	$0	-$917,491	-$917,491	-$917,491	-$917,491	-$917,491
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	$870,333	$856,485	$874,230	$867,376	$855,565

A.3 Standalone Retail Cost Summary

Standalone Retail	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$4,794	-$4,663	-$5,188	-$4,045	-$4,670	-$30,207	-$30,207	-$30,207	-$30,207	-$30,207
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	-$17	-$17	-$17	-$17	-$17
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	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
15	-$2,064	-$1,670	-$2,063	-$1,567	-$1,679	$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	$832	$832	$832	$832	$832	-$17	-$17	-$17	-$17	-$17
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	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$7,041	-$6,892	-$7,529	-$6,136	-$6,982	-$17	-$17	-$17	-$17	-$17
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	$202,518	$0	-$205,038	$3,568	$4,095	$6,578	$6,578	$6,578	$6,578	$6,578

Standalone Retail	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,736	$1,143	$1,143	$198	$198	-$33,265	-$33,727	-$34,252	-$34,054	-$34,679
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	-$17	-$17	-$17	-$17	-$17
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	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
15	$0	$0	$0	$0	$0	-$2,064	-$1,670	-$2,063	-$1,567	-$1,679
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	$814	$814	$814	$814	$814
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	-$46,046	-$46,046	-$46,046	-$46,046	-$46,046
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$7,058	-$6,909	-$7,547	-$6,153	-$7,000
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	$209,096	$6,578	-$198,459	$10,146	$10,673

A.4 Primary School Cost Summary

Primary School	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$20,220	-$768	-$13,667	-$8,947	-$10,692	-$145,557	-$145,557	-$145,557	-$145,557	-$145,557
Maintenance	-$10	-$15	$29	-$13	-$15					
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	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
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	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
15	-$11,959	-$5,885	-$2,237	-$3,685	-$5,319	$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	$90	$13,130	-$16	$323	$335	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
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	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$86,662	-$19,803	-$23,467	-$15,334	-$17,633	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
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	-$1,158	-$1,015	-$1,555	-$995	-$981	$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	$54,781	$12,111	$16,232	$9,847	$10,823	$20,594	$20,594	$20,594	$20,594	$20,594

Primary School	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$5,637	$1,883	$1,883	$947	$936	-$160,141	-$144,443	-$157,341	-$153,557	-$155,314
Maintenance	$0	$0	$0	$0	$0	-$10	-$15	$29	-$13	-$15
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	-$2,290	-$2,290	-$2,290	-$2,290	-$2,290
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	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
15	$0	$0	$0	$0	$0	-$11,959	-$5,885	-$2,237	-$3,685	-$5,319
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	-$2,200	$10,840	-$2,306	-$1,968	-$1,955
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	-$144,161	-$144,161	-$144,161	-$144,161	-$144,161
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$88,953	-$22,093	-$25,757	-$17,625	-$19,924
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	-$1,158	-$1,015	-$1,555	-$995	-$981
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	$75,375	$32,705	$36,826	$30,442	$31,418

A.5 Small Hotel Cost Summary

Small Hotel	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$195	-$240	-$117	$301	-$160	$28,669	$28,669	$28,669	$28,669	$28,669
Maintenance	-$2	-$2	-$2	-$1	-$2					
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
2	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
3	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
4	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
5	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
6	$0	$0	$0	$0	$0	-$100,064	-$100,064	-$100,064	-$100,064	-$100,064
7	$0	$0	$0	$0	$0	-$11,534	-$11,534	-$11,534	-$11,534	-$11,534
8	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
9	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
10	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
11	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
12	$0	$0	$0	$0	$0	-$98,419	-$98,419	-$98,419	-$98,419	-$98,419
13	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
14	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
15	-$984	-$1,017	-$888	-$825	-$759	-$58,975	-$58,975	-$58,975	-$58,975	-$58,975
16	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
17	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
18	$0	$0	$0	$0	$0	-$107,088	-$107,088	-$107,088	-$107,088	-$107,088
19	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
20	$183	$183	$183	$183	$183	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
21	$0	$0	$0	$0	$0	-$49,391	-$49,391	-$49,391	-$49,391	-$49,391
22	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
23	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
24	$0	$0	$0	$0	$0	-$101,390	-$101,390	-$101,390	-$101,390	-$101,390
25	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
26	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
27	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
28	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
29	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
30	-$3,821	-$3,854	-$3,726	-$3,095	-$3,880	-$100,297	-$100,297	-$100,297	-$100,297	-$100,297
31	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
32	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
33	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
34	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
35	$0	$0	$0	$0	$0	-$11,767	-$11,767	-$11,767	-$11,767	-$11,767
36	$0	$0	$0	$0	$0	-$105,443	-$105,443	-$105,443	-$105,443	-$105,443
37	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
38	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
39	$0	$0	$0	$0	$0	-$54,615	-$54,615	-$54,615	-$54,615	-$54,615
40	$2,220	$2,231	$2,188	$1,788	$2,334	$5,759	$5,759	$5,759	$5,759	$5,759

Small Hotel	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,388	$842	$842	$174	$172	$29,862	$29,271	$29,394	$29,143	$28,680
Maintenance	$0	$0	$0	$0	$0	-$2	-$2	-$2	-$1	-$2
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
2	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
3	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
4	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
5	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
6	$0	$0	$0	$0	$0	-$100,064	-$100,064	-$100,064	-$100,064	-$100,064
7	$0	$0	$0	$0	$0	-$11,534	-$11,534	-$11,534	-$11,534	-$11,534
8	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
9	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
10	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
11	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
12	$0	$0	$0	$0	$0	-$98,419	-$98,419	-$98,419	-$98,419	-$98,419
13	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
14	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
15	$0	$0	$0	$0	$0	-$59,958	-$59,992	-$59,863	-$59,799	-$59,733
16	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
17	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
18	$0	$0	$0	$0	$0	-$107,088	-$107,088	-$107,088	-$107,088	-$107,088
19	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
20	$0	$0	$0	$0	$0	-$20,935	-$20,935	-$20,935	-$20,935	-$20,935
21	$0	$0	$0	$0	$0	-$49,391	-$49,391	-$49,391	-$49,391	-$49,391
22	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
23	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
24	$0	$0	$0	$0	$0	-$101,390	-$101,390	-$101,390	-$101,390	-$101,390
25	$0	$0	$0	$0	$0	-$21,117	-$21,117	-$21,117	-$21,117	-$21,117
26	$0	$0	$0	$0	$0	-$16,758	-$16,758	-$16,758	-$16,758	-$16,758
27	$0	$0	$0	$0	$0	-$65,766	-$65,766	-$65,766	-$65,766	-$65,766
28	$0	$0	$0	$0	$0	$198,489	$198,489	$198,489	$198,489	$198,489
29	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
30	$0	$0	$0	$0	$0	-$104,118	-$104,152	-$104,023	-$103,392	-$104,177
31	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
32	$0	$0	$0	$0	$0	-$19,755	-$19,755	-$19,755	-$19,755	-$19,755
33	$0	$0	$0	$0	$0	-$58,742	-$58,742	-$58,742	-$58,742	-$58,742
34	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
35	$0	$0	$0	$0	$0	-$11,767	-$11,767	-$11,767	-$11,767	-$11,767
36	$0	$0	$0	$0	$0	-$105,443	-$105,443	-$105,443	-$105,443	-$105,443
37	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
38	$0	$0	$0	$0	$0	-$20,885	-$20,885	-$20,885	-$20,885	-$20,885
39	$0	$0	$0	$0	$0	-$54,615	-$54,615	-$54,615	-$54,615	-$54,615
40	$0	$0	$0	$0	$0	$7,979	$7,990	$7,947	$7,547	$8,093

A.6 Mid-rise Apartment Cost Summary

Mid-rise Apartment	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$9,017	$8,864	$7,591	$11,427	$11,720	-$21,989	-$21,989	-$21,989	-$21,989	-$21,989
Maintenance	$480	$480	$480	$480	$480					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
15	$9,684	$9,457	$7,583	$11,986	$12,425	$0	$0	$0	$0	$0
16	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$533	$533	$533	$533	$533
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$9,684	$9,457	$7,583	$11,986	$12,425	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	-$3,228	-$3,152	-$2,528	-$3,995	-$4,142	$9,971	$9,971	$9,971	$9,971	$9,971

Mid-rise Apartment	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$980	$736	$736	$595	$595	-$11,992	-$12,389	-$13,661	-$9,966	-$9,674
Maintenance	$0	$0	$0	$0	$0	$480	$480	$480	$480	$480
Replacement (Year)						$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
5	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
6	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
15	$0	$0	$0	$0	$0	$9,684	$9,457	$7,583	$11,986	$12,425
16	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$533	$533	$533	$533	$533
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
23	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
24	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$10,218	-$10,444	-$12,319	-$7,916	-$7,476
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$7,443	-$7,443	-$7,443	-$7,443	-$7,443
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
36	$0	$0	$0	$0	$0	-$19,902	-$19,902	-$19,902	-$19,902	-$19,902
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$0	$0	$0	$0	$0	$6,744	$6,819	$7,444	$5,976	$5,830

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 90.1-2016 and 90.1-2019.

B.1 Energy Cost and Savings Summary, 90.1-2016 and 90.1-2019

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

Climate Zone:	2A				3A				3B			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office												
Electricity	$0.881	$0.830	$0.050	5.7%	$0.805	$0.757	$0.047	5.8%	$0.817	$0.768	$0.049	6.0%
Gas	$0.000	$0.000	$0.000	-	$0.002	$0.002	$0.000	0.0%	$0.000	$0.000	$0.000	-
Totals	$0.881	$0.830	$0.050	5.7%	$0.807	$0.760	$0.047	5.8%	$0.818	$0.768	$0.049	6.0%
Large Office												
Electricity	$1.775	$1.704	$0.071	4.0%	$1.669	$1.603	$0.067	4.0%	$1.749	$1.687	$0.061	3.5%
Gas	$0.011	$0.010	$0.001	9.1%	$0.023	$0.016	$0.007	30.4%	$0.015	$0.016	-$0.001	-6.7%
Totals	$1.786	$1.714	$0.072	4.0%	$1.693	$1.619	$0.073	4.3%	$1.764	$1.704	$0.060	3.4%
Stand-Alone Retail												
Electricity	$1.256	$1.147	$0.109	8.7%	$1.064	$0.964	$0.100	9.4%	$1.082	$0.980	$0.102	9.4%
Gas	$0.037	$0.038	-$0.001	-2.7%	$0.093	$0.099	-$0.006	-6.5%	$0.051	$0.056	-$0.005	-9.8%
Totals	$1.293	$1.185	$0.108	8.4%	$1.157	$1.063	$0.093	8.0%	$1.133	$1.036	$0.097	8.6%
Primary School												
Electricity	$1.238	$1.154	$0.084	6.8%	$1.046	$0.971	$0.075	7.2%	$1.043	$0.951	$0.092	8.8%
Gas	$0.063	$0.062	$0.001	1.6%	$0.095	$0.088	$0.007	7.4%	$0.078	$0.076	$0.002	2.6%
Totals	$1.301	$1.216	$0.085	6.5%	$1.141	$1.058	$0.082	7.2%	$1.121	$1.028	$0.094	8.4%
Small Hotel												
Electricity	$1.079	$0.987	$0.093	8.6%	$0.985	$0.898	$0.087	8.8%	$0.974	$0.885	$0.089	9.1%
Gas	$0.194	$0.194	$0.000	0.0%	$0.213	$0.213	$0.000	0.0%	$0.206	$0.206	$0.000	0.0%
Totals	$1.273	$1.181	$0.093	7.3%	$1.198	$1.111	$0.087	7.3%	$1.180	$1.091	$0.089	7.5%
Mid-Rise Apartment												
Electricity	$1.151	$1.102	$0.049	4.3%	$1.070	$1.046	$0.024	2.2%	$1.080	$1.066	$0.014	1.3%
Gas	$0.003	$0.001	$0.002	66.7%	$0.034	$0.012	$0.022	64.7%	$0.011	$0.003	$0.008	72.7%
Totals	$1.154	$1.102	$0.052	4.5%	$1.104	$1.057	$0.047	4.3%	$1.090	$1.069	$0.022	2.0%

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

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity	$0.787	$0.744	$0.043	5.5%	$0.791	$0.748	$0.044	5.6%
Gas	$0.005	$0.005	$0.000	0.0%	$0.021	$0.022	-$0.001	-4.8%
Totals	$0.792	$0.749	$0.043	5.4%	$0.812	$0.770	$0.043	5.3%
Large Office								
Electricity	$1.606	$1.550	$0.056	3.5%	$1.566	$1.509	$0.058	3.7%
Gas	$0.028	$0.024	$0.003	10.7%	$0.039	$0.034	$0.005	12.8%
Totals	$1.634	$1.574	$0.060	3.7%	$1.605	$1.543	$0.062	3.9%
Standalone Retail								
Electricity	$0.993	$0.900	$0.093	9.4%	$0.926	$0.836	$0.091	9.8%
Gas	$0.175	$0.186	-$0.011	-6.3%	$0.257	$0.270	-$0.013	-5.1%
Totals	$1.168	$1.086	$0.082	7.0%	$1.183	$1.105	$0.078	6.6%
Primary School								
Electricity	$0.967	$0.900	$0.068	7.0%	$0.907	$0.842	$0.065	7.2%
Gas	$0.105	$0.099	$0.005	4.8%	$0.144	$0.135	$0.009	6.3%
Totals	$1.072	$0.999	$0.073	6.8%	$1.050	$0.977	$0.074	7.0%
Small Hotel								
Electricity	$0.958	$0.880	$0.078	8.1%	$0.958	$0.885	$0.074	7.7%
Gas	$0.233	$0.233	$0.000	0.0%	$0.251	$0.251	$0.001	0.4%
Totals	$1.191	$1.113	$0.078	6.5%	$1.209	$1.135	$0.074	6.1%
Mid-Rise Apartment								
Electricity	$1.056	$1.036	$0.020	1.9%	$1.050	$1.029	$0.021	2.0%
Gas	$0.030	$0.035	-$0.004	-13.3%	$0.058	$0.064	-$0.006	-10.3%
Totals	$1.087	$1.071	$0.016	1.5%	$1.108	$1.093	$0.015	1.4%

B.2 Energy Use and Savings Summary, 90.1-2016 and 90.1-2019

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

Climate Zone:	2A				3A				3B			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office												
Electricity, kWh/ft^2	8.285	7.810	0.475	5.7%	7.569	7.124	0.445	5.9%	7.690	7.226	0.464	6.0%
Gas, therm/ft^2	0.000	0.000	0.000	-	0.002	0.003	0.000	0.0%	0.000	0.000	0.000	-
Totals, kBtu/ft^2	28.277	26.657	1.620	5.7%	26.073	24.570	1.503	5.8%	26.273	24.692	1.581	6.0%
Large Office												
Electricity, kWh/ft^2	16.695	16.026	0.668	4.0%	15.705	15.078	0.627	4.0%	16.450	15.875	0.575	3.5%
Gas, therm/ft^2	0.012	0.010	0.001	8.3%	0.024	0.017	0.007	29.2%	0.015	0.016	-0.001	-6.7%
Totals, kBtu/ft^2	58.141	55.738	2.402	4.1%	55.955	53.141	2.814	5.0%	57.677	55.826	1.851	3.2%
Stand-Alone Retail												
Electricity, kWh/ft^2	11.818	10.790	1.029	8.7%	10.011	9.073	0.938	9.4%	10.177	9.222	0.955	9.4%
Gas, therm/ft^2	0.038	0.039	-0.001	-2.6%	0.094	0.101	-0.006	-6.4%	0.052	0.057	-0.005	-9.6%
Totals, kBtu/ft^2	44.091	40.687	3.403	7.7%	43.617	41.053	2.564	5.9%	39.981	37.186	2.795	7.0%
Primary School												
Electricity, kWh/ft^2	11.645	10.855	0.790	6.8%	9.836	9.132	0.703	7.1%	9.816	8.948	0.867	8.8%
Gas, therm/ft^2	0.064	0.063	0.002	3.1%	0.097	0.089	0.008	8.2%	0.080	0.078	0.002	2.5%
Totals, kBtu/ft^2	46.185	43.338	2.847	6.2%	43.268	40.102	3.166	7.3%	41.466	38.333	3.133	7.6%
Small Hotel												
Electricity, kWh/ft^2	10.153	9.281	0.873	8.6%	9.269	8.449	0.820	8.8%	9.166	8.328	0.839	9.2%
Gas, therm/ft^2	0.198	0.198	0.000	0.0%	0.217	0.217	0.000	0.0%	0.210	0.210	0.000	0.0%
Totals, kBtu/ft^2	54.461	51.496	2.965	5.4%	53.349	50.577	2.772	5.2%	52.273	49.455	2.818	5.4%
Mid-Rise Apartment												
Electricity, kWh/ft^2	10.830	10.365	0.465	4.3%	10.066	9.836	0.230	2.3%	10.157	10.025	0.132	1.3%
Gas, therm/ft^2	0.003	0.001	0.002	66.7%	0.035	0.012	0.023	65.7%	0.011	0.003	0.008	72.7%
Totals, kBtu/ft^2	37.254	35.430	1.824	4.9%	37.828	34.756	3.072	8.1%	35.749	34.514	1.235	3.5%

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

Climate Zone:	4A				5A			
Code:	90.1-2016	90.1-2019	Savings		90.1-2016	90.1-2019	Savings	
Small Office								
Electricity, kWh/ft^2	7.404	6.995	0.409	5.5%	7.446	7.033	0.413	5.5%
Gas, therm/ft^2	0.005	0.005	0.000	0.0%	0.021	0.022	-0.001	-4.8%
Totals, kBtu/ft^2	25.764	24.406	1.358	5.3%	27.537	26.249	1.288	4.7%
Large Office								
Electricity, kWh/ft^2	15.109	14.577	0.531	3.5%	14.735	14.192	0.543	3.7%
Gas, therm/ft^2	0.028	0.025	0.004	14.3%	0.040	0.035	0.005	12.5%
Totals, kBtu/ft^2	54.380	52.210	2.170	4.0%	54.269	51.951	2.318	4.3%
Standalone Retail								
Electricity, kWh/ft^2	9.337	8.462	0.875	9.4%	8.714	7.861	0.854	9.8%
Gas, therm/ft^2	0.179	0.190	-0.011	-6.1%	0.262	0.275	-0.013	-5.0%
Totals, kBtu/ft^2	49.767	47.862	1.905	3.8%	55.954	54.335	1.619	2.9%
Primary School								
Electricity, kWh/ft^2	9.101	8.464	0.637	7.0%	8.528	7.920	0.608	7.1%
Gas, therm/ft^2	0.107	0.101	0.006	5.6%	0.147	0.138	0.009	6.1%
Totals, kBtu/ft^2	41.724	38.991	2.733	6.6%	43.775	40.790	2.985	6.8%
Small Hotel								
Electricity, kWh/ft^2	9.010	8.277	0.732	8.1%	9.014	8.322	0.692	7.7%
Gas, therm/ft^2	0.238	0.238	0.000	0.0%	0.256	0.256	0.001	0.4%
Totals, kBtu/ft^2	54.510	52.008	2.502	4.6%	56.394	53.973	2.420	4.3%
Mid-Rise Apartment								
Electricity, kWh/ft^2	9.937	9.745	0.192	1.9%	9.877	9.677	0.201	2.0%
Gas, therm/ft^2	0.031	0.036	-0.004	-12.9%	0.060	0.066	-0.006	-10.0%
Totals, kBtu/ft^2	37.020	36.811	0.209	0.6%	39.676	39.591	0.085	0.2%

B.3 Energy by Usage Category, 90.1-2016 and 90.1-2019

Annual Energy Usage for Buildings in Climate Zone 2A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/
	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.013	0.000	0.139	0.003	0.000	0.004	0.000	0.006	0.030	0.001	0.000	0.003
Cooling	2.033	0.000	3.798	0.000	4.393	0.000	3.755	0.000	3.304	0.000	2.118	0.000
Fans, Pumps, Heat Recovery	0.978	0.000	1.533	0.000	1.506	0.000	1.767	0.000	1.097	0.000	0.810	0.000
Lighting, Interior & Exterior	1.913	0.000	1.956	0.000	3.732	0.000	1.422	0.000	2.136	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.604	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.105	2.639	0.000
Total	8.285	0.000	16.695	0.012	11.818	0.038	11.645	0.064	10.153	0.198	10.830	0.003
ASHRAE 90.1-2019												
Heating, Humidification	0.012	0.000	0.154	0.002	0.000	0.005	0.000	0.004	0.036	0.001	0.000	0.001
Cooling	1.957	0.000	3.487	0.000	4.151	0.000	3.469	0.000	3.139	0.000	1.844	0.000
Fans, Pumps, Heat Recovery	0.900	0.000	1.489	0.000	1.428	0.000	1.667	0.000	1.047	0.000	0.775	0.000
Lighting, Interior & Exterior	1.593	0.000	1.627	0.000	3.025	0.000	1.163	0.000	1.472	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.459	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.105	2.637	0.000
Total	7.810	0.000	16.026	0.010	10.790	0.039	10.855	0.063	9.281	0.198	10.365	0.001
Total Savings	0.475	0.000	0.668	0.001	1.029	-0.001	0.790	0.002	0.873	0.000	0.465	0.002

Annual Energy Usage for Buildings in Climate Zone 3A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr	kWh/ ft^2·yr	therms/ ft^2·yr
ASHRAE 90.1-2016												
Heating, Humidification	0.260	0.002	0.404	0.013	0.000	0.059	0.000	0.036	0.240	0.005	0.000	0.035
Cooling	1.107	0.000	2.637	0.000	2.439	0.000	2.150	0.000	2.223	0.000	1.145	0.000
Fans, Pumps, Heat Recovery	0.932	0.000	1.432	0.000	1.638	0.000	1.549	0.000	1.075	0.000	0.670	0.000
Lighting, Interior & Exterior	1.923	0.000	1.963	0.000	3.748	0.000	1.437	0.000	2.144	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.119	2.987	0.000
Total	7.569		15.705	0.024	10.011	0.094	9.836	0.097	9.269	0.217	10.066	0.035
ASHRAE 90.1-2019												
Heating, Humidification	0.265		0.439	0.007	0.000	0.066	0.000	0.029	0.276	0.006	0.000	0.012
Cooling	1.052	0.000	2.354	0.000	2.287	0.000	1.966	0.000	2.090	0.000	1.096	0.000
Fans, Pumps, Heat Recovery	0.858	0.000	1.385	0.000	1.554	0.000	1.437	0.000	1.020	0.000	0.647	0.000
Lighting, Interior & Exterior	1.601	0.000	1.632	0.000	3.044	0.000	1.175	0.000	1.477	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.119	2.983	0.000
Total	7.124		15.078	0.017	9.073	0.101	9.132	0.089	8.449	0.217	9.836	0.012
Total Savings	0.445	0.000	0.627	0.007	0.938	-0.006	0.703	0.008	0.820	0.000	0.230	0.023

Annual Energy Usage for Buildings in Climate Zone 3B

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	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 90.1-2016												
Heating, Humidification	0.098	0.000	0.851	0.006	0.000	0.018	0.000	0.020	0.085	0.002	0.000	0.011
Cooling	1.232	0.000	2.708	0.000	2.380	0.000	2.239	0.000	2.230	0.000	1.243	0.000
Fans, Pumps, Heat Recovery	1.090	0.000	1.666	0.000	1.767	0.000	1.429	0.000	1.120	0.000	0.752	0.000
Lighting, Interior & Exterior	1.921	0.000	1.955	0.000	3.843	0.000	1.451	0.000	2.144	0.000	1.055	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.599	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.116	2.897	0.000
Total	7.690	0.000	16.450	0.015	10.177	0.052	9.816	0.080	9.166	0.210	10.157	0.011
ASHRAE 90.1-2019												
Heating, Humidification	0.102	0.000	0.803	0.007	0.000	0.022	0.000	0.018	0.107	0.002	0.000	0.003
Cooling	1.169	0.000	2.556	0.000	2.228	0.000	2.018	0.000	2.096	0.000	1.252	0.000
Fans, Pumps, Heat Recovery	1.007	0.000	1.620	0.000	1.680	0.000	1.188	0.000	1.062	0.000	0.769	0.000
Lighting, Interior & Exterior	1.599	0.000	1.627	0.000	3.128	0.000	1.188	0.000	1.477	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.457	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.116	2.894	0.000
Total	7.226	0.000	15.875	0.016	9.222	0.057	8.948	0.078	8.328	0.210	10.025	0.003
Total Savings	0.464	0.000	0.575	-0.001	0.955	-0.005	0.867	0.002	0.839	0.000	0.132	0.008

Annual Energy Usage for Buildings in Climate Zone 4A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/
	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.503	0.005	0.435	0.017	0.000	0.143	0.000	0.045	0.551	0.013	0.000	0.031
Cooling	0.800	0.000	2.073	0.000	1.613	0.000	1.459	0.000	1.693	0.000	0.811	0.000
Fans, Pumps, Heat Recovery	0.855	0.000	1.370	0.000	1.707	0.000	1.514	0.000	1.054	0.000	0.608	0.000
Lighting, Interior & Exterior	1.897	0.000	1.961	0.000	3.831	0.000	1.429	0.000	2.125	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.016	0.000	0.132	3.256	0.000
Total	7.404	0.005	15.109	0.028	9.337	0.179	9.101	0.107	9.010	0.238	9.937	0.031
ASHRAE 90.1-2019												
Heating, Humidification	0.517	0.005	0.669	0.014	0.000	0.154	0.000	0.039	0.643	0.013	0.000	0.036
Cooling	0.760	0.000	1.705	0.000	1.514	0.000	1.370	0.000	1.583	0.000	0.786	0.000
Fans, Pumps, Heat Recovery	0.786	0.000	1.303	0.000	1.636	0.000	1.357	0.000	0.999	0.000	0.593	0.000
Lighting, Interior & Exterior	1.585	0.000	1.632	0.000	3.126	0.000	1.182	0.000	1.466	0.000	0.900	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.015	0.000	0.132	3.257	0.000
Total	6.995	0.005	14.577	0.025	8.462	0.190	8.464	0.101	8.277	0.238	9.745	0.036
Total Savings	0.409	0.000	0.531	0.004	0.875	-0.011	0.637	0.006	0.732	0.000	0.192	-0.004

Annual Energy Usage for Buildings in Climate Zone 5A

Energy	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
End-Use	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/	kWh/	therms/
	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$	$ft^2 \cdot yr$
ASHRAE 90.1-2016												
Heating, Humidification	0.855	0.021	0.706	0.028	0.000	0.225	0.000	0.084	0.975	0.022	0.000	0.060
Cooling	0.489	0.000	1.458	0.000	0.938	0.000	0.910	0.000	1.282	0.000	0.543	0.000
Fans, Pumps, Heat Recovery	0.854	0.000	1.341	0.000	1.760	0.000	1.503	0.000	1.047	0.000	0.586	0.000
Lighting, Interior & Exterior	1.899	0.000	1.960	0.000	3.831	0.000	1.416	0.000	2.123	0.000	1.054	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.602	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.142	3.485	0.000
Total	7.446	0.021	14.735	0.040	8.714	0.262	8.528	0.147	9.014	0.256	9.877	0.060
ASHRAE 90.1-2019												
Heating, Humidification	0.860	0.022	0.476	0.023	0.000	0.238	0.000	0.075	1.092	0.021	0.000	0.066
Cooling	0.458	0.000	1.522	0.000	0.873	0.000	0.858	0.000	1.188	0.000	0.510	0.000
Fans, Pumps, Heat Recovery	0.782	0.000	1.294	0.000	1.679	0.000	1.337	0.000	0.991	0.000	0.570	0.000
Lighting, Interior & Exterior	1.585	0.000	1.631	0.000	3.123	0.000	1.169	0.000	1.465	0.000	0.901	0.000
Plugs, Refrigeration, Other	2.439	0.000	9.269	0.000	2.186	0.000	4.458	0.046	3.587	0.092	4.209	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.142	3.486	0.000
Total	7.033	0.022	14.192	0.035	7.861	0.275	7.920	0.138	8.322	0.256	9.677	0.066
Total Savings	0.413	-0.001	0.543	0.005	0.854	-0.013	0.608	0.009	0.692	0.001	0.201	-0.006

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