PNNL-28206

Pacific Northwest NATIONAL LABORATORY

National Cost-Effectiveness of ANSI/ASHRAE/IES Standard 90.1-2016

April 2020

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Executive Summary

The U.S. Department of Energy (DOE) Building Energy Codes Program supports the technical analysis and implementation of building energy codes and standards, 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 for commercial and residential buildings. Through consensus-based code development processes, such as those administered by ASHRAE[1] and the International Code Countil (ICC), DOE provides technical analysis of potential code revisions and amendments, thus 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 2016 edition of ANSI/ASHRAE/IES[2] Standard 90.1,[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 90.1-2016, compared to the previous 90.1-2013 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 90.1-2016, 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 previously determined under the development of Standard 90.1-2016, as described below.

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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 (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010)
[3] ASHRAE. 2016. *ANSI/ASHRAE/IES 90.1-2016*, *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.

The current analysis builds on previous PNNL analyses (as outlined in Section 5.2) of the energy use and energy cost saving impacts of Standard 90.1-2016. The overall energy savings analysis used a suite of 16 prototype EnergyPlus[1] building models[2] simulated across all 16 U.S. climate zones. The detailed methodology and overall energy saving results from Standard 90.1-2016 are documented in the DOE technical report titled *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016*.[3]

The cost-effectiveness analysis presented in this report used a subset of prototype models and climate locations, providing coverage of the changes in Standard 90.1 from the 2013 to 2016 edition that affect energy savings, equipment and construction costs, and maintenance, including conventional HVAC systems used in commercial buildings. The individual changes included in the analysis are detailed in Section 3.0. The following prototype buildings and climate locations 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	

The subset of selected prototypes represents the energy impact of five of the eight commercial principal building activities and account for 74% of new construction by floor area. The five climate locations are from the set of representative cities approved by the SSPC 90.1 for establishing criteria for 90.1-2016. These climate locations were also used in the determination of energy savings of Standard 90.1-2016[1] and are different from those used in previous analyses. 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.

[1] Available at https://energyplus.net
[2] Download from http://www.energycodes.gov/development/commercial/90.1_models
[3] DOE. 2018. "Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016". U.S. Department of Energy, Washington D.C. https://www.energycodes.gov/sites/default/files/documents/02202018_Standard_90.1-2016_Determination_TSD.pdf
[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 summarizes the cost-effectiveness results. Findings demonstrate that the 2016 edition of Standard 90.1 is cost-effective overall (relative to the 2013 edition) under the LCCA and SSPC 90.1 Scalar Method for all representative prototypes and climate locations. The weighted results for building types, climate zones, and the U.S. as a whole, are based on construction weighting factors described in Section 2.4.

Table ES.1. Summary of Cost-Effectiveness Analysis

Prototype Model	Climate Zone and Location					
Life Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	$2.20	$2.17	$2.21	$1.88	$2.19	$2.13
Large Office	$0.95	$1.08	$0.43	$1.34	$1.59	$1.18
Standalone Retail	$12.54	$12.40	$12.16	$12.22	$12.08	$12.28
Primary School	$5.46	$5.62	$4.23	$5.00	$5.74	$5.32
Small Hotel	$5.99	$5.80	$5.51	$6.00	$6.44	$6.03
Mid-rise Apartment	$2.06	$1.96	$2.02	$1.68	$2.54	$2.03
Weighted Total	$6.63	$7.00	$6.01	$5.91	$7.57	$6.68
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	2.1	2.0	1.9	4.1	2.1	2.4
Large Office	6.9	6.6	10.2	7.1	4.9	6.8
Standalone Retail	6.6	7.0	7.6	7.8	7.8	7.3
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	1.1	0.1	0.03
Scalar Ratio, Limit = 18.25[1]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	Weighted
Small Office	1.26	1.11	0.91	3.30	1.08	1.55
Large Office	8.47	8.11	10.63	8.43	5.12	8.07
Standalone Retail	(46.36)	(51.93)	(62.66)	(53.77)	(60.57)	(54.73)
Primary School	(6.99)	(5.82)	(7.01)	(3.69)	(5.86)	(5.78)
Small Hotel	(16.34)	(17.24)	(18.79)	(15.26)	(13.92)	(15.85)
Mid-rise Apartment	(17.61)	(17.95)	(18.21)	(15.45)	(22.19)	(18.08)
Weighted Total	(21.64)	(24.83)	(27.95)	(21.56)	(33.51)	(25.74)

[1.] 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.

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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. The authors would like to thank the members of the ASHRAE Standing Standard Project Committee (SSPC) for 90.1 for their review of the cost estimates. 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, including Ellen Franconi, Matthew Wilburn, and Rosemarie Bartlett.

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Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
Btu	British thermal units
Btu/h	British thermal units per hour
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CFL	compact fluorescent lamp
CFM	cubic feet per minute
CHW	chilled water
DOE	U.S. Department of Energy
DX	direct expansion
EMS	Energy Management System
ESC	Envelope Subcommittee (90.1 SSPC)
ERV	energy recovery ventilator
Et	thermal efficiency
FEMP	Federal Energy Management Program
HVAC	heating, ventilating, and air conditioning
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
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
SWH	service water heating
VAV	variable air volume
VSD	variable speed drive
w.c.	water column
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 documents 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 90.1-2016, Energy Standard for Buildings Except Low-Rise Residential Buildings*, the national model energy standard for commercial buildings. The 2013 and 2016 editions of Standard 90.1 are the primary focus of this report (ASHRAE 2013a; 2016). These standards are referred to as 90.1-2013 and 90.1-2016 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 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.[1]

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 90.1-2016 as a whole, compared to the previous edition, based on the established life-cycle cost analysis (LCCA) methodology. Through this action, DOE seeks to provide states with cost-effectiveness information to aid in adopting updated editions of commercial energy codes based on Standard 90.1 and for use in the development of future

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

editions of the Standard. The cost-effectiveness analysis of Standard 90.1-2016, compared to the previous 2013 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 December 2019—applicable energy standard or code that most closely matches the state's regulation (DOE 2019).

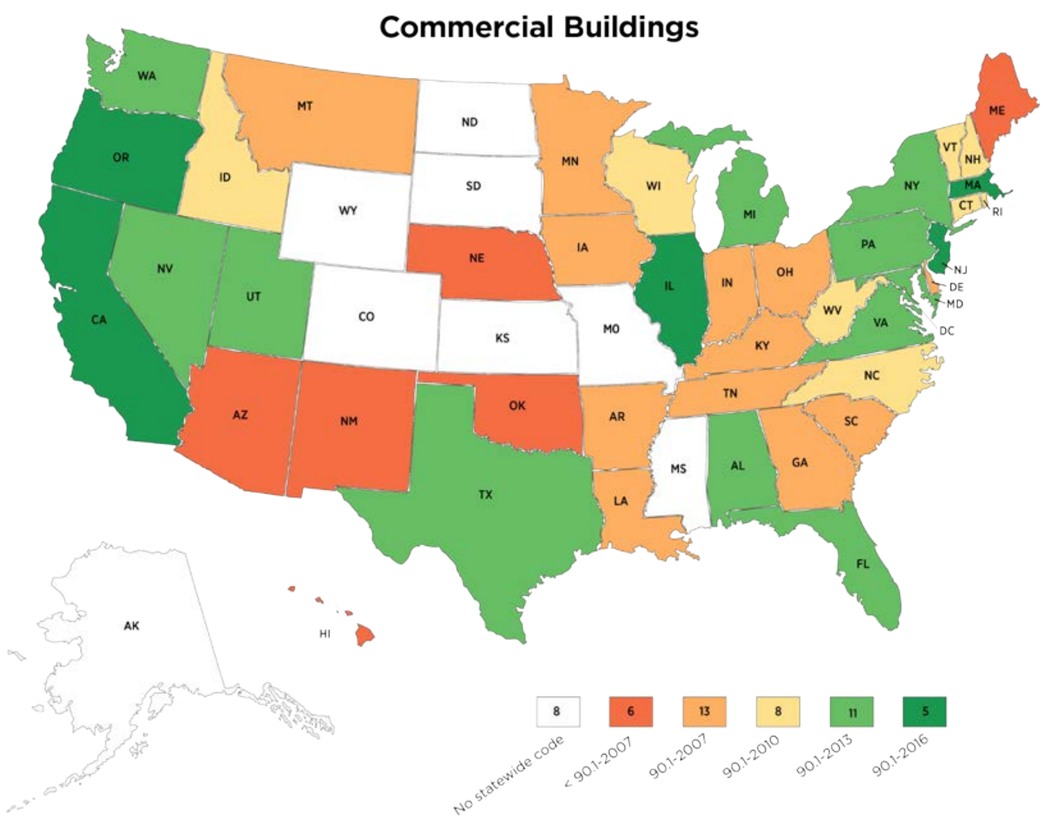

Figure 1.1. Commercial Building Energy Code Adoption Status (December 2019)

1.2 Contents of the Report

This report documents the approach and results for PNNL's analysis of the cost-effectiveness of 90.1-2016 compared to 90.1-2013. 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 (Thornton et al. 2013; Hart et al. 2015). The cost-effectiveness analysis began with the energy savings analysis for development of 90.1-2016, 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 two 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[2] (Halverson et al. 2014; DOE 2018a,b).

Six prototypes and five climate locations were chosen from those used for the energy savings analysis to represent the building construction, energy, and maintenance cost impacts of the changes from 90.1-2013 to 90.1-2016. Chapter 2 provides an overview of the selected prototypes and climate locations used for this analysis. Chapter 3 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 Chapter 4, with a summary of the incremental costs provided. An expanded summary of the incremental costs is also included in Appendix B of this report. The complete cost estimates are available in the spreadsheet *Cost-effectiveness_analysis_ASHRAE_90.1-2016.xlsx* (PNNL 2020). The cost-effectiveness analysis methodology and results are presented in Chapter 5.

The report has three appendixes. Appendix A includes prototype building descriptions for the six prototypes considered, adapted from *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*. Appendix B includes a summary of incremental cost estimate data. Appendix C includes the energy analysis results for 90.1-2016 compared to 90.1-2013.

[2] 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 90.1-2016 compared to 90.1-2013. The analysis used 16 prototype building models that were simulated in 16 climate locations, and developed in collaboration with SSPC 90.1. These prototype models, their development, and the climate locations are described in detail in the quantitative determination and are available for download (DOE 2018a). PNNL selected six of the prototype buildings and developed cost estimates for them 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 Chapter 5 and Appendix C.

2.1 Selection of Prototype Buildings

Six of the 16 prototype models were selected for the cost-effectiveness analysis and are shown in bold font in Table 2.1. They were chosen because they:

- 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 HVAC systems represented in the prototypes
- capture 15 of the 23 addenda that were included in PNNL's simulation of energy savings for 90.1-2016; the remaining eight addenda affect prototypes not included in the cost-effectiveness analysis, as discussed in Section 3.0
- represent the energy impact of five of the eight commercial principal building activities that account for 74% 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

Table 2.2 shows the six prototypes used and their corresponding HVAC systems.

Table 2.2. HVAC Systems in Selected Prototype Models

Building Prototype	Heating	Cooling	Main System
Small Office	Heat pump	Unitary direct expansion (DX)	Packaged constant air volume (CAV)
Large Office	Boiler	Chiller, cooling tower	Variable air volume (VAV) with hydronic reheat
Standalone Retail	Gas furnace	Unitary DX	Packaged CAV
Primary School	Boiler/Gas furnace	Unitary DX	Packaged VAV
Small Hotel	Electricity	DX	Packaged terminal air conditioner (PTAC)
Mid-rise Apartment	Gas furnace	DX	Split DX system

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. They cover the entire United States, as shown in Figure 2.1 (ASHRAE 2013b).

For analysis of 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 represent only areas outside the United States.

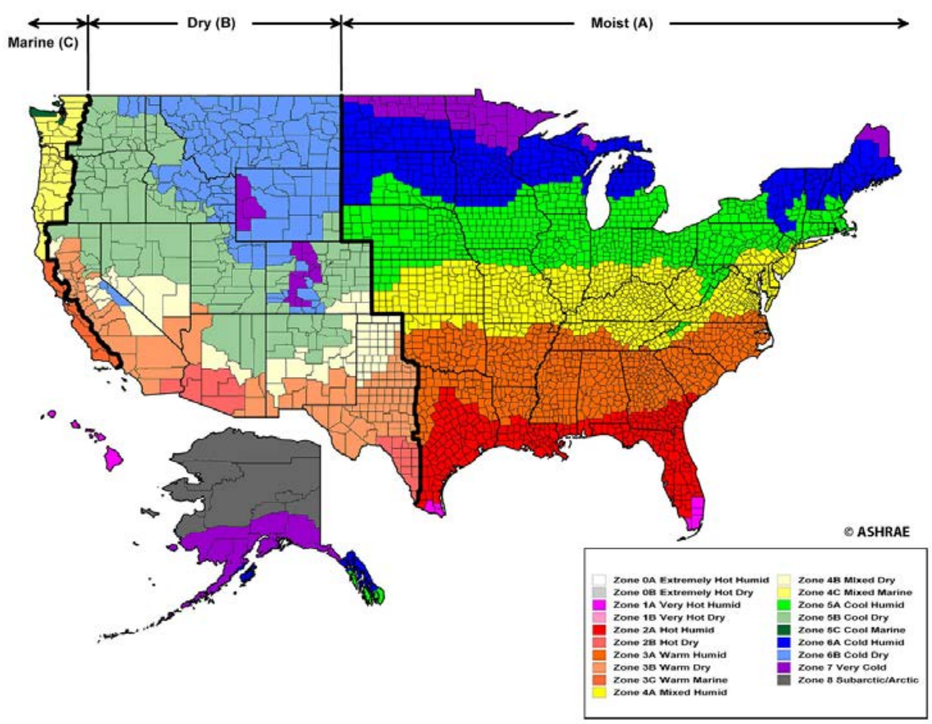

Figure 2.1. United States Climate Zone Map

[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.

The cities representing climate zones are listed in Table 2.3 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 from those used in previous analyses. These new climate locations are also consistent with those used in the determination of energy savings of Standard 90.1-2016 (DOE 2018b).

Table 2.3. 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 2.4 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. Included in Appendix A are profiles of each of the selected prototypes. These six profiles and similar profiles for the other 10 prototypes as well as the EnergyPlus input files and detailed modeling information for all the prototypes are available for download[2] (DOE 2018).

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

Table 2.4. Overview of Six Selected Prototypes

Building Prototype	Floor area (ft²)	Number of Floors	Window to Wall Ratio (WWR)	Floor-to-Floor Height (ft)	Roof	Exterior Wall	Occupancy (people/ 1,000 ft²)	Plug Loads (W/ft²)	Interior Lighting 2013 (W/ft²)	Interior Lighting 2016 (W/ft²)	Exterior Lighting 2013 (kW)	Exterior Lighting 2016 (kW)
Small Office	5,500	1	15%	10	Attic and Other	Wood Framed	5.6	0.63	0.82	0.79	0.94	0.61
Large Office	498,640	12[1]	40%	13	Insulation above deck	Mass	5.0	0.73	0.82	0.79	56.28	39.97
Standalone Retail	24,690	1	7%	20	Insulation above deck	Mass	15.0	0.50	1.32	1.13	4.74	3.37
Primary School	73,970	1	35%	13	Insulation above deck	Steel Framed	20.0	1.00[3]	1.05	0.84	3.49	2.38
Small Hotel	43,210	4	11%	9 11[2]	Insulation above deck	Steel Framed	6.0	0.95[3]	0.87	0.76	4.18	2.82
Mid-rise Apartment	33,740	4	20%	10	Insulation above deck	Steel Framed	2.3	0.56	0.53	1.31	2.55	1.65

[1] These buildings also include a basement that is not included in the number of floors
[2] First floor only
[3] Excludes any kitchen and or laundry electrical equipment

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. This data represents all new buildings, as well as additions to existing facilities, over a period of five years (2003-2007), and based on a set of 254,158 individual records of commercial building construction across the U.S. covering a total of 8.2 billion square feet. Details of their development are further discussed in a PNNL report (Jarnagin and Bandyopadhyay 2010).

Note that the climate zone assignments to individual U.S. counties were changed between 90.1-2013 and 90.1-2016 as discussed in Section 4.3. To match the new climate zone assignments, the construction weights used in this analysis were revised from previous analyses. New construction weights were determined for each building type in each climate zone based on the new county-climate zone mapping. 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 the determination report (DOE 2018b). For this analysis, the weightings for the selected prototypes and climate zones were normalized to the weightings shown in Table 2.5.

Table 2.5. 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	3.8%	1.3%	7.9%	3.3%	1.0%	4.0%	21.3%
3A	3.4%	1.6%	8.4%	3.2%	0.9%	2.7%	20.2%
3B	1.6%	0.9%	4.2%	1.5%	0.4%	2.9%	11.4%
4A	2.8%	3.5%	8.3%	2.9%	1.1%	5.3%	23.9%
5A	2.9%	1.5%	11.1%	2.7%	1.1%	3.8%	23.2%
U.S. Average	14.5%	8.9%	39.8%	13.6%	4.5%	18.6%	100.0%

Using the energy saving results from each building simulation, the incremental costs and 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.

3.0 Cost Estimate Items from 90.1-2013 Addenda

Of the 121 addenda included in 90.1-2016, 23 were considered to have quantifiable energy savings represented in the prototypes. Of those, 21 were modeled in DOE's 90.1-2016 determination and are described in more detail in the report documenting the determination quantitative analysis (DOE 2018b). The two that were not modeled for the determination analysis mirror federal appliance standards regulations. However, these two addenda and their associated savings are included in the cost-effectiveness analysis because they do have the potential to impact cost. The remaining 98 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 23 addenda with quantified savings, 15 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.

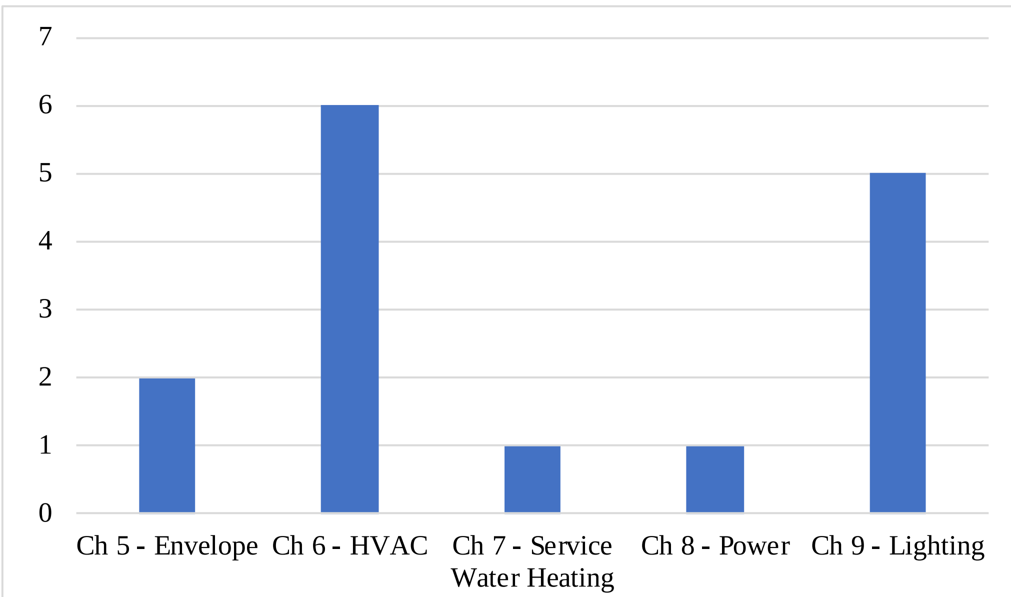

Figure 3.1. Quantity of Addenda Included in the Cost Estimate by Standard 90.1 Chapter

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 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 to 90.1-2013 is named according to a convention that begins with 90.1-13, followed by the letter identifier of the addendum (e.g., 90.1-13bb). In text it may be referred to by just the letter designation: *bb*.

Table 3.1. Addenda Included in Cost-Effectiveness Analysis

90.1 Addenda	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
	Standard 90.1 Chapter 5 Envelope						
		X	X	X	X	X	X
90.1-13ai	Prescribes lower solar heat gain coefficient (SHGC) for vertical fenestration in climate zone 0 and lower U-factors for vertical fenestration in climate zones 4 through 8.	X	X	X	X	X	X
90.1-13bc	Lowers U-factor criteria for doors.	X	X	X	X	X	
	Standard 90.1 Chapter 6 Heating Ventilating and Air Conditioning						
90.1-13d	Requires deeper thermostat setback for networked guestrooms or those unoccupied for more than 16 hours/day. Also requires ventilation to be turned off when guestrooms are unoccupied.					X	
90.1-13i	Eliminates separate cooling capacity thresholds for requiring an economizer in computer rooms. Computer rooms will be required to follow the same thresholds as comfort cooling applications.		X				
90.1-13j	Requires variable air volume (VAV) system ventilation optimization even when energy recovery ventilator (ERV) is installed.		X		X		
90.1-13u	Applies transfer air requirements more broadly than to just kitchen exhaust systems and clarifies the allowed sources of transfer air.				X		
90.1-13bj	Establishes minimum chilled water coil selection temperature difference.		X				
90.1-13dd	Generally reduces the threshold for variable flow pumping requirements for chilled water pumps and adds requirement for heating water pumps.		X		X		
	Standard 90.1 Chapter 7 Service Water Heating						
90.1-13by	Requires insulation of the first 8 feet of branch piping from recirculating service water heating (SWH) systems.		X		X	X	
	Standard 90.1 Chapter 8 Power						
90.1-13bt	Updates transformer efficiency requirements.		X		X		
	Standard 90.1 Chapter 9 Lighting						
90.1-13ah	Clarifies that all lighting, including egress lighting on emergency circuits, shall be turned off when the space is unoccupied with 0.02 W/ft^2 allowed as an exception.	X	X	X	X		
90.1-13as	Requires luminaires in parking areas with input power greater than 78W and mounting height less than 24 ft to reduce power by 50% in response to occupancy.	X	X	X	X		

90.1 Addenda	Description	Small Office	Large Office	Standalone Retail	Primary School	Small Hotel	Mid-rise Apartment
90.1-13cg	Reduces exterior lighting power allowances.	X	X	X	X	X	X
90.1-13ch	Reduces interior lighting power allowances.	X	X	X	X	X	X
90.1-13do	Adds efficacy requirements for lighting installed in dwelling units.						X

3.2 Addenda Not Included in Cost-Effectiveness Analysis

For the remaining eight addenda identified as saving energy in the determination analysis, one—the climate zone change addendum—is not explicitly modeled as discussed below.The remaining seven addenda affect prototypes not included in the six selected for the cost-effectiveness analysis or not applicable to the prototypes modeled. These are listed in Table 3.2 along with the reason for non-inclusion.

Climate Zone Shift. Addendum *w* incorporates several changes introduced by the 2013 edition of ASHRAE Standard 169, *Climatic Data for Building Design Standards* (ASHRAE 2013b). ASHRAE 169-2013 reassigned climate zones to U.S. counties based on a more recent period of weather data and also added a new, extremely hot climate zone 0. Approximately 300 U.S. counties out of more than 3,000 were reassigned, most to warmer climate zones.

Addendum *w* references ASHRAE 169-2013 for climatic data and adds a new annex that reproduces multiple sections from ASHRAE 169-2013. It also adds requirements for climate zone 0 throughout the Standard. Climate zone 0 is not found in the United States, so the related requirements in addendum *w* are not applicable to this analysis (see discussion of climate zones in Section 2.2).

The other change in addendum *w*—the reassignment of counties to different climate zones—does have an indirect impact because buildings constructed to ASHRAE 90.1-2016 in counties that were reassigned may now have different requirements from those that would have been in effect before this change, independent of other specific 2016 addenda. The Standard 90.1 committee reviewed these impacts when considering whether to incorporate the updated Standard 169, and Athalye et al. (2016) quantified the energy impact of county-climate zone reassignment. At a national level it was very small, with an increase of 0.18% in the site energy consumption of buildings compared to those compliant with ASHRAE 90.1-2013. In this analysis, the change in requirements due to climate zone reassignment between the 2013 and 2016 editions of the Standard are not captured and both are modeled as having the same climate zone assignments. As discussed in Section 2.4, the construction weights by climate zone used in this analysis were revised from previous analyses. These new construction weights were applied to both the baseline and advanced cases.

Table 3.2. Addenda Not Included In Cost-Effectiveness Analysis

90.1 Addenda	Description	Reason
90.1-13al	Prescribes air leakage criteria for metal coiling doors in semi-heated spaces.	Addendum applies to Warehouse prototype, which is not modeled in the CE analysis.
90.1-13w	Refers 90.1 to new climatic data based on Standard 169-2013 resulting in changes to climate zone assignments for some locations, the creation of a new climate zone 0, and the addition of criteria for climate zone 0. Adds method for rating the solar reflectance index of walls with glass spandrel area and adjusts criteria for minimum skylight area in climate zone 0.	This change indirectly affects how climate zones are defined and applied through Standard 90.1. For example, the recent update shifted a relatively small number of locations to warmer climate zones where they were typically subject to less stringent insulation requirements, therefore increasing energy use in those instances. The analysis used the new climate zones for both the 90.1-2013 and 2016 cases, so there was no calculated energy savings attributable to this addendum.
90.1-13ci	Modifies fenestration orientation requirements.	Addendum applies only to Restaurant prototype as other buildings have long exposure to the south. This prototype is not modeled in the CE analysis.
90.1-13ca	Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp. Eliminates the exception for climate zones 1 and 2.	Addendum applies only to High-Rise Apartment prototype, which is not modeled in the CE analysis.
90.1-13ce	Raises minimum threshold for energy recovery.	Addendum does not impact any prototypes modeled in the CE analysis.
90.1-13cq	Bases variable speed thresholds for heat rejection fans on motor power, including service factor.	Addendum applies only to High-Rise Apartment prototype, which is not modeled in the CE analysis.
90.1-13dq	Reduces retail display lighting adder.	Addendum only applies to Strip Mall prototype, which is not modeled in the CE analysis.
90.1-13cv	Increases motor efficiencies.	Addendum applies only to motors greater than 200 hp, which are not included in any of the prototypes modeled in the CE analysis.

CE is cost-effectiveness.

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 90.1-2013 and 90.1-2016. 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 2018 time frame, and earlier estimates are adjusted with equipment-specific inflation factors. Costs are for national average construction, and 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 2018b). 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 B of this report. The cost estimates are available in the spreadsheet *Cost-effectiveness_analysis_ASHRAE_90.1-2016.xlsx* (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, 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 2018a,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 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 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 (e.g., HVAC). 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 controls items. These earlier cost estimates from 2012 and 2014 have been adjusted to 2018 values by applying inflation factors developed using RS Means Cost Handbooks from 2012, 2014 and 2018 (RS Means 2012a,b,c, 2014a,b,c, 2018a,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).

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.*
HVAC Ductwork, piping, selected controls items	MEP consulting engineers provided ductwork and plumbing costs based on one-line diagrams they created, and the model outputs, including system airflows, capacity and other factors, and provided detailed costs by duct and piping components using *RS Means 2012*. The MEP consulting engineers also provided costs for several control items.* Additional items were costed using *RS Means 2018*.
HVAC Selected items	PNNL utilized staff expertise and experience supplemented with online sources.*
Lighting Interior lighting power allowance and occupancy sensors	PNNL staff with oversight from a member of 90.1 LSC. Product catalogs were used for consistency with some other online sources where needed.
Lighting Exterior lighting	PNNL staff with oversight from a member of 90.1 LSC. Product catalogs were used for consistency with some other online sources where needed.
Envelope; Opaque insulation and fenestration	Costs dataset developed by specialist cost estimator with additional input from the 90.1 ESC.*
Commissioning	Cost estimator, RS Means, MEP consulting engineers, or PNNL staff expertise.
Labor	*RS Means 2018* 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	From the originator of the other costs for the affected items, or PNNL staff expertise.

* Where detailed costs were developed in 2012 or 2014, they were updated to 2018 using equipment-specific inflation factors developed from RS Means handbooks.

4.1.2 Cost Parameters

Several general parameters were applied to all of 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 is 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 2018* or other sources.

Table 4.2. Cost Estimate Adjustment Parameters

Cost Items	Value[1]	Description[2]
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, and sales taxes. 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 are added to the subcontractor subtotal as an alternative to calculating detailed general contractor costs (RS Means 2018c).

1 Values shown and used are rounded to first decimal place.
2 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
   c. Exterior lighting
4. Envelope, power, and other cost estimates
5. Cost estimate summaries and cost-effectiveness analysis results

4.2 Cost Estimate Descriptions

Cost estimate items are tied to each specific 90.1-2013 addendum listed in Table 3.1 and as identified in the descriptions of the cost items in this section. The remaining portion of this section provides more detailed descriptions of the additional information developed to establish the basis for estimating costs, as well as information about the cost estimates themselves. These are organized in five major sections: (1) building envelope, (2) HVAC, (3) lighting, (4) service water heating, and (5) power.

4.3 Modeling of Individual Addenda

This section details the modeling of the 15 addenda to Standard 90.1-2013 simulated for the quantitative analysis. The procedures for implementing the addenda into the prototype models include identifying the changes to the prototypes required by each addendum, developing model inputs to simulate those changes, applying those changes to the prototype models, running the simulations, and extracting and post-processing the results. This section explains the addenda and their impact on energy savings, the modeling strategies, and the development of the simulation inputs for EnergyPlus. The terms “baseline” and “advanced” or “target” are used in some cases to describe the modeling of the addenda. The baseline case is Standard 90.1-2013 and the advanced case is Standard 90.1-2016. In some instances, a new addendum to Standard 90.1-2013 identifies the need for a change to baseline 2013 models. There are generally two reasons why a baseline change was necessary: (1) in the course of modeling an addendum, an opportunity to increase the accuracy of the simulation was identified and (2) to add additional detail to the models so that the impact of a particular addendum could be captured. For example, prior to simulation of the 2016 standard, exterior doors were not explicitly simulated in most of the prototypes. In order to accurately simulate addendum *bc*, which reduced door factor requirements, explicit modeling of exterior doors was added to most prototypes.

The climate zone reassignment addendum (*w*) impact is not explicitly modeled, as it applies to both the base and target codes as described in Section 3.0. It does represent a change in baseline, since 90.1-2013 was modeled with the re-assigned climate zones, as was 90.1-2016.

4.3.1 Building Envelope

Building envelope addenda included both an improvement in door insulation and changes in requirements to reduce fenestration heat loss and heat gain.

4.3.1.1 Fenestration U-factors and SHGC

Location in 90.1-2016:	Tables 5.5-0 through 5.5-8
Addendum:	90.1-13ai
Prototypes Affected:	All

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

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

To determine the incremental cost of the changes introduced to the prototype models by addendum 90.1-13ai, cost estimates compiled by a cost estimating consultant were used. The ESC of ASHRAE SSPC 90.1 compiled a list of assemblies for which they desired cost estimates. These assemblies included those required by addendum 90.1-13ai along with more and less stringent assemblies. PNNL collected costs for these assemblies by contracting with a consultant who specializes in construction cost estimation. The cost estimates provided by the consultant were sufficient to calculate all the incremental costs incurred from the requirements of addendum 90.1-13ai. In the estimates, fenestration costs are specified per square foot of the component area. Labor costs and total costs including overhead and profit are also provided.

It is more difficult to develop cost estimates for fenestration improvements than for opaque envelope improvements, mainly because the requirements can be met by a number of different fenestration assemblies. For example, a lower U-factor for metal-frame fixed windows could be achieved through improved glazing, an improved gas layer, or an improved frame. The way a lower U-factor is met has significant impact on the cost. The cost consultant's estimates have costs for a limited number of glazing and gas layer combinations (a glazing unit) and costs for a few frame types. Costs are also provided for a few combinations of frame types (e.g., metal fixed without thermal break and metal fixed with thermal break) and a single type of glazing (e.g., low-e, 1 in. double glazing with ½ in. air space). The cost estimates from the consultant were evaluated as a group to contrast the incremental cost of going from one frame type to another while keeping the same glazing unit. This incremental frame cost was used to develop the cost of fenestration assemblies that were not covered in the consultant's estimates. The cost of a new fenestration assembly was calculated as follows:

1. The cost of the glazing unit was subtracted from each of the complete assembly costs. The remaining cost would be that of a frame without a glazing unit.
2. The cost of individual glazing units was added to the frame cost in step 1 to determine the cost of a new fenestration assembly.

To model fenestration requirements in the prototypes, the U-factor for the four frame types in each climate zone was weighted by the respective fraction typically found in each of the prototype buildings (Thornton et al. 2011). This produced a weighted fenestration U-factor used for modeling. The SHGC prescribed by Standard 90.1 is the same for all frame types. Costs were developed for each frame type, prototype, and Standard edition, and then combined per the weighting factors. The following steps describe the process used to determine the fenestration cost for the 90.1-2013 and 90.1-2016 models.

1. The U-factor and SHGC for each prototype and Standard edition were determined.
2. Data from Tables 4 and 10 in Chapter 15 (Fenestration) in the *ASHRAE Handbook of Fundamentals 2013* (ASHRAE 2013c) were used to determine the fenestration assembly that just met the Standard requirements. It was found that all the U-factor requirements could be met using insulated double glazing units.
3. Using the fenestration glazing and frame assembly determined in step 2, the cost was determined using the consultant estimates or the new fenestration assembly costs developed from the consultant estimates as previously described.

Using the calculated cost per square foot of individual opaque and fenestration assemblies for each prototype in every climate zone, the total cost was then calculated by multiplying the cost per square foot by the area of each component (walls, roofs, windows, etc.) for the prototype. Since these base costs were developed in 2012, product-specific inflation factors were developed by comparing *RS Means Handbook* edition costs and were then used to bring the costs forward to 2018.

4.3.1.2 Door U-factors

Location in 90.1-2016:	Tables 5.5-0 through 5.5-8
Addendum:	90.1-13bc
Prototypes Affected:	All but Mid-rise Apartment

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

This addendum affects all prototypes except mid-rise apartment. It involved a baseline change because none of the prototypes have doors that have been explicitly modeled. For all other prototypes, exterior doors were added to capture the impact of this addendum. Assumptions developed previously to calculate exterior lighting power allowance for illuminating doors were used to calculate the number of doors in each prototype. These assumptions are based on the National Commercial Construction

Characteristics (NC^3) database (Richman et al. 2008). Only opaque doors were added to capture the impact of addendum *bc*; glass doors were not considered. The number of opaque doors added to each prototype are summarized in Table 4.3. Swinging doors were assumed to be 7 ft tall by 3 ft wide, and rollup doors were assumed to be 10 ft tall by 8 ft wide. Note that exterior doors in the Mid-rise Apartment are primarily sliding glass doors that are treated as fenestration.

Table 4.3. Number of Opaque Doors Added to Prototypes

Prototype	Number of Swinging Doors Added	Number of Rollup Doors Added
Large Office	12	0
Small Hotel	3	0
Primary School	25	0
Standalone Retail	8	5
Small Office	2	0

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

1. Doors were not placed in exterior bathroom zones.
2. A few prototypes, such as the Large Office and Primary School, have ribbon windows spanning the entire perimeter. For these prototypes, adding doors required a break in the ribbon window. In such cases, the sill height of the window was lowered to ensure that the total glazed area remained the same, and so that there was no impact on the daylight area.
3. Zones with daylighting controls have photosensors; in such zones, care was taken to not place an opaque door near the daylighting sensor.
4. The addition of doors only changed the U-factor of the overall wall, since doors typically have more heat loss than opaque wall assemblies. Infiltration was not changed, as infiltration factors in the base models are based on buildings with typical doors.

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

Costs for different levels of door insulation were acquired from online building supply web sites such as lowes.com and combined with base costs from *RS Means 2018* (Lowes 2018).

4.3.2 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 90.1-2013 and 90.1-2016 for corresponding prototype and climate location models. Costs for capacity changes for HVAC system and plant equipment are described together in Section 4.3.2.1 of this report.

Other cost estimates were tied to specific 90.1-2013 addenda. In some cases there was a net decrease in HVAC costs due to the decreased cost from reductions in system capacity, airflow, and water flow offsetting the 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 the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For example, the change in equipment capacity requires costs for different equipment sizes. Costs for various sizes of equipment were obtained during the previous analysis. For this round of analysis, costs for HVAC items from the previous analysis were brought forward to 2018 costs by applying inflation adjustment factors that were calculated by comparing corresponding items in *RS Means 2014* and *RS Means 2012 to RS Means 2018*.

4.3.2.1 HVAC System and Plant Equipment Capacity Changes

Location in 90.1-2016:	Not covered by a specific section in 90.1-2016
Addenda:	None, but affected by all addenda that impact space HVAC loads such as LPD, 90.1-13ai
Prototypes Affected:	All

Costs were estimated to address changes in HVAC system and plant equipment capacity between the 90.1-2013 and 90.1-2016 prototype models. HVAC equipment capacity changes result from reductions in heating and cooling loads due to changes in opaque envelope insulation, fenestration U-factor, and SHGC requirements, lighting power, and lighting controls. 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. As mentioned earlier, these costs were developed originally for the analysis that compared the cost-effectiveness of 90.1-2010 with 90.1-2007. For capacity changes going from 90.1-2013 to 90.1-2016, the same costs were used but were brought forward to 2018 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 2014* or *RS Means 2012* with those in *RS Means 2018*. Labor costs were updated by using current labor crew rates from *RS Means 2018*.

Many of the HVAC capacity-related equipment costs in the component cost worksheet are the same for 90.1-2013 and 90.1-2016 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. In the case of central plant equipment, required efficiency increases were captured along with changes in capacity. Ductwork and piping cost results were calculated separately as a total cost for each combination of prototype and climate location, and values for 90.1-2013 and 90.1-2016 are different, relative to system airflow or water flow.

Piping and ductwork costs were developed for the previous analysis by the 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 2018 by applying an inflation factor. Most of the incremental differences from 90.1-2013 to 90.1-2016 are based on changes in load and airflow and 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 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 Chicago climate location the 90.1-2007 material cost is $5,561 and the 90.1-2010 cost is $5,573. More detailed costs are shown in the associated cost 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 2018 with separate inflation factors for material and labor.

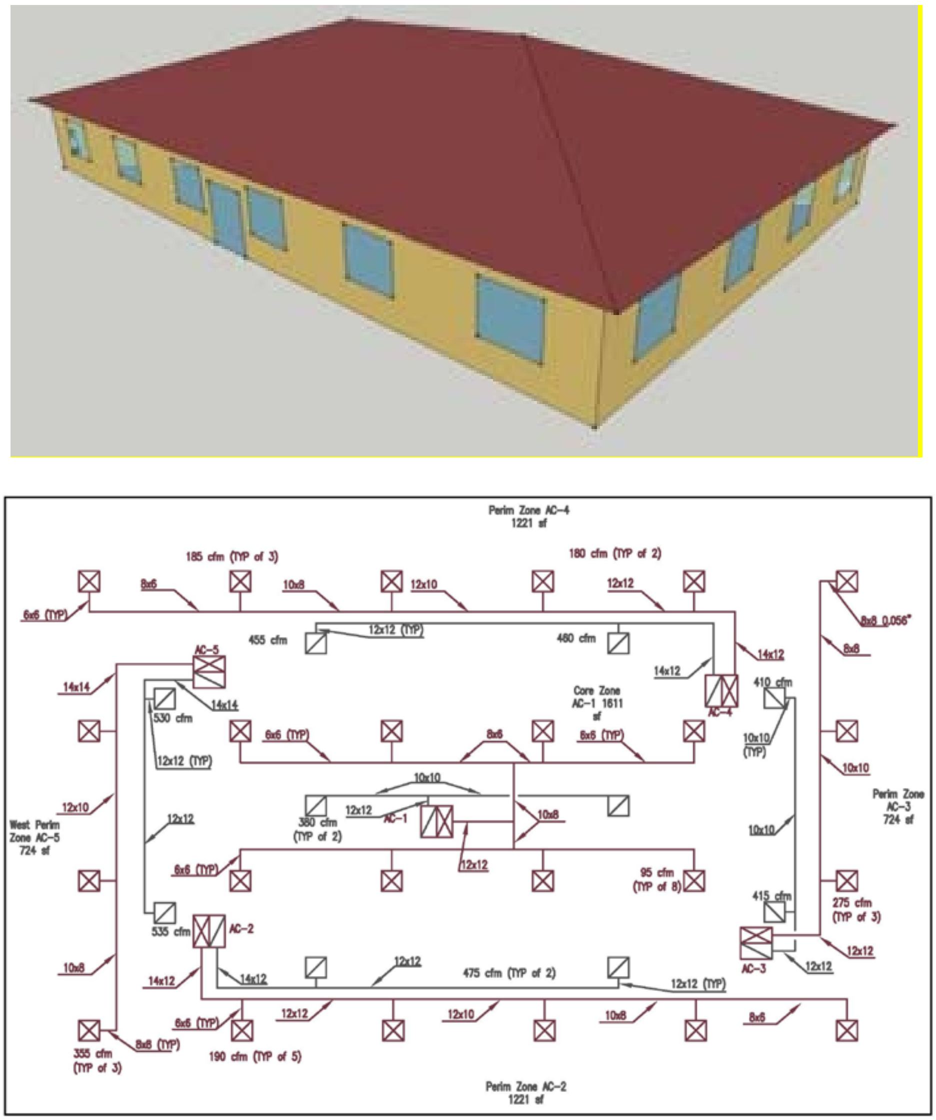

Figure 4.1. Small Office Air Distribution System

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	

4.3.2.2 Hotel Guest Room Controls

Location in 90.1-2016: Section 6.4.3.3.5

Addendum: 90.1-13d

Prototypes Affected: Small Hotel

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

This addendum only impacts the Small Hotel prototype. The Small Hotel already had separate blocks of vacant guest rooms and has 65% occupancy on average. The ventilation for rented rooms is turned off 6 hours per day, and the ventilation for unrented rooms is turned off 23 hours per day, with a 1-hour daily ventilation purge. Lighting schedules remained the same as lighting controls were affected by a previous addendum in the last cycle. The baselines had minor temperature setback in occupied rooms, as this was previously required in the general thermostat requirements. The temperature setpoints and ventilation operation for the various modes are as shown in Table 4.5.

Table 4.5. Addendum d Guest Room Setpoints and Ventilation Control

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

Costs are based on the incremental cost analysis developed when the proposal was made to SSPC 90.1. Using a combination of unit costs from manufacturer reports, hospitality industry representatives, and *RS Means,* both stand alone and central exhaust system cost estimates were developed.

4.3.2.3 Separate Computer Room Economizer Thresholds Eliminated

Location in 90.1-2016: Section 6.5.1

Addendum: 90.1-13i

Prototypes Affected: Large Office

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

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

Costs are developed in a similar way to the *HVAC System and Plant Equipment Capacity Changes* described in Section 4.3.2.1. The base economizer costs were applied where required respectively in 90.1-2013 and 90.1-2016, with the differences reflecting the cost impact of this addendum.

4.3.2.4 ERV with Ventilation Optimization

Location in 90.1-2016: Section 6.5.3.3

Addendum:	90.1-13j
Prototypes Affected:	Large Office, Primary School

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

Dynamic ventilation optimization or dynamic ventilation reset was simulated using the mechanical controller object in EnergyPlus. This object has an option to turn on the ventilation rate procedure calculations for optimizing system outdoor airflow in multi-zone VAV systems. Previously, dynamic ventilation reset was only turned on when there was no energy recovery ventilator (ERV) in the system. This was done using an automated process, where Perl[1] scripts read the output of a sizing run and dynamically assign ERVs to systems where necessary, and the final model is simulated again. To implement addendum *j*, an exception was created in the script for 90.1-2016 cases so that dynamic ventilation reset was turned on even when the system required an ERV.

Costs were based on the original costs developed when ventilation optimization was included in 90.1-2010, brought forward to 2018 with controls inflation factors from a comparison of *RS Means 2012* to 2018.

4.3.2.5 Expand Use of Transfer Air

Location in 90.1-2016:	Section 6.5.7.1
Addendum:	90.1-13u
Prototypes Affected:	Primary School

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

Different methods were applied depending on how restrooms were implemented in the prototype models.

- For the Small Hotel and Mid-rise Apartment, the ventilation rate previously calculated for the baseline had transfer air already accounted for relative to restroom exhaust in the spaces, so there was no change.
- For the Large Office prototype there were not separate zones or exhaust fans set up in the baseline for the restrooms; consequently, the minimum damper position according to the multi-space calculation

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

could not be properly determined if transfer air to the restrooms was implemented, so it was not modeled.

- For the Small Office and Standalone Retail prototypes, there were not separate zones or exhaust fans set up in the baseline for the restrooms, and if restrooms were located on the perimeter of the building, transfer air is not likely to meet thermal loads; consequently, the use of transfer air was not modeled.
- In the Primary School prototype, the restrooms were modeled as a separate zone, and transfer air was modeled.

Costs for increased transfer air were a tradeoff. Including transfer louvers in restroom doors was a cost increase, while removing duct runouts and supply air grilles for the restrooms was a cost decrease. Costs were based on *RS Means 2018.*

4.3.2.6 Minimum Hydronic Cooling Coil Design Temperature Difference

Location in 90.1-2016:	Section 6.5.4.7
Addendum:	90.1-13bj
Prototypes Affected:	Large Office

Addendum *bj* requires that hydronic cooling coils be designed for a minimum of 15°F waterside temperature difference at design conditions. The requirement is in a new Section 6.5.4.7. There are several exceptions, such as design airflow rates below 5,000 cfm, high pressure drop coils (>0.70 in.w.c.), constant volume air systems, chiller limitations, convective coils, high design chilled water supply temperatures (≥50°F), and low entering air temperatures (≤65°F). The purpose of this addendum is to reduce system chilled water flow and pump energy use; there is also potential chiller efficiency increase due to greater temperature differences.

To account for the impact of addendum *bj* in the Large Office prototype model, the design waterside temperature difference was increased from the baseline 12°F to 15°F for the coil design in the EnergyPlus model for the advanced cases. Reviewing coil selections for hydronic coils designed for 12°F vs. 15°F temperature difference found that both designs required six-row coils, so there was no cost increase resulting from coil selection for the higher temperature difference. Design airflow and temperature difference remained constant. There is a slight increase in airside static pressure (e.g., from about 0.73 to 0.85 in.w.c. in one example); however, this was not accounted for in the model, as the fan power limit would require that the ductwork or other parts of the fan system be made more efficient to compensate. The higher waterside temperature differential reduces the design chilled water flow, reducing the sizing of the piping and pumps. The cost impact for the change in piping and equipment size was covered in the capacity adjustment calculations described in Section 4.3.2.1.

4.3.2.7 Modified Threshold for VSD Pumps

Location in 90.1-2016:	Section 6.5.4.2
Addendum:	90.1-13dd
Prototypes Affected:	Large Office, Primary School

Addendum *dd* changes the threshold for requiring variable speed drive (VSD) pump control from >5 hp to a threshold that varies by climate zone as shown in Table 4.6. Where formerly only chilled water pumps were covered, large heating water pumps are now included. The requirements are revisions to Section 6.5.4.2.

Table 4.6. Addendum dd Modified Thresholds for VSD Pumps

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

This addendum potentially impacts the following prototypes with hydronic heating or cooling systems: Large Office for heating and cooling and Primary School for heating. The baseline was modified to include a pump motor sizing factor of 1.25 times the required brake horsepower. Heating pumps did not require VSD in the baseline, so pumps are assumed to vary flow by “riding the pump curve.” For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table 4.6. For cooling pumps, the baseline was a VSD when the pump nameplate hp was greater than 5 hp, otherwise riding the pump curve. For 90.1-2016, a variable speed pump is included when the thresholds were greater than the values in Table 4.6.

Where required, the added cost reflects the addition of a VSD to modeled pumps. Costs are sourced from *RS Means 2012* VSD prices, brought forward to 2018 using equipment-specific inflation factors. The base and advanced code pump motor sizes are extracted from the EnergyPlus models.

4.3.3 Lighting

90.1-2016 incorporates a number of addenda that reduce lighting energy usage. Basic LPD allowances were changed for both interior and exterior lighting. Dwelling unit efficacy requirements for residential occupancies were also updated. Control requirement changes included removing the exception for egress lighting from occupancy controls. Exterior lighting requirement changes included both a reduction in allowed power and an expansion of control requirements.

4.3.3.1 Egress Lighting Control

Location in 90.1-2016:	Section 9.4.1.1
Addendum:	90.1-13ah
Prototypes Affected:	Large Office, Small Office, Standalone Retail, Primary School

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

The addendum is not applicable to prototypes with 24-hour operation (Mid-rise Apartment and Small Hotel). Thus, the prototypes where the addendum was applied are: Large Office, Small Office, Standalone Retail, and Primary School.

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

During implementation, several cases were discovered that required special treatment. For the corridor space, which is found in schools and other prototypes, the occupancy is always modeled as zero, and therefore building level occupancy data is used as a surrogate in the EMS program. For the data center in the basement of the Large Office prototype, the addendum is not implemented because the space operates continuously.

Costs were based on additional occupancy sensors and associated relay packs (RS Means 2018b).

4.3.3.2 Parking Area Luminaire Control

Location in 90.1-2016:	Section 9.4.1.4
Addendum:	90.1-13as
Prototypes Affected:	Large Office, Small Office, Standalone Retail, Primary School

Addendum *as* modifies Section 9.4.1.4 and adds two requirements:

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

Prototypes with 24/7 operation, including the Mid-rise Apartment and Small Hotel are considered exempt from the requirements of addendum *as* because the requirement is between the later of midnight or closing and 6:00 am. The Apartment and Hotel are considered not to close and are exempt. For the remaining prototypes (Large Office, Small Office, Standalone Retail, and Primary School), the following steps were followed to implement addendum as:

1. Previously, exterior lighting power was modeled using two exterior lighting objects in EnergyPlus: one for façade lighting and another for entrance and parking lot lighting because of the different lighting control requirements for those exterior lighting categories. For addendum *as*, the lighting power for entrance and parking lots was separated into two objects, one for entrances and another for parking lots. Thus there are now three exterior lighting objects for the 90.1-2016 cases.
2. For entrance door exterior lighting, the automatic reduction was changed from 30% to 50% per the requirements of addendum *as*. This change was implemented simply by changing the lighting schedule value from 0.7 to 0.5 for the applicable hours for the entrance door exterior lighting object.
3. For the parking lot lighting, *Parking Generation* 4th ed. (McCourt and Hooper 2010) was used to determine the fraction of lights that would be off for each hour for each prototype. Using this data, a lighting schedule was formulated that reduced the peak lighting power for the parking lot exterior lighting object.

A review of the requirements found that there was no cost increase for control, as control of 30% of exterior lighting was already required, and the addenda just increased that control to 50% of the affected wattage. Creating that difference is primarily a design and fixture selection decision, as similar control was previously required.

4.3.3.3 Exterior Lighting Power

Location in 90.1-2016:	Sections 9.1.1, 9.1.2, and 9.4.2
Addendum:	90.1-13cg
Prototypes Affected:	Large Office, Small Office, Standalone Retail, Primary School

Addendum *cg* reduces the exterior lighting power allowances for all categories except building facades and:

1. Clarifies that the scope includes all lighting served through the building's electrical service.
2. Exempts public art display lighting.
3. Revises the exterior lighting power allowance table as follows:
   a. Adds allowances for exterior dining areas.
   b. Combines the categories of "Main Entries" and "Other Doors" into a single category of "Pedestrian and Vehicular Entrances and Exits."
   c. Clarifies that the allowance for building facades is applicable for the entire area of the wall being lit.
   d. Clarifies that the allowance for building entrances is also applicable to "Uncovered Entrances."

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

The addendum modifies Sections 9.1.1, 9.1.2, 9.4.2, and Table 9.4.2-2. The exterior lighting allowance in 90.1-2013 and those in addendum *cg* are summarized in Table 4.7. Where more than one lighting zone is shown in Table 4.7, the allowances of the listed lighting zones have been averaged.

Table 4.7. Exterior Lighting Power Allowances for 90.1-2013 and 90.1-2016

	Parking Lots (W/ft^2)		Building Facade (W/ft^2)		Doors (W/linear ft)			
					90.1-2013		90.1-2016	
Lighting Zone	90.1-2013	90.1-2016	90.1-2013	90.1-2016	Main Doors	Other Doors	Main Doors	Other Doors
0	0	0	0	0	0	0	0	0
1	0.04	0.03	0	0	20	20	14	14
2	0.06	0.04	0.10	0.10	20	20	14	14
3	0.1	0.06	0.15	0.15	30	20	21	21
4	0.13	0.08	0.20	0.20	30	20	21	21
2,3	0.08	0.05	0.125	0.125	25	20	17.5	17.5

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

Table 4.8 shows exterior lighting zones selected for each prototype. Where more than one lighting zone is selected, an average of the requirements for the multiple zones is used.

Table 4.8. Exterior Lighting Zones for Prototypes

Prototype	Exterior Lighting Zone
Small Office	2,3
Large Office	4
Standalone Retail	2,3
Primary School	2
Small Hotel	3
Mid-rise Apartment	2,3

The development of assumptions for exterior lighting in prototypes has been described in Thornton et al. (2011). Using the exterior lighting power allowances in addendum *cg*, the total exterior lighting power was calculated for parking lots, building facades, and building entrances for all prototypes. Table 4.9 summarizes the total exterior lighting power for each prototype for 90.1-2013 and for 90.1-2016. The implementation of addendum *cg* was straightforward. The calculated exterior lighting power is assigned to the three exterior lighting objects in EnergyPlus models as described previously in Section 4.3.3.2.

Table 4.9. Exterior Lighting Power in Prototypes for 90.1-2013 and 90.1-2016

Prototype	Parking Lot		Building Entrances		Building Facade	
	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)	90.1-2013 (W)	90.1-2016 (W)
Small Office	713	446	149	115	51	51
Large Office	42,265	26,027	1,037	968	12,979	12,979
Standalone Retail	2,800	1,751	1,528	1,304	316	316
Primary School	881	584	2,351	1,646	151	151
Small Hotel	3,368	2,022	247	225	573	573
Mid-rise Apartment	2,286	1,429	0	0	222	222

The cost analysis for exterior lighting power was based on an LED to LED comparison, as LED lighting is already predominant for exterior lighting. It was found that a reduced power requirement combined with attention to fixture selection generally resulted in a cost reduction for all prototypes.

4.3.3.4 Interior Lighting Power

Location in 90.1-2016: Tables 9.5.1 and 9.6.1

Addendum: 90.1-13ch

Prototypes Affected: All

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

The addendum affects 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 (Table 9.5.1).
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.
4. A room cavity ratio adjustment has been applied to a few small spaces such as corridors, and exercise rooms.

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

The changes in LPD for 90.1-2016 are the result of improving lighting technology and changes to Illuminating Engineering Society (IES) recommended light levels. Changes in existing technology efficacy and choice of technologies result in LPD changes. In spaces or areas with the same fixture and lamp type, lower recommended light levels would result in fewer fixtures, and higher light levels would result in more fixtures. Feedback from the 90.1 LSC suggested that there was a significant technology improvement, primarily the growth in use of LED or light emitting diodes, with some advances in fluorescent technology. This implies that new fixtures may provide adequate illumination with fewer fixtures. Thus, the reduction of LPDs may result from more efficient fixtures that may or may not be more expensive.

In developing the LPD limits, 90.1 LSC design experts determined an appropriate mix of fixture types and lighting sources and the portion of the recommended light level(s) provided by each combination. The mix of lighting technology for each space type was defined for both 90.1-2013 and 90.1-2016. Finally, the combined lamp efficacy, loss factors, and coefficient of utilization values for the various fixtures and sources were used to calculate the wattage needed to provide the recommended level of lighting. When the LPD for a space is increased as a result in an increase in recommended IES lighting levels, no cost increase is included, as 90.1-2016 does not require the building designer to increase the lighting to this level, the Standard just allows the increase.

Each space type or building area type was assigned up to four lighting systems, each of which provided an assigned percentage of the overall total illumination for that space. These percentages determined the quantity per square foot of each fixture and luminaire type and the respective lighting power in watts.

Material and labor costs were estimated for each fixture type and lamp type. These costs were applied to the lighting design information to calculate a cost per square foot for each space type or building area type. In the few cases where the LSC incorporated a significant shift in lighting design philosophy from 2010 to 2013, resulting 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 (including ballast and lamp) costs were primarily determined using Grainger and Goodmart online catalogs (Grainger 2014; Goodmart 2018). *RS Means 2018* was used for labor costs and for a few lighting equipment items not available in the other sources (RS Means 2018b). Besides cost, lamp 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, $/ft^2, was multiplied by the area of each space type represented in each prototype to determine the total interior lighting power cost for each prototype. The model assumed a mixture of fluorescent and LED fixtures. Some of the spaces assume LED in both 90.1-2013 as well as 90.1-2016. Some space types converted from fluorescent to LED fixtures and in some cases, fluorescent fixtures were upgraded to improved fluorescent fixtures with better efficacy.

Replacement life for each lamp and ballast was determined by dividing the lamp or ballast life by the annual full load equivalent hours from the corresponding energy model schedule for the assigned space type. Modeling schedules were described in Halverson et al. 2014 for 90.1-2013 models and did not change for 2016 models. Replacement costs were separated into the different replacement lives; for example, a space type may have included lamp replacement costs every 3 years and every 5 years for two different types of lamps.

4.3.3.5 Dwelling Unit Lamp Efficacy

Location in 90.1-2016: Section 9.4.4

Addendum:	90.1-13do
Prototypes Affected:	Mid-rise Apartment

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

Prior to addendum *do*, lighting in dwelling units, i.e., the Mid-rise Apartment prototype, was based on a Building America Research Index Report[2] from 2005. Since then, a number of other studies have been published with more recent data on typical lighting usage in multifamily buildings. A study by Gifford et al. (2012) was used to update the baseline lighting usage in the two apartment prototypes. The baseline LPD and the mix of lamp types was calculated from the report using the following data:

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

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

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

Costs were based on a comparison of screw-in CFLs vs. incandescent lamps for the proportion of lamps that were changed in the analysis, as described above. Current prices are from www.1000bulbs.com (1000bulbs 2018).

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

4.3.4 Service Water Heating Addenda

SWH included an increase in required piping insulation.

4.3.4.1 Require First 8 feet of SWH Piping Runout to be Insulated

Location in 90.1-2016: Section 7.4.3

Addendum: 90.1-13by

Prototypes Affected: Large Office, Small Hotel, Primary School

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

This addendum impacts the following prototypes with recirculating service hot water systems: Large Office, Small Hotel, and Primary School. The baseline was changed to add the heat loss from runout piping not previously included. The total pipe loss heating use was modified in the EnergyPlus model as shown in Table 4.10.

Table 4.10. Addendum by Service Hot Water Runout Insulation

	Total (Main Loop + Branches with the new method)			
Prototype/Zone	New Total Pipe Heat Loss for 90.1-2004, 2007 (W)	New Total Pipe Heat Loss for 90.1-2010, 2013 (W)	New Total Pipe Heat Loss for 90.1-2016 (W)	Estimated Saving of Addendum *by*, comparing to 90.1-2013 (%)
Large Office	8,376	8,146	7,280	10.6
Primary School	1,065	1,006	970	3.6
Small Hotel	8,432	8,296	7,231	12.8

Costs are based on adding piping insulation to the first 8 feet of runouts from recirculation piping to fixtures in each building, based on pricing from *RS Means 2018*.

4.3.5 Power Addenda

Transformer efficiency requirements were upgraded to match federal requirements.

4.3.5.1 Transformer Efficiency Improvement

Location in 90.1-2016: Table 8.4.4

Addendum: 90.1-13bt

Prototypes Affected: Large Office, Primary School

Addendum *bt* modifies low-voltage dry-type distribution transformer requirements by adding an extra significant digit “0” on the end of the efficiency levels for single-phase transformers and increasing the efficiency levels for three-phase transformers. Addendum *bt* was implemented by using the three-phase transformer efficiency levels in Standard 90.1-2013 for the 90.1-2013 prototypes and the new three-phase transformer efficiency levels in Standard 90.1-2016 for the 90.1-2016 prototypes. No implementation was needed for the single-phase transformers.

This addendum impacts the Large Office and Primary School only. The old and new levels of transformer efficiency for three-phase transformers are shown in Table 4.11.

Table 4.11. Standard 90.1-2013 and Standard 90.1-2016 Three-Phase Transformer Efficiency Levels

KVA	Standard 90.1-2013 Efficiency	Standard 90.1-2016 Efficiency
15	97.0	97.89
30	97.5	98.23
45	97.7	98.40
75	98.0	98.60
112.5	98.2	98.74
150	98.3	98.83
225	98.5	98.94
300	98.6	99.02
500	98.7	99.14
750	98.8	99.23
1000	98.9	99.28

The cost difference for more efficient transformers is based on cost differences estimated in 2012 for a similar efficiency increase, adjusted forward to 2018 based on comparison of *RS Means 2012* and 2018.

4.4 Cost Estimate Results

The cost estimates result in incremental costs for new construction and replacement material, labor, construction equipment plus overhead and profit, as well as maintenance and commissioning. Appendix B 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 of this report, 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 B, 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 90.1-2013 that was greater than the replacement cost for 90.1-2016. The useful lives of corresponding items such as lamps and ballasts may not be the same for the 90.1-2013 and 90.1-2016 cases, so replacement cost values can be positive or negative throughout the 30-year analysis period.

Table 4.12 includes total incremental first costs for each prototype and climate combination in units of total cost and cost per ft^2. Table 4.13 includes estimated total building costs per ft^2 from *RS Means 2018* 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 90.1-2013). As described in Section 4.1 these costs were not adjusted for climate location. In many cases moving from 90.1-2013 to 90.1-2016 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.

Table 4.12. Incremental Initial Construction Costs

Prototype	Value	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo
Small Office	First Cost	$1,197	$1,111	$1,043	$2,178	$1,177
	$/ft²	$0.22	$0.20	$0.19	$0.40	$0.21
Large Office	First Cost	$252,564	$259,401	$190,525	$345,183	$217,025
	$/ft²	$0.51	$0.52	$0.38	$0.69	$0.44
Standalone Retail	First Cost	$20,836	$21,475	$20,972	$22,789	$20,581
	$/ft²	$0.84	$0.87	$0.85	$0.92	$0.83
Primary School	First Cost	-$126,995	-$122,030	-$115,701	-$94,757	-$122,926
	$/ft²	-$1.72	-$1.65	-$1.56	-$1.28	-$1.66
Small Hotel	First Cost	-$108,452	-$108,217	-$107,988	-$104,823	-$106,651
	$/ft²	-$2.51	-$2.50	-$2.50	-$2.43	-$2.47
Mid-rise Apartment	First Cost	-$18,175	-$17,353	-$17,944	-$12,430	-$24,614
	$/ft2	-$0.54	-$0.51	-$0.53	-$0.37	-$0.73

Table 4.13. Comparison of Total Building Cost and Incremental Cost (per ft^2 and percentage)

Prototype	Building First Cost ($/ft²)	Incremental Cost for 90.1-2016				
		2A Tampa $/ft²)	3A Atlanta ($/ft²)	3B El Paso ($/ft²)	4A New York ($/ft²)	5A Buffalo ($/ft²)
Small Office	$205	$0.22 0.11%	$0.20 0.10%	$0.19 0.09%	$0.40 0.19%	$0.21 0.10%
Large Office	$184	$0.51 0.28%	$0.52 0.28%	$0.38 0.21%	$0.69 0.38%	$0.44 0.24%
Standalone Retail	$106	$0.84 0.80%	$0.87 0.82%	$0.85 0.80%	$0.92 0.87%	$0.83 0.79%
Primary School	$206	-$1.72 -0.83%	-$1.65 -0.80%	-$1.56 -0.76%	-$1.28 -0.62%	-$1.66 -0.81%
Small Hotel	$184	-$2.51 -1.36%	-$2.50 -1.36%	-$2.50 -1.36%	-$2.43 -1.32%	-$2.47 -1.34%
Mid-rise Apartment	$194	-$0.54 -0.28%	-$0.51 -0.27%	-$0.53 -0.27%	-$0.37 -0.19%	-$0.73 -0.38%

5.0 Cost-Effectiveness Analysis

The purpose of this analysis is to determine the overall cost-effectiveness of Standard 90.1-2016 compared to the 90.1-2013 edition. Cost-effectiveness was analyzed using the incremental cost information presented in Chapter 4 and the energy cost information presented in this Chapter. 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 C.

5.1 Cost-effectiveness Analysis Methodology

The methodology for cost-effectiveness assessments has been established[1] for analysis of prior editions of Standard 90.1 (Hart and Liu 2015). This report presents a cost-effectiveness assessment using a life-cycle cost analysis (LCCA) and the SSPC 90.1 Scalar Method for the combined changes in Standard 90.1-2013 to 2016 for each of the 30 combinations of prototype and climate evaluated. The commonly used metric of simple payback period is also included.

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] See methodology at: http://www.energycodes.gov/development/commercial/methodology.

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 present value life-cycle cost analysis, the present value of the incremental costs for new construction, replacement, maintenance, and energy of the 2016 edition of Standard 90.1 are analyzed and compared to similar results for the 2013 edition. If the present value cost of the 2016 edition is less than the present value cost of the 2013 edition there is positive net present value savings and Standard 90.1-2016 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 comparison between 90.1-2007 and 90.1-2010 (Thornton et al. 2013) and between 90.1-2010 and 90.1-2013 (Hart et al. 2015). 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 the increasing uncertainty of these costs, the further into the future they are considered.

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 what the value of money today is 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 April 2018 (Lavappa and Kneifel 2018) 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 2018 annual supplement without citation; Lavappa and Kneifel 2018). The mandated procedure would result in a discount rate for 2018 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 2018. The implied long-term average rate of inflation was calculated as -0.2 % (Lavappa and Kneifel 2018). 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[1 4]	3.1%	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2018*, NIST annual update (Lavappa and Kneifel 2018).
Real Discount Rate[2 4]	3.0%	
Inflation Rate[3 4]	-0.2%	
Electricity and Gas Price	$0.1013/kWh, $1.00/therm	SSPC-90.1 for 90.1-2016 scalar
Energy Price Escalation	Uniform present value factors	*Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2018*, NIST annual update (Lavappa and Kneifel 2018).
	Electricity 21.94 Natural gas 23.69	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.

[1] 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.
[2] 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.
[3] 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.
[4] 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 Chapter 4) 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 allowed payback. The simple payback perspective is reported for information purposes only in this analysis, not as a basis for concluding that 90.1-2016 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. However, cost-effectiveness is often 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 18.2 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 with a 40 year life requires the simple payback to be shorter than 18.2 years to be considered cost-effective.

Table 5.2 shows the economic parameters used for the 90.1-2016 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 - %*	4.56*	2.85*
Nominal Discount Rate - %†	9.34	9.34
Loan Interest Rate - %	7.0	7.0
Heating – Natural Gas Price, $/therm	$1.000	
Cooling - Electricity Price $/kWh		$0.1013
Measure Life Example:		
Economic Life - Years	40	40
Scalar Ratio Limit (Weighted: 18.25)	**21.4**	**18.2**

* The energy escalation rate used in the scalar calculation for 90.1-2016 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, while the 90.1 Scalar

Method was developed to evaluate single measures with individual lives. This extended method takes into account the replacement of different components in the total package of 90.1-2016 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 redidual costs, divided by the difference of the energy cost savings and incremental maintenance cost, as shown in this formula:

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

The result is compared to the scalar ratio limit for the 40-year period, 18.25 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 is 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. So 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 18.25 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 18.25 years accounts for the fact that energy savings received in the future is 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 90.1-2016 models compared to the corresponding 90.1-2013 models. The energy costs for each edition of Standard 90.1 were determined previously under the development of Standard 90.1-2016, based primarily on DOE’s determination of energy savings of 90.1-2016. Detailed methodology and overall energy savings results from Standard 90.1-2016 are documented in the DOE technical report titled *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016* (DOE 2018b).

The current savings analysis builds on the 90.1-2016 determination analysis by including savings from equipment efficiency upgrades that are specifically excluded[2] from the determination analysis. Table 5.3 shows the resulting annual energy cost savings, (total and cost/ft^2). Appendix C 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 $1.000/therm for fossil fuel[3] and $0.1013/kWh for electricity. These rates were used for the 90.1-2016 energy analysis, and derived from the U.S. DOE Energy Information Administration data. These were the values approved by the SSPC 90.1 for cost-effectiveness for the evaluation of individual addenda during the development of 90.1-2016.

Table 5.3. Annual Energy Cost Savings, 90.1-2016 Compared to 90.1-2013

Prototype		Climate Zone and Location 2A Tampa	 3A Atlanta	 3B El Paso	 4A New York	 5A Buffalo
Small Office	Total	$569	$555	$561	$531	$563
	$/ft²	$0.10	$0.10	$0.10	$0.10	$0.10
Large Office	Total	$35,838	$38,567	$18,748	$47,896	$44,478
	$/ft²	$0.07	$0.08	$0.04	$0.10	$0.09
Standalone Retail	Total	$3,168	$3,060	$2,757	$2,925	$2,642
	$/ft²	$0.13	$0.12	$0.11	$0.12	$0.11
Primary School	Total	$14,530	$15,383	$11,281	$14,854	$15,644
	$/ft²	$0.20	$0.21	$0.15	$0.20	$0.21
Small Hotel	Total	$6,649	$6,290	$5,749	$6,857	$7,644
	$/ft²	$0.15	$0.15	$0.13	$0.16	$0.18
Mid-rise Apartment	Total	$1,634	$1,537	$1,571	$1,391	$1,794
	$/ft²	$0.05	$0.05	$0.05	$0.04	$0.05

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 90.1-2016 is cost-effective relative to 90.1-2013 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:

[2] 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.

[3] 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 on propane, or boilers that are modeled as 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 90.1-2016 compared to 90.1-2013, 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 $6.68 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 0.03 years. This very short overall payback 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, Total $ per Prototype Model	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	
Small Office	$12,127	$11,917	$12,169	$10,339	$12,066	
Large Office	$474,209	$536,885	$212,668	$670,593	$791,346	
Standalone Retail	$309,676	$306,147	$300,121	$301,824	$298,326	
Primary School	$403,772	$416,063	$313,114	$370,007	$424,432	
Small Hotel	$258,818	$250,525	$238,300	$259,341	$278,087	
Mid-rise Apartment	$69,594	$66,142	$68,097	$56,817	$85,577	
Life Cycle Cost Net Savings, $/ft^2	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	U.S. Weighted
Small Office	$2.20	$2.17	$2.21	$1.88	$2.19	$2.13
Large Office	$0.95	$1.08	$0.43	$1.34	$1.59	$1.18
Standalone Retail	$12.54	$12.40	$12.16	$12.22	$12.08	$12.28
Primary School	$5.46	$5.62	$4.23	$5.00	$5.74	$5.32
Small Hotel	$5.99	$5.80	$5.51	$6.00	$6.44	$6.03
Mid-rise Apartment	$2.06	$1.96	$2.02	$1.68	$2.54	$2.03
Weighted Total	$6.63	$7.00	$6.01	$5.91	$7.57	$6.68
Simple Payback Period (years)	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	U.S. Weighted
Small Office	2.1	2.0	1.9	4.1	2.1	2.4
Large Office	6.9	6.6	10.2	7.1	4.9	6.8
Standalone Retail	6.6	7.0	7.6	7.8	7.8	7.3
Primary School	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Small Hotel	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Mid-rise Apartment	Immediate	Immediate	Immediate	Immediate	Immediate	Immediate
Weighted Total	Immediate	Immediate	Immediate	1.1	0.1	0.03
Scalar Ratio, Limit = 18.25[1]	2A Tampa	3A Atlanta	3B El Paso	4A New York	5A Buffalo	U.S. Weighted
Small Office	1.26	1.11	0.91	3.30	1.08	1.55
Large Office	8.47	8.11	10.63	8.43	5.12	8.07
Standalone Retail	(46.36)	(51.93)	(62.66)	(53.77)	(60.57)	(54.73)
Primary School	(6.99)	(5.82)	(7.01)	(3.69)	(5.86)	(5.78)
Small Hotel	(16.34)	(17.24)	(18.79)	(15.26)	(13.92)	(15.85)
Mid-rise Apartment	(17.61)	(17.95)	(18.21)	(15.45)	(22.19)	(18.08)
Weighted Total	(21.64)	(24.83)	(27.95)	(21.56)	(33.51)	(25.74)

[1.] 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.

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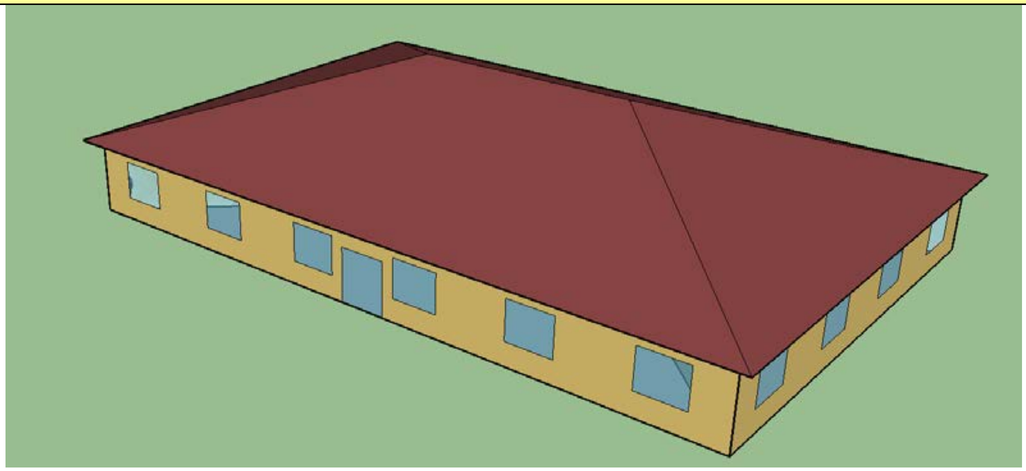
Appendix A

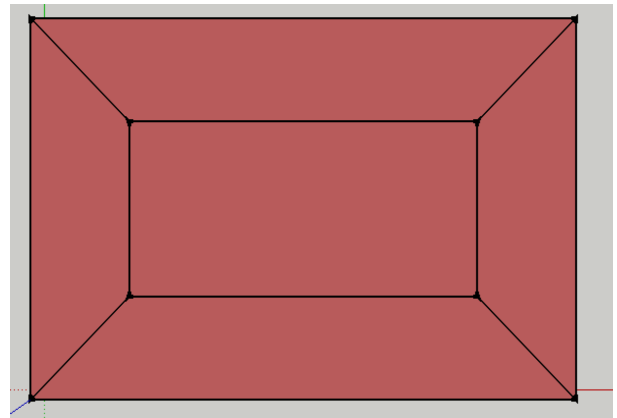
Energy Modeling Prototype Building Descriptions

This appendix includes information from the prototype profiles (also referred to as “scorecards”) that can be found at the website http://www.energycodes.gov/commercial-prototype-building-models. The appendix includes 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. More detailed information, including EnergyPlus input files for the prototypes, can also be found at the website.

A.1 Small Office Modeling Description

	Item	Descriptions			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine)	"Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)"	"Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**OFFICE**			
	Building Prototype	**Small Office**			
Form					
	Total Floor Area (sq. feet)	5500 (90.8 ft x 60.5ft)			

	Item	Descriptions	Data Source
	Building shape		
	Aspect Ratio	1.5	
	Number of Floors	1	
	Window Fraction (Window-to-Wall Ratio)	24.4% for South and 19.8% for the other three orientations (Window Dimensions: 6.0 ft x 5.0 ft punch windows for all façades)	2003 CBECS Data and PNNL's CBECS Study 2007.
	Window Locations	evenly distributed along four façades	
	Shading Geometry	none	
	Azimuth	non-directional	

	Item	Descriptions	Data Source
	Thermal Zoning	Perimeter zone depth: 16.4 ft. Four perimeter zones, one core zone and an attic zone. Percentages of floor area: Perimeter 70%, Core 30% 	
	Floor to floor height (feet)	10	
	Floor to ceiling height (feet)	10	
	Glazing sill height (feet)	3 (top of the window is 8 ft high with 5 ft high glass)	
Architecture			
	Exterior walls		
	Construction	Wood-Frame Walls (2X4 16in OC) 1in. Stucco + 5/8 in. gypsum board + wall Insulation+ 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Base assembly from 90.1 appendix A
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Wood-Framed	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		
	Construction	Attic Roof with Wood Joist: Roof insulation + 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007.

	Item	Descriptions	Data Source
			Base assembly from 90.1 Appendix A
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Attic	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	Hipped roof: 10.76 ft attic ridge height, 2 ft overhang-soffit	
Window			
	Dimensions	punch window, each 5 ft high by 6 ft wide	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential; Vertical Glazing	Applicable codes or standards
	SHGC (all)		
	Visible transmittance	Hypothetical window with the exact U-factor and SHGC shown above	
	Operable area	0	Ducker Fenestration Market Data provided by the 90.1 envelope subcommittee
Skylight			
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
Foundation			
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	8" concrete slab poured directly on to the earth	
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Slab-on-Grade Floors, unheated	Applicable codes or Standards
	Thermal properties for basement walls	NA	
	Dimensions	based on floor area and aspect ratio	
Interior Partitions			
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	

	Item	Descriptions	Data Source
	Internal Mass	6 inches standard wood (16.6 lb/ft²)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on) Additional infiltration through building entrance	Reference: PNNL-18898. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis*. PNNL-20026. *Energy Saving Impact of ASHRAE 90.1 Vestibule Requirements: Modeling of Air Infiltration through Door Openings.* Modeled peak infiltration rate may be different for different codes or standards because of their continuous air barrier requirements.
HVAC			
	System Type		
	Heating type	Air-source heat pump with gas furnace as back up	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Air-source heat pump	
	Distribution and terminal units	Single zone, constant air volume air distribution, one unit per occupied thermal zone	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	

	Item	Descriptions	Data Source
	HVAC Efficiency		
	Air Conditioning	Varies by climate location and design cooling capacity Requirements in codes and standards Minimum equipment efficiency for Packaged Heat Pumps	Applicable codes or standards
	Heating	Varies by climate location and design heating capacity Requirements in codes and standards Minimum equipment efficiency for Packaged Heat Pumps and Warm Air Furnaces	Applicable codes or standards
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	85°F Cooling/60°F Heating	
	Supply air temperature	Maximum 104°F, Minimum 55°F	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	Requirements in codes and standards	Applicable codes or standards
	Ventilation	ASHRAE Ventilation Standard 62.1 or International Mechanical Code See under **Outdoor Air**	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	Requirements in codes and standards	Applicable codes or standards
	Energy Recovery	Requirements in codes and standards	Applicable codes or standards
	Supply Fan		
	Fan Schedules	See under **Schedules**	
	Supply Fan Total Efficiency (%)	Depending on the fan motor size and requirements in codes and standards	Requirements in applicable codes or standards for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Varies depending on the fan supply air cfm	
	Pump		
	Pump Type	NA	
	Rated Pump Head	NA	
	Pump Power	NA	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Efficiency	NA	

	Item	Descriptions	Data Source
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Electric	
	Thermal efficiency (%)	Requirements in codes or standards	Applicable codes or standards
	Tank Volume (gal)	40	
	Water temperature setpoint	140F	
	Water consumption	See under **Schedules**	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	Requirements in codes or standards See **Zone Summary**	Applicable codes or standards
	Schedule	Requirements in codes or standards	Applicable codes or standards
	Daylighting Controls	Requirements in codes or standards	Applicable codes or standards
	Occupancy Sensors	Requirements in codes or standards	Applicable codes or standards
	Plug load		
	Average power density (W/ft^2)	See under **Zone Summary**	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
	Schedule	See under **Schedules**	
	Occupancy		
	Average people	See under **Zone Summary**	ASHRAE Standard 62.1
	Schedule	See under **Schedules**	
Misc.			
	Elevator		
	Quantity	NA	
	Motor type	NA	Reference: DOE Commercial Reference Building Models of the National Building Stock
	Peak Motor Power(W/elevator)	NA	
	Heat Gain to Building	NA	

	Item	Descriptions	Data Source
	Peak Fan/lights Power(W/elevator)	NA	
	Motor and fan/lights Schedule	NA	
	Exterior Lighting		
	Peak Power (W)	Based on design assumptions for façade, parking, entrance, etc. and requirements in codes or standards	Applicable codes or standards
	Schedule	See under **Schedules** and control requirements in codes or standards	

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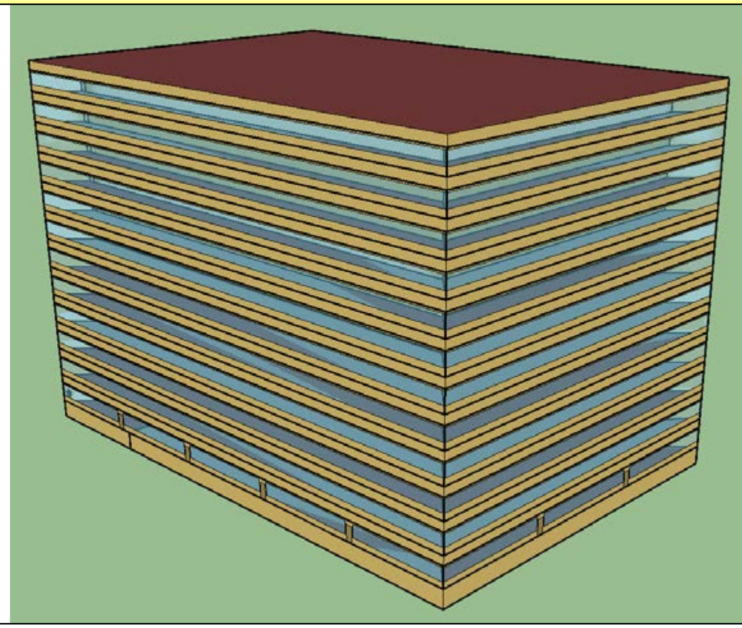
A.2 Large Office Modeling Description

	Item	Descriptions			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine)	"Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)"	"Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**OFFICE**			
	Building Prototype	**LARGE OFFICE**			
Form					
	Total Floor Area (sq. feet)	498,600 (240 ft x 160 ft)			*Time Saver Standards;* Large Office studies

	Item	Descriptions	Data Source
	Building shape		(ConEd, EPRI, MEOS, NEU1(1-4), NEU2, PNL) cited in Huang et al. 1991
	Aspect Ratio	1.5	
	Number of Floors	12 (plus basement)	
	Window Fraction (Window-to-Wall Ratio)	40% of above-grade gross walls 37.5% of gross walls (including the below-grade walls)	
	Window Locations	Even distribution among all four sides	PNNL's CBECS Study
	Shading Geometry	none	
	Azimuth	Non-directional	
	Thermal Zoning		*Time Saver Standards;* Large Office studies (ConEd, EPRI, MEOS, NEU1(1-4), NEU2, PNL) cited in Huang et al. 1992

	Item	Descriptions	Data Source
		Perimeter zone depth: 15 ft. Each floor has four perimeter zones, one core zone and one IT closet zone. Percentages of floor area: Perimeter 29%, Core 70%, IT Closet 1% The basement has a datacenter zone occupying 28% of the basement floor area.	
	Floor to floor height (feet)	13	
	Floor to ceiling height (feet)	9	
	Glazing sill height (feet)	3	
Architecture			
	Exterior walls		
	Construction	Mass (pre-cast concrete panel): 8 in. Heavy-Weight Concrete + Wall Insulation + 0.5 in. gypsum board	Construction type: PNNL's CBECS Study
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Steel-Framed	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Construction type: PNNL's CBECS Study Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Insulation entirely above deck	Applicable codes or standards ASHRAE 90.1
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the U-factor and SHGC shown below	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential	Applicable codes or standardsASHRAE 90.1
	SHGC (all)		
	Visible transmittance	Hypothetical window with the exact U-factor and SHGC shown above	
	Operable area	0%	Ducker Fenestration Market Data provided by the envelope subcommittee
	Skylight		
	Dimensions	Not Modeled	

	Item	Descriptions	Data Source
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
	Foundation		
	Foundation Type	Basement (unconditioned)	
	Construction	8" concrete wall; 6" concrete slab, 140 lbs. heavy-weight aggregate	
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Floors, Mass	Applicable codes or standardsASHRAE 90.1
	Thermal properties for basement walls	No insulation	
	Dimensions	based on floor area and aspect ratio	
	Interior Partitions		
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
	Internal Mass	6 inches standard wood (16.6 lb/ft^2)	
	Air Barrier System		
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)	PNNL's Infiltration Study
HVAC			
	System Type		
	Heating type	Gas boiler	PNNL's CBECS Study
	Cooling type	Water-source DX cooling coil with fluid cooler for datacenter and IT closets and two water-cooled centrifugal chillers for the rest of the building	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Distribution and terminal units	VAV terminal box with damper and hot-water reheating coil except non-datacenter portion of the basement and IT closets that are served by CAV units. Zone control type: minimum damper positions are determined using the multizone calculation method.	
	HVAC Sizing		
	Air Conditioning	autosized to design day	
	Heating	autosized to design day	
	HVAC Efficiency		

	Item	Descriptions	Data Source
	Air Conditioning	Requirements in codes or standards	Applicable codes or standardsASHRAE 90.1
	Heating		
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	90.1 Simulation Working Group
	Thermostat Setback	85°F Cooling/60°F Heating	
	Supply air temperature	Maximum 110°F, Minimum 52°F	
	Chilled water supply temperatures	44°F	
	Hot water supply temperatures	180°F	
	Economizers	Requirements in codes or standards	Applicable codes or standards
	Ventilation	ASHRAE Standard 62.1 or International Mechanical Code See under **Outdoor Air**	Applicable codes or standards
	Demand Control Ventilation	Requirements in codes or standards	Applicable codes or standards
	Energy Recovery	Requirements in codes or standards	Applicable codes or standards
	Supply Fan		
	Fan schedules	See under **Schedules**	
	Supply Fan Total Efficiency (%)	Depending on the fan motor size and requirements in codes or standards	Requirements in applicable codes or standards for motor efficiency and fan power limitation.
	Supply Fan Pressure Drop	Depending on the fan supply air cfm	
	Pump		
	Pump Type	Primary chilled water (CHW) pumps: constant speed; secondary CHW pump: variable speed; IT closet (water loop heat pump) pump: constant speed; cooling tower pump: variable speed: service hot water (SWH): constant speed; hot water (HW) pump: variable speed	
	Rated Pump Head	Use the pump power assumptions as specified in 90.1 Appendix G, i.e., 22 W/gpm for chilled water pump, 19 W/gpm for hot water and condensing water pumps. For SWH pump, first estimated based on circulation flow and then adjusted based on modeled design flow.	"If applicable, model inputs for other codes or standards may be different. PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Pump Power	autosized	
	Cooling Tower		
	Cooling Tower Type	open cooling tower with two-speed fans; two-speed fluid-cooler for data center and IT closets	

	Item	Descriptions	Data Source
	Cooling Tower Power	autosized	
	Service Water Heating		
	SWH type	One main water heater with storage Tank	
	Fuel type	Natural Gas	
	Thermal efficiency (%)	Requirements in codes or standards	**Applicable codes or standards**
	Tank Volume (gal)	300	
	Water temperature setpoint	140°F	
	Water consumption	See under Schedules	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	Requirements in codes or standards. See **Zone Summary**	Applicable codes or standards
	Schedule	See under **Schedules**	
	Daylighting Controls	Requirements in codes or standards	Applicable codes or standards
	Occupancy Sensors	Requirements in codes or standards	Applicable codes or standards
	Plug load		
	Average power density (W/ft^2)	See under **Zone Summary**	For data center and IT closet, see PNNL-23269 Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Schedule	See under **Schedules**	
	Occupancy		
	Average people	See under **Zone Summary**	ASHRAE Ventilation Standard 62.1
	Schedule	See under **Schedules**	
Misc.			
	Elevator		
	Quantity	12	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0).
	Motor type	Traction	
	Peak Motor Power (W/elevator)	20370	
	Heat Gain to Building	Exterior	

	Item	Descriptions	Data Source
	Peak Fan/lights Power (W/elevator)	161.9	90.1 Mechanical Subcommittee, Elevator Working Group
	Motor and fan/lights Schedules	See under **Schedules**	DOE Commercial Reference Building TSD (unpublished) and models (V1.3_5.0) and Appendix DF 2007
Exterior Lighting			
	Peak Power (W)	Based on design assumptions for façade, parking lot, entrance, etc. and requirements in codes or standards	Applicable codes or standards
	Schedule	See under **Schedules** and control requirements in codes or standards	Applicable codes or standards

References

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LBNL (1991). Huang, Joe, Akbari, H., Rainer, L. and Ritschard, R. 481 Prototypical Commercial Buildings for 20 Urban Market Areas, prepared for the Gas Research Institute, Chicago IL, also LBL-29798, Berkeley CA.

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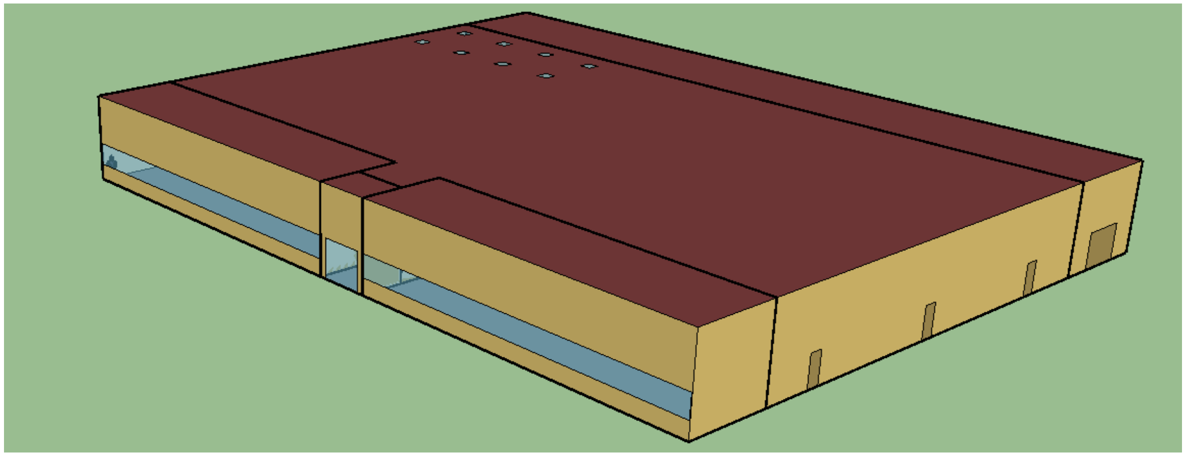
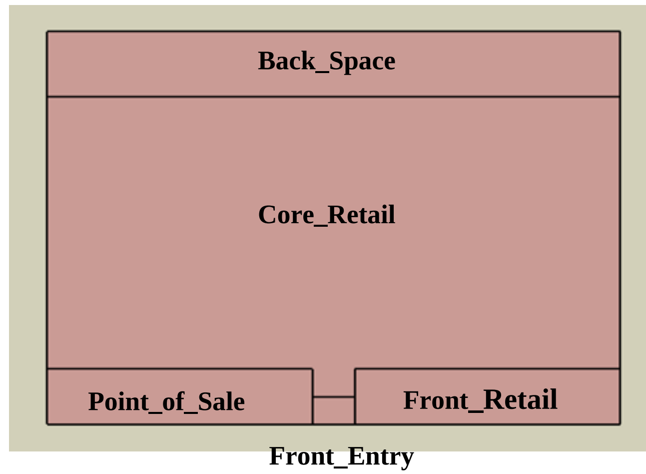
PNNL's CBECS Study. 2006. *Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment.* Dave Winiarski, Wei Jiang and Mark Halverson. Pacific Northwest National Laboratory. December 2006.

Goel S, M. Rosenberg, R Athalye, Y Xie, W Wang, R Hart, J Zhang, V Mendion. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. Pacific Northwest National Laboratory, Richland, Washington. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23269.pdf.

A.3 Standalone Retail Modeling Description

	Item	Descriptions	Data Source
Program			
	Vintage	**NEW CONSTRUCTION**	

	Item	Descriptions	Data Source
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine) "Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)" "Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity	
	Building Type (Principal Building Function)	**RETAIL**	
	Building Prototype	**Standalone Retail**	
Form			
	Total Floor Area (sq. feet)	24695 (178 ft x 139 ft)	
	Building shape		
	Aspect Ratio	1.28	
	Number of Floors	1	
	Window Fraction (Window-to-Wall Ratio)	7.1% (Window Dimensions: 82.136 ft x 5 ft, 9.843 ft x 8.563 ft and 82.136 ft x 5 on the street facing facade)	2003 CBECS Data and PNNL's CBECS Study 2007.

	Item	Descriptions		Data Source
	Window Locations	Windows only on the street facing façade (25.4% WWR)		
	Shading Geometry	none		
	Azimuth	non-directional		
	Thermal Zoning	Five thermal zones (See scorecard at www.energycodes.gov/commercial-prototype-building-models)		
	Floor to floor height (feet)	N/A		
	Floor to ceiling height (feet)	20		
	Glazing sill height (feet)	5 (top of the window is 8.73 ft high with 3.74 ft high glass)		
Architecture				
	Exterior walls			
	Construction	Concrete Block Wall: 8 in. CMU+Wall Insulation+0.5 in. gypsum board		Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Exterior wall layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Mass		Applicable codes or standards
	Dimensions	based on floor area and aspect ratio		

	Item	Descriptions	Data Source
	Tilts and orientations	Vertical	
Roof			
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Roof layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Insulation entirely above deck	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
Window			
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential; Vertical Glazing	Applicable codes or standards
	SHGC (all)		
	Visible transmittance		Ducker Fenestration Market Data provided by the 90.1 envelope subcommittee
	Operable area	2%	Ducker Fenestration Market Data provided by the envelope subcommittee
Skylight			
	Dimensions	Core Retail, Rectangular skylight 4 ft x 4 ft = 16 ft² per skylight Number of skylights and total skylight area vary according to requirements in codes or standards	Applicable codes or standards
	Glass-Type and frame	Hypothetical glass and frame meeting requirements in codes or standards below	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential; Skylight with Curb, Glass	Applicable codes or standards
	SHGC (all)		
	Visible transmittance		
Foundation			

	Item	Descriptions	Data Source
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	6" concrete slab poured directly on to the earth with carpet	
	Thermal properties for ground level floor: U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Slab-on-Grade Floors, unheated	Applicable codes or standards
	Thermal properties for basement walls	NA	
	Dimensions	Based on floor area and aspect ratio	
Interior Partitions			
	Construction	0.5 in gypsum board + 0.5 in gypsum board	
	Dimensions	Based on floor plan and floor-to-floor height	
Internal Mass		6 inches standard wood (16.6 lb/ft²)	
Air Barrier System			
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on) Additional infiltration through building entrance	"Reference: PNNL-18898. Infiltration Modeling Guidelines for Commercial Building Energy Analysis. PNNL-20026. Energy Saving Impact of ASHRAE 90.1 Vestibule Requirements: Modeling of Air Infiltration through Door Openings. Modeled peak infiltration rate may be different for different codes or standards because of their continuous air barrier requirements."
HVAC			
System Type			

	Item	Descriptions	Data Source
	Heating type	Gas furnace inside the packaged air conditioning unit for back_space, core_retail, point_of_sale, and front_retail. Standalone gas furnace for front_entry.	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Packaged air conditioning unit for back_space, core_retail, point_of_sale, and front_retail; No cooling for front_entry.	
	Distribution and terminal units	Constant air volume air distribution 4 single-zone roof top units serving four thermal zones (back_space, core_retail, point_of_sale, and front_retail)	
HVAC Sizing			
	Air Conditioning	Autosized to design day	
	Heating	Autosized to design day	
HVAC Efficiency			
	Air Conditioning	Varies by climate location and design cooling capacity Requirements in codes or standards Minimum equipment efficiency for Air Conditioners and Condensing Units	Applicable codes or standards
	Heating	Varies by climate location and design heating capacity Requirements in codes or standards Minimum equipment efficiency for Warm Air Furnaces	Applicable codes or standards
HVAC Control			
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	85°F Cooling/60°F Heating	
	Supply air temperature	Maximum 104°F, Minimum 55°F	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	Requirements in codes or standards	Applicable codes or standards
	Ventilation	ASHRAE Standard 62.1 or International Mechanical Code See under **Outdoor Air**	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	Requirements in codes or standards	Applicable codes or standards
	Energy Recovery	Requirements in codes or standards	Applicable codes or standards
Supply Fan			
	Fan schedules	See under **Schedules**	
	Supply Fan Mechanical Efficiency (%)	Depending on the fan motor size	Requirements in applicable codes or standards for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Depending on the fan supply air CFM	

	Item	Descriptions	Data Source
	Pump		
	Pump Type	N/A	
	Rated Pump Heat	N/A	
	Pump Power	N/A	
	Cooling Tower		
	Cooling Tower Type	NA	
	Cooling Tower Efficiency	NA	
	Service Water Heating		
	SWH type	Storage Tank	
	Fuel type	Natural Gas	Reference: PNNL 2014. *Enhancements to ASHRAE Standard 90.1 Prototype Building Models"*
	Thermal efficiency (%)	Requirements in codes or standards	Applicable codes or standards
	Tank Volume (gal)	40	
	Water temperature setpoint	140°F	
	Water consumption	BLDG_SWH_SCH See scorecard at www.energycodes.gov/commercial-prototype-building-models	
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	ASHRAE 90.1 Lighting Power Densities Using the Building Area Method	
	Schedule	See under **Schedules**	
	Daylighting Controls	Requirements in codes or standards	
	Occupancy Sensors	Requirements in codes or standards	
	Plug load		
	Average power density (W/ft^2)	Requirements in codes or standards See **Zone Summary**	User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
	Schedule	See under **Schedules**	
	Occupancy		
	Average people	See under **Zone Summary**	

	Item	Descriptions	Data Source
	Schedule	See under **Schedules**	
Misc.			
	Elevator		
	Peak Power	NA	
	Schedule	NA	
	Exterior Lighting		
	Peak Power	Based on design assumptions for façade, parking lot, entrance, etc. and requirements in codes or standards	Applicable codes or standards
	Schedule	See under **Schedules** and control requirements in codes or standards	

References

ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. Climatic Data for Building Design Standards. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia. Relevant information available as Annex 1 in ASHRAE 2016

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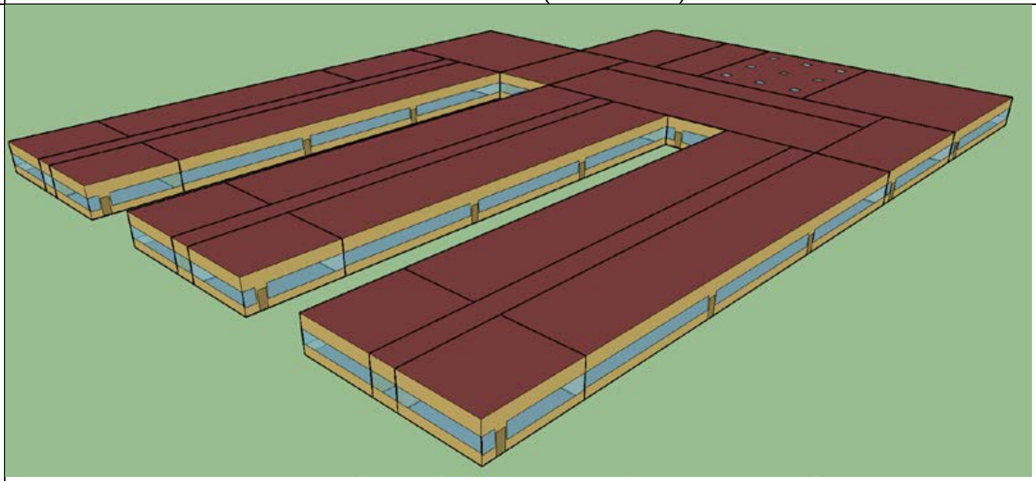
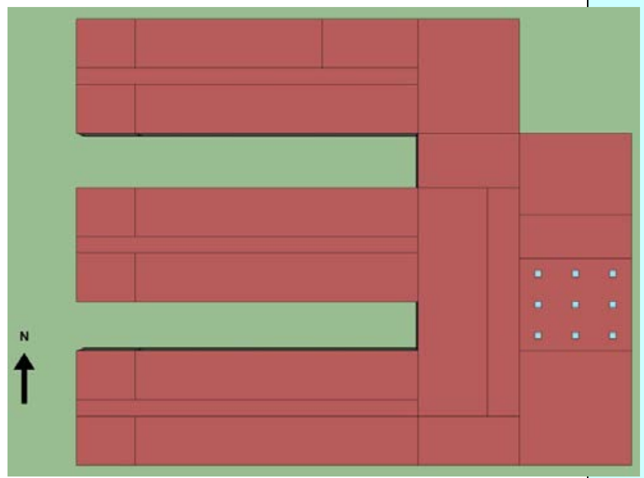
Gowri K, DW Winiarski, and RE Jarnagin. 2009. Infiltration modeling guidelines for commercial building energy analysis. PNNL-18898, Pacific Northwest National Laboratory, Richland, WA. http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18898.pdf

Goel S, M. Rosenberg, R Athalye, Y Xie, W Wang, R Hart, J Zhang, V Mendion. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. Pacific Northwest National Laboratory, Richland, Washington. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23269.pdf.

A.4 Primary School Modeling Description

	Item	Descriptions			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine)	"Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)"	"Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic)"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**EDUCATION**			
	Building Prototype	**Primary School**			
Form					
	Total Floor Area (sq. feet)	73, 960 (340 ft x 270 ft)			
	Building shape				
	Aspect Ratio	1.3			
	Number of Floors	1			

	Item	Descriptions	Data Source
	Window Fraction (Window-to-Wall Ratio)	35% for all facades Ribbon window across all facades	
	Window Locations	Continuous Band	
	Shading Geometry	None	
	Azimuth	non-directional	
	Thermal Zoning	Classrooms zoned by exposure. Corner classrooms separated out from single exposure classrooms. Double loaded corridors zoned separately. Administrative area, gymnasium, mechanical, media center, lobby, kitchen, and cafeteria are single zones. See scorecard at www.energycodes.gov/commercial-prototype-building-models 	
	Floor to floor height (feet)	13	
	Floor to ceiling height (feet)	13	
	Glazing sill height (feet)	3.6 (top of the window is 8.1 ft high with 4.5 ft high glass)	
Architecture			
	Exterior walls		
	Construction	Steel-framed Walls (2x4, 16" OC) 0.75" stucco + 0.625" gypsum board + Cavity insulation + 0.625" gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Exterior wall layers: default 90.1 layering
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Steel-Framed	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	

Item	Descriptions	Data Source
Tilts and orientations	Vertical	
Roof		
Construction	Built-up Roof Roof membrane + Roof insulation + Metal decking	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Roof layers: default 90.1 layering
U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Insulation entirely above deck	Applicable codes or standards
Area (ft2)	73,960	
Tilts and orientations	Horizontal	
Window		
Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio	
Glass-Type and frame	Hypothetical window with weighted U-factor and SHGC	
U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential; Vertical Glazing, 30.1-40%	Applicable codes or standards
SHGC (all)		
Visible transmittance		
Operable area	35%	PNNL 's Glazing Market Data for ASHRAE spreadsheet
Skylight		
Dimensions	Gymnasium/Multipurpose Room (4 ft x 4 ft) x 9 skylights = 144 ft² total Skylight Area 3.75% of gym roof area	AEDG K-12 Guide
Glass-Type and frame	Hypothetical glass and frame meeting Requirements in codes or standards below	
U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential; Skylight with curb, Glass, 2.1-5%	Applicable codes or standards
SHGC		
Visible transmittance		
Foundation		
Foundation Type	Slab-on-grade floors (unheated)	
Construction	6" concrete slab poured directly on to the earth + carpet	
Thermal properties for ground level floor: F-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Slab-on-Grade Floors, unheated	Applicable codes or standards

Item		Descriptions	Data Source
	Thermal properties for basement walls:	NA	
	Dimensions	based on floor area and aspect ratio	
Interior Partitions			
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	based on floor plan and floor-to-floor height	
Internal Mass		6 inches standard wood (16.6 lb/ft²)	
Air Barrier System			
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on) Additional infiltration through building entrance	Reference: PNNL-18898. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis*. PNNL-20026. *Energy Saving Impact of ASHRAE 90.1 Vestibule Requirements: Modeling of Air Infiltration through Door Openings.* Modeled peak infiltration rate may be different for different codes or standards because of their continuous air barrier requirements.
HVAC			
System Type			
	Heating type	1. Gas furnace inside packaged air conditioning unit 2. Hot water from a gas boiler for heating	2003 CBECS Data, PNNL's CBECS Study 2006, and 90.1 Mechanical Subcommittee input.
	Cooling type	Packaged air conditioning unit	
	Distribution and terminal units	1. CAV systems: direct air from the packaged air conditioning unit 2. VAV systems: VAV terminal box with damper and hot water reheating coil Zone Control Type: minimum supply air at 30% of the zone design peak supply air	
HVAC Sizing			
	Air Conditioning	Autosized to design day	

Item	Descriptions	Data Source
Heating	Autosized to design day	
HVAC Efficiency		
Air Conditioning	Varies by climate location and design cooling capacity Requirements in codes or standards Minimum equipment efficiency for Air Conditioners and Condensing Units	Applicable codes or standards
Heating	Varies by climate location and design heating capacity Requirements in codes or standards Minimum equipment efficiency for Warm Air Furnaces Minimum equipment efficiency for Gas and Oil-fired Boilers	Applicable codes or standards
HVAC Control		
Thermostat Setpoint	75°F Cooling/70°F Heating	
Thermostat Setback	80°F Cooling/60°F Heating	
Supply air temperature	Minimum 50°F and maximum 122°F	
Chilled water supply temperatures	NA	
Hot water supply temperatures	180°F	
Economizers	Varies by climate location and cooling capacity Control type: differential dry bulb	Applicable codes or standards
Outdoor Air Ventilation	ASHRAE Ventilation Standard 62.1 or International Mechanical Code. See under **Outdoor Air**	Applicable codes or standards
Demand Control Ventilation	Requirements in codes or standards	Applicable codes or standards
Energy Recovery	Requirements in codes or standards	Applicable codes or standards
Supply Fan		
Fan schedules	See under **Schedules**	
Supply Fan Mechanical Efficiency	Depending on the fan motor size and type of fan	Requirements applicable codes or standards for motor efficiency and fan power limitation
Supply Fan Pressure Drop	Depending on the fan supply air CFM	
Pump		
Pump Type	Variable speed	
Rated Pump Head	60 ft	
Pump Power	autosized	
Cooling Tower		
Cooling Tower Type	NA	
Cooling Tower Power	NA	
Service Water Heating		
SWH type	Storage Tank	

Item	Descriptions		Data Source
Fuel type	Natural Gas (main); Electric (dishwasher booster)		Reference: PNNL 2014. *Enhancements to ASHRAE Standard 90.1 Prototype Building Models*
Thermal efficiency (%)	Requirements in codes or standards		Applicable codes or standards
Tank Volume (gal)	200 (main); 6 (dishwasher booster)	Reference: PNNL 2014. *Enhancements to ASHRAE Standard 90.1 Prototype Building Models*	
Water temperature setpoint	140°F (main); 180°F (dishwasher booster)		
Water consumption (peak gpm)	See under Schedules		
Internal Loads & Schedules			
Lighting			
Lighting power density (W/ft²)	Requirements in codes and schedules See **Zone Summary**		Applicable codes or standards
Schedule	See under **Schedules**		
Daylighting Controls	Requirements in codes or standards		
Occupancy Sensors	Requirements in codes or standards		
Plug load			
Average power density (W/ft²)	See under Zone Summary		User's Manual for ASHRAE Standard 90.1-2004 (Appendix G)
Schedule	See under Schedules		
Occupancy			
Average people	See under **Zone Summary**		
Schedule	See under Schedules		
Misc.			
Elevator			
Peak Power	Not modeled		
Schedule	Not modeled		
Exterior Lighting			
Peak Power (W)	Based on design assumptions for façade, parking lot, entrance, etc. and requirements in codes or standards		Applicable codes or standards
Schedule	See under Schedules and control requirements in codes or standards		Applicable codes or standards

References

1 ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. Climatic Data for Building Design Standards. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia. Relevant information available as Annex 1 in ASHRAE 2016

2 PNNL's CBECS Study. 2007. Analysis of Building Envelope Construction in 2003 CBECS Buildings. Dave Winiarski, Mark Halverson, and Wei Jiang. Pacific Northwest National Laboratory. March 2007.

3 PNNL's CBECS Study. 2006. *Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment.* Dave Winiarski, Wei Jiang and Mark Halverson. Pacific Northwest National Laboratory. December 2006.

"Study of the U.S. Market For Windows, Doors, and Skylights", American Architectural Manufacturers Association, Window & Door Manufacturers Association, 2006.

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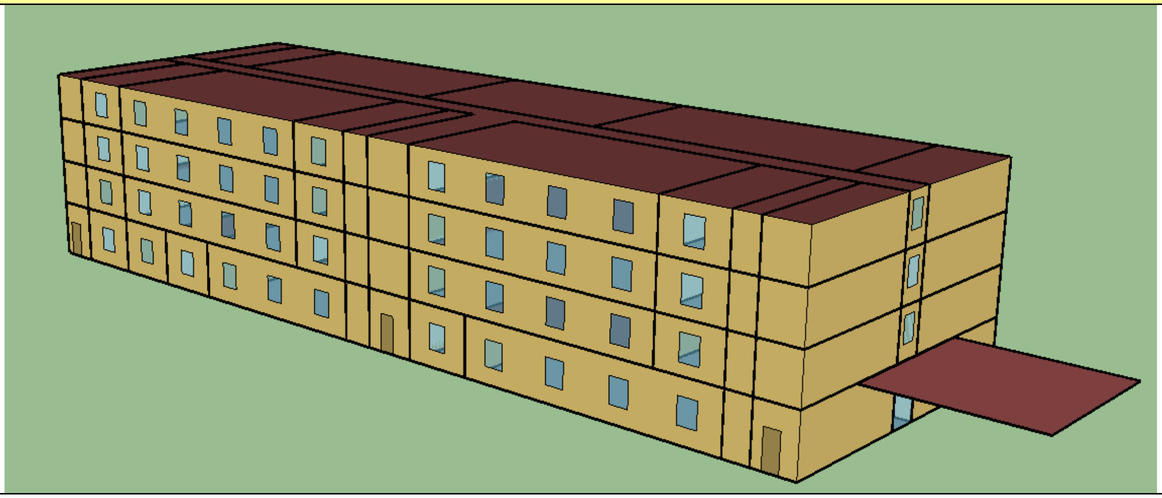
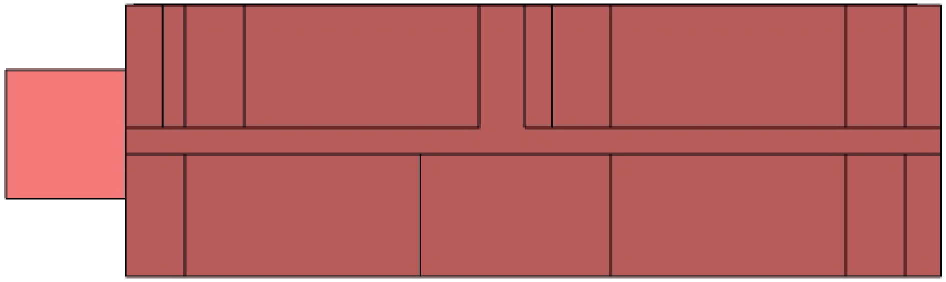
A.5 Small Hotel Modeling Description

	Item	Input			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine)	"Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)"	"Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**Lodging**			
	Building Prototype	**Small Hotel**			
Form					
	Total Floor Area (sq. feet)	43200 (180 ft x 60 ft)			Hampton Inn Prototype from Hilton Hotels Corporation, Version 5.1, September 2004 (URL: http://www.hamptonfranchise.com), referred as Hilton prototype; F.W.Dodge Database

	Item	Input	Data Source
	Building shape		Hilton prototype and CBECS 2003
	Aspect Ratio	3	Hilton prototype
	Number of Floors	4	
	Window Fraction (Window-to-Wall Ratio)	South: 3.1%, East: 11.4%, North: 4.0%, West: 15.2% Average Total: 10.9%	Hilton prototype
	Window Locations	One per guest room (4' x 5')	
	Shading Geometry	none	
	Azimuth	non-directional	
	Thermal Zoning		

	Item	Input	Data Source
		Ground Floor: 19 zones including guest rooms, lobby, office space, meeting room, laundry room, employee lounge, restrooms, exercise room, mechanical room, corridor, stairs, storage; *2nd-4th Floor*: 16 zones per floor, including guest rooms, corridor, stairs and storage; Guest rooms accounts for 63% of total floor area.	
	Floor to floor height (feet)	Ground floor: 11 ft Upper floors: 9 ft	
	Floor to ceiling height (feet)	same as above	
	Glazing sill height (feet)	3 ft in ground floor, 2 ft. in upper floors	
Architecture			
	Exterior walls		
	Construction	Steel-Frame Walls (2x4 16 in. OC) 1 in. Stucco + 5/8 in. gypsum board + wall Insulation + 5/8 in. gypsum board	Construction type: 2003 CBECS Data and PNNL's CBECS Study 2007. Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Steel-Framed	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		
	Construction	Built-up Roof: Roof membrane + Roof insulation + metal decking	AEDG Highway Lodging Committee Recommendation
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Insulation entirely above deck	Applicable codes or standards
	Dimensions	Based on floor area and aspect ratio	
	Tilts and orientations	horizontal	
	Window		
	Dimensions	Based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with weighed U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Nonresidential for ground floor and residential for upper floors; Vertical Glazing	Applicable codes or standards
	SHGC (all)		

	Item	Input	Data Source
	Visible transmittance	Same as above requirements	
	Operable area	0.00%	
Skylight			
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft² * °F)		
	SHGC (all)		
	Visible transmittance		
Foundation			
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	6" concrete slab poured directly on to the earth	
	Thermal properties for slab-on-grade floor F-factor (Btu / h * ft2 * °F) and/or R-value (h * ft2 * °F / Btu)	Requirements in codes or standards	Applicable codes or standards
	Thermal properties for basement walls	NA	
	Dimensions	Based on floor area and aspect ratio	
Interior Partitions			
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	Based on floor plan and floor-to-floor height	
Internal Mass		6 inches standard wood (16.6 lb/ft²)	
Air Barrier System			
	Infiltration	Peak: 0.2016 CFM/sf of above grade exterior wall surface area, adjusted by wind (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on) Additional infiltration through building entrance	"Reference: PNNL-18898. Infiltration Modeling Guidelines for Commercial Building Energy Analysis. PNNL-20026. Energy Saving Impact of ASHRAE 90.1 Vestibule Requirements: Modeling of Air Infiltration through Door Openings.

	Item	Input	Data Source
			Modeled peak infiltration rate may be different for different codes or standards because of their continuous air barrier requirements."
HVAC			
	System Type		
	Heating type	Guest rooms: PTAC with electric resistance heating Public spaces (office, laundry, lobby, and meeting room): gas furnace inside the packaged air conditioning units Storage and stairs: electric cabinet heaters	2003 CBECS, NC3, Ducker report
	Cooling type	Guest rooms and corridors: PTAC and make-up air unit for outdoor air ventilation Public space: Split system with DX cooling Storage and stairs: No cooling	
	Distribution and terminal units	Constant air volume systems	
	HVAC Sizing		
	Air Conditioning	PTAC: 9,000 Btu/hr Split system and packaged MAU system: autosized to design day	PTAC: Ducker report
	Heating	Autosized to design day	
	HVAC Efficiency		
	Air Conditioning	PTAC: 9000 Btu/hr Split system: varies by climate locations based on cooling capacity	Applicable codes or standards
	Heating	PTAC and electric cabinet heater: Et = 100% Gas furnace: varies by climate locations based on heating capacity	Applicable codes or standards
	HVAC Control		
	Thermostat Setpoint	70°F Cooling/Heating for rented guest rooms 74°F Cooling/66°F Heating for vacant guest rooms 75°F Cooling/70°F Heating for air conditioned public spaces (lobby, meeting room etc.) 45°F heating for stairs and storage rooms	AEDG Highway Lodging Committee Recommendation
	Thermostat Setback	74°F Cooling/66°F Heating for rented guest rooms	
	Supply air temperature	No seasonal supply air temperature reset.	
	Chilled water supply temperatures	NA	
	Hot water supply temperatures	NA	
	Economizers	Requirements in codes or standards	Applicable codes or standards

	Item	Input	Data Source
	Ventilation	See under **Outdoor Air**	ASHRAE Ventilation Standard 62.1
	Demand Control Ventilation	No	Applicable codes or standards
	Energy Recovery Ventilation	No	Applicable codes or standards
Supply Fan			
	Fan schedules	See under **Schedules**	
	Supply Fan Mechanical Efficiency (%)	Varies by fan motor size	AEDG-SR Technical Support Document (Liu 2006)
	Supply Fan Pressure Drop	PTAC: 1.33 in. w.c. Cabinet Heater: 0.2 in w.c. Split DX units and MAU: 90.1 fan power limitation (depends on design flow rate)	PTAC Manufacture's Catalogs Split System: Wassmer and Brandemuehl, 2006,
Pump			
	Pump Type	Constant speed (recirculating pump for main water heater)	Reference: PNNL-23269 Enhancements to ASHRAE Standard 90.1 Prototype Building Models"
	Rated Pump Head	10ft	
	Pump Power	Autosized	
Cooling Tower			
	Cooling Tower Type	NA	
	Cooling Tower Power	NA	
Service Water Heating			
	SWH type	Main water heater and laundry water heater, both with storage tanks	
	Fuel type	Natural Gas	
	Thermal efficiency (%)	Requirements in codes or standards	Applicable codes or standards
	Tank Volume (gal)	300 (main); 200 (laundry)	Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Water temperature setpoint	140 F for guest rooms and 180 F for laundry	
	Water consumption	See under Schedules	Guest room: ASHRAE Handbook of Applications 2007, Chapter 49, Table 7 Laundry: AEDG Highway Lodging Committee Recommendation

	Item	Input	Data Source
Internal Loads & Schedules			
	Lighting		
	Average power density (W/ft^2)	Requirements in codes or standards See **Zone Summary**	Applicable codes or standards
	Schedule	See under **Schedules**	
	Daylighting Controls	Requirements in codes or standards	Applicable codes or standards
	Occupancy Sensors	Requirements in codes or standards	Applicable codes or standards
	Plug load		
	Average power density (W/ft^2)	See under **Zone Summary.**	AEDG Highway Lodging Committee Recommendation
	Schedule	See under **Schedules**	
	Occupancy		
	Average people	See under **Zone Summary**	Guest Room: AEDG Highway Lodging Committee Recommendation All other spaces: ASHRAE 62.1-1999
	Schedule	See under Schedules	
Misc.			
	Elevator		
	Quantity	2	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0).
	Motor type	hydraulic	
	Peak Motor Power (W/elevator)	16055	
	Heat Gain to Building	Interior	
	Peak Fan/lights Power Watts per elevator	161.9	90.1 Mechanical Subcommittee, Elevator Working Group
	Peak Fan/lights Power Schedules	See under **Schedules**	DOE Commercial Reference Building TSD (Deru et al. 2011) and models (V1.3_5.0) and Appendix DF 2007
	Exterior Lighting		
	Peak Power, kW	Based on design assumptions for façade, parking lot, entrance, etc. and requirements in codes or standards	Derived based on ASHRAE 90.1-2004 and inputs from 90.1 Lighting Subcommittee Applicable codes or standards

	Item	Input	Data Source
	Schedule	See under **Schedules** and control requirements in codes or standards	Applicable codes or standards

References

ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. Climatic Data for Building Design Standards. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia. Relevant information available as Annex 1 in ASHRAE 2016

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PNNL's CBECS Study. 2007. *Analysis of Building Envelope Construction in 2003 CBECS Buildings.* Dave Winiarski, Mark Halverson, and Wei Jiang. Pacific Northwest National Laboratory. March 2007.PNNL. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/development/commercial/90.1_models.

PNNL's CBECS Study. 2006. *Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment.* Dave Winiarski, Wei Jiang and Mark Halverson. Pacific Northwest National Laboratory. December 2006.

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Sachs, H., 2005. Opportunities for Elevator Energy Efficiency Improvements, ACEEE.

Wassmer and Brandemuehl, 2006, Effect of Data Availability on Modeling of Residential Air Conditioners and Heat Pumps for Energy Calculations

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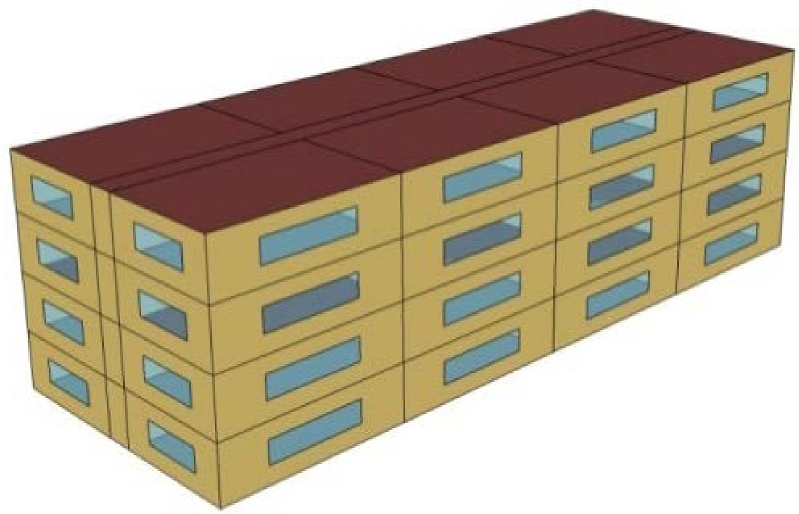
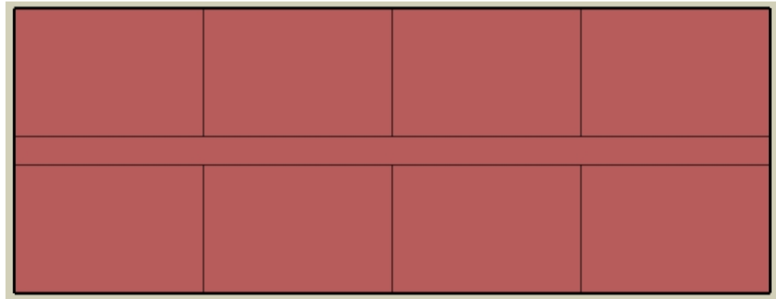
Liu B, RE Jarnagin, DW Winiarski, W Jiang, MF McBride, and C Crall. 2006. Technical Support Document: The Development of the Advanced Energy Design Guide for Small Retail Buildings PNNL-16031, Pacific Northwest National Laboratory, Richland, WA. http://www.pnl.gov/publications/abstracts.asp?report=221540

Goel S, M Rosenberg, R Athalye, Y Xie, W Wang, R Hart, J Zhang, V Mendon. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. PNNL-23269, Pacific Northwest National Laboratory, Richland, Washington. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23269.pdf

A.6 Mid-Rise Apartment Modeling Description

	Item	Descriptions			Data Source
Program					
	Vintage	**NEW CONSTRUCTION**			
	Location (Representing 8Climate Zones)	Zone 1A: Honolulu, Hawaii (very hot, humid) Zone 1B: Delhi New, India ((very hot, dry) Zone 2A: Tampa, Florida (hot, humid) Zone 2B: Tucson, Arizona (hot, dry) Zone 3A: Atlanta, Georgia (warm, humid) Zone 3B: El Paso, Texas (warm, dry) Zone 3C: San Diego, California (warm, marine)	"Zone 4A: New York, New York (mixed, humid) Zone 4B: Albuquerque, New Mexico (mixed, dry) Zone 4C: Seattle, Washington (mixed, marine) Zone 5A: Buffalo, NY (cool, humid) Zone 5B: Denver, Colorado (cool, dry) Zone 5C: Port Angeles, Washington (cool, marine)"	"Zone 6A: Rochester, Minnesota (cold, humid) Zone 6B: Great Falls, Montana (cold, dry) Zone 7: International Falls, Minnesota (very cold) Zone 8: Fairbanks, Alaska (subarctic"	Selection of representative climates based on ASHRAE Standard 169-2013
	Available fuel types	gas, electricity			
	Building Type (Principal Building Function)	**Multifamily**			
	Building Prototype	**Mid-rise Apartment**			
Form					
	Total Floor Area (sq. feet)	33,700 (152 ft x 55.5 ft)			Reference: PNNL-16770: *Analysis of Energy Saving*

	Item	Descriptions	Data Source
	Building shape		*Impacts of Applicable codes or standards-2004 for the State of New York*
	Aspect Ratio	2.74	
	Number of Floors	4	90.1 Envelop Subcommittee
	Window Fraction (Window-to-Wall Ratio)	South: 20%, East: 20%, North: 20%, West: 20% Average Total: 20%	Reference: Based on feedback from the National Multifamily Housing Council (NMHC)
	Window Locations	See image	
	Shading Geometry	none	
	Azimuth	non-directional	

	Item	Descriptions	Data Source
	Thermal Zoning	 Each floor has 8 apartments except ground floor (7 apartments and 1 lobby with equivalent apartment area) Total 8 apartments per floor with corridor in center. Zone depth is 25 ft for each apartment from side walls and each apt is 25' x 38' (950 ft²).	Reference: PNNL-16770: *Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York*
	Floor to floor height (ft)	10	
	Floor to ceiling height (ft)	10 (No drop-in ceiling plenum is modeled)	
	Glazing sill height (ft)	3 ft (4 ft high windows)	
Architecture			
	Exterior walls		
	Construction	Steel-Frame Walls (2X4 16IN OC) 0.4 in. Stucco+5/8 in. gypsum board + wall Insulation+5/8 in.	Reference: PNNL-16770: *Analysis of Energy Saving Impacts of Applicable codes or standards-2004 for the State of New York*. Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Residential; Walls, above grade, Steel Frame	Applicable codes or standards
	Dimensions	based on floor area and aspect ratio	
	Tilts and orientations	vertical	
	Roof		

	Item	Descriptions	Data Source
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	Reference: PNNL-16770: Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for the State of New York Base Assembly from 90.1 Appendix A.
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	Requirements in codes or standards Residential; Roofs, Insulation entirely above deck	Applicable codes or standards
	Dimensions	Based on floor area and aspect ratio	
	Tilts and orientations	Horizontal	
Window			
	Dimensions	Based on window fraction, location, glazing sill height, floor area and aspect ratio	
	Glass-Type and frame	Hypothetical window with a weighted exact U-factor and SHGC	
	U-factor (Btu / h * ft^2 * °F)	Requirements in codes or standards Residential; vertical glazing	Applicable codes or standards
	SHGC (all)		
	Visible transmittance		
	Operable area	100%	
Skylight			
	Dimensions	Not Modeled	
	Glass-Type and frame	NA	
	U-factor (Btu / h * ft^2 * °F)		
	SHGC (all)		
	Visible transmittance		
Foundation			
	Foundation Type	Slab-on-grade floors (unheated)	
	Construction	8" concrete slab poured directly on to the earth	
	Slab-on-grade floor insulation level (F-factor)	Requirements in codes or standards	Applicable codes or standards
	Dimensions	Based on floor area and aspect ratio	
Interior Partitions			
	Construction	2 x 4 uninsulated stud wall	
	Dimensions	Based on floor plan and floor-to-floor height	

	Item	Descriptions	Data Source
	Internal Mass	8 lbs/ft^2 of floor area	Reference: Building America Research Benchmark
	Air Barrier System		
	Infiltration (ACH)	Peak infiltration: 0.2016 CFM/ft² of gross exterior wall area, adjusted by wind. Additional infiltration through building entrance	"Reference: PNNL-18898. Infiltration Modeling Guidelines for Commercial Building Energy Analysis. PNNL-20026. Energy Saving Impact of ASHRAE 90.1 Vestibule Requirements: Modeling of Air Infiltration through Door Openings. Modeled peak infiltration rate may be different for different codes or standards because of their continuous air barrier requirements."
HVAC			
	System Type		
	Heating type	Gas Furnace	90.1 Mechanical Subcommittee
	Cooling type	Split system DX (1 per apt)	
	Distribution and terminal units	Constant volume	
	HVAC Sizing		
	Air Conditioning	Autosized to design day	
	Heating	Autosized to design day	
	HVAC Efficiency		
	Air Conditioning	Requirements in codes or standards Minimum Equipment Efficiency for Air Conditioners and Condensing Units	Applicable codes or standards
	Heating	Requirements in codes or standards Minimum equipment efficiency for warm air furnaces	Applicable codes or standards
	HVAC Control		
	Thermostat Setpoint	75°F Cooling/70°F Heating	
	Thermostat Setback	No setback for apartments	
	Supply air temperature	Maximum 113F, Minimum 55F	
	Economizers	Requirements in codes or standards	Applicable codes or standards
	Ventilation	ASHRAE Ventilation Standard 62.1 or International Mechanical Code See under **Outdoor Air**	Applicable codes or standards
	Demand Control Ventilation	Requirements in codes or standards	Applicable codes or standards
	Energy Recovery	Requirements in codes or standards	Applicable codes or standards
	Supply Fan		
	Fan schedules	See under **Schedules**	

	Item	Descriptions			Data Source
	Supply Fan Total Efficiency (%)	Depending on the fan motor size			Requirements in applicable codes or standards for motor efficiency and fan power limitation
	Supply Fan Pressure Drop	Depending on the fan supply air CFM			
Service Water Heating					
	SWH type	Individual residential water heater with storage tank			
	Fuel type	Electricity			Reference: RECS 2005
	Thermal efficiency (%)	Requirements in codes or standards			Applicable codes or standards
	Tank Volume (gal)	50			Reference: PNNL 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models
	Water temperature setpoint	140 F			
	Water consumption	See under Schedules			Reference: Building America Research Benchmark
Internal Loads & Schedules					
Lighting					
	Average power density (W/ft^2)	Apartment units: 0.36 W/ft^2 (daily peak for hard-wired lighting) and 0.09 W/ft^2 (daily peak for plug-in lighting) - See under Lighting Load for the detailed calculations. When applicable, the power density of sleeping units is based on requirements in codes and standards. Corridor: 0.5 W/ft^2			Apartment: Building America Research Benchmark and applicable codes or standards
	Schedule	See scorecard at www.energycodes.gov/commercial-prototype-building-models			Reference: Building America Research Benchmark
	Daylighting Controls	Requirements in codes or standards			Applicable codes or standards
	Occupancy Sensors	Requirements in codes or standards			Applicable codes or standards
Plug load					
	Average power density (W/ft^2)	0.62 W/ft^2 daily peak per apartment, including all the home appliances See under **Plug Load** for the detailed calculations			Reference: Building America Research Benchmark
	Schedule	See under **Schedules**			
Occupancy					
	Average people	See under **Zone Summary**			Reference: Building America Research Benchmark
	Schedule	See under **Schedules**			
Misc.					
Elevator					
	Quantity		1		Reference: DOE Commercial Reference Building Models of the National Building Stock
	Motor type		hydraulic		
	Peak Motor Power (watts/elevator)		16,055		
	Heat Gain to Building		Interior		

	Item	Descriptions			Data Source
	Peak Fan/lights Power (watts/elevator)		161.9		90.1 Mechanical Subcommittee, Elevator Working Group
	Motor and fan/lights Schedules		See under **Schedules**		Reference: DOE Commercial Reference Building Models of the National Building Stock
Exterior Lighting					
	Peak Power (W)	Based on design assumptions for façade, parking lot, entrance, etc. and requirements in codes or standards			Applicable codes or standards
	Schedule	See under **Schedules** and control requirements in codes or standards			

References

ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. Climatic Data for Building Design Standards. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia. Relevant information available as Annex 1 in ASHRAE 2016

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Building America Research Benchmark. http://www1.eere.energy.gov/buildings/building_america/index.html

DOE Commercial Reference Building Models of the National Building Stock: http://www.nrel.gov/docs/fy11osti/46861.pdf

RECS 2005 EIA's Residential Energy Consumption Survey. http://www.eia.doe.gov/emeu/recs/

Goel S, M. Rosenberg, R Athalye, Y Xie, W Wang, R Hart, J Zhang, V Mendion. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. Pacific Northwest National Laboratory, Richland, Washington. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23269.pdf.

Appendix B

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 90.1-2016 compared to 90.1-2013. Incremental costs include New Construction or initial cost, annual maintenance cost, replacement costs for years 1 through 29, and residual costs in year 30.

B.1 Lighting Cost Summary

While lighting costs are included in the following building cost summary tables, the lighting costs include multiple addenda with different impacts. To help illustrate the differences between cost impacts for interior vs. exterior lighting vs. control cost impacts, the following table breaks the initial incremental construction cost apart into those categories by building type. Both whole prototype and per square foot costs are shown. Note that the lighting costs are the same for all climate zones.

Lighting Incremental Cost Summary: Increase from 90.1-2013 to 90.1-2016

	Value	Interior Lighting	Egress Controls	Exterior Lighting	**Total**
Small Office	Incremental cost	$2,971	$3,784	-$5,299	**$1,456**
	$/ft^2	$0.54	$0.69	-$0.96	**$0.26**
Large Office	Incremental cost	$269,325	$134,345	-$162,216	**$241,453**
	$/ft^2	$0.54	$0.27	-$0.33	**$0.48**
Standalone Retail	Incremental cost	$59,742	$0	-$36,023	**$23,719**
	$/ft^2	$2.42	$0.00	-$1.46	**$0.96**
Primary School	Incremental cost	-$87,615	$13,245	-$16,184	**-$90,554**
	$/ft^2	-$1.18	$0.18	-$0.22	**-$1.22**
Small Hotel	Incremental cost	-$137,699	$0	-$19,975	**-$157,675**
	$/ft^2	-$3.19	$0.00	-$0.46	**-$3.65**
Mid-rise Apartment	Incremental cost	$3,481	$0	-$16,220	**-$12,739**
	$/ft^2	$0.10	$0.00	-$0.48	**-$0.38**
Weighted Total	$/ft^2	**$0.80**	**$0.15**	**-$0.89**	**$0.06**

B.2 Small Office Cost Summary

Small Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$324	-$413	-$482	-$170	-$850	$1,456	$1,456	$1,456	$1,456	$1,456
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	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
10	$0	$0	$0	$0	$0	$27	$27	$27	$27	$27
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$3,510	-$3,510	-$3,510	-$3,510	-$3,510
15	-$184	-$190	-$271	-$101	-$206	$5,235	$5,235	$5,235	$5,235	$5,235
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	$3,203	$3,203	$3,203	$3,203	$3,203
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$27	$27	$27	$27	$27
21	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	-$10,613	-$10,613	-$10,613	-$10,613	-$10,613
24	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
28	$0	$0	$0	$0	$0	-$3,510	-$3,510	-$3,510	-$3,510	-$3,510
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$469	-$617	-$698	-$244	-$1,345	$5,261	$5,261	$5,261	$5,261	$5,261
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	-$51	-$51	-$51	-$51	-$51
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$4,842	$4,842	$4,842	$4,842	$4,842
36	$0	$0	$0	$0	$0	$3,203	$3,203	$3,203	$3,203	$3,203
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	-$51	-$51	-$51	-$51	-$51
40	$251	$348	$375	$129	$828	-$5,139	-$5,139	-$5,139	-$5,139	-$5,139

Small Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$65	$68	$68	$892	$571	$1,197.4	$1,111	$1,043	$2,178	$1,177
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	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
10	$0	$0	$0	$0	$0	$27	$27	$27	$27	$27
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$3,510	-$3,510	-$3,510	-$3,510	-$3,510
15	$0	$0	$0	$0	$0	$5,050	$5,045	$4,963	$5,133	$5,029
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	$3,203	$3,203	$3,203	$3,203	$3,203
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	$27	$27	$27	$27	$27
21	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
22	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	$0	$0	$0	$0	$0	-$10,613	-$10,613	-$10,613	-$10,613	-$10,613
24	$0	$0	$0	$0	$0	-$51	-$51	-$51	-$51	-$51
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	-$51	-$51	-$51	-$51	-$51
28	$0	$0	$0	$0	$0	-$3,510	-$3,510	-$3,510	-$3,510	-$3,510
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	$4,792	$4,644	$4,563	$5,017	$3,916
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	-$51	-$51	-$51	-$51	-$51
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$4,842	$4,842	$4,842	$4,842	$4,842
36	$0	$0	$0	$0	$0	$3,203	$3,203	$3,203	$3,203	$3,203
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	-$51	-$51	-$51	-$51	-$51
40	$0	$0	$0	$0	$0	-$4,888	-$4,791	-$4,764	-$5,010	-$4,311

B.3 Large Office Cost Summary

Large Office	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$9,941	$16,537	-$52,339	$34,834	-$68,409	$241,453	$241,453	$241,453	$241,453	$241,453
Maintenance	$647	$666	$0	$645	$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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	-$64,820	-$64,820	-$64,820	-$64,820	-$64,820
12	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
13	$0	$0	$0	$0	$0	$2,520	$2,520	$2,520	$2,520	$2,520
14	$0	$0	$0	$0	$0	-$9,847	-$9,847	-$9,847	-$9,847	-$9,847
15	$55,307	$57,528	-$14,177	$69,876	-$6,125	$183,894	$183,894	$183,894	$183,894	$183,894
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	$40,428	$40,428	$40,428	$40,428	$40,428
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	-$15,838	-$12,345	-$10,189	-$11,956	-$14,308	$0	$0	$0	$0	$0
21	$0	$0	$0	$0	$0	$2,799	$2,799	$2,799	$2,799	$2,799
22	$0	$0	$0	$0	$0	-$64,820	-$64,820	-$64,820	-$64,820	-$64,820
23	-$267	$1,203	$7,381	$1,138	$1,993	-$56,883	-$56,883	-$56,883	-$56,883	-$56,883
24	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$2,520	$2,520	$2,520	$2,520	$2,520
27	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
28	$0	$0	$0	$0	$0	-$9,847	-$9,847	-$9,847	-$9,847	-$9,847
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$9,548	-$6,617	-$145,322	-$3,551	-$137,315	$183,894	$183,894	$183,894	$183,894	$183,894
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	-$68,575	-$68,575	-$68,575	-$68,575	-$68,575
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$8,157	$7,578	$7,795	$8,852	$7,510	$56,883	$56,883	$56,883	$56,883	$56,883
36	$0	$0	$0	$0	$0	$40,428	$40,428	$40,428	$40,428	$40,428
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	-$1,235	-$1,235	-$1,235	-$1,235	-$1,235
40	$17,879	$16,778	$83,548	$17,775	$82,545	-$106,302	-$106,302	-$106,302	-$106,302	-$106,302

Large Office	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,170	$1,412	$1,412	$68,896	$43,981	$252,564	$259,401	$190,525	$345,183	$217,025
Maintenance	$0	$0	$0	$0	$0	$647	$666	$0	$645	$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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
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	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
10	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	-$64,820	-$64,820	-$64,820	-$64,820	-$64,820
12	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
13	$0	$0	$0	$0	$0	$2,520	$2,520	$2,520	$2,520	$2,520
14	$0	$0	$0	$0	$0	-$9,847	-$9,847	-$9,847	-$9,847	-$9,847
15	$0	$0	$0	$0	$0	$239,201	$241,422	$169,717	$253,770	$177,769
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	$40,428	$40,428	$40,428	$40,428	$40,428
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	-$15,838	-$12,345	-$10,189	-$11,956	-$14,308
21	$0	$0	$0	$0	$0	$2,799	$2,799	$2,799	$2,799	$2,799
22	$0	$0	$0	$0	$0	-$64,820	-$64,820	-$64,820	-$64,820	-$64,820
23	$0	$0	$0	$0	$0	-$57,151	-$55,680	-$49,502	-$55,746	-$54,891
24	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
25	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
26	$0	$0	$0	$0	$0	$2,520	$2,520	$2,520	$2,520	$2,520
27	$0	$0	$0	$0	$0	-$3,755	-$3,755	-$3,755	-$3,755	-$3,755
28	$0	$0	$0	$0	$0	-$9,847	-$9,847	-$9,847	-$9,847	-$9,847
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$15,807	$15,807	$15,807	$15,807	$15,807	$190,153	$193,084	$54,379	$196,150	$62,387
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	-$68,575	-$68,575	-$68,575	-$68,575	-$68,575
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$65,041	$64,461	$64,679	$65,736	$64,393
36	$0	$0	$0	$0	$0	$40,428	$40,428	$40,428	$40,428	$40,428
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	-$1,235	-$1,235	-$1,235	-$1,235	-$1,235
40	-$10,538	-$10,538	-$10,538	-$10,538	-$10,538	-$98,961	-$100,062	-$33,291	-$99,065	-$34,295

B.4 Standalone Retail Cost Summary

Standalone Retail	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$4,078	-$3,466	-$3,969	-$3,047	-$4,831	$23,719	$23,719	$23,719	$23,719	$23,719
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	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
5	$0	$0	$0	$0	$0	-$137	-$137	-$137	-$137	-$137
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	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$56,057	-$56,057	-$56,057	-$56,057	-$56,057
11	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
12	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$334,222	$334,222	$334,222	$334,222	$334,222
15	-$1,525	-$787	-$929	-$663	-$1,498	-$137	-$137	-$137	-$137	-$137
16	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$5,631	$5,631	$5,631	$5,631	$5,631
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	-$312,695	-$312,695	-$312,695	-$312,695	-$312,695
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
23	$0	$0	$0	$0	$0	-$45,222	-$45,222	-$45,222	-$45,222	-$45,222
24	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
25	$0	$0	$0	$0	$0	-$137	-$137	-$137	-$137	-$137
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	$77,583	$77,583	$77,583	$77,583	$77,583
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$5,006	-$4,269	-$4,885	-$3,749	-$5,929	-$56,057	-$56,057	-$56,057	-$56,057	-$56,057
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
33	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$35,691	$35,691	$35,691	$35,691	$35,691
36	$0	$0	$0	$0	$0	-$251,007	-$251,007	-$251,007	-$251,007	-$251,007
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	$181,654	$0	-$183,481	$2,278	$3,453	-$67,925	-$67,925	-$67,925	-$67,925	-$67,925

Standalone Retail	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,196	$1,222	$1,222	$2,117	$1,694	$20,836	$21,475	$20,972	$22,789	$20,581
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	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
5	$0	$0	$0	$0	$0	-$137	-$137	-$137	-$137	-$137
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	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$56,057	-$56,057	-$56,057	-$56,057	-$56,057
11	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
12	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$334,222	$334,222	$334,222	$334,222	$334,222
15	$0	$0	$0	$0	$0	-$1,661	-$924	-$1,066	-$800	-$1,635
16	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$5,631	$5,631	$5,631	$5,631	$5,631
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	-$312,695	-$312,695	-$312,695	-$312,695	-$312,695
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
23	$0	$0	$0	$0	$0	-$45,222	-$45,222	-$45,222	-$45,222	-$45,222
24	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
25	$0	$0	$0	$0	$0	-$137	-$137	-$137	-$137	-$137
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	$77,583	$77,583	$77,583	$77,583	$77,583
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$0	$0	$0	$0	$0	-$61,063	-$60,326	-$60,942	-$59,806	-$61,986
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$256,638	-$256,638	-$256,638	-$256,638	-$256,638
33	$0	$0	$0	$0	$0	-$8,563	-$8,563	-$8,563	-$8,563	-$8,563
34	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	$0	$0	$0	$0	$0	$35,691	$35,691	$35,691	$35,691	$35,691
36	$0	$0	$0	$0	$0	-$251,007	-$251,007	-$251,007	-$251,007	-$251,007
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	$113,729	-$67,925	-$251,406	-$65,647	-$64,472

B.5 Primary School Cost Summary

Primary School	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$37,499	-$33,142	-$26,813	-$15,102	-$37,158	-$90,554	-$90,554	-$90,554	-$90,554	-$90,554
Maintenance	$22	$8	$20	$7	$24					
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
5	$0	$0	$0	$0	$0	-$39,238	-$39,238	-$39,238	-$39,238	-$39,238
6	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$377,616	-$377,616	-$377,616	-$377,616	-$377,616
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$523,596	$523,596	$523,596	$523,596	$523,596
15	-$27,010	-$23,815	-$14,498	-$10,586	-$25,475	-$20,738	-$20,738	-$20,738	-$20,738	-$20,738
16	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$5,979	-$5,979	-$5,979	-$5,979	-$5,979
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	-$97	-$146	-$150	-$78	-$226	-$377,616	-$377,616	-$377,616	-$377,616	-$377,616
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
23	$0	$0	$0	$0	$0	-$36,518	-$36,518	-$36,518	-$36,518	-$36,518
24	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
25	$0	$0	$0	$0	$0	-$39,238	-$39,238	-$39,238	-$39,238	-$39,238
26	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$523,596	$523,596	$523,596	$523,596	$523,596
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$106,665	-$43,757	-$38,092	-$20,220	-$49,066	-$359,115	-$359,115	-$359,115	-$359,115	-$359,115
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
35	$54	-$159	-$175	$138	-$510	-$38,382	-$38,382	-$38,382	-$38,382	-$38,382
36	$0	$0	$0	$0	$0	-$5,979	-$5,979	-$5,979	-$5,979	-$5,979
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	$62,060	$21,369	$20,712	$9,833	$24,656	-$76,987	-$76,987	-$76,987	-$76,987	-$76,987

Primary School	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$1,058	$1,666	$1,666	$10,899	$4,786	-$126,995	-$122,030	-$115,701	-$94,757	-$122,926
Maintenance	$0	$0	$0	$0	$0	$22	$8	$20	$7	$24
Replacement (Year)										
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
3	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
5	$0	$0	$0	$0	$0	-$39,238	-$39,238	-$39,238	-$39,238	-$39,238
6	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
7	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
9	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
10	$0	$0	$0	$0	$0	-$377,616	-$377,616	-$377,616	-$377,616	-$377,616
11	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
12	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	$523,596	$523,596	$523,596	$523,596	$523,596
15	$0	$0	$0	$0	$0	-$47,748	-$44,552	-$35,236	-$31,323	-$46,213
16	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	-$5,979	-$5,979	-$5,979	-$5,979	-$5,979
19	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
20	$0	$0	$0	$0	$0	-$377,713	-$377,762	-$377,766	-$377,694	-$377,842
21	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
23	$0	$0	$0	$0	$0	-$36,518	-$36,518	-$36,518	-$36,518	-$36,518
24	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
25	$0	$0	$0	$0	$0	-$39,238	-$39,238	-$39,238	-$39,238	-$39,238
26	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
27	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
28	$0	$0	$0	$0	$0	$523,596	$523,596	$523,596	$523,596	$523,596
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	$4,917	$4,917	$4,917	$4,917	$4,917	-$460,863	-$397,955	-$392,290	-$374,418	-$403,264
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
33	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
34	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
35	$0	$0	$0	$0	$0	-$38,328	-$38,541	-$38,557	-$38,244	-$38,892
36	$0	$0	$0	$0	$0	-$5,979	-$5,979	-$5,979	-$5,979	-$5,979
37	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
38	$0	$0	$0	$0	$0	-$10,280	-$10,280	-$10,280	-$10,280	-$10,280
39	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
40	-$3,278	-$3,278	-$3,278	-$3,278	-$3,278	-$18,205	-$58,897	-$59,553	-$70,432	-$55,610

B.6 Small Hotel Cost Summary

Small Hotel	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$49,125	$49,292	$49,520	$50,110	$50,296	-$157,675	-$157,675	-$157,675	-$157,675	-$157,675
Maintenance	$0	$0	$0	$0	$0					
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
2	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
3	$0	$0	$0	$0	$0	-$43,843	-$43,843	-$43,843	-$43,843	-$43,843
4	$0	$0	$0	$0	$0	-$5,336	-$5,336	-$5,336	-$5,336	-$5,336
5	$0	$0	$0	$0	$0	-$37,930	-$37,930	-$37,930	-$37,930	-$37,930
6	$0	$0	$0	$0	$0	-$31,193	-$31,193	-$31,193	-$31,193	-$31,193
7	$0	$0	$0	$0	$0	-$10,784	-$10,784	-$10,784	-$10,784	-$10,784
8	$0	$0	$0	$0	$0	-$5,336	-$5,336	-$5,336	-$5,336	-$5,336
9	$0	$0	$0	$0	$0	-$25,984	-$25,984	-$25,984	-$25,984	-$25,984
10	$0	$0	$0	$0	$0	-$42,937	-$42,937	-$42,937	-$42,937	-$42,937
11	$0	$0	$0	$0	$0	-$11,529	-$11,529	-$11,529	-$11,529	-$11,529
12	$0	$0	$0	$0	$0	-$23,730	-$23,730	-$23,730	-$23,730	-$23,730
13	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
14	$0	$0	$0	$0	$0	$6,757	$6,757	$6,757	$6,757	$6,757
15	$45,467	$45,470	$45,757	$46,093	$46,329	-$81,770	-$81,770	-$81,770	-$81,770	-$81,770
16	$0	$0	$0	$0	$0	$84	$84	$84	$84	$84
17	$0	$0	$0	$0	$0	-$4,738	-$4,738	-$4,738	-$4,738	-$4,738
18	$0	$0	$0	$0	$0	-$7,947	-$7,947	-$7,947	-$7,947	-$7,947
19	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
20	$0	$0	$0	$0	$0	-$43,263	-$43,263	-$43,263	-$43,263	-$43,263
21	$0	$0	$0	$0	$0	-$54,624	-$54,624	-$54,624	-$54,624	-$54,624
22	$0	$0	$0	$0	$0	-$16,536	-$16,536	-$16,536	-$16,536	-$16,536
23	$0	$0	$0	$0	$0	-$1,542	-$1,542	-$1,542	-$1,542	-$1,542
24	$0	$0	$0	$0	$0	-$18,561	-$18,561	-$18,561	-$18,561	-$18,561
25	$0	$0	$0	$0	$0	-$37,930	-$37,930	-$37,930	-$37,930	-$37,930
26	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
27	$0	$0	$0	$0	$0	-$25,984	-$25,984	-$25,984	-$25,984	-$25,984
28	$0	$0	$0	$0	$0	$6,430	$6,430	$6,430	$6,430	$6,430
29	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
30	$44,103	$44,379	$44,665	$45,547	$45,783	-$69,121	-$69,121	-$69,121	-$69,121	-$69,121
31	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
32	$0	$0	$0	$0	$0	$84	$84	$84	$84	$84
33	$0	$0	$0	$0	$0	-$55,369	-$55,369	-$55,369	-$55,369	-$55,369
34	$0	$0	$0	$0	$0	-$9,744	-$9,744	-$9,744	-$9,744	-$9,744
35	$9,194	$9,194	$9,194	$9,194	$9,194	-$39,007	-$39,007	-$39,007	-$39,007	-$39,007
36	$0	$0	$0	$0	$0	-$483	-$483	-$483	-$483	-$483
37	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
38	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
39	$0	$0	$0	$0	$0	-$43,843	-$43,843	-$43,843	-$43,843	-$43,843
40	-$22,126	-$22,309	-$22,405	-$22,881	-$22,959	-$1,199	-$1,199	-$1,199	-$1,199	-$1,199

Small Hotel	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$98	$166	$166	$2,741	$727	-$108,452	-$108,217	-$107,988	-$104,823	-$106,651
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)										
1	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
2	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
3	$0	$0	$0	$0	$0	-$43,843	-$43,843	-$43,843	-$43,843	-$43,843
4	$0	$0	$0	$0	$0	-$5,336	-$5,336	-$5,336	-$5,336	-$5,336
5	$0	$0	$0	$0	$0	-$37,930	-$37,930	-$37,930	-$37,930	-$37,930
6	$0	$0	$0	$0	$0	-$31,193	-$31,193	-$31,193	-$31,193	-$31,193
7	$0	$0	$0	$0	$0	-$10,784	-$10,784	-$10,784	-$10,784	-$10,784
8	$0	$0	$0	$0	$0	-$5,336	-$5,336	-$5,336	-$5,336	-$5,336
9	$0	$0	$0	$0	$0	-$25,984	-$25,984	-$25,984	-$25,984	-$25,984
10	$0	$0	$0	$0	$0	-$42,937	-$42,937	-$42,937	-$42,937	-$42,937
11	$0	$0	$0	$0	$0	-$11,529	-$11,529	-$11,529	-$11,529	-$11,529
12	$0	$0	$0	$0	$0	-$23,730	-$23,730	-$23,730	-$23,730	-$23,730
13	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
14	$0	$0	$0	$0	$0	$6,757	$6,757	$6,757	$6,757	$6,757
15	$0	$0	$0	$0	$0	-$36,303	-$36,300	-$36,013	-$35,677	-$35,442
16	$0	$0	$0	$0	$0	$84	$84	$84	$84	$84
17	$0	$0	$0	$0	$0	-$4,738	-$4,738	-$4,738	-$4,738	-$4,738
18	$0	$0	$0	$0	$0	-$7,947	-$7,947	-$7,947	-$7,947	-$7,947
19	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
20	$0	$0	$0	$0	$0	-$43,263	-$43,263	-$43,263	-$43,263	-$43,263
21	$0	$0	$0	$0	$0	-$54,624	-$54,624	-$54,624	-$54,624	-$54,624
22	$0	$0	$0	$0	$0	-$16,536	-$16,536	-$16,536	-$16,536	-$16,536
23	$0	$0	$0	$0	$0	-$1,542	-$1,542	-$1,542	-$1,542	-$1,542
24	$0	$0	$0	$0	$0	-$18,561	-$18,561	-$18,561	-$18,561	-$18,561
25	$0	$0	$0	$0	$0	-$37,930	-$37,930	-$37,930	-$37,930	-$37,930
26	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
27	$0	$0	$0	$0	$0	-$25,984	-$25,984	-$25,984	-$25,984	-$25,984
28	$0	$0	$0	$0	$0	$6,430	$6,430	$6,430	$6,430	$6,430
29	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
30	$0	$0	$0	$0	$0	-$25,018	-$24,742	-$24,456	-$23,574	-$23,338
31	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
32	$0	$0	$0	$0	$0	$84	$84	$84	$84	$84
33	$0	$0	$0	$0	$0	-$55,369	-$55,369	-$55,369	-$55,369	-$55,369
34	$0	$0	$0	$0	$0	-$9,744	-$9,744	-$9,744	-$9,744	-$9,744
35	$0	$0	$0	$0	$0	-$29,813	-$29,813	-$29,813	-$29,813	-$29,813
36	$0	$0	$0	$0	$0	-$483	-$483	-$483	-$483	-$483
37	$0	$0	$0	$0	$0	-$3	-$3	-$3	-$3	-$3
38	$0	$0	$0	$0	$0	-$5,009	-$5,009	-$5,009	-$5,009	-$5,009
39	$0	$0	$0	$0	$0	-$43,843	-$43,843	-$43,843	-$43,843	-$43,843
40	$0	$0	$0	$0	$0	-$23,326	-$23,509	-$23,604	-$24,080	-$24,158

B.7 Mid-rise Apartment Cost Summary

Mid-rise Apartment	HVAC					Lighting				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	-$5,436	-$4,928	-$5,519	-$3,305	-$11,756	-$12,739	-$12,739	-$12,739	-$12,739	-$12,739
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	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
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	-$3,104	-$3,104	-$3,104	-$3,104	-$3,104
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	-$6,988	-$6,988	-$6,988	-$6,988	-$6,988
12	$0	$0	$0	$0	$0	-$9,176	-$9,176	-$9,176	-$9,176	-$9,176
13	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
15	-$8,097	-$7,335	-$8,218	-$4,925	-$17,486	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
16	$0	$0	$0	$0	$0	$12,548	$12,548	$12,548	$12,548	$12,548
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$1,492	$1,492	$1,492	$1,492	$1,492
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
22	$0	$0	$0	$0	$0	-$7,449	-$7,449	-$7,449	-$7,449	-$7,449
23	$0	$0	$0	$0	$0	-$4,412	-$4,412	-$4,412	-$4,412	-$4,412
24	$0	$0	$0	$0	$0	-$9,176	-$9,176	-$9,176	-$9,176	-$9,176
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
28	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
29	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
30	-$8,097	-$7,335	-$8,218	-$4,925	-$17,486	-$3,104	-$3,104	-$3,104	-$3,104	-$3,104
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$12,548	$12,548	$12,548	$12,548	$12,548
33	$0	$0	$0	$0	$0	-$9,631	-$9,631	-$9,631	-$9,631	-$9,631
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$4,412	$4,412	$4,412	$4,412	$4,412
36	$0	$0	$0	$0	$0	-$4,580	-$4,580	-$4,580	-$4,580	-$4,580
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
40	$2,699	$2,445	$2,739	$1,642	$5,829	-$4,358	-$4,358	-$4,358	-$4,358	-$4,358

Mid-rise Apartment	Envelope, Power and Other					Total				
	2A	3A	3B	4A	5A	2A	3A	3B	4A	5A
New Construction	$0	$313	$313	$3,614	-$120	-$18,175	-$17,353	-$17,944	-$12,430	-$24,614
Maintenance	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement (Year)						$0	$0	$0	$0	$0
1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
3	$0	$0	$0	$0	$0	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
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	-$3,104	-$3,104	-$3,104	-$3,104	-$3,104
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
10	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
11	$0	$0	$0	$0	$0	-$6,988	-$6,988	-$6,988	-$6,988	-$6,988
12	$0	$0	$0	$0	$0	-$9,176	-$9,176	-$9,176	-$9,176	-$9,176
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	-$10,740	-$9,978	-$10,861	-$7,568	-$20,129
16	$0	$0	$0	$0	$0	$12,548	$12,548	$12,548	$12,548	$12,548
17	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	$0	$0	$0	$0	$0	$1,492	$1,492	$1,492	$1,492	$1,492
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
22	$0	$0	$0	$0	$0	-$7,449	-$7,449	-$7,449	-$7,449	-$7,449
23	$0	$0	$0	$0	$0	-$4,412	-$4,412	-$4,412	-$4,412	-$4,412
24	$0	$0	$0	$0	$0	-$9,176	-$9,176	-$9,176	-$9,176	-$9,176
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
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	-$11,200	-$10,438	-$11,321	-$8,029	-$20,590
31	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
32	$0	$0	$0	$0	$0	$12,548	$12,548	$12,548	$12,548	$12,548
33	$0	$0	$0	$0	$0	-$9,631	-$9,631	-$9,631	-$9,631	-$9,631
34	$0	$0	$0	$0	$0	-$461	-$461	-$461	-$461	-$461
35	$0	$0	$0	$0	$0	$4,412	$4,412	$4,412	$4,412	$4,412
36	$0	$0	$0	$0	$0	-$4,580	-$4,580	-$4,580	-$4,580	-$4,580
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	-$2,643	-$2,643	-$2,643	-$2,643	-$2,643
40	$0	$0	$0	$0	$0	-$1,659	-$1,913	-$1,619	-$2,716	$1,470

Appendix C

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 90.1-2013 and 90.1-2016.

C.1 Energy Cost and Savings Summary, 90.1-2013 and 90.1-2016

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

Climate Zone:	2A				3A				3B			
Code:	90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings	
Small Office												
Electricity	$0.898	$0.795	$0.103	11.5%	$0.853	$0.752	$0.101	11.8%	$0.867	$0.765	$0.102	11.8%
Gas	$0.000	$0.000	$0.000	-	$0.002	$0.002	$0.000	0.0%	$0.001	$0.001	$0.000	0.0%
Totals	$0.898	$0.795	$0.103	11.5%	$0.855	$0.754	$0.101	11.8%	$0.868	$0.766	$0.102	11.8%
Large Office												
Electricity	$2.105	$2.036	$0.069	3.3%	$1.996	$1.937	$0.059	3.0%	$2.055	$2.018	$0.037	1.8%
Gas	$0.015	$0.012	$0.003	20.0%	$0.047	$0.029	$0.018	38.3%	$0.017	$0.017	$0.001	5.9%
Totals	$2.120	$2.048	$0.072	3.4%	$2.043	$1.966	$0.077	3.8%	$2.073	$2.035	$0.038	1.8%
Stand-Alone Retail												
Electricity	$1.264	$1.135	$0.129	10.2%	$1.117	$0.992	$0.126	11.3%	$1.172	$1.059	$0.113	9.6%
Gas	$0.038	$0.039	$0.000	0.0%	$0.060	$0.062	-$0.002	-3.3%	$0.063	$0.065	-$0.001	-1.6%
Totals	$1.302	$1.174	$0.128	9.8%	$1.178	$1.054	$0.124	10.5%	$1.235	$1.124	$0.112	9.1%
Primary School												
Electricity	$1.251	$1.055	$0.196	15.7%	$1.145	$0.940	$0.206	18.0%	$1.057	$0.904	$0.153	14.5%
Gas	$0.085	$0.085	$0.000	0.0%	$0.119	$0.117	$0.002	1.7%	$0.118	$0.119	-$0.001	-0.8%
Totals	$1.336	$1.139	$0.196	14.7%	$1.264	$1.056	$0.208	16.5%	$1.175	$1.023	$0.153	13.0%
Small Hotel												
Electricity	$1.152	$1.002	$0.149	12.9%	$1.073	$0.930	$0.143	13.3%	$1.047	$0.917	$0.130	12.4%
Gas	$0.204	$0.200	$0.004	2.0%	$0.223	$0.220	$0.002	0.9%	$0.215	$0.212	$0.003	1.4%
Totals	$1.356	$1.202	$0.154	11.4%	$1.296	$1.150	$0.146	11.3%	$1.262	$1.129	$0.133	10.5%
Mid-Rise Apartment												
Electricity	$1.214	$1.165	$0.049	4.0%	$1.164	$1.118	$0.046	4.0%	$1.241	$1.194	$0.047	3.8%
Gas	$0.003	$0.003	$0.000	0.0%	$0.034	$0.035	-$0.001	-2.9%	$0.004	$0.004	$0.000	0.0%
Totals	$1.217	$1.169	$0.048	3.9%	$1.198	$1.153	$0.046	3.8%	$1.244	$1.198	$0.047	3.8%

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

Climate Zone:	4A				5A			
Code:	90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings	
Small Office								
Electricity	$0.832	$0.735	$0.097	11.7%	$0.830	$0.726	$0.103	12.4%
Gas	$0.002	$0.003	$0.000	0.0%	$0.010	$0.011	-$0.001	-10.0%
Totals	$0.835	$0.738	$0.096	11.5%	$0.840	$0.738	$0.102	12.1%
Large Office								
Electricity	$1.951	$1.891	$0.060	3.1%	$1.890	$1.847	$0.044	2.3%
Gas	$0.086	$0.050	$0.036	41.9%	$0.128	$0.083	$0.045	35.2%
Totals	$2.038	$1.942	$0.096	4.7%	$2.018	$1.929	$0.089	4.4%
Standalone Retail								
Electricity	$1.059	$0.937	$0.122	11.5%	$0.997	$0.887	$0.110	11.0%
Gas	$0.081	$0.085	-$0.003	-3.7%	$0.114	$0.117	-$0.003	-2.6%
Totals	$1.140	$1.022	$0.118	10.4%	$1.110	$1.003	$0.107	9.6%
Primary School								
Electricity	$1.075	$0.879	$0.196	18.2%	$1.026	$0.822	$0.204	19.9%
Gas	$0.137	$0.132	$0.005	3.6%	$0.166	$0.159	$0.008	4.8%
Totals	$1.212	$1.011	$0.201	16.6%	$1.192	$0.981	$0.211	17.7%
Small Hotel								
Electricity	$1.071	$0.913	$0.158	14.8%	$1.099	$0.923	$0.176	16.0%
Gas	$0.242	$0.241	$0.001	0.4%	$0.262	$0.261	$0.001	0.4%
Totals	$1.314	$1.155	$0.159	12.1%	$1.361	$1.184	$0.177	13.0%
Mid-Rise Apartment								
Electricity	$1.224	$1.182	$0.042	3.4%	$1.210	$1.157	$0.053	4.4%
Gas	$0.030	$0.031	-$0.001	-3.3%	$0.058	$0.057	$0.000	0.0%
Totals	$1.254	$1.213	$0.041	3.3%	$1.268	$1.215	$0.053	4.2%

C.2 Energy use and Savings Summary, 90.1-2013 and 90.1-2016

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

Climate Zone:	2A				3A				3B			
Code:	90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings	
Small Office												
Electricity, kWh/ft^2	8.867	7.846	1.021	11.5%	8.419	7.421	0.998	11.9%	8.564	7.556	1.008	11.8%
Gas, therm/ft^2	0.000	0.000	0.000	-	0.002	0.002	0.000	0.0%	0.001	0.001	0.000	0.0%
Totals, kBtu/ft^2	30.271	26.787	3.484	11.5%	28.943	25.554	3.389	11.7%	29.285	25.853	3.432	11.7%
Large Office												
Electricity, kWh/ft^2	20.779	20.102	0.677	3.3%	19.705	19.120	0.585	3.0%	20.290	19.925	0.365	1.8%
Gas, therm/ft^2	0.015	0.012	0.003	20.0%	0.047	0.029	0.018	38.3%	0.017	0.017	0.001	5.9%
Totals, kBtu/ft^2	72.407	69.766	2.642	3.6%	71.953	68.145	3.807	5.3%	70.970	69.661	1.309	1.8%
Stand-Alone Retail												
Electricity, kWh/ft^2	12.478	11.209	1.270	10.2%	11.029	9.790	1.240	11.2%	11.567	10.454	1.113	9.6%
Gas, therm/ft^2	0.038	0.039	0.000	0.0%	0.060	0.062	-0.002	-3.3%	0.063	0.065	-0.001	-1.6%
Totals, kBtu/ft^2	46.416	42.114	4.302	9.3%	43.670	39.604	4.066	9.3%	45.826	42.137	3.689	8.1%
Primary School												
Electricity, kWh/ft^2	12.345	10.410	1.934	15.7%	11.306	9.276	2.030	18.0%	10.437	8.925	1.512	14.5%
Gas, therm/ft^2	0.085	0.085	0.000	0.0%	0.119	0.117	0.002	1.7%	0.118	0.119	-0.001	-0.8%
Totals, kBtu/ft^2	50.673	44.023	6.650	13.1%	50.483	43.318	7.165	14.2%	47.437	42.344	5.093	10.7%
Small Hotel												
Electricity, kWh/ft^2	11.367	9.892	1.475	13.0%	10.593	9.177	1.416	13.4%	10.336	9.050	1.286	12.4%
Gas, therm/ft^2	0.204	0.200	0.004	2.0%	0.223	0.220	0.002	0.9%	0.215	0.212	0.003	1.4%
Totals, kBtu/ft^2	59.241	53.763	5.478	9.2%	58.410	53.367	5.043	8.6%	56.797	52.130	4.667	8.2%
Mid-Rise Apartment												
Electricity, kWh/ft^2	11.985	11.505	0.480	4.0%	11.489	11.032	0.458	4.0%	12.247	11.787	0.461	3.8%
Gas, therm/ft^2	0.003	0.003	0.000	0.0%	0.034	0.035	-0.001	-2.9%	0.004	0.004	0.000	0.0%
Totals, kBtu/ft^2	41.226	39.606	1.620	3.9%	42.636	41.154	1.482	3.5%	42.153	40.590	1.563	3.7%

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

Climate Zone:	4A				5A			
Code:	90.1-2013	90.1-2016	Savings		90.1-2013	90.1-2016	Savings	
Small Office								
Electricity, kWh/ft^2	8.216	7.261	0.955	11.6%	8.191	7.170	1.021	12.5%
Gas, therm/ft^2	0.002	0.003	0.000	0.0%	0.010	0.011	-0.001	-10.0%
Totals, kBtu/ft^2	28.266	25.034	3.232	11.4%	28.971	25.599	3.372	11.6%
Large Office								
Electricity, kWh/ft^2	19.264	18.670	0.594	3.1%	18.662	18.229	0.434	2.3%
Gas, therm/ft^2	0.086	0.050	0.036	41.9%	0.128	0.083	0.045	35.2%
Totals, kBtu/ft^2	74.380	68.764	5.615	7.5%	76.494	70.487	6.007	7.9%
Standalone Retail								
Electricity, kWh/ft^2	10.453	9.251	1.202	11.5%	9.839	8.752	1.087	11.0%
Gas, therm/ft^2	0.081	0.085	-0.003	-3.7%	0.114	0.117	-0.003	-2.6%
Totals, kBtu/ft^2	43.826	40.054	3.772	8.6%	44.943	41.539	3.404	7.6%
Primary School								
Electricity, kWh/ft^2	10.611	8.681	1.931	18.2%	10.129	8.116	2.012	19.9%
Gas, therm/ft^2	0.137	0.132	0.005	3.6%	0.166	0.159	0.008	4.8%
Totals, kBtu/ft^2	49.948	42.835	7.113	14.2%	51.214	43.583	7.631	14.9%
Small Hotel								
Electricity, kWh/ft^2	10.575	9.018	1.558	14.7%	10.849	9.112	1.737	16.0%
Gas, therm/ft^2	0.242	0.241	0.001	0.4%	0.262	0.261	0.001	0.4%
Totals, kBtu/ft^2	60.330	54.926	5.405	9.0%	63.216	57.194	6.022	9.5%
Mid-Rise Apartment								
Electricity, kWh/ft^2	12.085	11.672	0.412	3.4%	11.946	11.426	0.520	4.4%
Gas, therm/ft^2	0.030	0.031	-0.001	-3.3%	0.058	0.057	0.000	0.0%
Totals, kBtu/ft^2	44.268	42.916	1.352	3.1%	46.550	44.727	1.824	3.9%

C.3 Energy by Usage Category, 90.1-2013 and 90.1-2016

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 90.1-2013												
Heating, Humidification	0.033	0.000	0.003	0.006	0.000	0.005	0.000	0.027	0.079	0.001	0.000	0.003
Cooling	1.578	0.000	4.394	0.000	3.122	0.000	3.325	0.000	3.396	0.000	2.128	0.000
Fans, Pumps, Heat Recovery	0.987	0.000	1.719	0.000	2.466	0.000	1.460	0.000	1.783	0.000	1.528	0.000
Lighting, Interior & Exterior	2.920	0.000	2.276	0.000	4.704	0.000	2.840	0.000	2.524	0.000	1.486	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.623	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.111	2.635	0.000
Total	8.867	0.000	20.779	0.015	12.478	0.038	12.345	0.085	11.367	0.204	11.985	0.003
ASHRAE 90.1-2016												
Heating, Humidification	0.036	0.000	0.235	0.003	0.000	0.005	0.000	0.026	0.052	0.001	0.000	0.003
Cooling	1.525	0.000	3.863	0.000	2.965	0.000	2.953	0.000	2.932	0.000	2.064	0.000
Fans, Pumps, Heat Recovery	0.970	0.000	1.679	0.000	2.345	0.000	1.319	0.000	1.168	0.000	1.469	0.000
Lighting, Interior & Exterior	1.967	0.000	1.951	0.000	3.713	0.000	1.445	0.000	2.155	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.374	0.000	2.186	0.000	4.597	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.009	0.000	0.034	0.097	0.013	0.000	0.106	2.635	0.000
Total	7.846	0.000	20.102	0.012	11.209	0.039	10.410	0.085	9.892	0.200	11.505	0.003
Total Savings	1.021	0.000	0.677	0.003	1.270	0.000	1.934	0.000	1.475	0.004	0.480	0.000

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/	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 90.1-2013												
Heating, Humidification	0.209	0.002	0.010	0.037	0.000	0.025	0.000	0.058	0.520	0.007	0.000	0.034
Cooling	0.951	0.000	3.439	0.000	1.896	0.000	2.224	0.000	2.163	0.000	1.228	0.000
Fans, Pumps, Heat Recovery	0.985	0.000	1.587	0.000	2.230	0.000	1.492	0.000	1.792	0.000	1.586	0.000
Lighting, Interior & Exterior	2.925	0.000	2.282	0.000	4.717	0.000	2.871	0.000	2.534	0.000	1.487	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.621	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.123	2.981	0.000
Total	8.419		19.705	0.047	11.029	0.060	11.306	0.119	10.593	0.223	11.489	0.034
ASHRAE 90.1-2016												
Heating, Humidification	0.217		0.626	0.019	0.000	0.027	0.000	0.056	0.322	0.007	0.000	0.035
Cooling	0.914	0.000	2.604	0.000	1.791	0.000	1.872	0.000	1.938	0.000	1.185	0.000
Fans, Pumps, Heat Recovery	0.968	0.000	1.559	0.000	2.089	0.000	1.230	0.000	1.168	0.000	1.528	0.000
Lighting, Interior & Exterior	1.973	0.000	1.958	0.000	3.724	0.000	1.481	0.000	2.164	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.374	0.000	2.186	0.000	4.596	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.121	2.981	0.000
Total	7.421		19.120	0.029	9.790	0.062	9.276	0.117	9.177	0.220	11.032	0.035
Total Savings	0.998	0.000	0.585	0.018	1.240	-0.002	2.030	0.002	1.416	0.002	0.458	-0.001

Annual Energy Usage for Buildings in Climate Zone 3B

Energy End-Use	Small Office		Large Office		Stand-Alone Retail		Primary School		Small Hotel		Mid-Rise Apartment	
	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas
	kWh/ ft^2·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 90.1-2013												
Heating, Humidification	0.123	0.001	1.021	0.007	0.000	0.029	0.000	0.058	0.229	0.003	0.000	0.004
Cooling	1.021	0.000	2.891	0.000	2.009	0.000	1.956	0.000	2.136	0.000	1.427	0.000
Fans, Pumps, Heat Recovery	1.149	0.000	1.712	0.000	2.529	0.000	0.899	0.000	1.849	0.000	2.236	0.000
Lighting, Interior & Exterior	2.922	0.000	2.278	0.000	4.844	0.000	2.864	0.000	2.537	0.000	1.486	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.388	0.000	2.186	0.000	4.621	0.046	3.585	0.092	4.208	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	2.890	0.000
Total	8.564	0.001	20.290	0.017	11.567	0.063	10.437	0.118	10.336	0.215	12.247	0.004
ASHRAE 90.1-2016												
Heating, Humidification	0.129	0.001	1.020	0.007	0.000	0.030	0.000	0.059	0.134	0.003	0.000	0.004
Cooling	0.982	0.000	2.883	0.000	1.919	0.000	1.857	0.000	1.936	0.000	1.377	0.000
Fans, Pumps, Heat Recovery	1.131	0.000	1.696	0.000	2.517	0.000	0.880	0.000	1.228	0.000	2.182	0.000
Lighting, Interior & Exterior	1.966	0.000	1.952	0.000	3.831	0.000	1.496	0.000	2.166	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.374	0.000	2.186	0.000	4.595	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.010	0.000	0.035	0.097	0.014	0.000	0.117	2.890	0.000
Total	7.556	0.001	19.925	0.017	10.454	0.065	8.925	0.119	9.050	0.212	11.787	0.004
Total Savings	1.008	0.000	0.365	0.001	1.113	-0.001	1.512	-0.001	1.286	0.003	0.461	0.000

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·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr	ft^2·yr
ASHRAE 90.1-2013												
Heating, Humidification	0.294	0.002	0.018	0.075	0.000	0.045	0.000	0.075	1.147	0.017	0.000	0.030
Cooling	0.740	0.000	3.034	0.000	1.320	0.000	1.566	0.000	1.581	0.000	1.063	0.000
Fans, Pumps, Heat Recovery	0.946	0.000	1.542	0.000	2.129	0.000	1.547	0.000	1.770	0.000	2.077	0.000
Lighting, Interior & Exterior	2.887	0.000	2.282	0.000	4.819	0.000	2.781	0.000	2.492	0.000	1.486	0.000
Plugs, Refrigeration, Other	2.438	0.000	12.388	0.000	2.186	0.000	4.621	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.016	0.000	0.133	3.250	0.000
Total	8.216	0.002	19.264	0.086	10.453	0.081	10.611	0.137	10.575	0.242	12.085	0.030
ASHRAE 90.1-2016												
Heating, Humidification	0.313	0.003	0.847	0.040	0.000	0.049	0.000	0.070	0.665	0.016	0.000	0.031
Cooling	0.716	0.000	1.987	0.000	1.243	0.000	1.353	0.000	1.482	0.000	1.025	0.000
Fans, Pumps, Heat Recovery	0.938	0.000	1.504	0.000	2.011	0.000	1.190	0.000	1.145	0.000	2.060	0.000
Lighting, Interior & Exterior	1.946	0.000	1.958	0.000	3.811	0.000	1.446	0.000	2.140	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.438	0.000	12.374	0.000	2.186	0.000	4.595	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.011	0.000	0.036	0.097	0.016	0.000	0.133	3.250	0.000
Total	7.261	0.003	18.670	0.050	9.251	0.085	8.681	0.132	9.018	0.241	11.672	0.031
Total Savings	0.955	0.000	0.594	0.036	1.202	-0.003	1.931	0.005	1.558	0.001	0.412	-0.001

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 90.1-2013												
Heating, Humidification	0.511	0.010	0.997	0.116	0.000	0.077	0.000	0.104	1.872	0.026	0.000	0.058
Cooling	0.492	0.000	1.497	0.000	0.807	0.000	1.068	0.000	1.125	0.000	0.728	0.000
Fans, Pumps, Heat Recovery	0.946	0.000	1.501	0.000	2.027	0.000	1.552	0.000	1.773	0.000	2.046	0.000
Lighting, Interior & Exterior	2.893	0.000	2.279	0.000	4.819	0.000	2.791	0.000	2.495	0.000	1.486	0.000
Plugs, Refrigeration, Other	2.438	0.000	12.388	0.000	2.186	0.000	4.620	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.144	3.479	0.000
Total	8.191	0.010	18.662	0.128	9.839	0.114	10.129	0.166	10.849	0.262	11.946	0.058
ASHRAE 90.1-2016												
Heating, Humidification	0.536	0.011	0.995	0.071	0.000	0.080	0.000	0.096	1.141	0.025	0.000	0.057
Cooling	0.445	0.000	1.466	0.000	0.769	0.000	0.846	0.000	1.100	0.000	0.657	0.000
Fans, Pumps, Heat Recovery	0.888	0.000	1.436	0.000	1.987	0.000	1.140	0.000	1.144	0.000	1.952	0.000
Lighting, Interior & Exterior	1.952	0.000	1.957	0.000	3.811	0.000	1.438	0.000	2.142	0.000	1.130	0.000
Plugs, Refrigeration, Other	2.439	0.000	12.374	0.000	2.186	0.000	4.595	0.046	3.585	0.092	4.208	0.000
Service Water Heating (SWH)	0.910	0.000	0.000	0.012	0.000	0.037	0.097	0.017	0.000	0.143	3.480	0.000
Total	7.170	0.011	18.229	0.083	8.752	0.117	8.116	0.159	9.112	0.261	11.426	0.057
Total Savings	1.021	-0.001	0.434	0.045	1.087	-0.003	2.012	0.008	1.737	0.001	0.520	0.000

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