ESL-TR-11-10-07

COST-EFFECTIVE ENERGY EFFICIENCY MEASURES FOR ABOVE CODE (ASHRAE 90.1-2001 and 2007): SMALL OFFICE BUILDINGS IN THE CITY OF ARLINGTON

A Research Project for the City of Arlington

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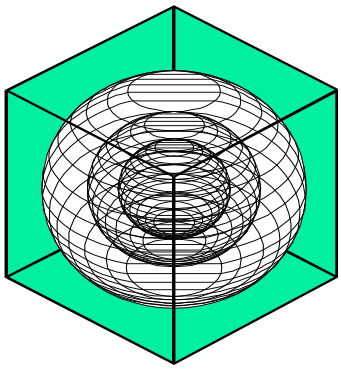

ENERGY SYSTEMS LABORATORY

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EXECUTIVE SUMMARY

The Energy Systems Laboratory was requested to develop cost-effective recommendations to maximize energy savings for residential and commercial buildings in the City of Arlington (CoA). This report presents the analysis results for small office buildings in the CoA.

For more realistic recommendations, the CoA provided two years of commercial building energy compliance reports from 2008 to 2010 which exceeded the energy efficiency requirements of the CoA (i.e., ASHRAE 90.1-2001). From a statistical analysis of energy compliance reports provided for eleven commercial, above-code approaches that had been made in the CoA were summarized for commercial applications. Based on a summary of above-code approaches, recommendations were developed to achieve above-code energy performance based on the ASHRAE 90.1-2001 and 2007 standard reference buildings, for small office buildings in the CoA.

The deliverables for the CoA in this report consist of three parts:

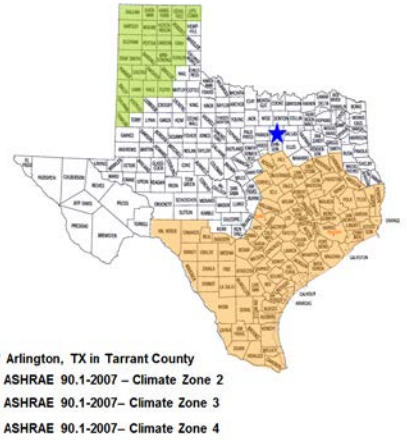
- A review of two years of building energy compliance reports from 2008 to 2010 for eleven commercial projects in the CoA;
- A summary of above-code approaches that have been made in the CoA during the 2008-2010; and
- Recommendations of 17 energy efficiency measures (EEMs) to maximize energy savings for small office buildings in the CoA with estimated cost of the improvement, simple payback calculations, and emissions savings.

A total of 17 recommendations based on the energy savings above the base-case building were selected. These measures include building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. The implementation costs of each individual measure were also calculated along with simple payback calculations. Figures 1 and 2 present a description of the individual measures and combinations of these measures which achieve 15% source energy savings above the ASHRAE 90.1-2001 and 2007 code-compliant building. Annual energy savings, estimated costs, simple payback, and NOx, SO_2, and CO_2 emissions reduction are provided.

[ASHRAE 90.1-2001 Code-Compliant Small Office Building]

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)[1]		Annual Energy Savings ($/year)[2]	Annual Demand Savings (%)	Annual Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($)		Simple Estimated Payback (yrs)
		Site	Source					Marginal Cost[4]	New System Cost[5]	
A	**Envelope and Fenestration Measures**									
1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	1.9%	1.1%	$163	0.5%	$16	$179	$14,332 - $21,499		80.3 - 120.4
2	Decreased Glazing U-Value (from 1.22 to 0.35)	9.6%	3.4%	$373	0.2%	$8	$381	$16,773 - $25,160		44.0 - 66.0
3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	0.1%	0.6%	$130	1.0%	$35	$165		$14,159 - $21,238	85.9 - 128.9
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	0.9%	1.1%	$217	1.1%	$39	$256		$14,159 - $21,238	55.3 - 83.0
5	High Albedo Roof (Roof Absorptance from 0.7 to 0.3)	-0.1%	0.3%	$75	0.3%	$10	$85	$4,400 - $6,600		51.6 - 77.4
B	**HVAC System Measures**									
6	CO_2 Based Demand-Controlled Ventilation (DCV)	6.2%	3.6%	$561	0.9%	$31	$592		$7,367 - $11,051	12.4 - 18.7
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	3.5%	4.1%	$796	6.6%	$227	$1,023	$12,288 - $18,432		12.0 - 18.0
8	Improved Furnace Efficiency (from 80% to 90% Et)	2.0%	0.8%	$102	0.0%	$0	$102	$7,900 - $11,850		77.3 - 115.9
9	Improved Fan Efficiency (from 55% to 65%)	2.1%	3.1%	$628	2.7%	$91	$719	$6,869 - $10,303		9.6 - 14.3
C	**Service Hot Water Measures**									
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	0.9%	0.4%	$48	0.0%	$0	$48	$3,456 - $5,184		72.1 - 108.1
11	Tankless Gas Water Heater	1.6%	1.5%	$268	0.5%	$17	$284	$1,414 - $2,120		5.0 - 7.5
12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	3.2%	1.2%	$146	-0.2%	-$6	$140		$2,880 - $4,320	20.6 - 30.9
D	**Lighting and Receptacle Measures**									
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	6.7%	9.5%	$1,906	11.3%	$386	$2,292	$9,344 - $14,016		4.1 - 6.1
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	9.1%	13.0%	$2,612	15.5%	$532	$3,144	$10,484 - $15,726		3.3 - 5.0
15	Daylight Dimming Control	6.4%	8.7%	$1,733	11.9%	$409	$2,141		$15,723 - $23,584	7.3 - 11.0
16	Automatic Receptacle Control for Offices using Occupancy Sensors	1.7%	2.3%	$466	3.2%	$109	$575		$7,587 - $11,380	13.2 - 19.8
E	**Renewable Power Measure**									
17	40 kW Photovoltaic Array	26.0%	30.7%	$5,979	24.2%	$829	$6,808		$200,000 - $300,000	29.4 - 44.1



Description of Combined Measures

	Combination of Measures[6]	Combined Annual Energy Savings (%)[1]		Combined Energy Savings ($/year)[2]	Combined Demand Savings (%)	Combined Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($)		Simple Estimated Payback (yrs)	NOx Emissions Savings	SO_2 Emissions Savings	CO_2 Emissions Savings
		Site	Source					Marginal Cost[4]	New System Cost[5]		Annual (lbs/yr)	Annual (lbs/yr)	Annual (tons/yr)
	Combination 1												
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	10.7%	15.0%	$2,878	16.0%	$549	$3,426	$10,484 - $15,726		3.5 - 5.2	48.2	31.4	20.0
11	Tankless Gas Water Heater							$1,414 - $2,120					
	Combination 2												
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	11.0%	15.4%	$3,087	19.8%	$678	$3,765	$9,344 - $14,016		6.7 - 10.0	51.8	34.0	21.3
15	Daylight Dimming Control								$15,723 - $23,584				
	Combination 3												
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	16.4%	16.8%	$3,172	18.2%	$623	$3,795	$9,344 - $14,016		7.6 - 11.5	52.5	31.4	22.7
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
6	CO_2 Based Demand-Controlled Ventilation (DCV)								$7,367 - $11,051				

Note:
1. Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
2. Savings depend on fuel mix used.
   * Energy Cost: Electricity = $0.095/kWh & Demand = $5.00/kW
     Natural gas = $0.65/therm
3. Yearly demand cost = Sum of monthly demand cost for 12 months
4. Marginal cost = new system cost - original system cost
5. New system cost = new system cost only
6. See individual measures above for specific savings

[ASHRAE 90.1-2001 Code-Compliant Building Description]
* Building type: Small Office
* Gross area: 20,000 sq-ft
* Building dimension: 100 ft x 100 ft x 13 ft (WxLxH)
* Number of floors: 2
* Floor-to-floor height: 13 ft
* Window-to-wall ratio: 20.0%
* HVAC system: SEER 13 or EER 10.8 Rooftop PSZ & 80% Et Furnace
* DHW: 80% Et Gas Water heater

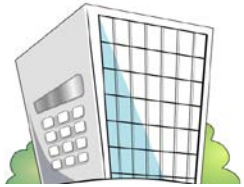
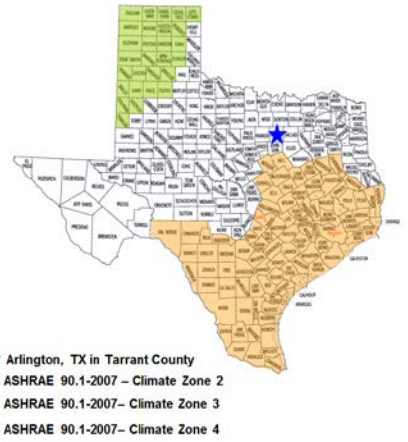


Figure 1. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2001 Code-Compliant Small Office Building for CoA

[ASHRAE 90.1-2007 Code-Compliant Small Office Building]

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)[1]		Annual Energy Savings ($/year)[2]	Annual Demand Savings (%)	Annual Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($)		Simple Estimated Payback (yrs)
		Site	Source					Marginal Cost[4]	New System Cost[5]	
A	**Envelope and Fenestration Measures**									
1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	1.7%	0.9%	$112	0.4%	$13	$126	$9,092 - $13,639		72.2 - 108.3
2	Decreased Glazing U-Value (from 0.65 to 0.35)	4.5%	1.5%	$145	0.0%	$1	$146	$7,039 - $10,558		48.4 - 72.5
3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	0.0%	0.6%	$128	1.0%	$32	$160		$14,159 - $21,238	88.3 - 132.5
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	0.6%	1.0%	$193	1.2%	$37	$230		$14,159 - $21,238	61.6 - 92.4
B	**HVAC System Measures**									
6	CO_2 Based Demand-Controlled Ventilation (DCV)	2.1%	1.3%	$200	0.7%	$23	$223		$7,367 - $11,051	33.1 - 49.6
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	3.7%	4.3%	$763	6.8%	$214	$977	$12,288 - $18,432		12.6 - 18.9
8	Improved Furnace Efficiency (from 80% to 90% Et)	1.7%	0.7%	$76	0.0%	$0	$76	$7,900 - $11,850		103.5 - 155.2
9	Improved Fan Efficiency (from 55% to 65%)	2.4%	3.4%	$615	3.0%	$93	$708	$6,869 - $10,303		9.7 - 14.5
C	**Service Hot Water Measures**									
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	1.0%	0.4%	$48	0.0%	$0	$48	$3,456 - $5,184		72.1 - 108.1
11	Tankless Gas Water Heater	1.8%	1.6%	$265	0.6%	$18	$283	$1,414 - $2,120		5.0 - 7.5
12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	3.6%	1.4%	$146	-0.2%	-$6	$140		$2,880 - $4,320	20.6 - 30.9
D	**Lighting and Receptacle Measures**									
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	1.9%	2.6%	$476	3.1%	$97	$573	$4,913 - $7,369		8.6 - 12.9
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	4.8%	6.6%	$1,196	7.8%	$243	$1,439	$6,052 - $9,079		4.2 - 6.3
15	Daylight Dimming Control	5.7%	7.5%	$1,341	10.4%	$325	$1,666		$15,723 - $23,584	9.4 - 14.2
16	Automatic Receptacle Control for Offices using Occupancy Sensors	1.9%	2.6%	$465	3.5%	$110	$575		$7,587 - $11,380	13.2 - 19.8
E	**Renewable Power Measure**									
17	40 kW Photovoltaic Array	29.3%	34.1%	$5,979	25.5%	$800	$6,779		$200,000 - $300,000	29.5 - 44.3



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		Site	Source					Marginal Cost[4]	New System Cost[5]		Annual (lbs/yr)	Annual (lbs/yr)	Annual (tons/yr)
	Combination 1												
15	Daylight Dimming Control	11.2%	15.5%	$2,812	18.6%	$583	$3,395		$15,723 - $23,584	8.4 - 12.7	47.2	31.0	19.4
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)							$6,052 - $9,079					
9	Improved Fan Efficiency (from 55% to 65%)							$6,869 - $10,303					
	Combination 2												
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	11.9%	14.9%	$2,639	18.3%	$572	$3,212	$6,052 - $9,079		8.5 - 12.8	44.1	28.2	18.4
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
16	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
11	Tankless Gas Water Heater							$1,414 - $2,120					
	Combination 3												
15	Daylight Dimming Control	13.1%	15.3%	$2,682	20.5%	$642	$3,324		$15,723 - $23,584	12.9 - 19.4	44.7	28.1	18.9
14	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
16	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
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Note:
1. Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
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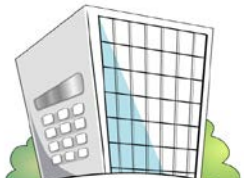

Figure 2. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for CoA

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1 INTRODUCTION

The Energy Systems Laboratory was requested to develop cost-effective recommendations to maximize energy savings for residential and commercial buildings in the City of Arlington (CoA). This report presents the analysis results for small office buildings in the CoA.

For more realistic recommendations, the CoA provided two years of commercial building energy compliance reports from 2008 to 2010 which exceeded the energy efficiency requirements of the CoA (i.e., ASHRAE 90.1-2001). From a statistical analysis of energy compliance reports provided for eleven commercial, above-code approaches that had been made in the CoA were summarized for commercial applications. Based on a summary of above-code approaches, recommendations were developed to achieve above-code energy performance based on the ASHRAE 90.1-2001 and 2007 standard reference buildings, for small office buildings in the CoA

The deliverables for the CoA consist of three parts:

- A review of two years of building energy compliance reports from 2008 to 2010 for eleven commercial projects in the CoA;
- A summary of above-code approaches that have been made in the CoA during the 2008-2010; and
- Recommendations of 17 energy efficiency measures (EEMs) to maximize energy savings for small office buildings in the CoA with estimated cost of the improvement, simple payback calculations, and emissions savings.

1.1 Organization of the Report

The report is organized in the following order:

- Section 1 presents the introduction and purpose of the report.
- Section 2 presents the methodology that was used.
- Section 3 provides a review of the eleven commercial buildings' energy compliance reports, including the results from statistical analysis and above-code approaches that have been made for the past two years from 2008 to 2010.
- Section 4 presents the proposed energy efficiency measures for small office buildings in the CoA, including savings from 17 individual measures along with the simple payback calculations.
- Section 5 is a summary which is followed by references.

2 METHODOLOGY

This section describes the methodology and assumptions that were used in this analysis: to analyze information on energy certification for eleven commercial buildings, and to develop the cost-effective recommendations for achieving energy performance better than ASHRAE 90.1-2001 and 2007 code-compliant buildings for small offices in the CoA. Section 2.1 presents an overall approach used in this analysis. Section 2.2 describes the base-case building characteristics. Section 2.3 presents assumptions used in cost analysis.

2.1 Overview

To define important building parameters used to achieve above-code performance, a review of the building energy compliance reports for the past two years from 2008 to 2010 was performed for eleven commercial projects in the CoA. The buildings' envelope, fenestration, and system characteristics were summarized and then statistically compared with the 2003 IECC Section 806 requirements for commercial buildings. Finally, a summary table of energy efficiency measures used for the commercial buildings in the CoA during the 2008-2010 was developed.

Based on the summary of commercial above-code approaches, recommendations were developed to achieve above-code energy performance based on the ASHRAE 90.1-2001 and 2007 standard reference building, for small offices in the CoA. The analysis was performed using an ESL simulation tool based on the DOE-2.1e simulation of ASHRAE 90.1-2001 and 2007 code-compliant, small office buildings for Tarrant County where the CoA is located and the Fort Worth TMY2 weather file (Figure 3). A total of 17 energy efficiency measures were then applied to the base-case models to determine the savings of each measure. These measures were simulated by modifying the selected parameters used for the DOE-2 simulation tool. The solar measures including solar PV and solar SHW were simulated using the PV-F Chart (Klein and Beckman 1994) and F-Chart (Klein and Beckman 1983) programs, respectively. The implementation costs of each measure were also calculated along with simple payback calculations.

The measures were then combined to achieve the total source energy savings of the group is 15% above the base-case ASHRAE 90.1-2001 and 2007 code-compliant buildings. The results from individual measures and cost analysis were used to guide the selection of measures. As a result, three combinations were proposed for each base case. Each combination was formed to have a different payback period. Finally, the corresponding emissions savings of each combination were calculated based on the eGrid for Texas.

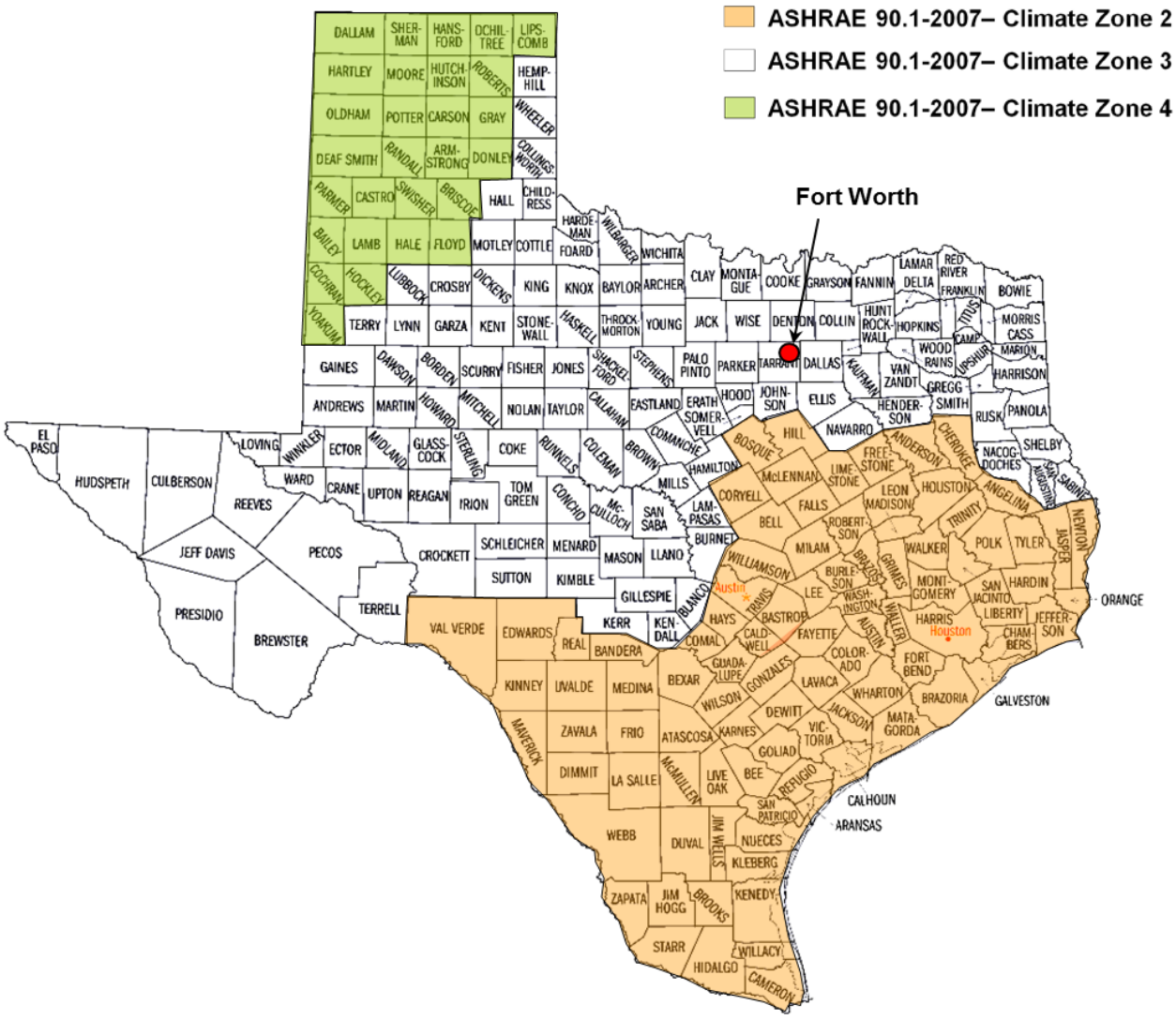


Figure 3. Tarrant County and Fort Worth TMY2 Weather File Used in the Analysis

2.2 Base-Case Building Description

The base-case building simulation model in this analysis is based on the *standard* design as defined in the ASHRAE 90.1-2001[1] and 2007[2] and certain assumptions, which are described throughout this document. The base-case building is a 20,000 sq. ft., square-shape, two story, wood-frame building oriented N, S, E, W, with a 20% window-to-wall ratio. Four perimeter zones and a central core zone were modeled for each floor with a floor-to-ceiling height of 13 feet. The other envelope and system characteristics were determined from the general characteristics and the climate-specific characteristics as specified in the ASHRAE 90.1-2001 and 2007. Table 1 summarizes the base-case, ASHRAE 90.1-2001 and 2007 code-compliance building characteristics used in the DOE-2 simulation tool in this analysis.

2.3 Assumptions for Cost Analysis

The cost analysis for different measures was carried out based on utility costs of $0.095/kWh for electricity, $5.00/kW for demand charge, and $0.65/therm for natural gas. The electricity rate was determined based on the annual average prices of Texas commercial electricity for 2010 published by the U.S. DOE EIA (2011), and demand charges were from the previous study by Cho et al. (2007). For natural gas rates, the annual average rates calculated for Arlington were used (Atmos Energy 2011).

[1] per 2003 IECC Section 801.2
[2] per 2009 IECC Section 501.2

Table 1. Base-Case Building Description

Characteristics	Information Source	Assumptions		Comments
		ASHRAE 90.1-2001	ASHRAE 90.1-2007	
Building				
Building Type		Small office		Number of occupants = 73
Gross Area (sq. ft.)	PNNL-19341 (Thornton et al. 2010) and CoA	20,000		
Aspect Ratio	PNNL-19341 (Thornton et al. 2010)	1:1		Square shape
Number of Floors	PNNL-19341 (Thornton et al. 2010)	2		
Floor-to-Floor Height (ft.)	ASHRAE 90.1-1989 13.7.1	13		Floor-to-Ceiling Height = 9 ft
Orientation	PNNL-19341 (Thornton et al. 2010)	South facing		
Construction				
Wall Construction	CoA	Wood frame with 2x4 studs spaced at 16" on center		
Roof Configuration	PNNL-19341 (Thornton et al. 2010)	Flat built-up, Insulation entirely above deck		
Foundation Construction	PNNL-19341 (Thornton et al. 2010)	6" concrete slab-on-grade floor		
Wall Absorptance	DOE 2.1E BDL SUMMARY, Page 12	0.75		Assuming gray, light oil paint
Wall Insulation (hr-sq.ft.-°F/Btu)	ASHRAE 90.1-2001 Table B-8 and ASHRAE 90.1-2007 Table 5.5-3	R-13		
Roof Absorptance	ASHRAE 90.1-1999 11.4.2b and ASHRAE 90.1-2007 Sec. 5.5.3.1.1	0.7	0.3	Roof reflectance = 0.3 for 2001 and 0.7 for 2007
Roof Insulation (hr-sq.ft.-°F/Btu)	ASHRAE 90.1-2001 Table B-8 and ASHRAE 90.1-2007 Table 5.5-3	R-15 ci	R-20 ci	
Slab Perimeter Insulation	ASHRAE 90.1-2001 Table B-8 and ASHRAE 90.1-2007 Table 5.5-3	None		Slab-on-grade floor, unheated
Ground Reflectance	DOE 2.1E BDL SUMMARY, Page 20	0.24		Assuming grass
U-Factor of Glazing (Btu/hr-sq.ft.-°F)	ASHRAE 90.1-2001 Table B-8 and ASHRAE 90.1-2007 Table 5.5-3	1.22	0.65	Fixed fenestration
Solar Heat Gain Coefficient (SHGC)	ASHRAE 90.1-2001 Table B-8 and ASHRAE 90.1-2007 Table 5.5-3	0.25		
Window Area	PNNL-19341 (Thornton et al. 2010)	20% Window to wall ratio		
Exterior Shading	ASHRAE 90.1-1999 11.4.2c and ASHRAE 90.1-2007 Table 11.3.1 No.5	None		
Space Conditions				
Space Heating Set point	PNNL-19341 (Thornton et al. 2010)	70 F(Occupied), 5 F setback		
Space Cooling Set point		75 F(Occupied), 5 F setup		
Lighting Power Density (W/ft^2)	ASHRAE 90.1-2001 Table 9.3.1.1 and ASHRAE 90.1-2007 Table 9.5.1	1.3	1.0	
Equipment Power Density (W/ft^2)	PNNL-19341 (Thornton et al. 2010)	0.75		
Mechanical Systems				
HVAC System Type	ASHRAE 90.1-2001 11.4.3 and ASHRAE 90.1-2007 11.3.2	Packaged rooftop air conditioner (CAV, DX, gas furnace)		
Air Conditioning System Efficiency	FEDERAL MINIMUM EFFICIENCY STANDARDS	13 SEER (<65,000 Btu/h) 10.8 EER (≥135,000 Btu/h and <240,000 Btu/h)		
Heating System Efficiency (%)	ASHRAE 90.1-2001 Table 6.2.1E and ASHRAE 90.1-2007 Table 6.8.1E	80% Et		Gas-fired furnace Capacity < 225,000 Btu/hr
Cooling Capacity (Btu/hr)		Autosized		
Heating Capacity (Btu/hr)		Autosized		
Economizer	ASHRAE 90.1-2001 Table 6.3.1 and ASHRAE 90.1-2007 Table 6.5.1	No		
Ventilation (cfm)	ASHRAE 62.1-1999 and ASHRAE 62.1-2004	1,460	1,565	ASHRAE 62.1-1999: 20cfm/person; and ASHRAE 62.1-2004: 5 cfm/person & 0.06 cfm.sq.ft.
Supply Air Flow (cfm/sq.ft)		1		
SHW System Type	PNNL-19341 (Thornton et al. 2010)	Gas-fired storage water heater (75 gallon, 75,100 Btu/hr)		
SHW Heater Efficiency (%)	ASHRAE 90.1-2001 Table 7.2.2 and ASHRAE 90.1-2007 Table 7.8	80 % Et (SL=1046.5 Btu/h)		
SHW Temperature Setpoint (F)	PNNL-19341 (Thornton et al. 2010)	120 F		

3 REVIEW OF COMMERCIAL BUILDING ENERGY COMPLIANCE REPORTS

This section provides a review of the eleven commercial buildings' energy compliance reports, including the results from statistical analysis and above-code approaches made during the past two years (2008-2010) in the CoA. A statistical analysis was performed based on the 2003 IECC Section 806 performance path requirements. A summary table of the energy efficiency measures (EEMs) that had been used in the eleven commercial buildings was developed.

Section 3.1 presents a master table that summarizes important building characteristics of the eleven sample buildings, including a brief description of energy certification, general building information, envelope and fenestration characteristics, and mechanical system characteristics. Section 3.2 provides a statistical analysis of summarized results with the 2003 IECC requirements. Section 3.3 gives a summary of the EEMs used in the eleven sample commercial buildings.

3.1 **Master Summary Table**

A master summary table was developed to describe and summarize important building characteristics of the eleven sample commercial buildings for the following five categories: identification, building, envelope, interior lighting, and system. First, the identification section presents information associated with their certification, as shown in Table 7. This includes the RSN number, building type, occupancy class and activity type, new or addition construction, compliant option and software version, certification date, and above code percentage. The activity type of eleven buildings quite varies, including restaurants, retails, medical and clinics, schools, offices, industries, and a multi-family. Eight buildings are new construction, and other three buildings are additions. Of eleven buildings, ten comply with the 2003 IECC, and one complies with the ASHRAE Standard 90.1-1999. All eleven buildings used the COMcheck software to generate their energy compliance reports. Eight buildings (73%) have above-code percentage between 30% and 40% for their envelope performance, and seven buildings (63%) have above-code percentage between 10% and 30% for their lighting system performance.

Next, the building section presents information associated with general building characteristics, as shown in Table 8. This includes climate zone, number of floors, and floor area. Of eleven buildings, nine are single-story buildings, and other two are either two-story or eleven-story buildings. Eight buildings (72%) have a total floor less than 8,000 ft^2.

The envelope section presents information associated with construction property, including windows, walls, roofs, floors, and doors, as shown in Tables 9 and 10. Nine buildings have less than or equal to 15% of window-to-wall ratio. For construction, seven buildings use wood frames, and two buildings use metal frames. Ten buildings do not have any slab insulations. The glass door U-values vary from 0.5 to 1.1 Btu/hr-sq.ft.-F.

The interior lighting section presents information associated with lighting electricity usage, as shown in Table 10. The interior lighting power density (W/sq-ft) was calculated by dividing proposed total lighting electricity usages (W) by the floor area. Ten buildings (91%) use less than 1.5 W/ft^2 for their interior lighting.

Finally, the system section presents information associated with mechanical systems, as shown in Table 11. This includes the number of systems, type, efficiency, and capacity of air conditioning, heating, and water heater systems. The rooftop units (RTU) are most typically used for air conditioning. For heating, electric or natural gas furnaces are most widely used. For service water heating, electric and natural gas water heaters are used evenly.

Table 2. Identification Information of Eleven Commercial Buildings

No.	Certification Info.																
	RSN #	Bldg. Type	Occuapncy Class	Activity Type	New/ Addition	Compliant Option			COMcheck Software Version			Certificate Date			% Above Code		
						Envelop	Lighting	Mech.	Envelop	Lighting	Mech.	Envelop	Lighting	Mech.	Envelop	Lighting	Mech.
1	110209	Non-Res	Assembly	Restaurant	New	2003 IECC			3.5.1	3.5.3	3.5.3	08/18/08	10/02/08	08/18/08	20.0%	15.4%	-
2	187810	Non-Res	Assembly	Restaurant	New	90.1 ('99) Standard			3.7.1	3.7.1	3.7.1	04/28/10	04/28/10	04/28/10	1.0%	13.0%	-
3	215767	Non-Res	Business	Retail Sales	New	2003 IECC			3.7.1	3.8.0	3.8.0	09/02/10	09/02/10	09/02/10	37.0%	23.0%	-
4	185594	Non-Res	Business	Medical & Clinical Care	New	2003 IECC			3.7.0	3.7.0	3.7.0	03/26/10	03/26/10	03/26/10	35.0%	20.0%	-
5	213901	Non-Res	Educational	School	New	2003 IECC			Web	3.8.0	3.6.1	08/04/10	08/30/10	08/05/10	33.0%	26.0%	-
6	183349	Non-Res	Factory	Office & Industrial Work	New	2003 IECC			3.7.0	3.7.0	3.7.0	03/25/10	03/25/10	03/25/10	31.0%	56.0%	-
7	228539	Res	Residential	Multifamily	New	2003 IECC			3.7.1	3.7.1	3.7.1	07/15/10	07/15/10	07/15/10	39.0%	54.0%	-
8	218026	Non-Res	Utility & Misc	Industrial Work	New	2003 IECC			3.8.0	3.8.0	3.8.0	08/23/10	08/23/10	08/23/10	52.0%	39.0%	-
9	184065	Non-Res	Assembly-Church	Classroom & Lecture Hall	Addition	2003 IECC			3.7.0	3.7.0	3.7.0	02/18/10	02/18/10	02/18/10	33.0%	74.0%	-
10	218392	Non-Res	Business	Medical & Clinical Care	Addition	2003 IECC		-	3.6.1	3.6.1	-	08/09/10	08/09/10	-	30.0%	17.0%	-
11	210641	Non-Res	Assembly	Restaurant	Addition	2003 IECC			3.6.0	3.7.1	3.7.1	07/14/10	07/13/10	07/13/10	32.0%	11.0%	-

Table 3. Basic Building Information of Eleven Commercial Buildings

No.	Building Info.					
	Climate			# of Floor[1]	Total Floor Area[2] (sq ft)	
	Zone	HDD (Base F)	CDD (Base F)		From Envelope Compliance	From Interior Lighting Compliance
1	5b	2407(65)	2603(65)	1	2,729	2,656
2	-	2407(65)	6334(50)	1	7,341	
3	5b	2407(65)	2603(65)	1	4,903	
4	5b	2407(65)	2603(65)	1	5,829	
5	5b	2407(65)	2603(65)	2	34,903	37,282
6	5b	2407(65)	2603(65)	1	24,148	
7	5b	2407(65)	2603(65)	11	294,557	
8	5b	2407(65)	2603(65)	1	112	
9	5b	2407(65)	2603(65)	1	1,056	
10	5b	2407(65)	2603(65)	1	1,368	
11	5b	2407(65)	2603(65)	1	5,251	

Note: Numbers in blue stand for the calculated values. Numbers in red stand for mismatched information (See note 2).

1. Number of floors was calculated by using # of floor = Floor Area (ft^2) / Roof Area (ft^2).
2. There are floor area information mismatches between the envelope compliance certificate and the interior lighting compliance certificate for the following two buildings: No.1 and 5.

Table 4. Envelope Information of Eleven Commercial Buildings

No.	Envelope																
	Window												Wall				
	Area (sq ft)[1]	Construction	Thermal Break	Pane	Low-E	Tint	Fixed/ Operable	WWR %	WFR %[2]	U-value[3]	SHGC[3]	PF[3]	Construction	Area (sq ft)	Cavity R-value	Cont. R-value	U-value
1	287	Metal Frame	Yes	Double	No	Tinted	-	12%	13%	0.90	0.78	0	Wood Frame, Any Spacing	3,317	R-19	0	0.068
	71		No										Solid Conc./Masonry <=8", No Framing	72	-	0	0.505
2	172	Wood Frame	No	Double	No	Clear	Fixed	15%	4%	0.61	0.67	0.41	Wood Frame, Any Spacing	5,094	R-19	0	0.067
	99	Metal Frame															
3	418	Metal Frame	No	Single	No	Clear	-	9%	9%	1.10	0.83	0.83	CMU <=8" with Empty Cells, No Framing	4,621	-	R-7.5	0.099
													Metal Frame, 16" o.c.	327	0	R-7.5	0.102
4	365	Metal Frame	Yes	Double	Yes	Tinted	-	14%	7%	0.53	0.32	0	Wood Frame, 16" o.c.	3,475	R-19	0	0.068
	54	Other-Block	-	-	No	Clear											
5	4,096	Metal Frame	No	Double	Yes	Tinted	-	22%	12%	0.29	0.24	0	Metal Frame, 16" o.c.	18,447	0	R-10	0.081
6	612	Metal Frame	No	Double	Yes	Tinted	-	7%	4%	0.65	0.40	0	Metal Frame, 24" o.c.	12,916	R-11	0	0.124
	279	Other	No	-	No	Tinted											
7	10,319	Metal Frame	No	Double	Yes	Tinted		12%	4%	0.60	0.40	0	Wood Frame, Any Spacing	92,790	R-13	0	0.091
8	0	N/A											Solid Conc./Masonry <=8", No Framing	354	-	R-18	0.050
9	102	Metal Frame	No	Double	No	Tinted		7%	10%	0.69	0.57	0	Wood Frame, Any Spacing	1,416	R-13	0	0.091
10	115	Metal Frame	No	Double	Yes	Tinted	-	10%	8%	0.60	0.60	0	Wood Frame, Any Spacing	1,187	R-19	0	0.068
11	153	Metal Frame	Yes	Double	Yes	Clear	-	8%	4%	0.70	0.60	0	Wood Frame, Any Spacing	3,316	R-11	0	0.103
	38	Wood Frame	No	Single	No	Tinted											

Note: Numbers in blue stand for the calculated values. N/A is "Not Applicable".

1. Window area values come from the Envelope Compliance Certificate.
2. A window to floor ratio was calculated using WFR (%) = Window Area (ft^2) / Floor Area (ft^2).
3. For a window U-value and SHGC, area-weighted average values are used.

Table 5. Envelope (Cont.) and Interior Lighting Information of Eleven Commercial Buildings

No.	Envelope													Interior Lighting	
	Roof					Floor				Door[1]				Total Watts, Proposed	Elec. Usage[2]
	Construction	Area (sq ft)	Cavity R-value	Cont. R-value	U-value	Slab Floors		Frame Floors		Glass			Solid		
						Area (sq ft)	R-value	Construction	c.i. R-value	U-value	SHGC	PF	U-value	watts	watts/ sq ft
1	All-Wood Joist/Rafter/Truss	2,583	0	R-19	0.049	227	Uninsulated	-	-	1.06	0.78	-	0.5	3,372	1.27
2	All-Wood Joist/Rafter/Truss	4,786 1,923	R-19 0	0 R-18	0.053 0.051	416	Uninsulated	-	-	0.92	0.44	1.0	0.7	12,066	1.64
3	Non-Wood Joist/Rafter/Truss	4,818	0	R-20.4	0.047	331	Vertical 3ft, R-10	-	-	0.9	0.87	0.7	0.65	6,428	1.31
4	Attic Roof with Wood Joist	5,829	R-30	0	0.035	348	Uninsulated	-	-	0.81	0.44	-	0.58	5,610	0.96
5	Non-Wood Joist/Rafter/Truss	17,980	0	R-24	0.04	680	Uninsulated	-	-	N/A				33,060	0.89
6	Metal Roof with Thermal Blocks	25,392	R-19	0	0.07	646	Uninsulated	-	-	-	-	-	0.75	12,382	0.51
7	All-Wood Joist/Rafter/Truss	26,194	R-30	0	0.035	2701	Uninsulated	Concrete	R-19	0.6	0.4	0.8	0.6	14,296	0.45
8	Structural Slab	112	-	R-18	0.052	44	Uninsulated	-	-	-	-	-	0.3	93	0.83
9	All-Wood Joist/Rafter/Truss	1,056	R-30	0	0.035	140	Uninsulated	-	-	-	-	-	0.7	390	0.37
10	All-Wood Joist/Rafter/Truss	1,368	0	R-20	0.47	125	Uninsulated	-	-	-	-	-	0.35	1,362	1.00
11	All-Wood Joist/Rafter/Truss	5,514	0	R-19	0.049	320	Uninsulated	-	-	0.7	0.6	-	0.7	7,518	1.43

Note: Numbers in blue stand for the calculated values. N/A is “Not Applicable”.

1. An average door U-value is used for the buildings No.1, 4 and 6.
2. Interior lighting power density was calculated using Elec. Usage (Watts/ft^2) = Total proposed watts (Watts) / Floor Area (ft^2).

Table 6. System Information of Eleven Commercial Buildings

No.	System														
	Total No. of System	Single Zone / Multi Zone	A/C				Heating System					Water Heater			
			System (#)	EER (#)	Average Increased EER[1]	Condenser	Capacity, Btu/h (#)	System (#)	Type	HSPF (#)	COP (#)	Capacity, kBtu/h (#)	# of System	Type	Input Rating (Btu/h)	EF
1	2	SZ	RTU (2)	-	-	Air-cooled	135k - 240k (2)	Furnace (2)	Elec.	-	-	-	None			
2	4	SZ	RTU (4)	9.7 (3), 11.8 (1)	1.0	Air-cooled	138MM (1), 148MM (1), 149MM (1), 180MM (1)	N/A					1	Gas	75	0.82
3	2	SZ	RTU (2)	11.7 (1), 12.0 (1)	1.9	Air-cooled	78k (1), 188k(1)	N/A					1	-		
4	6	SZ	Split System (6)	13 (6)	2.2	Evap. cooled	30MM (1), 42MM (2), 48MM (1), 60MM (2)	Furnace (6)	Gas	-	-	60 (1), 80 (3), 100 (2)	2	Gas	-	0.9
5	36	SZ	RTU (32) Split System (3)	-	-	Air-cooled	34k (21), 47k (9), 60k (2) 18k (3)	Furnace (32) Unit Heater (1)	Gas Elec.	- -	- -	65 (32) 10 (1)	2	Elec.	-	
6	6	SZ	Rooftop Pack. Heat Pnmp (6)	9.7 (6)	0	Air-cooled	24k (1), 48k (5)	Rooftop Pack. Heat Pump (6)	Elec.	6.6 (6)	-	24 (1), 48 (5)	None			
7	77	SZ	Split System (77)	11 (72), 11.5 (5)	1.0	Air-cooled	30k (72), 58k (5)	Furnace (77)	Elec.	-	-	27 (72), 51 (5)	73	Elec.	-	0.93
8	1	-	None					Unit Heater (1)	Elec.	-	-	10 (1)	None			
9	2	SZ	Pack. Terminal Heat Pump (2)	9.5 (2)	0.2	Air-cooled	14k (2)	Pack. Terminal Heat Pump (2)	Elec.	-	2.85 (2)	14 (2)	None			
10	None															
11	3	SZ	RTU (3)	9.7 (2), 10.1 (1)	0.0	Air-cooled	57k (2), 85k (1)	Furnace (3)	Gas	-	-	80 (2), 120 (1)	None			

Note: Numbers in blue stand for the calculated values.

1. An average increased EER is the average EER difference of proposed system against minimum code requirement.

3.2 **Analysis of Energy Certificate Information**

A statistical analysis was performed to identify the energy efficiency measures that applied in the eleven sample commercial buildings in the COA. For the selected building parameters, a comparison was conducted with the 2003 IECC Section 806 requirements using frequency and percentage bar graphs. In the graphs, a color coding was used to help readers easily understand the compassion.

- : Above-code (Better than 2003 IECC Section 806 performance path)
- : Below code (Worse than 2003 IECC Section 806 performance path)
- : Just code (Same as 2003 IECC Section 806 performance path)
- : Not required (A code house is same as proposed.)

This section presents major comparison results for the five categories: identification, building, envelope, interior lighting, and system. Additional results are presented in Appendix A.

3.2.1 Identification

1) Above-Code Percentage (Performance Path)

Figures 4 and 5 show the frequency and percentage distribution of eleven buildings by their above-code percentage calculated from performance path analysis for envelope and lighting, respectively. All eleven buildings have energy performance better than the code requirements for both envelope and lighting. The 2003 IECC and the ASHRAE Standard 90.1-1999 were used for their compliant codes and standards.[3]

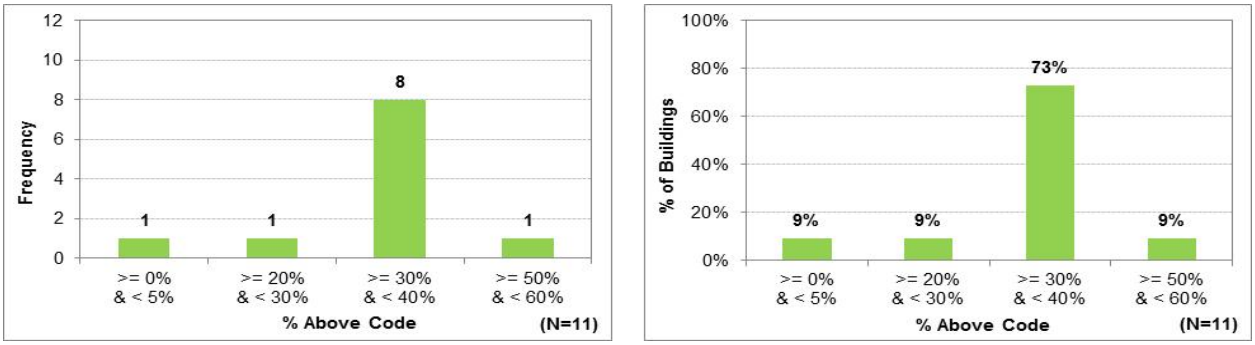


Figure 4. Frequency and Percentage Distribution of Eleven Buildings by Above-Code Percentage for Envelope

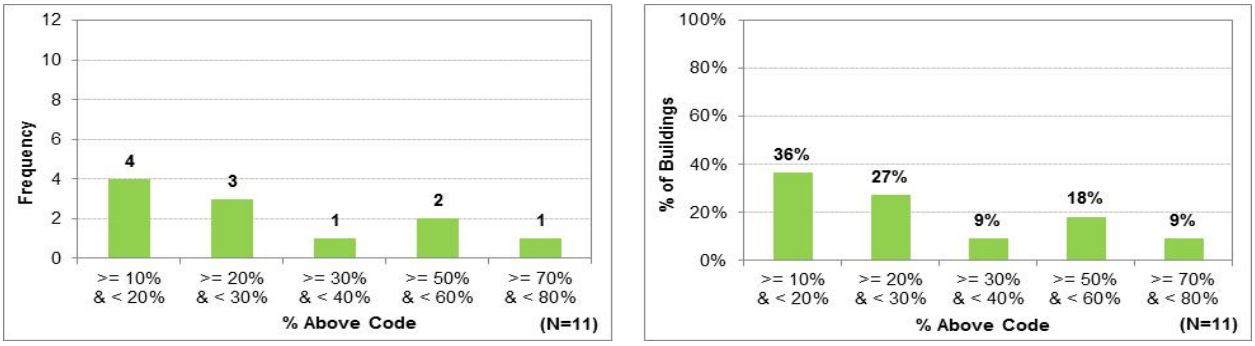


Figure 5. Frequency and Percentage Distribution of Eleven Buildings by Above-Code Percentage for Lighting

[3] Building No. 2 used the ASHRAE Standard 90.1-1999 for its compliant code, and other ten buildings used the 2003 IECC.

3.2.2 Building

1) Number of Floors

Figure 6 shows the frequency and percentage distribution of eleven buildings by the number of floors. Nine buildings are single-story buildings, and other two buildings are either two-story or eleven-story buildings.

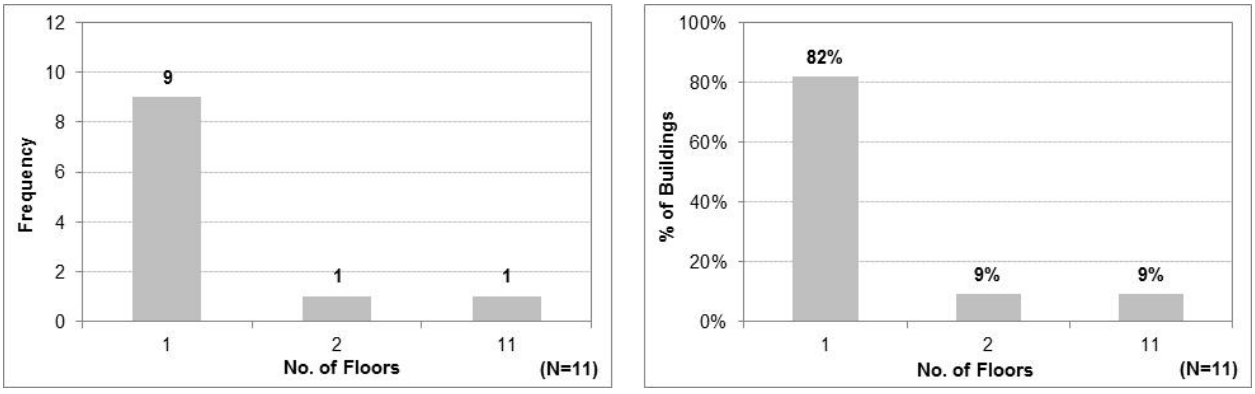


Figure 6. Frequency and Percentage Distribution of Eleven Buildings by Number of Floors

2) Total Floor Area

Figure 7 shows the frequency and percentage distribution of eleven buildings by total floor area. A total floor area of ten buildings (91%) varies from 112 ft^2 to 34,903 ft^2. One eleven-story multi-family building has a total floor area of 294,557 ft^2.

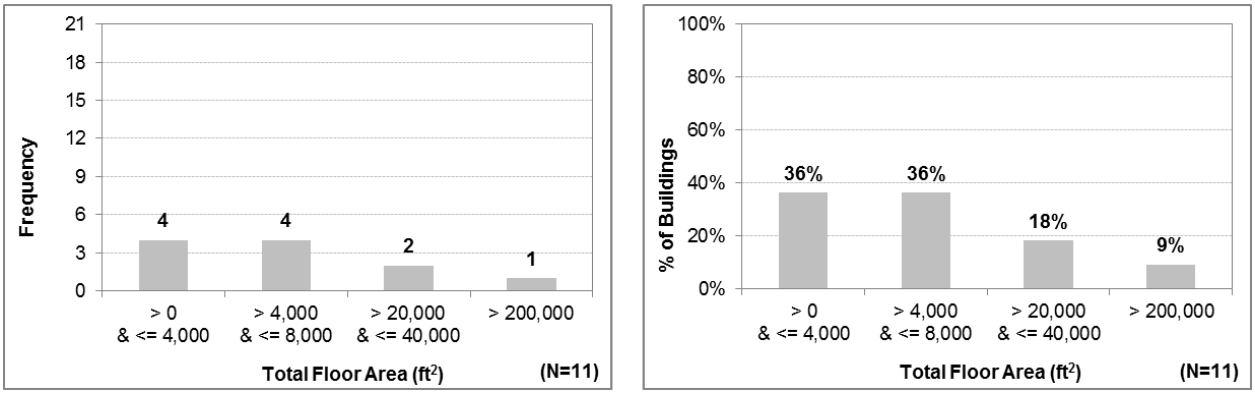


Figure 7. Frequency and Percentage Distribution of Eleven Buildings by Total Floor Area

3.2.3 Envelope

1) Floor

Figures 8 and 9 show the frequency and percentage distribution of one multi-story building by its frame floor insulation R-value and of eleven buildings by slab floor insulation, respectively. The multi-story building has frame floor insulation better than code. Ten buildings (91%) do not have any slab insulation, which meets the 2003 IECC code requirements.

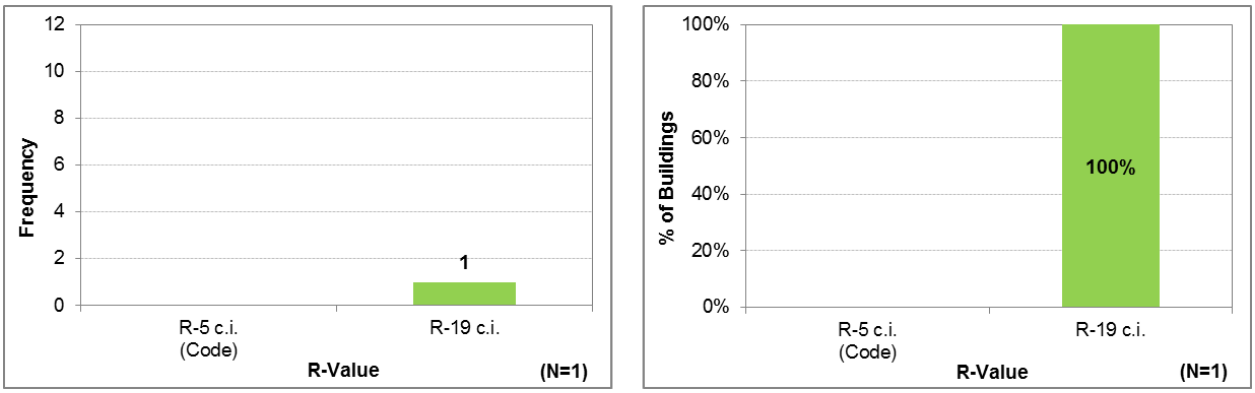


Figure 8. Frequency and Percentage Distribution of One Building by Its Frame Floor R-Value

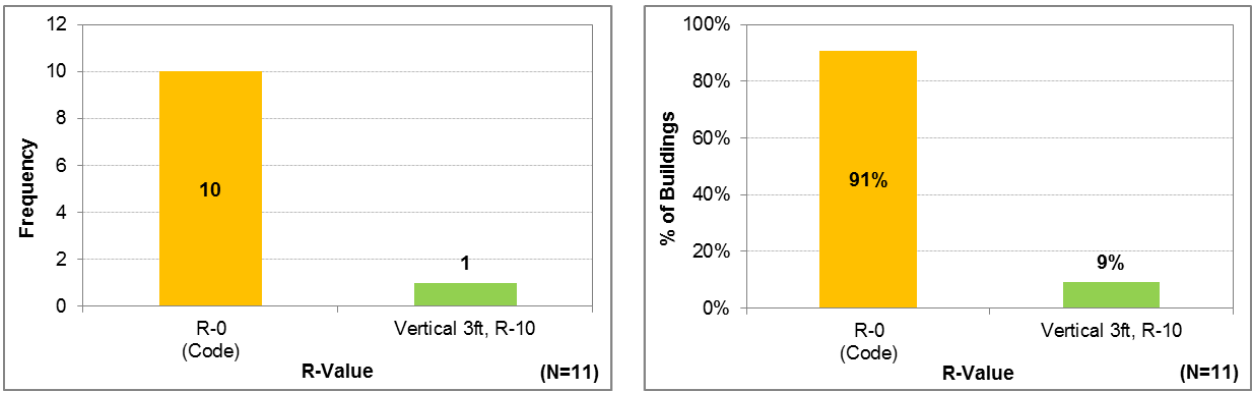


Figure 9. Frequency and Percentage Distribution of Eleven Buildings by Slab Floor R-Value

2) Window

Figures 10 to 13 show the frequency and percentage distribution of ten buildings by window-to-floor ratio (WFR), window U-value, SHGC, and projection factor (PF). One building which has no windows was excluded for this analysis. Eight buildings (80%) have a WFR less than 10%, and two (20%) have a WFR between 10% and 15%. Seven buildings (70%) have a window U-value between 0.35 and 0.7 Btu/hr-sq.ft.-F[4]. A window SHGC varies by buildings from 0.24 to 0.83. One building has a SHGC better than code while the other nine buildings do not have any code requirements based on 2003 IECC Section 806. Two buildings (20%) have overhangs while the other eight (80%) do not have any shading devices.

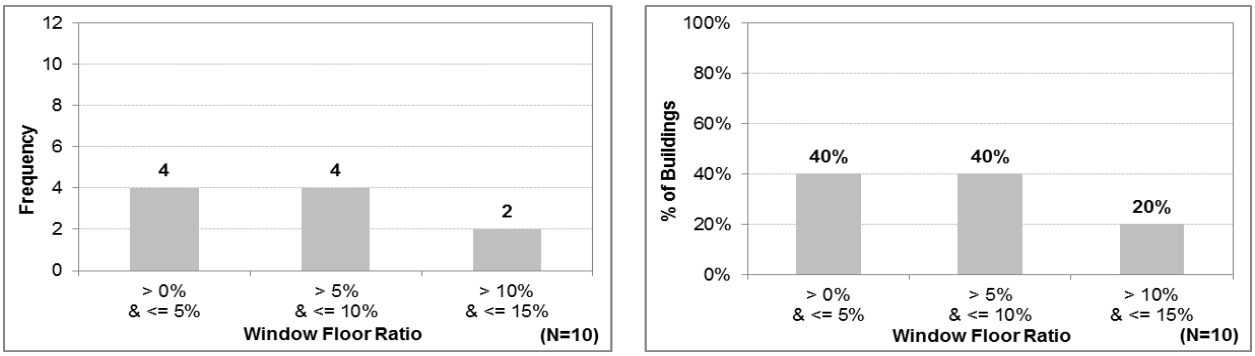


Figure 10. Frequency and Percentage Distribution of Ten Buildings by Window-to-Floor Ratio

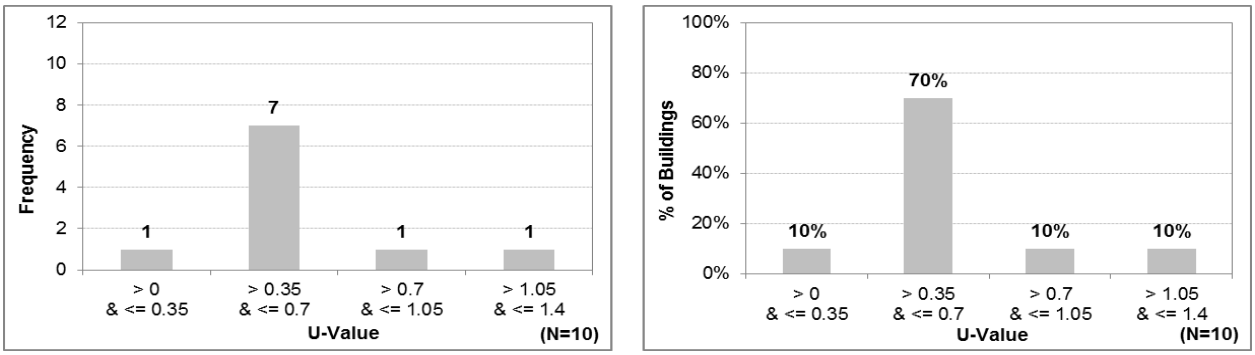


Figure 11. Frequency and Percentage Distribution of Ten Buildings by Window U-Value

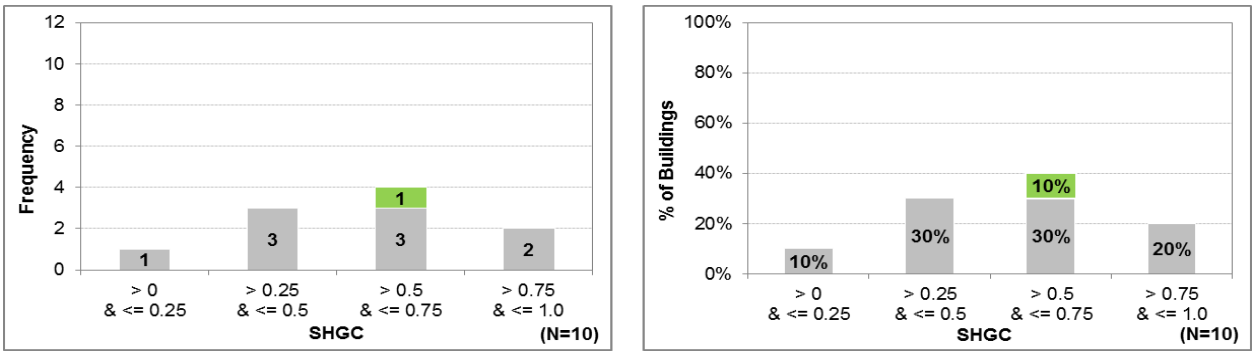


Figure 12. Frequency and Percentage Distribution of Ten Buildings by Window SHGC

[4] All eleven buildings do not have any code requirements based on 2003 IECC Chapter 8.

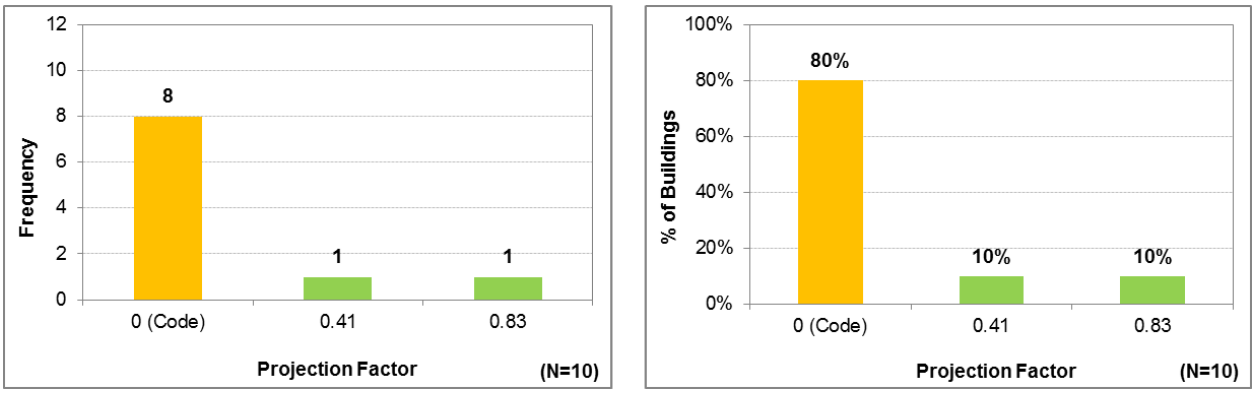


Figure 13. Frequency and Percentage Distribution of Ten Buildings by Window PF

3) Wall

Figures 14 and 15 show the frequency and percentage distribution of eleven buildings by the type of wall construction and wall insulation R-value, respectively. Of eleven buildings, seven (64%) use wood frames. For wall insulation, two buildings (18%) just meet the code requirement, and eight buildings (72%) have wall insulation better than code. Appendix A presents more details for this section.

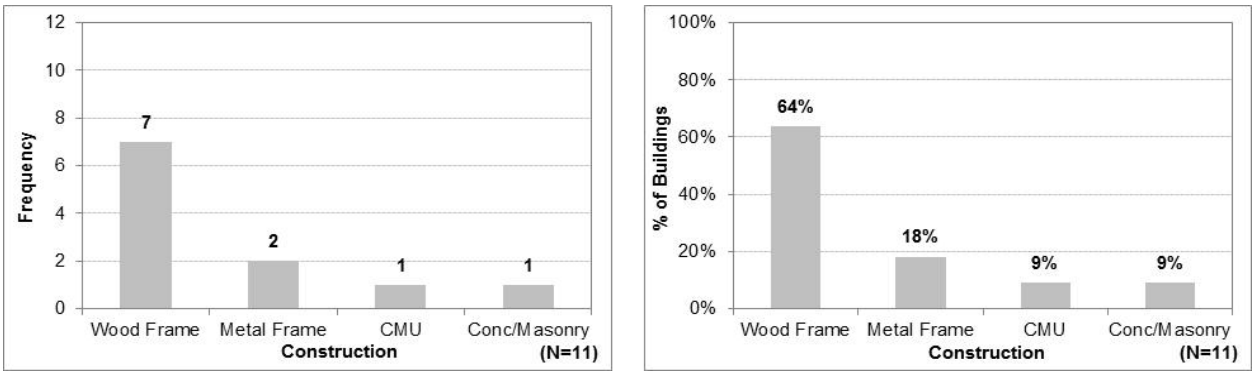


Figure 14. Frequency and Percentage Distribution of Eleven Buildings by Wall Construction

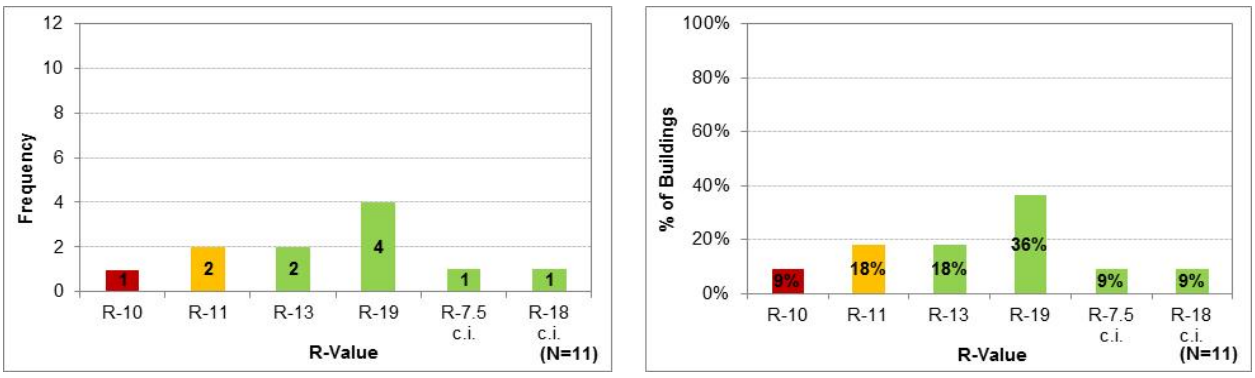


Figure 15. Frequency and Percentage Distribution of Eleven Buildings by Wall Insulation R-Value

4) Roof

Figures 16 and 17 show the frequency and percentage distribution of eleven buildings by the type of roof construction and roof insulation R-value, respectively[5]. Of eleven buildings, seven (64%) have an all-wood joist/truss. Two buildings (18%) have a metal joist/truss, one (9%) has metal with a thermal block, and one (9%) has a concrete slab. For roof insulation R-value, one building (8%) just meets the code requirement, and eight buildings (67%) have roof insulation better than code. Appendix A presents more details for this section.

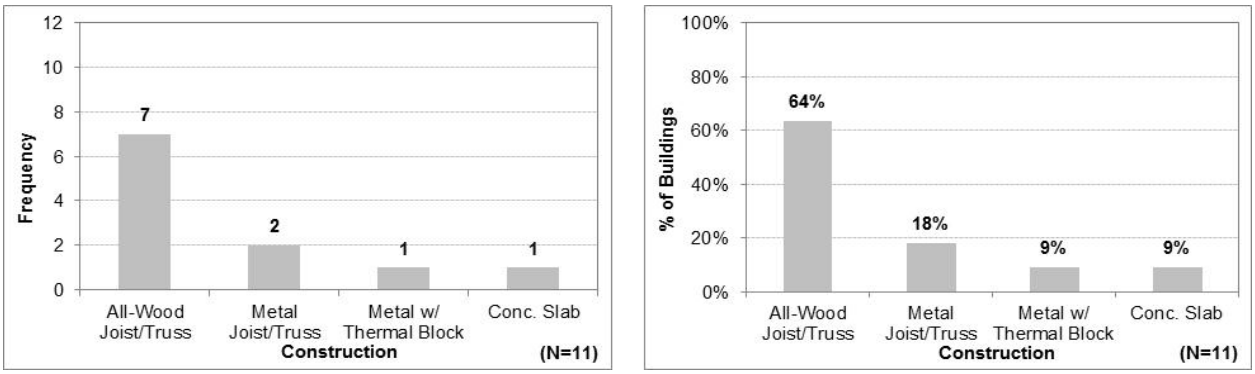


Figure 16. Frequency and Percentage Distribution of Eleven Buildings by Roof Construction

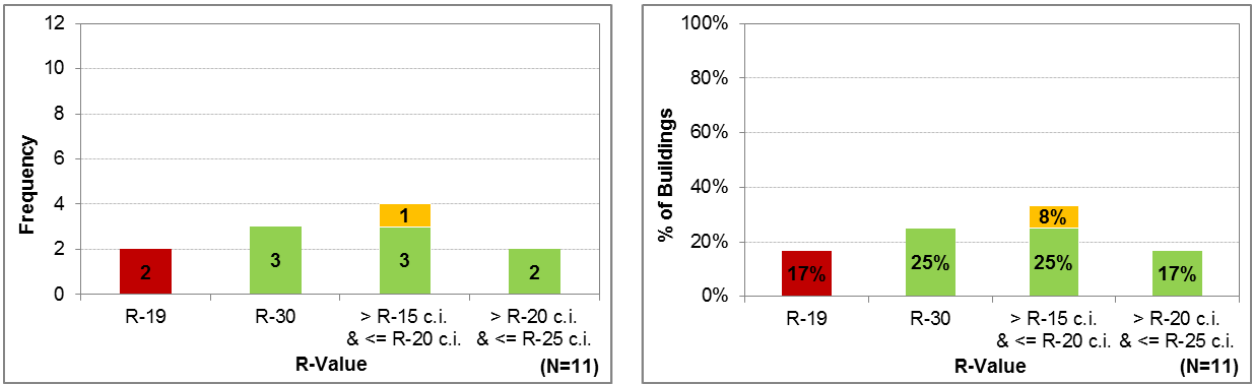


Figure 17. Frequency and Percentage Distribution of Eleven Buildings by Roof R-Value

[5] Building No. 2 has two roof types. In this analysis, the major roof type (R-19) is only considered.

3.2.4 Interior Lighting

Figures 18 and 19 show the frequency and percentage distribution of eleven buildings by average interior lighting power density and average decreased interior lighting power density when compared with the 2003 IECC code requirements, respectively[6]. Of eleven buildings, ten (91%) have interior lighting power density less than the code requirements. The code requirements vary according to the activity type of a building. When compared with the 2003 IECC code requirements, five buildings (45%) use less electricity for lighting up to 0.25 W/ft^2, and three buildings (27%) are supposed to have a decrease in their lighting power consumption between 0.25 and 0.5 W/ft^2. Two buildings (18%) reduce lighting power to from 0.5 to 1.0 W/ft^2. Appendix A presents more details for this section.

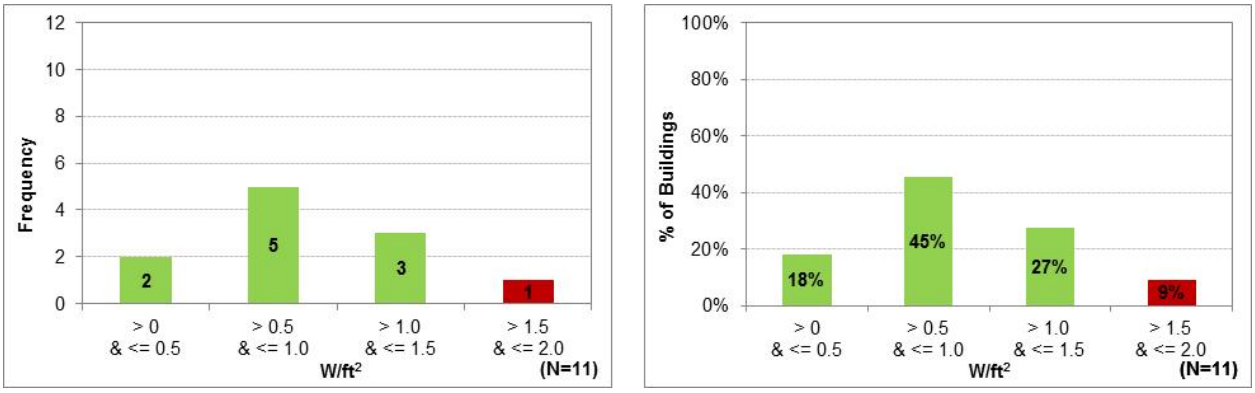


Figure 18. Frequency and Percentage Distribution of Eleven Buildings by Average Interior Lighting Power Density

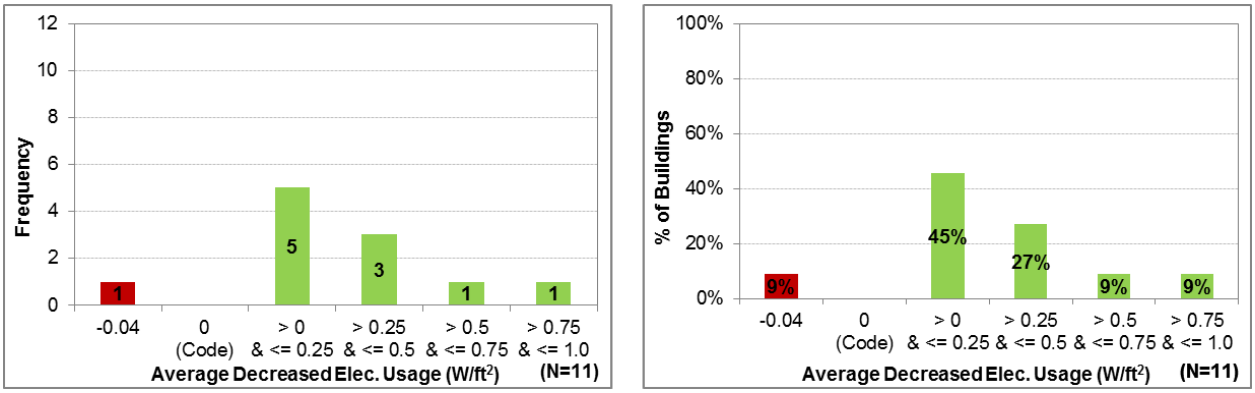


Figure 19. Frequency and Percentage Distribution of Eleven Buildings by Average Decreased Interior Lighting Power Density Compared with the 2003 IECC Code Requirements

[6] Building number 2 uses 1.64 watts per sq ft. This building does not comply with the IECC 2003, but does with ASHRAE 90.1.

3.2.5 System

1) Number of HVAC Systems

Figure 20 shows the frequency and percentage distribution of eleven buildings by a number of HVAC systems in the building. One building (9%) does not have any HVAC system[7]. Eight buildings (55%) have systems less than six, two buildings (18%) have six to ten systems, and two buildings (18%) have 36 and 77 systems.

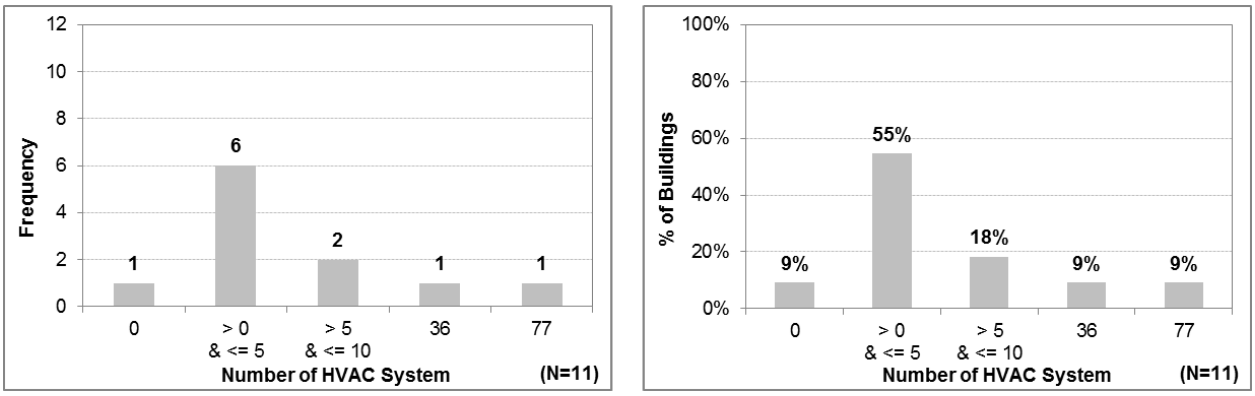


Figure 20. Frequency and Percentage Distribution of Eleven Buildings by Number of HVAC Systems

[7] Building No.10, addition.

2) Main A/C System

Figures 21 and 22 show the frequency and percentage distribution of nine buildings by type of main A/C systems and the corresponding system efficiency, respectively[8]. Five buildings (56% of nine buildings) have the Roof Top Units (RTUs), two buildings (22% of nine buildings) have the split systems, one building (11% of nine buildings) has the rooftop packaged heat pump, and one building (11% of nine buildings) has the packaged terminal heat pump system. For their A/C system efficiency, five buildings (56% of nine buildings) have A/C systems with EERs higher than the code requirements, and two buildings (22% of nine buildings) just meet the code requirements. No information was provided for other two buildings[9].

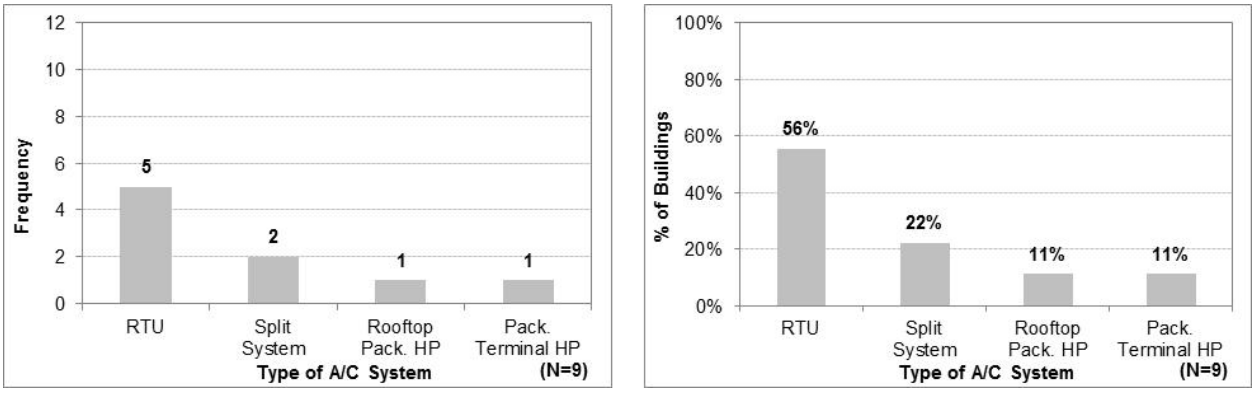


Figure 21. Frequency and Percentage Distribution of Nine Buildings by Type of Main A/C System

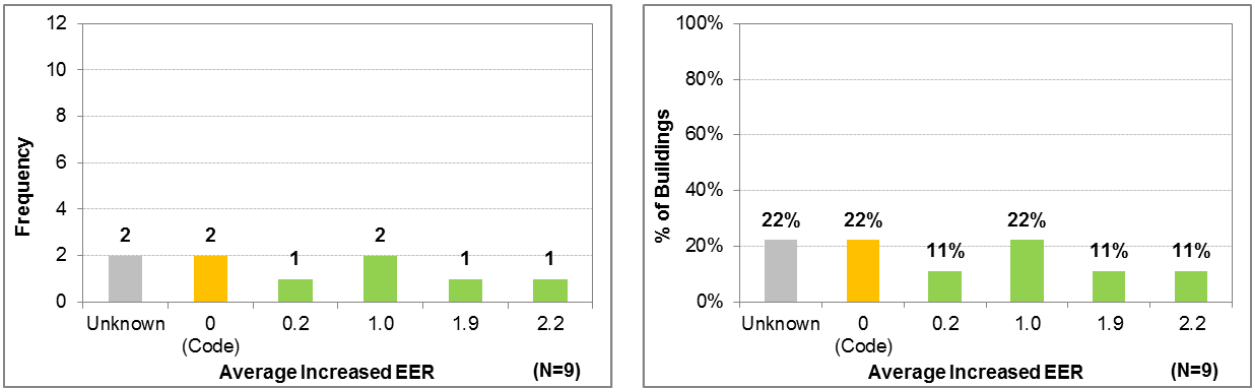


Figure 22. Frequency and Percentage Distribution of Nine Buildings by A/C System Efficiency

[8] Building No. 8 (activity type=industrial work, 112 sq.ft.) and No.10 (an addition) have no A/C systems.
[9] Buildings No.1 and 5 do not have A/C EER information in their compliance reports.

3) Main Heating System

Figure 23 shows the frequency and percentage distribution of eight buildings by the types of main heating systems[10]. Figures 24 and 25 show the frequency and percentage distribution of one rooftop packaged heat pump system by its efficiency and of one packaged terminal heat pump system by its efficiency, respectively[11]. The type of heating system varies by buildings. Two buildings (25% of eight buildings) use electric furnace heating systems, three buildings (38% of eight buildings) use the N.G. furnace heating system, one building (11% of eight buildings) uses a unit heater, one building (11% of eight buildings) uses the rooftop packaged heat pump system, and one building (11% of eight buildings) uses the packaged terminal heat pump system. For the heating system efficiency, one building using the rooftop packaged heat pump systems just meets the code requirements, and one building using the packaged terminal heat pump systems has a COP higher than the code requirements.

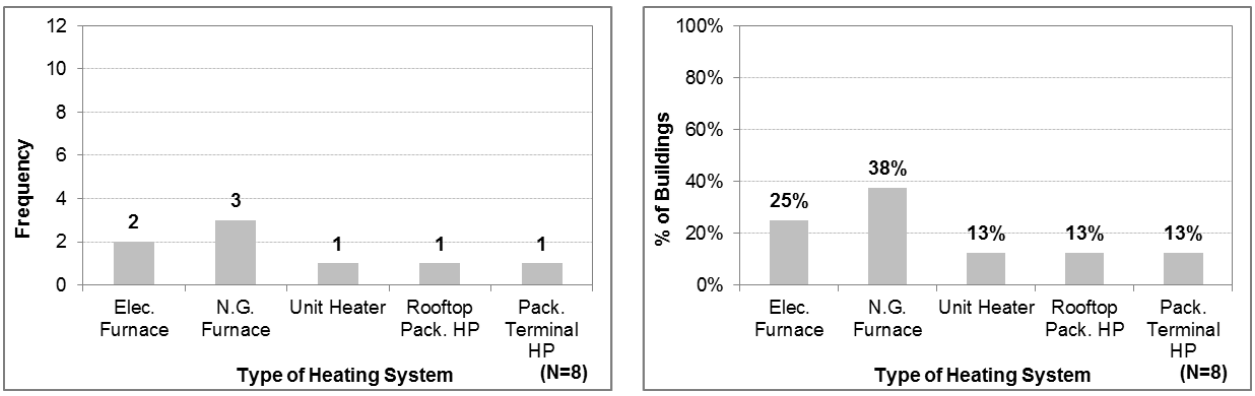


Figure 23. Frequency and Percentage Distribution of Eight Buildings by Type of Main Heating System

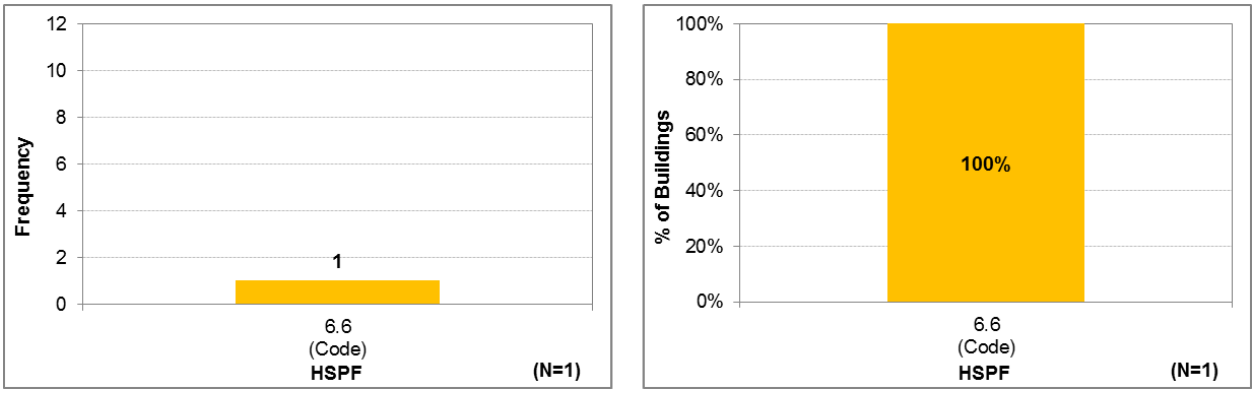


Figure 24. Frequency and Percentage Distribution of One Building by Rooftop Packaged Heat Pump System Efficiency

[10] Building No. 2, 3, and 10 do not have heating system. If the building has more than two different types of heating systems, a main heating system was considered in this analysis.

[11] Only two buildings (Building No. 6 and 9) have information on their heating system efficiency.

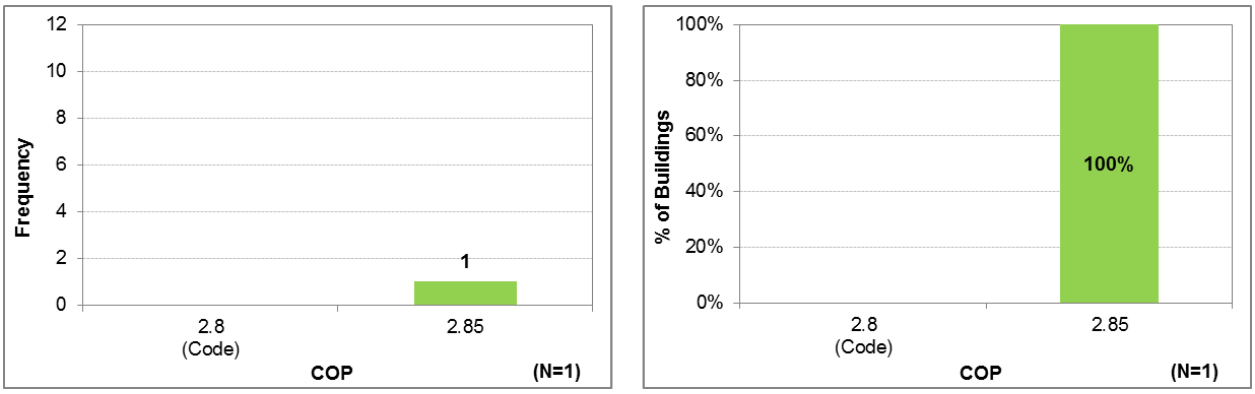


Figure 25. Frequency and Percentage Distribution of One Building by Packaged Terminal Heat Pump System Efficiency

4) Water Heater

Figures 26 and 27 show the frequency and percentage distribution of five buildings by type of water heater and the corresponding system efficiency. Of five buildings that have new SHW systems[12], two buildings use electric water heaters, and two buildings use natural gas water heaters. One building did not provide any information on its water heater type[13]. For the water heater efficiency, two buildings exceed the code requirements while one building just meets the code. No information was provided for the water heater efficiency of other two buildings[14].

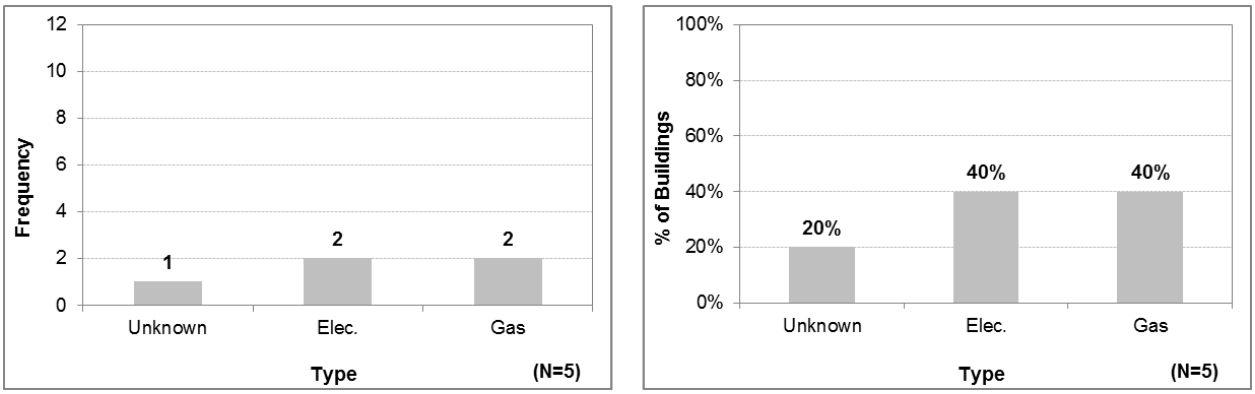


Figure 26. Frequency and Percentage Distribution of Five Buildings by Type of Water Heater

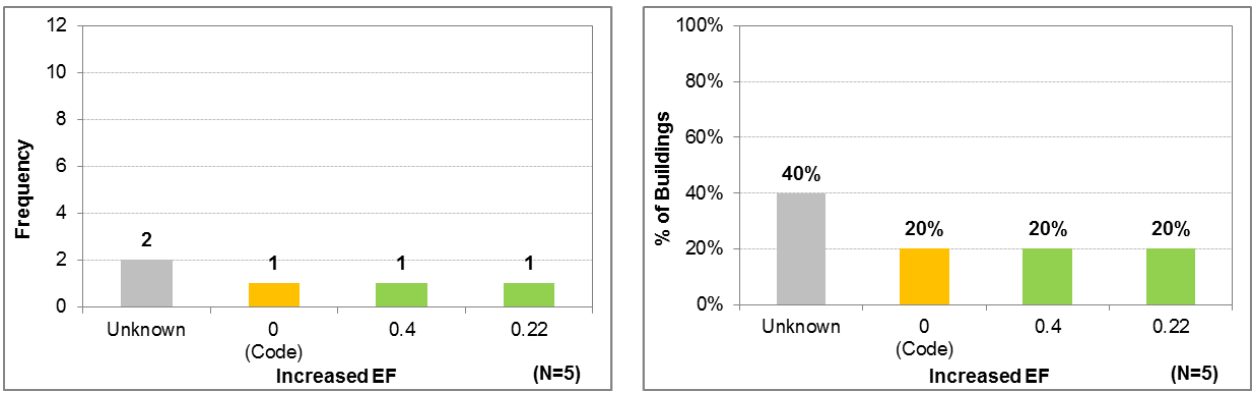


Figure 27. Frequency and Percentage Distribution of Five Buildings by Water Heater EF

[12] Only five buildings (No.2, 3, 4, 5, and 7) have water heaters.
[13] No information was provided for the water heat type of building No. 3.
[14] No information was provided for the water heater efficiency (i.e., EF) for buildings No. 3 and 5.

3.3 **Energy Efficiency Measures**

Table 7 lists nine energy efficiency measures (EEMs) used in the eleven commercial buildings to achieve above-code energy performance based on the 2003 IECC Section 806 performance path analysis. This includes envelope and fenestration, lighting, HVAC system, and service hot water system (SHW) measures. For envelope and fenestration measures, eight buildings (73%) have roof and wall insulation higher than the code requirements. One multi-story building has frame floor insulation better than code. One building (10%) has a window SHGC less than the code requirement, and two buildings (20%) installed window overhangs as one of the above-code measures. For lighting measures, ten buildings (91%) have interior lighting power density less than the code requirements.

For HVAC system measures, of nine buildings that have new A/C systems, five (56%) have A/C systems with EERs higher than the code requirements. Of eight buildings that have new heating systems, one (13%) uses a heating system that has a higher energy-efficient than the code requirement. For SHW system measures, of five buildings that have SHW systems, two (40%) have more energy-efficient water heater systems.

Table 7. Summary on Energy Efficiency Measures Applied for Commercial Buildings in CoA (2008-2010)

EEM #	Energy Efficiency Measure (EEM)	Description of EEM					Number of Buildings	% of Buildings
		Unit/Condition			Base Case (2003 IECC Code Building)	EEM (Proposed Building)		
Envelope and Fenestration Measures								
1	Increased Roof Insulation	R-Value	WWR 0-10%	All-Wood Joist/Truss	R-19 or R-14 c.i.	R-30	1	73%
						R-19 c.i./R-20 c.i.	2	
				Metal Joist/Truss	R-19 or R-15 c.i.	R-20.4 c.i.	1	
				Concrete Slab or Deck	R-14 c.i.	R-18 c.i.	1	
			WWR 10-25%	All-Wood Joist/Truss	R-25 or R-19 c.i.	R-30	2	
				Metal Joist/Truss	R-25 or R-20 c.i.	R-24 c.i.	1	
							/ 11	
2	Increased Wall Insulation	R-Value/ U-Value	Wood Framing		R-11 + R-0 c.i.	R-13 + R-0 c.i.	2	73%
						R-19 + R-0 c.i.	4	
			Solid Conc./Masonry <=8" & WWR 0-10%		R-0 c.i.	R-18 c.i.	1	
			CMU <= 8" with Empty Cells[1]		U-0.58	U-0.099	1	
							/ 11	
3	Increased Frame Floor Insulation (For multi-story buildings)	R-Value			R-5 c.i.	R-19 c.i.	1 / 1	100%
4	Decreased Window SHGC[2]	SHGC	WWR 12-25% & PF 0.25-0.5		0.7	0.67	1 / 10	10%
5	Window Overhang[2]	PF			0	0.41/0.83	2 / 10	20%
Lighting Measures								
6	Increased Lighitng Efficiency	Decreased Watts/ft^2	0-0.25	Restaurant	1.6	1.4	1	91%
				Clinic	1.2	1.0	2	
				Retail Sales[3]	1.5	1.3	2	
			0.25-0.5	School	1.2	0.9	1	
				Industrial Work	1.2	0.8	1	
				Multifamily	0.97	0.5	1	
			0.5-0.75	Office & Industrial Work	1.16	0.5	1	
			0.75-1.0	ClassRM & Lecture Hall	1.4	0.4	1	
							/ 11	
HVAC System Measures								
7	Improved AC Efficiency[4]	Increased EER	0.2	PTHP (Packaged Terminal Heat Pump) for new consturction	9.3	9.5	1	56%
			1.0	RTU, Size >=760 kBtu/h	9.2	9.7/11.8	1	
				Split, Size <65 kBtu/h	10	11/11.5	1	
			1.9	RTU, Size>=65 & <135 kBtu/h	10.3	11.7	1	
				RTU, Size>=135 & <240 kBtu/h	9.7	12		
			2.2	Split, Evap. Cooled, Size>=240 kBtu/h, with heating	10.8	13	1	
							/ 9	
8	Imporved Heating System Efficiency	COP	PTHP (Packaged Terminal Heat Pump)		2.8	2.85	1 / 8	13%
Service Hot Water Measures								
9	Improved SHW Heater Efficiency[5]	EF	Gas		0.5	0.9	1	40%
					0.62	0.82	1	
							/ 5	

Note:

1 Table B-8 in ASHRAE/IESNA 90.1-2001 was referenced for the insulation requirements of the wall using CMU <=8" with empty cells.

2 Building No. 8 (activity type=industrial work, 112 sq.ft.) was not counted in the total number of buildings for these EEMs because it had no windows.

3 Building No.1 was categorized in Restaurant in its main report, but for lighting compliance, it was categorized in Retail Sales.

4 Building No. 8 (activity type=industrial work, 112 sq.ft.) and No.10 (addition) were not counted in the total number of buildings for this EEM because they had no A/C systems. The Buildings No.1 and No.5 do not have A/C EER information in their compliance reports.

5 Only five buildings (No.2, No.3, No.4, No.5, and No.7) have water heaters. The building No.3 does not have EF information for its water heater in its compliance report.

4 PROPOSED ENERGY EFFICIENCY MEASURES FOR SMALL OFFICE BUILDINGS

This section documents 17 energy efficiency measures (EEMs) for small office buildings to achieve above-code energy performance based on the ASHRAE 90.1-2001 and 2007 code-compliant small office building in Tarrant County, Texas, where the CoA is located. Section 4.1 gives a brief description of 17 individual EEMs and provides input parameters used in the simulation of each EEM. Section 4.2 presents the results of simulation and cost analysis.

4.1 **Individual EEMs**

Table 8 lists 17 energy efficiency measures considered in this analysis. These include measures for the building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. These measures were simulated by modifying the selected parameters used for the DOE-2 simulation tool. Tables 9 and 10 show the details on the simulation input parameters.

Table 8. Energy Efficiency Measures

	EEM No.	EEM Description
Envelope and Fenestration Measures	1	Increased Roof and Wall Insulation R-Value (ASHRAE 90.1-2001: from 15 to 25 for roof and 13 to 13+3.8c.i. for walls; and ASHRAE 90.1-2007: from 20 to 25 for roof and 13 to 13+3.8c.i. for walls)
	2	Decreased Glazing U-Value (ASHRAE 90.1-2001: from 1.22 to 0.35; and ASHRAE 90.1-2007: from 0.65 to 0.35)
	3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)
	4	0.5 PF Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)
	5	High Albedo Roof for ASHRAE 90.1-2001 (Roof Absorptance from 0.7 to 0.3)
HVAC System Measures	6	CO_2-Based Demand-Controlled Ventilation (DCV)
	7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)
	8	Improved Furnace Efficiency (from 80% to 90% Et)
	9	Improved Fan Efficiency (from 55% to 65%)
Service Hot Water Measures	10	Improved SHW Heater Efficiency (from 80% to 95% Et)
	11	Tankless Gas Water Heater
	12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)
Lighting and Receptacle Measures	13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (ASHRAE 90.1-2001: from 1.3 to 0.9 W/sq.ft.; and ASHRAE 90.1-2007: from 1.0 to 0.9 W/sq.ft.)
	14	Decreased Lighting Power Density based on AEDG-SMO-2011 (ASHRAE 90.1-2001: from 1.3 to 0.75 W/sq.ft.; and ASHRAE 90.1-2007: from 1.0 to 0.75 W/sq.ft.)
	15	Daylight Dimming Control
	16	Automatic Receptacle Control for Offices using Occupancy Sensors
Renewable Power Measure	17	40 kW Photovoltaic Array

Table 9. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2001 Code-Compliant Small Office Building in CoA

	EEM #	Energy Efficiency Measure	Roof Insulation R-Value	Wall c.i. R-Value	U-Value	SHGC	Shading (ft)				WWR (%)				Roof Absorptance	OA Demand Control	EER for Perimeter Zone	EER for Core Zone	Furnace Eff. for PSZ (%)	Fan Eff. (%)	DHW Eff., Et(%)	DHW Tank Heat Loss	DHW Pump Electric Power	Lighting Power Density (W/ft^2)	Daylight Dimming Control	Auto. Receptacle Control
							Front	Right	Back	Left	Front	Right	Back	Left												
		90.1-2001 Base case (CoA)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
Envelope and Fenestration Measures	1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	**25**	**3.8**	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
	2	Decreased Glazing U-Value (from 1.22 to 0.35)	15	0	**0.35**	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
	3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	15	0	1.22	0.25	**2.5**	**2.5**	0	**2.5**	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
	4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	15	0	1.22	0.25	**2.5**	**2.5**	0	**2.5**	**36**	**12**	**20**	**12**	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
	5	High Albedo Roof (Roof Absorptance from 0.7 to 0.3)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	**0.3**	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
HVAC Measures	6	CO_2-Based Demand-Controlled Ventilation (DCV)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	**Y**	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
	7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	**17.19**	**15.05**	80	55	80	0.0139	0.0038	1.3	N	N
	8	Improved Furnace Efficiency (from 80% to 90% Et)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	**90**	55	80	0.0139	0.0038	1.3	N	N
	9	Improved Fan Efficiency (from 55% to 65%)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	**65**	80	0.0139	0.0038	1.3	N	N
SHW Measures	10	Improved SHW Heater Efficiency (from 80% to 95% Et)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	**95**	0.0139	0.0038	1.3	N	N
	11	Tankless Gas Water Heater	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	**0.0017**	**0**	1.3	N	N
	12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N
Lighting and Receptacle Measures	13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	**0.9**	N	N
	14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	**0.75**	N	N
	15	Daylight Dimming Control	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	**Y**	N
	16	Automatic Receptacle Control for Offices using Occupancy Sensors	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	**Y**
Renewable Measure	17	40 kW Photovoltaic Array	15	0	1.22	0.25	0	0	0	0	20	20	20	20	0.7	N	13.29	12.55	80	55	80	0.0139	0.0038	1.3	N	N

Table 10. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in CoA

	EEM #	Energy Efficiency Measure	Roof Insulation R-Value	Wall c.i. R-Value	U-Value	SHGC	Shading (ft)				WWR (%)				Roof Absorptance	OA Demand Control	EER for Perimeter Zone	EER for Core Zone	Furnace Eff. for PSZ (%)	Fan Eff. (%)	DHW Eff., Et(%)	DHW Tank Heat Loss	DHW Pump Electric Power	Lighting Power Density (W/ft^2)	Daylight Dimming Control	Auto. Receptacle Control
							Front	Right	Back	Left	Front	Right	Back	Left												
		90.1-2007 Base case (CoA)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
Envelope and Fenestration Measures	1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	**25**	**3.8**	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
	2	Decreased Glazing U-Value (from 0.65 to 0.35)	20	0	**0.35**	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
	3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	20	0	0.65	0.25	**2.5**	**2.5**	0	**2.5**	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
	4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	20	0	0.65	0.25	**2.5**	**2.5**	0	**2.5**	**36**	**12**	**20**	**12**	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
HVAC Measures	6	CO_2-Based Demand-Controlled Ventilation (DCV)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	**Y**	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
	7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	**17.19**	**15.05**	80	55	80	0.0139	0.0038	1.0	N	N
	8	Improved Furnace Efficiency (from 80% to 90% Et)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	**90**	55	80	0.0139	0.0038	1.0	N	N
	9	Improved Fan Efficiency (from 55% to 65%)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	**65**	80	0.0139	0.0038	1.0	N	N
SHW Measures	10	Improved SHW Heater Efficiency (from 80% to 95% Et)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	**95**	0.0139	0.0038	1.0	N	N
	11	Tankless Gas Water Heater	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	**0.0017**	**0**	1.0	N	N
	12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N
Lighting and Receptacle Measures	13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	**0.9**	N	N
	14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	**0.75**	N	N
	15	Daylight Dimming Control	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	**Y**	N
	16	Automatic Receptacle Control for Offices using Occupancy Sensors	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	**Y**
Renewable Measure	17	40 kW Photovoltaic Array	20	0	0.65	0.25	0	0	0	0	20	20	20	20	0.3	N	13.29	12.55	80	55	80	0.0139	0.0038	1.0	N	N

4.2 **Results of Simulation and Cost Analysis**

4.2.1 Base-Case Energy Use

The annual total energy consumption of the ASHRAE 90.1-2001 base case:

a) Site energy use by end-uses: 825.6 MMBtu/yr, including
   - 17.3% for cooling;
   - 17.7% for heating;
   - 41.9% for lighting and equipment;
   - 17.2% for fans and pumps; and
   - 5.9% for service water heating.

b) Source energy use by fuel type: 2,208 MMBtu/yr, including
   - 90.3% for electricity; and
   - 9.7% for natural gas.

The annual total energy consumption of the ASHRAE 90.1-2007 base case:

a) Site energy use by end-uses: 733.2 MMBtu/yr, including
   - 18.6% for cooling;
   - 14.9% for heating;
   - 40.9% for lighting and equipment;
   - 19.1% for fans and pumps; and
   - 6.6% for service water heating.

b) Source energy use by fuel type: 1,993 MMBtu/yr, including
   - 91.3% for electricity; and
   - 8.7% for natural gas.

These results suggest that the measures that reduce the lighting and equipment energy use would have the highest impact on the total energy use for small office buildings in the CoA. Since the above-code performance is determined based on source energy consumption, the measures reducing electricity consumption will yield higher savings percentage than the measures decreasing natural gas consumption.

4.2.2 Energy Savings from Various Individual EEMs

Table 111 and 12 summarize the savings achieved from proposed EEMs and cost analysis for the ASHRAE 90.1-2001 and 2007 code-compliant small office buildings, including:

- Annual site energy consumption for different end-uses and total;
- Annual source energy consumption for different fuel types;
- Above-code savings (%) for site and source and $ savings;
- Increased cost of implementation (obtained from various resources listed in Appendix B); and
- Simple payback period for each measure.

The annual site energy use was obtained from the BEPS report of the DOE-2 output and then converted to source energy[15]. Figures 28-31 provide a graphical representation of the site/source energy consumption of the individual EEMs for the ASHRAE 90.1-2001 and 2007 code-compliant base-case small office building.

[15] The source energy multipliers used in this analysis were 3.16 for electricity and 1.1 for natural gas based on Section 405.3 of the 2009 IECC.

The savings results are:

a) Increased Roof and Wall Insulation R-Value:
- ASHRAE 90.1-2001: 1.9% (site energy savings) and 1.1% (source energy savings) and
- ASHRAE 90.1-2007: 1.7% (site energy savings) and 0.9% (source energy savings).

b) Decreased Glazing U-Value:
- ASHRAE 90.1-2001: 9.6% (site energy savings) and 3.4% (source energy savings) and
- ASHRAE 90.1-2007: 4.5% (site energy savings) and 1.5% (source energy savings).

c) 0.5 PF Window Shading:
- ASHRAE 90.1-2001: 0.1% (site energy savings) and 0.6% (source energy savings) and
- ASHRAE 90.1-2007: 0.0% (site energy savings) and 0.6% (source energy savings).

d) Window Shading and Redistribution:
- ASHRAE 90.1-2001: 0.9% (site energy savings) and 1.1% (source energy savings) and
- ASHRAE 90.1-2007: 0.6% (site energy savings) and 1.0% (source energy savings).

e) High Albedo Roof:
- ASHRAE 90.1-2001: -0.1% (site energy savings) and 0.3% (source energy savings).

f) CO_2-Based Demand-Controlled Ventilation:
- ASHRAE 90.1-2001: 6.2% (site energy savings) and 3.6% (source energy savings) and
- ASHRAE 90.1-2007: 2.1% (site energy savings) and 1.3% (source energy savings).

g) Improved Air Conditioner Efficiency:
- ASHRAE 90.1-2001: 3.5% (site energy savings) and 4.1% (source energy savings) and
- ASHRAE 90.1-2007: 3.7% (site energy savings) and 4.3% (source energy savings).

h) Improved Furnace Efficiency:
- ASHRAE 90.1-2001: 2.0% (site energy savings) and 0.8% (source energy savings) and
- ASHRAE 90.1-2007: 1.7% (site energy savings) and 0.7% (source energy savings).

i) Improved Fan Efficiency:
- ASHRAE 90.1-2001: 2.1% (site energy savings) and 3.1% (source energy savings) and
- ASHRAE 90.1-2007: 2.4% (site energy savings) and 3.4% (source energy savings).

j) Improved SHW Heater Efficiency:
- ASHRAE 90.1-2001: 0.9% (site energy savings) and 0.4% (source energy savings) and
- ASHRAE 90.1-2007: 1.0% (site energy savings) and 0.4% (source energy savings).

k) Tankless Gas Water Heater:
- ASHRAE 90.1-2001: 1.6% (site energy savings) and 1.5% (source energy savings) and
- ASHRAE 90.1-2007: 1.8% (site energy savings) and 1.6% (source energy savings).

l) Solar SHW System (64 sq. ft. collector, 80 gal tank):
- ASHRAE 90.1-2001: 3.2% (site energy savings) and 1.2% (source energy savings) and
- ASHRAE 90.1-2007: 3.6% (site energy savings) and 1.4% (source energy savings).

m) Decreased Lighting Power Density to 0.9 W/sq.ft.:
- ASHRAE 90.1-2001: 6.7% (site energy savings) and 9.5% (source energy savings) and
- ASHRAE 90.1-2007: 1.9% (site energy savings) and 2.6% (source energy savings).

n) Decreased Lighting Power Density to 0.75 W/sq.ft.:
- ASHRAE 90.1-2001: 9.1% (site energy savings) and 13.0% (source energy savings) and
- ASHRAE 90.1-2007: 4.8% (site energy savings) and 6.6% (source energy savings).

o) Daylight Dimming Control:
- ASHRAE 90.1-2001: 6.4% (site energy savings) and 8.7% (source energy savings) and
- ASHRAE 90.1-2007: 5.7% (site energy savings) and 7.5% (source energy savings).

p) Automatic Receptacle Control for Offices using Occupancy Sensors:
- ASHRAE 90.1-2001: 1.7% (site energy savings) and 2.3% (source energy savings) and
- ASHRAE 90.1-2007: 1.9% (site energy savings) and 2.6% (source energy savings).

q) 40 kW Photovoltaic Array:
- ASHRAE 90.1-2001: 26.0% (site energy savings) and 30.7% (source energy savings) and
- ASHRAE 90.1-2007: 29.3% (site energy savings) and 34.1% (source energy savings).

Of 17 measures for both ASHRAE 90.1-2001 and 2007 code-compliant buildings, a solar PV measure presents the most savings (30.7% and 34.1% source energy savings). A daylight dimming control measure also shows a high savings for both base cases (8.7% and 7.5% source energy savings), while a decreased lighting power density measure yields much higher savings for an ASHRAE 90.1-2001 base case compared to an ASHRAE 90.1-2007 base-case building. Among the envelope and fenestration measures, a decreased glazing u-value measure results in a high site energy savings (9.6% and 4.5% site energy savings), while the source energy savings becomes lower (3.4% and 1.5% source energy savings) due to high savings in natural gas. Among the HVAC system measures, an improved air conditioner efficiency measure results in high source energy savings (4.1% and 4.3% source energy savings), and an improved fan efficiency measure yields 3.1% and 3.4% source energy savings. A CO_2-based demand-controlled ventilation measure is effective only for an ASHRAE 90.1-2001 base-case building with 3.6% source energy savings. In service hot water measures, the solar SHW system measure with 64 ft^2 collector and 80 gallon tank is found to be effective only for site energy savings (3.2% and 3.6% site energy savings and 1.2% and 1.4% source energy savings). Finally, an automatic receptacle control measure presents a source energy savings of 2.3% and 2.6%.

4.2.3 Cost Effectiveness of Various Individual EEMs

It should be noted that, due to the difference in the unit cost of electricity and gas, the energy cost savings for a measure will not always coincide with the energy savings. These savings depend on the fuel type associated with the end use affected from that measure. Because of this, measures that reduce electricity use for space cooling or lighting and equipment resulted in significant energy cost savings compared to the measures that reduce only gas use.

The solar PV and three lighting measures that show a significant reduction in electricity use are very effective in reducing the overall energy cost. The measures that reduce electricity use for cooling and fans and pumps also result in high energy cost savings. These measures include improved air conditioner efficiency and improved fan efficiency. An automatic receptacle control measure also shows high cost

savings while a CO_2 based demand-controlled ventilation measure is effective only for an ASHRAE 90.1-2001 base case.

To estimate the cost-effectiveness of measures, the implementation costs of each measure (obtained from various resources listed in Appendix B), were surveyed along with simple payback calculations. The cost-effectiveness of a measure depends upon the energy cost savings versus the cost of implementation. The most cost-effective measure is a decreased lighting power density to 0.75 W/sq.ft. measure (EEM 14) with the shortest payback periods of 3.3 to 5.0 years for an ASHRAE 90.1-2001 base case and 4.2 to 6.3 years for an ASHRAE 90.1-2007 base case. The other two lighting measures (EEM 13 and EEM 15) yield relatively short payback periods: 4.1 to 6.1 years (ASHRAE 90.1-2001 base case) and 8.6 to 12.9 years (ASHRAE 90.1-2007 base case) for EEM 13 and 7.3 to 11.0 years (ASHRAE 90.1-2001 base case) and 9.4 to 14.2 years (ASHRAE 90.1-2007 base case) for EEM 15. Tankless gas water heater and improved fan efficiency also yield short payback periods.

4.2.4 Combined EEMs

Grouped measures are the combination of individual measures. The results from individual measures and cost analysis were used to guide the selection of measures for this group analysis. The measures were combined to achieve the total source energy savings[16] of the group is 15% above the base-case simulation of each ASHRAE 90.1-2001 and 2007 code-compliant small office building. Because the measures are interdependent in many cases, the resultant savings of grouped measures are not always the same as the sum of the savings of the individual measures. In a similar fashion as the analysis of the individual measures, the group measures were simulated by modifying all the parameters of combined individual measures.

As shown in Figures 32 and 33, three group measures were proposed for each base case. In each figure, the first table summarizes the results obtained from individual measures in terms of annual site energy savings, annual source energy savings, annual demand savings, energy cost savings, estimated costs for each measure implemented individually, and payback period. The second table summarizes the results obtained by implementing combined measures to achieve 15% or more total source energy savings, and includes: energy savings, energy cost savings, estimated costs, payback period for each combination, and annual NOx, SO_2, and CO_2 emission savings.

The example groups represent one way of grouping to achieve 15% savings above the base case. In this analysis, each combination was intended to have a different payback period. The most cost-effective combination (combination 1) has a payback period of:

a) ASHRAE 90.1-2001: 3.5 to 5.2 years and
b) ASHRAE 90.1-2007: 8.4 to 12.7 years.

A payback period of the least cost-effective combination (combination 3) is:

a) ASHRAE 90.1-2001: 7.6 to 11.5 years and
b) ASHRAE 90.1-2007: 12.9 to 19.4 years.

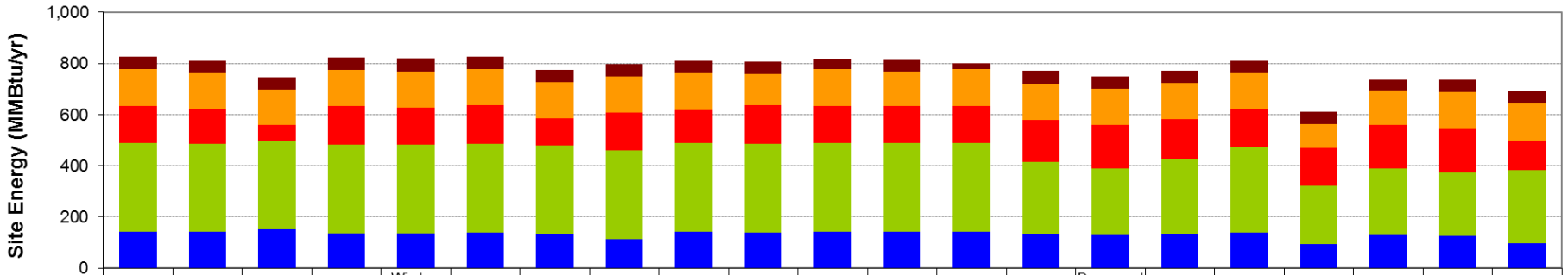
[16] The estimated total source energy savings include heating, cooling, lighting, equipment, and SHW for emissions reductions determination.

Table 11. Simulation Results of Individual EEMs for an ASHRAE 90.1-2001 Code-Compliant Small Office Building in CoA

	EEM #	Energy Efficiency Measure	Site Energy Use by End-Uses (MMBtu/yr)						Source Energy Use by Fuel Type (MMBtu/yr)		Savings Above Base case (%)		$ Savings ($/yr)	Increased Marginal Cost ($)	Increased New System Cost ($)	Payback (yrs)
			Cooling	Heating	Ltg & Equip	Fans &Pumps	DHW	Total	Elec.	Gas	Site	Source				
		90.1-2001 Base case (CoA)	143	146	346	142	48	825.6	1994	214	0.0%	0.0%	$0			
Envelope and Fenestration Measures	1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	141	134	346	141	48	810	1985	200	1.9%	1.1%	$163	$14,332 - $21,499		80.3 - 120
	2	Decreased Glazing U-Value (from 1.22 to 0.35)	152	61	346	139	48	746	2013	120	9.6%	3.4%	$373	$16,773 - $25,160		44.0 - 66.0
	3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	137	151	346	142	48	824	1976	219	0.1%	0.6%	$130		$14,159 - $21,238	85.9 - 129
	4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	135	147	346	142	48	818	1969	215	0.9%	1.1%	$217		$14,159 - $21,238	55.3 - 83.0
	5	High Albedo Roof (Roof Absorptance from 0.7 to 0.3)	139	151	346	142	48	826	1983	219	-0.1%	0.3%	$75	$4,400 - $6,600		51.6 - 77.4
HVAC Measures	6	CO_2-Based Demand-Controlled Ventilation (DCV)	132	106	346	142	48	774	1960	170	6.2%	3.6%	$561		$7,367 - $11,051	12.4 - 18.7
	7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	114	146	346	142	48	797	1904	214	3.5%	4.1%	$796	$12,288 - $18,432		12.0 - 18.0
	8	Improved Furnace Efficiency (from 80% to 90% Et)	143	130	346	142	48	809	1994	196	2.0%	0.8%	$102	$7,900 - $11,850		77.3 - 116
	9	Improved Fan Efficiency (from 55% to 65%)	139	153	346	122	48	808	1918	221	2.1%	3.1%	$628	$6,869 - $10,303		9.6 - 14.3
SHW Measures	10	Improved SHW Heater Efficiency (from 80% to 95% Et)	143	146	346	142	41	818	1994	206	0.9%	0.4%	$48	$3,456 - $5,184		72.1 - 108
	11	Tankless Gas Water Heater	143	146	346	134	44	813	1967	209	1.6%	1.5%	$268	$1,414 - $2,120		5.0 - 7.5
	12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	143	146	346	143	21	799	1997	184	3.2%	1.2%	$146		$2,880 - $4,320	20.6 - 30.9
Lighting and Receptacle Measures	13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	132	163	284	143	48	770	1766	232	6.7%	9.5%	$1,906	$9,344 - $14,016		4.1 - 6.1
	14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	128	170	261	143	48	750	1681	240	9.1%	13.0%	$2,612	$10,484 - $15,726		3.3 - 5.0
	15	Daylight Dimming Control	133	158	291	142	48	773	1789	227	6.4%	8.7%	$1,733		$15,723 - $23,584	7.3 - 11.0
	16	Automatic Receptacle Control for Offices using Occupancy Sensors	140	150	331	142	48	812	1939	218	1.7%	2.3%	$466		$7,587 - $11,380	13.2 - 19.8
Renewable Measure	17	40 kW Photovoltaic Array	94	146	228	94	48	611	1316	214	26.0%	30.7%	$5,979		$200,000 - $300,000	29.4 - 44.1

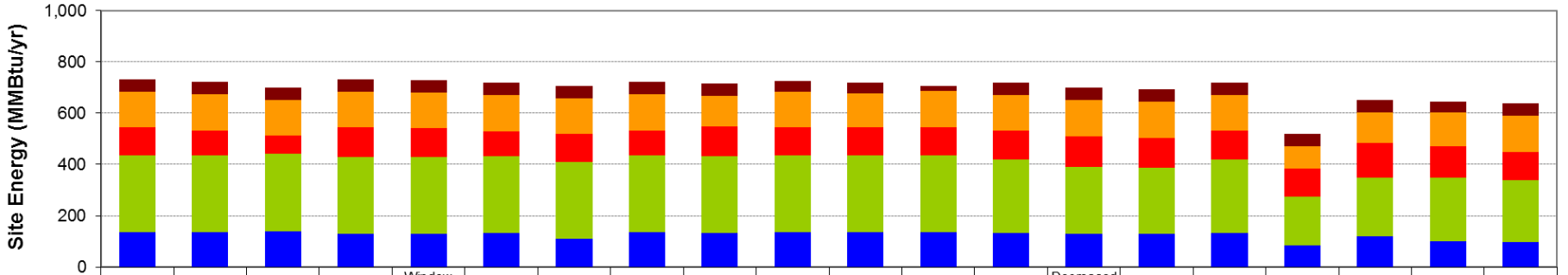
Table 12. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in CoA

	EEM #	Energy Efficiency Measure	Site Energy Use by End-Uses (MMBtu/yr)						Source Energy Use by Fuel Type (MMBtu/yr)		Savings Above Base case (%)		$ Savings ($/yr)	Increased Marginal Cost ($)	Increased New System Cost ($)	Payback (yrs)
			Cooling	Heating	Ltg & Equip	Fans &Pumps	DHW	Total	Elec.	Gas	Site	Source				
		90.1-2007 Base case (CoA)	136	109	300	140	48	733.2	1820	173	0.0%	0.0%	$0			
Envelope and Fenestration Measures	1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	135	98	300	139	48	721	1815	161	1.7%	0.9%	$112	$9,092 - $13,639		72.2 - 108
	2	Decreased Glazing U-Value (from 0.65 to 0.35)	141	73	300	138	48	700	1829	134	4.5%	1.5%	$145	$7,039 - $10,558		48.4 - 72.5
	3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	130	115	300	140	48	733	1801	179	0.0%	0.6%	$128		$14,159 - $21,238	88.3 - 132
	4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	129	112	300	139	48	729	1795	177	0.6%	1.0%	$193		$14,159 - $21,238	61.6 - 92.4
HVAC Measures	6	CO_2-Based Demand-Controlled Ventilation (DCV)	132	98	300	140	48	718	1805	161	2.1%	1.3%	$200		$7,367 - $11,051	33.1 - 49.6
	7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	109	109	300	140	48	706	1733	173	3.7%	4.3%	$763	$12,288 - $18,432		12.6 - 18.9
	8	Improved Furnace Efficiency (from 80% to 90% Et)	136	97	300	140	48	721	1820	160	1.7%	0.7%	$76	$7,900 - $11,850		103 - 155
	9	Improved Fan Efficiency (from 55% to 65%)	132	115	300	120	48	716	1745	180	2.4%	3.4%	$615	$6,869 - $10,303		9.7 - 14.5
SHW Measures	10	Improved SHW Heater Efficiency (from 80% to 95% Et)	136	109	300	140	41	726	1820	165	1.0%	0.4%	$48	$3,456 - $5,184		72.1 - 108
	11	Tankless Gas Water Heater	136	109	300	131	44	720	1793	168	1.8%	1.6%	$265	$1,414 - $2,120		5.0 - 7.5
	12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	136	109	300	141	21	707	1822	143	3.6%	1.4%	$146		$2,880 - $4,320	20.6 - 30.9
Lighting and Receptacle Measures	13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	133	113	284	140	48	719	1763	178	1.9%	2.6%	$476	$4,913 - $7,369		8.6 - 12.9
	14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	129	119	261	140	48	698	1677	184	4.8%	6.6%	$1,196	$6,052 - $9,079		4.2 - 6.3
	15	Daylight Dimming Control	128	118	257	140	48	692	1661	182	5.7%	7.5%	$1,341		$15,723 - $23,584	9.4 - 14.2
	16	Automatic Receptacle Control for Offices using Occupancy Sensors	133	113	285	140	48	719	1764	177	1.9%	2.6%	$465		$7,587 - $11,380	13.2 - 19.8
Renewable Measure	17	40 kW Photovoltaic Array	85	109	188	88	48	518	1141	173	29.3%	34.1%	$5,979		$200,000 - $300,000	29.5 - 44.3



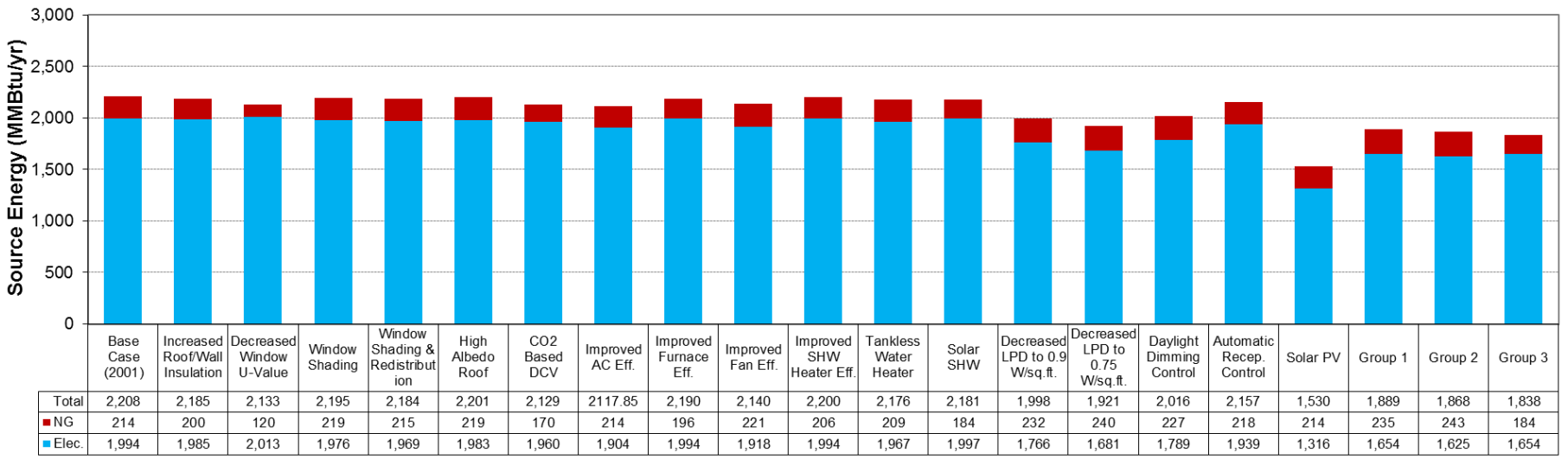
	Base Case (2001)	Increased Roof/Wall Insulation	Decreased Window U-Value	Window Shading	Window Shading & Redistribution	High Albedo Roof	CO2 Based DCV	Improved AC Eff.	Improved Furnace Eff.	Improved Fan Eff.	Improved SHW Heater Eff.	Tankless Water Heater	Solar SHW	Decreased LPD to 0.9 W/sq.ft.	Decreased LPD to 0.75 W/sq.ft.	Daylight Dimming Control	Automatic Recep. Control	Solar PV	Group 1	Group 2	Group 3
Total	826	810	746	824	818	826	774	797	809	808	818	813	799	770	750	773	812	611	737	735	691
SHW	48	48	48	48	48	48	48	48	48	48	41	44	21	48	48	48	48	48	44	48	48
Fans+Pumps	142	141	139	142	142	142	142	142	142	122	142	134	143	143	143	142	142	94	134	143	142
Heating	146	134	61	151	147	151	106	146	130	153	146	146	146	163	170	158	150	146	170	172	119
Lgt+Appl	346	346	346	346	346	346	346	346	346	346	346	346	346	284	261	291	331	228	261	246	284
Cooling	143	141	152	137	135	139	132	114	143	139	143	143	143	132	128	133	140	94	128	126	97

Figure 28. Site Energy Use of Various EEMs for an ASHRAE 90.1-2001 Code-Compliant Small Office Building in the CoA



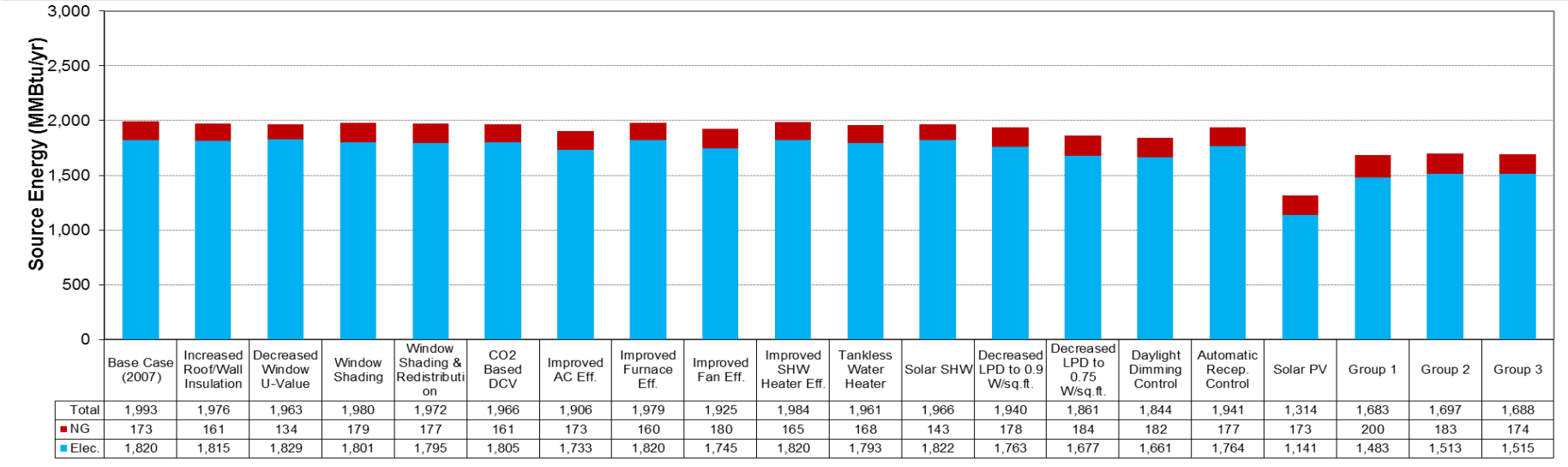
	Base Case (2007)	Increased Roof/Wall Insulation	Decreased Window U-Value	Window Shading	Window Shading & Redistribution	CO2 Based DCV	Improved AC Eff.	Improved Furnace Eff.	Improved Fan Eff.	Improved SHW Heater Eff.	Tankless Water Heater	Solar SHW	Decreased LPD to 0.9 W/sq.ft.	Decreased LPD to 0.75 W/sq.ft.	Daylight Dimming Control	Automatic Recep. Control	Solar PV	Group 1	Group 2	Group 3
Total	733	721	700	733	729	718	706	721	716	726	720	707	719	698	692	719	518	651	646	637
SHW	48	48	48	48	48	48	48	48	48	41	44	21	48	48	48	48	48	48	44	48
Fans+Pumps	140	139	138	140	139	140	140	140	120	140	131	141	140	140	140	140	88	120	132	140
Heating	109	98	73	115	112	98	109	97	115	109	109	109	113	119	118	113	109	133	123	110
Lgt+Appl	300	300	300	300	300	300	300	300	300	300	300	300	284	261	257	285	188	229	246	242
Cooling	136	135	141	130	129	132	109	136	132	136	136	136	133	129	128	133	85	120	101	97

Figure 29. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in the CoA



	Base Case (2001)	Increased Roof/Wall Insulation	Decreased Window U-Value	Window Shading	Window Shading & Redistribution	High Albedo Roof	CO2 Based DCV	Improved AC Eff.	Improved Furnace Eff.	Improved Fan Eff.	Improved SHW Heater Eff.	Tankless Water Heater	Solar SHW	Decreased LPD to 0.9 W/sq.ft.	Decreased LPD to 0.75 W/sq.ft.	Daylight Dimming Control	Automatic Recep. Control	Solar PV	Group 1	Group 2	Group 3
Total	2,208	2,185	2,133	2,195	2,184	2,201	2,129	2117.85	2,190	2,140	2,200	2,176	2,181	1,998	1,921	2,016	2,157	1,530	1,889	1,868	1,838
NG	214	200	120	219	215	219	170	214	196	221	206	209	184	232	240	227	218	214	235	243	184
Elec.	1,994	1,985	2,013	1,976	1,969	1,983	1,960	1,904	1,994	1,918	1,994	1,967	1,997	1,766	1,681	1,789	1,939	1,316	1,654	1,625	1,654

Figure 30. Source Energy Use of Various EEMs for an ASHRAE 90.1-2001 Code-Compliant Small Office Building in the CoA



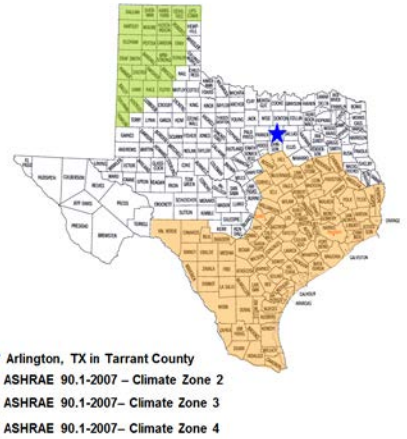
	Base Case (2007)	Increased Roof/Wall Insulation	Decreased Window U-Value	Window Shading	Window Shading & Redistribution	CO2 Based DCV	Improved AC Eff.	Improved Furnace Eff.	Improved Fan Eff.	Improved SHW Heater Eff.	Tankless Water Heater	Solar SHW	Decreased LPD to 0.9 W/sq.ft.	Decreased LPD to 0.75 W/sq.ft.	Daylight Dimming Control	Automatic Recep. Control	Solar PV	Group 1	Group 2	Group 3
Total	1,993	1,976	1,963	1,980	1,972	1,966	1,906	1,979	1,925	1,984	1,961	1,966	1,940	1,861	1,844	1,941	1,314	1,683	1,697	1,688
NG	173	161	134	179	177	161	173	160	180	165	168	143	178	184	182	177	173	200	183	174
Elec.	1,820	1,815	1,829	1,801	1,795	1,805	1,733	1,820	1,745	1,820	1,793	1,822	1,763	1,677	1,661	1,764	1,141	1,483	1,513	1,515

Figure 31. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in the CoA

[ASHRAE 90.1-2001 Code-Compliant Small Office Building]

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)[1]		Annual Energy Savings ($/year)[2]	Annual Demand Savings (%)	Annual Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($)		Simple Estimated Payback (yrs)
		Site	Source					Marginal Cost[4]	New System Cost[5]	
A	**Envelope and Fenestration Measures**									
1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	1.9%	1.1%	$163	0.5%	$16	$179	$14,332 - $21,499		80.3 - 120.4
2	Decreased Glazing U-Value (from 1.22 to 0.35)	9.6%	3.4%	$373	0.2%	$8	$381	$16,773 - $25,160		44.0 - 66.0
3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	0.1%	0.6%	$130	1.0%	$35	$165		$14,159 - $21,238	85.9 - 128.9
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	0.9%	1.1%	$217	1.1%	$39	$256		$14,159 - $21,238	55.3 - 83.0
5	High Albedo Roof (Roof Absorptance from 0.7 to 0.3)	-0.1%	0.3%	$75	0.3%	$10	$85	$4,400 - $6,600		51.6 - 77.4
B	**HVAC System Measures**									
6	CO_2 Based Demand-Controlled Ventilation (DCV)	6.2%	3.6%	$561	0.9%	$31	$592		$7,367 - $11,051	12.4 - 18.7
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	3.5%	4.1%	$796	6.6%	$227	$1,023	$12,288 - $18,432		12.0 - 18.0
8	Improved Furnace Efficiency (from 80% to 90% Et)	2.0%	0.8%	$102	0.0%	$0	$102	$7,900 - $11,850		77.3 - 115.9
9	Improved Fan Efficiency (from 55% to 65%)	2.1%	3.1%	$628	2.7%	$91	$719	$6,869 - $10,303		9.6 - 14.3
C	**Service Hot Water Measures**									
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	0.9%	0.4%	$48	0.0%	$0	$48	$3,456 - $5,184		72.1 - 108.1
11	Tankless Gas Water Heater	1.6%	1.5%	$268	0.5%	$17	$284	$1,414 - $2,120		5.0 - 7.5
12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	3.2%	1.2%	$146	-0.2%	-$6	$140		$2,880 - $4,320	20.6 - 30.9
D	**Lighting and Receptacle Measures**									
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	6.7%	9.5%	$1,906	11.3%	$386	$2,292	$9,344 - $14,016		4.1 - 6.1
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	9.1%	13.0%	$2,612	15.5%	$532	$3,144	$10,484 - $15,726		3.3 - 5.0
15	Daylight Dimming Control	6.4%	8.7%	$1,733	11.9%	$409	$2,141		$15,723 - $23,584	7.3 - 11.0
16	Automatic Receptacle Control for Offices using Occupancy Sensors	1.7%	2.3%	$466	3.2%	$109	$575		$7,587 - $11,380	13.2 - 19.8
E	**Renewable Power Measure**									
17	40 kW Photovoltaic Array	26.0%	30.7%	$5,979	24.2%	$829	$6,808		$200,000 - $300,000	29.4 - 44.1



Description of Combined Measures

	Combination of Measures[6]	Combined Annual Energy Savings (%)[1]		Combined Energy Savings ($/year)[2]	Combined Demand Savings (%)	Combined Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($)		Simple Estimated Payback (yrs)	NOx Emissions Savings	SO_2 Emissions Savings	CO_2 Emissions Savings
		Site	Source					Marginal Cost[4]	New System Cost[5]		Annual (lbs/yr)	Annual (lbs/yr)	Annual (tons/yr)
	Combination 1												
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	10.7%	15.0%	$2,878	16.0%	$549	$3,426	$10,484 - $15,726		3.5 - 5.2	48.2	31.4	20.0
11	Tankless Gas Water Heater							$1,414 - $2,120					
	Combination 2												
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	11.0%	15.4%	$3,087	19.8%	$678	$3,765	$9,344 - $14,016		6.7 - 10.0	51.8	34.0	21.3
15	Daylight Dimming Control								$15,723 - $23,584				
	Combination 3												
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	16.4%	16.8%	$3,172	18.2%	$623	$3,795	$9,344 - $14,016		7.6 - 11.5	52.5	31.4	22.7
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
6	CO_2 Based Demand-Controlled Ventilation (DCV)								$7,367 - $11,051				

Note:
1. Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
2. Savings depend on fuel mix used.
   * Energy Cost: Electricity = $0.095/kWh & Demand = $5.00/kW
     Natural gas = $0.65/therm
3. Yearly demand cost = Sum of monthly demand cost for 12 months
4. Marginal cost = new system cost - original system cost
5. New system cost = new system cost only
6. See individual measures above for specific savings

[ASHRAE 90.1-2001 Code-Compliant Building Description]
* Building type: Small Office
* Gross area: 20,000 sq-ft
* Building dimension: 100 ft x 100 ft x 13 ft (WxLxH)
* Number of floors: 2
* Floor-to-floor height: 13 ft
* Window-to-wall ratio: 20.0%
* HVAC system: SEER 13 or EER 10.8 Rooftop PSZ & 80% Et Furnace
* DHW: 80% Et Gas Water heater

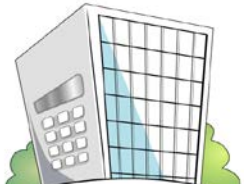
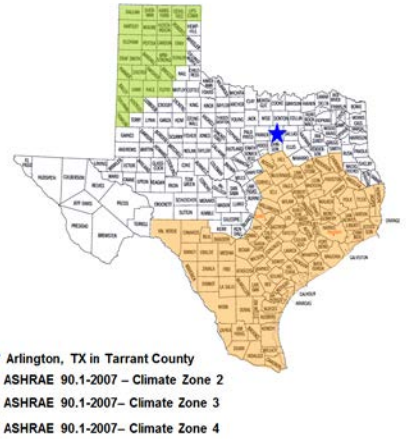


Figure 32. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2001 Code-Compliant Small Office Building for the CoA

[ASHRAE 90.1-2007 Code-Compliant Small Office Building]

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)[1]		Annual Energy Savings ($/year)[2]	Annual Demand Savings (%)	Annual Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($)		Simple Estimated Payback (yrs)
		Site	Source					Marginal Cost[4]	New System Cost[5]	
A	**Envelope and Fenestration Measures**									
1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	1.7%	0.9%	$112	0.4%	$13	$126	$9,092 - $13,639		72.2 - 108.3
2	Decreased Glazing U-Value (from 0.65 to 0.35)	4.5%	1.5%	$145	0.0%	$1	$146	$7,039 - $10,558		48.4 - 72.5
3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	0.0%	0.6%	$128	1.0%	$32	$160		$14,159 - $21,238	88.3 - 132.5
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	0.6%	1.0%	$193	1.2%	$37	$230		$14,159 - $21,238	61.6 - 92.4
B	**HVAC System Measures**									
6	CO_2 Based Demand-Controlled Ventilation (DCV)	2.1%	1.3%	$200	0.7%	$23	$223		$7,367 - $11,051	33.1 - 49.6
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	3.7%	4.3%	$763	6.8%	$214	$977	$12,288 - $18,432		12.6 - 18.9
8	Improved Furnace Efficiency (from 80% to 90% Et)	1.7%	0.7%	$76	0.0%	$0	$76	$7,900 - $11,850		103.5 - 155.2
9	Improved Fan Efficiency (from 55% to 65%)	2.4%	3.4%	$615	3.0%	$93	$708	$6,869 - $10,303		9.7 - 14.5
C	**Service Hot Water Measures**									
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	1.0%	0.4%	$48	0.0%	$0	$48	$3,456 - $5,184		72.1 - 108.1
11	Tankless Gas Water Heater	1.8%	1.6%	$265	0.6%	$18	$283	$1,414 - $2,120		5.0 - 7.5
12	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	3.6%	1.4%	$146	-0.2%	-$6	$140		$2,880 - $4,320	20.6 - 30.9
D	**Lighting and Receptacle Measures**									
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	1.9%	2.6%	$476	3.1%	$97	$573	$4,913 - $7,369		8.6 - 12.9
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	4.8%	6.6%	$1,196	7.8%	$243	$1,439	$6,052 - $9,079		4.2 - 6.3
15	Daylight Dimming Control	5.7%	7.5%	$1,341	10.4%	$325	$1,666		$15,723 - $23,584	9.4 - 14.2
16	Automatic Receptacle Control for Offices using Occupancy Sensors	1.9%	2.6%	$465	3.5%	$110	$575		$7,587 - $11,380	13.2 - 19.8
E	**Renewable Power Measure**									
17	40 kW Photovoltaic Array	29.3%	34.1%	$5,979	25.5%	$800	$6,779		$200,000 - $300,000	29.5 - 44.3



Description of Combined Measures

	Combination of Measures[6]	Combined Annual Energy Savings (%)[1]		Combined Energy Savings ($/year)[2]	Combined Demand Savings (%)	Combined Demand Savings ($/year)[3]	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($)		Simple Estimated Payback (yrs)	NOx Emissions Savings	SO_2 Emissions Savings	CO_2 Emissions Savings
		Site	Source					Marginal Cost[4]	New System Cost[5]		Annual (lbs/yr)	Annual (lbs/yr)	Annual (tons/yr)
	Combination 1												
15	Daylight Dimming Control	11.2%	15.5%	$2,812	18.6%	$583	$3,395		$15,723 - $23,584	8.4 - 12.7	47.2	31.0	19.4
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)							$6,052 - $9,079					
9	Improved Fan Efficiency (from 55% to 65%)							$6,869 - $10,303					
	Combination 2												
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	11.9%	14.9%	$2,639	18.3%	$572	$3,212	$6,052 - $9,079		8.5 - 12.8	44.1	28.2	18.4
7	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
16	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
11	Tankless Gas Water Heater							$1,414 - $2,120					
	Combination 3												
15	Daylight Dimming Control	13.1%	15.3%	$2,682	20.5%	$642	$3,324		$15,723 - $23,584	12.9 - 19.4	44.7	28.1	18.9
14	Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
16	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
6	CO_2 Based Demand-Controlled Ventilation (DCV)								$7,367 - $11,051				

Note:
1. Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
2. Savings depend on fuel mix used.
   * Energy Cost: Electricity = $0.095/kWh & Demand = $5.00/kW
     Natural gas = $0.65/therm
3. Yearly demand cost = Sum of monthly demand cost for 12 months
4. Marginal cost = new system cost - original system cost
5. New system cost = new system cost only
6. See individual measures above for specific savings

[ASHRAE 90.1-2007 Code-Compliant Building Description]
* Building type: Small Office
* Gross area: 20,000 sq-ft
* Building dimension: 100 ft x 100 ft x 13 ft (WxLxH)
* Number of floors: 2
* Floor-to-floor height: 13 ft
* Window -to-wall ratio: 20.0%
* HVAC system: SEER 13 or EER 10.8 Rooftop PSZ & 80% Et Furnace
* DHW: 80% Et Gas Water heater

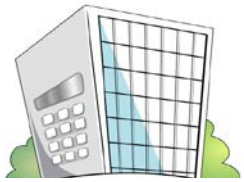


Figure 33. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for the CoA

5 SUMMARY

This report presents cost-effective recommendations to maximize energy savings for small office buildings in the City of Arlington (CoA). For more realistic recommendations, the CoA provided two years of commercial building energy compliance reports from 2008 to 2010 which exceeded the energy efficiency requirements of the CoA (i.e., 2003 International Energy Conservation Code (IECC)). The buildings' envelope, fenestration, and system characteristics were summarized and then statistically compared with the 2003 IECC Section 806 requirements for commercial buildings, and a summary table of energy efficiency measures used in the CoA during the past two years (2008-2010) was developed. Based on a summary of above-code approaches, recommendations were developed to achieve above-code energy performance based on the ASHRAE 90.1-2001 and 2007 standard reference buildings, for small office buildings in the CoA.

A total of 17 recommendations based on the energy savings above the base-case small office building were selected. These measures include building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. The implementation costs of each individual measure were also calculated along with simple payback calculations. These measures were then combined to achieve the total source energy savings of the group is 15% above the base-case, ASHRAE 90.1-2001 and 2007 code-compliant small office buildings. As a result, three combinations were proposed for each base case. Each combination was formed to have a different payback period. Finally, the corresponding emissions savings (NOx, SO_2, and CO_2) of each combination were calculated based on the eGrid for Texas.

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APPENDIX A

Appendix A includes details on the statistical analysis of the eleven commercial sample buildings on identification, building, envelope, interior lighting, and system parameters associated with the 2003 IECC requirements. The "Frequency" plot presents a number of commercial sample buildings complied with each condition. The "% of Buildings" plot presents the percentage of the "Frequency" plot.

: Above-code (Better than 2003 IECC Section 806 performance path)
: Below code (Worse than 2003 IECC Section 806 performance path)
: Just code (Same as 2003 IECC Section 806 performance path)
: Not required (Code house is same as proposed)

1) Identification
   a. Certification Type

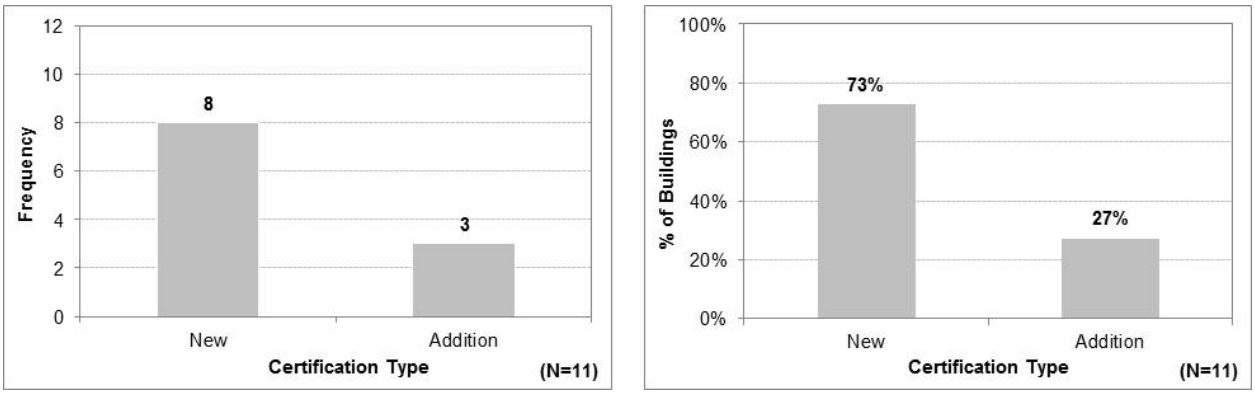


Figure A-1. Frequency and Percentage Distribution of Eleven Buildings by Certification Type

   b. Activity Type for New

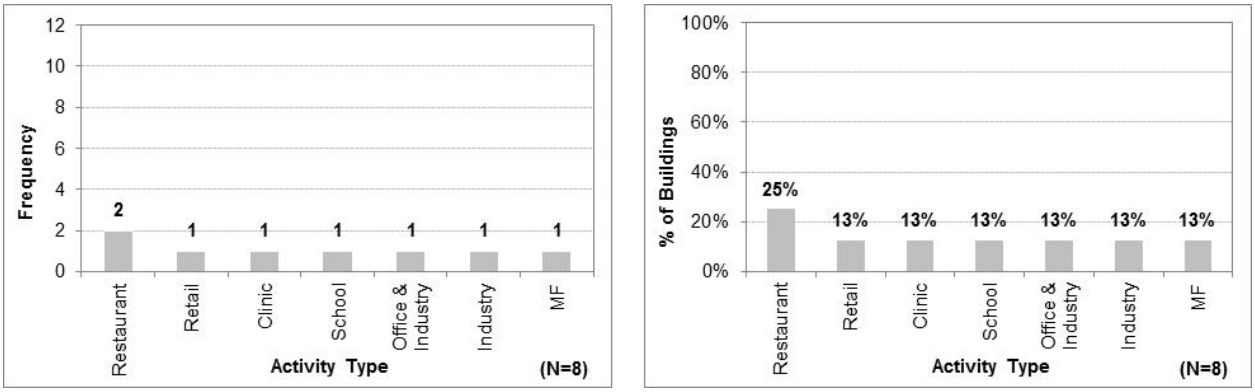


Figure A-2. Frequency and Percentage Distribution of Eight Buildings by Activity Type for New Construction

c. Activity Type for Addition

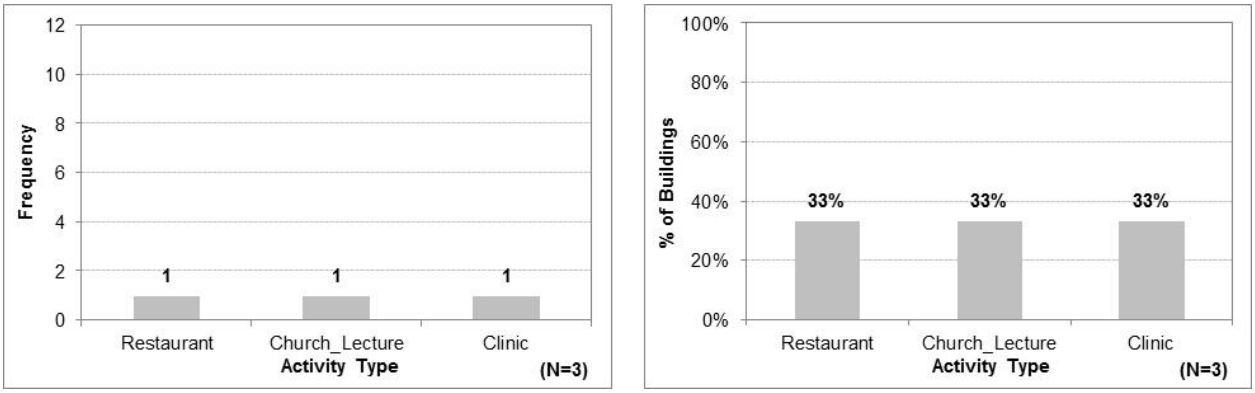


Figure A-3. Frequency and Percentage Distribution of Three Buildings by Activity Type for Addition Construction

2) Compliant Option

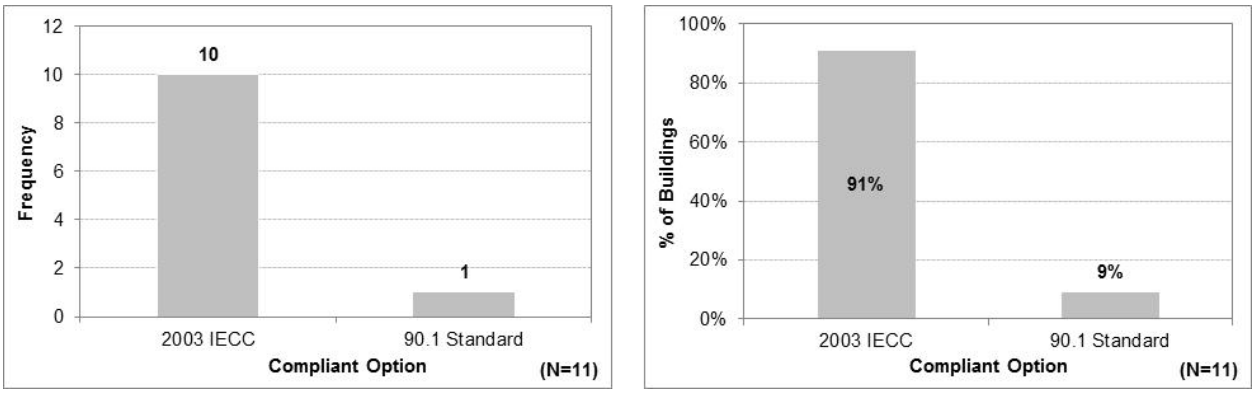
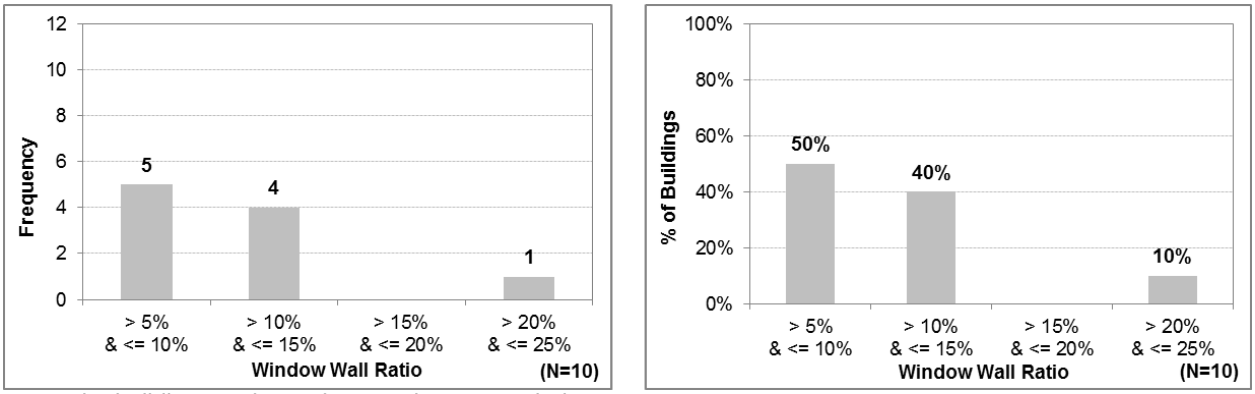


Figure A-4. Frequency and Percentage Distribution of Eleven Buildings by Compliant Option

3) Window to Wall Ratio



Note: The building number 8 does not have any window.

Figure A-5. Frequency and Percentage Distribution of Ten Buildings by Window to Wall Ratio

4) Wall Insulation

a. R-Value for Wood Framing Wall

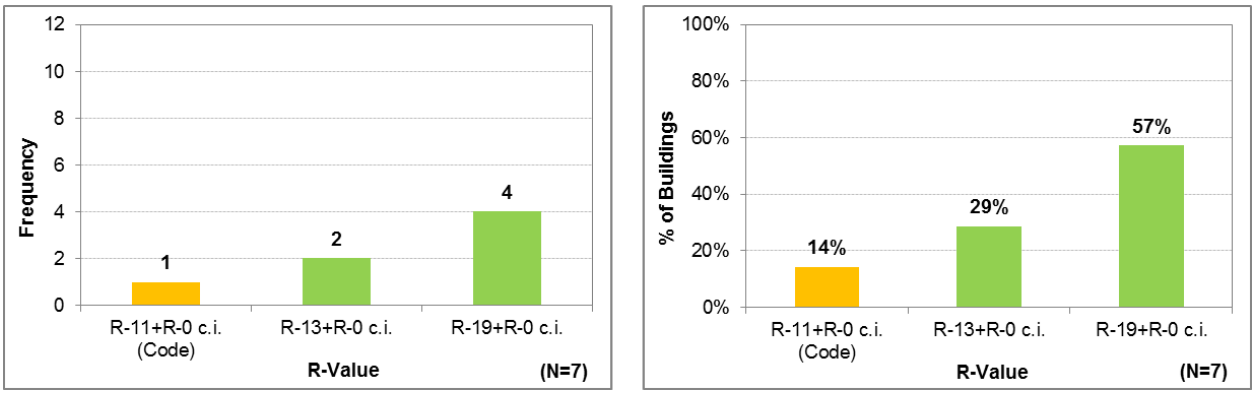


Figure A-6. Frequency and Percentage Distribution of Seven Buildings by R-Value of Wood Framing Wall

b. R-Value for Metal Framing Wall

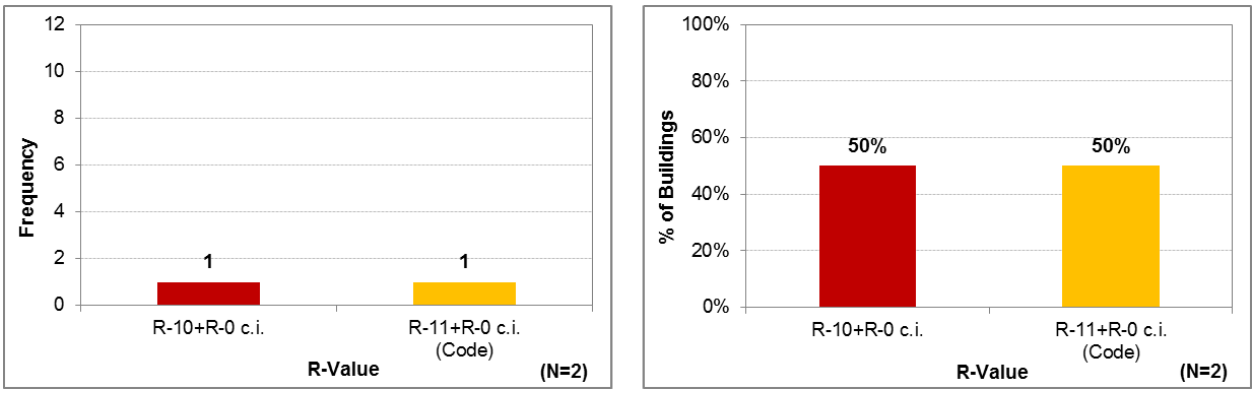
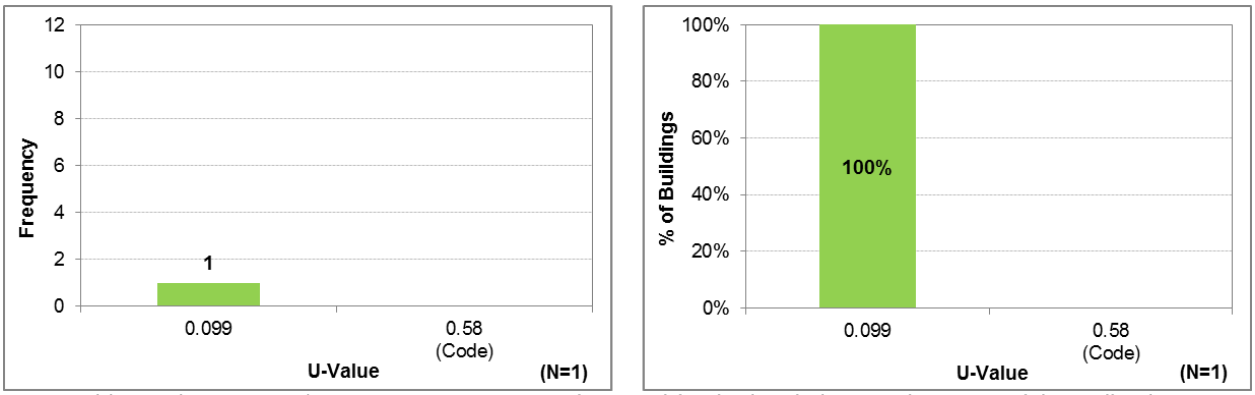


Figure A-7. Frequency and Percentage Distribution of Two Buildings by R-Value of Metal Framing Wall

c. U-Value for CMU <=8" with Empty Cells Wall



Note: Table B-8 in ASHRAE/IESNA 90.1-2001 was referenced for the insulation requirements of the wall using CMU <=8" with empty cells.

Figure A-8. Frequency and Percentage Distribution of One Building by U-Value of CMU <=8" with Empty Cells Wall

d. R-Value for Solid Conc./Masonry <=8" Wall (WWR 0-10%)

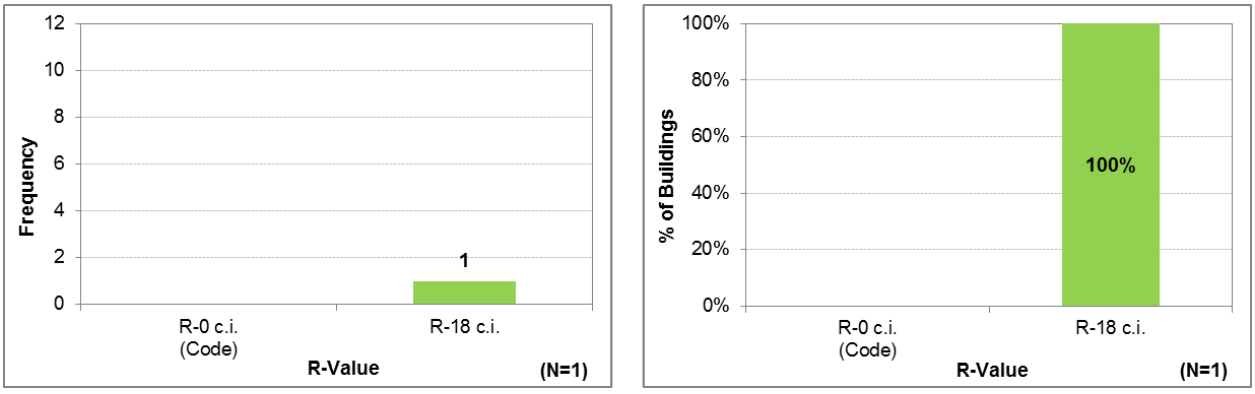


Figure A-9. Frequency and Percentage Distribution of One Building by R-Value of Solid Conc./Masonry<=8" Wall (WWR 0-10%)

5) Roof Insulation

a. Roof R-Value for Insulation between Framing of All-Wood Joist/Truss (WWR 0-10%)

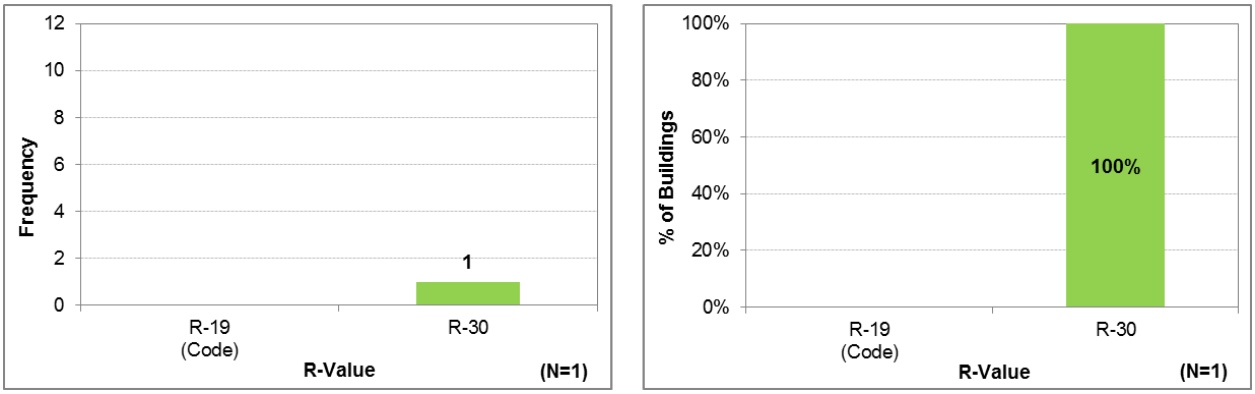


Figure A-10. Frequency and Percentage Distribution of One Building by Roof R-Value, Insulation between Framing of All-Wood Joist/Truss (WWR 0-10%)

b. Roof R-Value for Continuous Insulation of All-Wood Joist/Truss (WWR 0-10%)

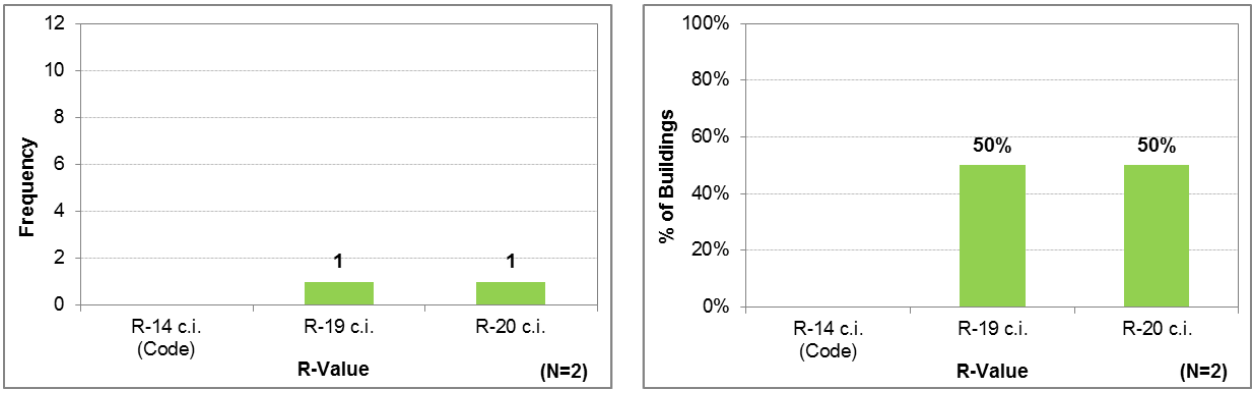


Figure A-11. Frequency and Percentage Distribution of Two Buildings by Roof R-Value, Continuous Insulation of All-Wood Joist/Truss (WWR 0-10%)

c. Roof R-Value for Continuous Insulation of Concrete Slab or Deck (WWR 0-10%)

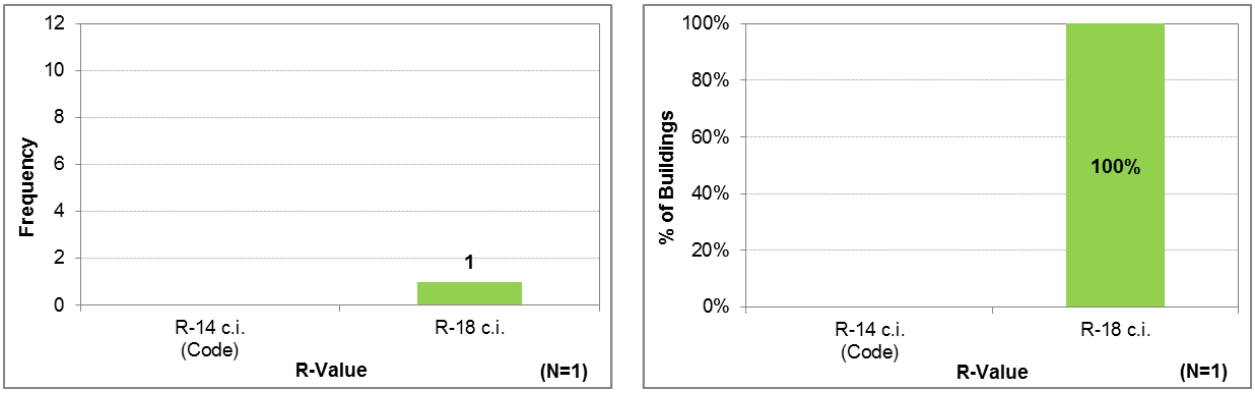


Figure A-12. Frequency and Percentage Distribution of One Building by Roof R-Value, Continuous Insulation of Concrete Slab or Deck (WWR 0-10%)

d. Roof R-Value for Insulation between Framing of Metal Roof with Thermal Blocks (WWR 0-10%)

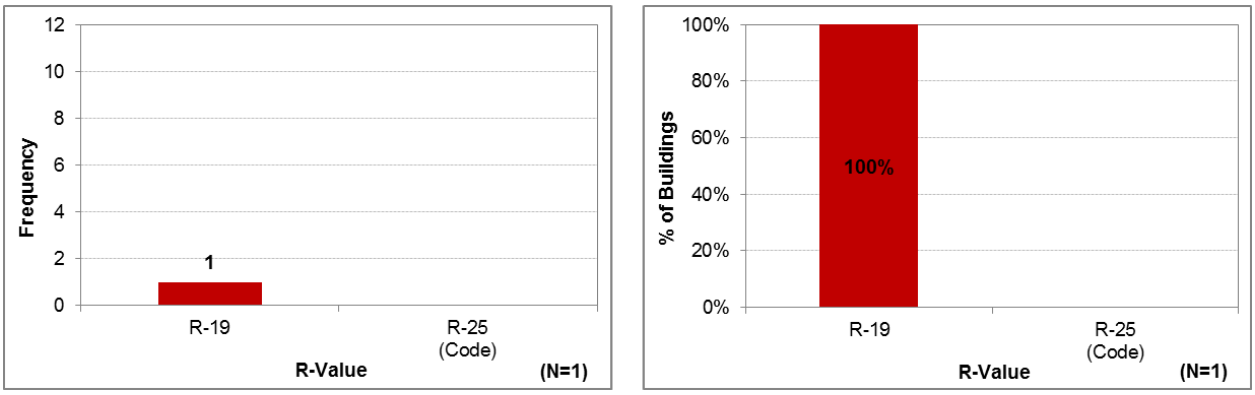


Figure A-13. Frequency and Percentage Distribution of One Building by Roof R-Value, Insulation between Framing of Metal Roof with Thermal Blocks (WWR 0-10%)

e. R Roof R-Value for Continuous Insulation of Metal Joist/Truss (WWR 0-10%)

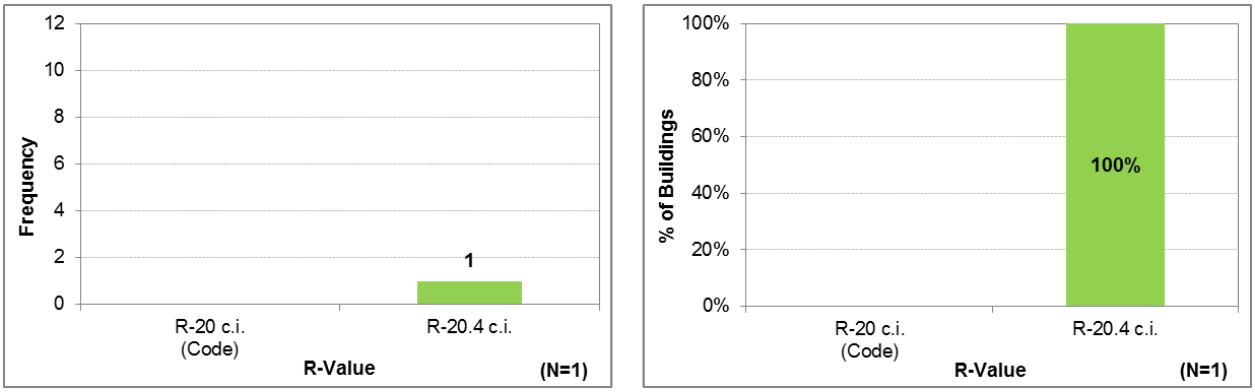


Figure A-14. Frequency and Percentage Distribution of One Building by Roof R-Value, Continuous Insulation of Metal Joist/Truss (WWR 0-10%)

f. Roof R-Value for Insulation between Framing of All-Wood Joist/Truss (WWR 10-25%)

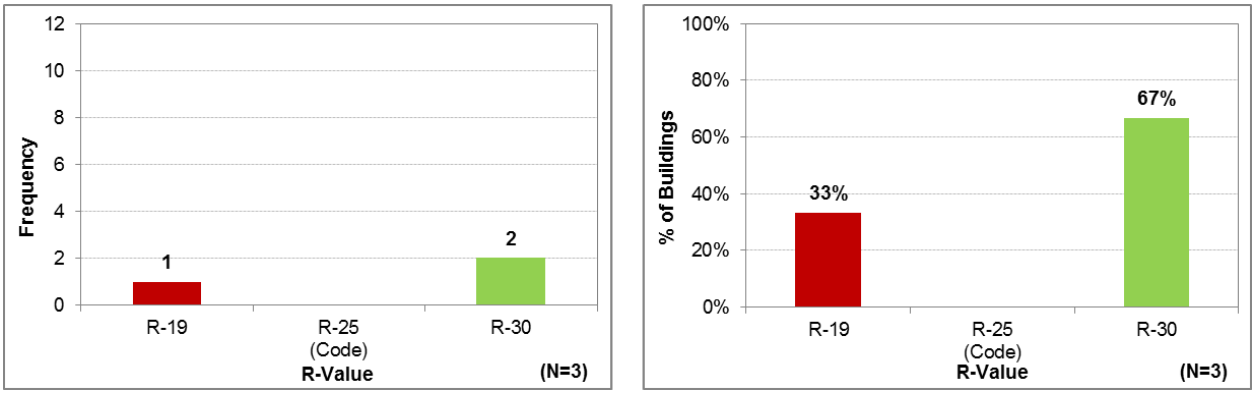


Figure A- 15. Frequency and Percentage Distribution of Three Buildings by Roof R-Value, Insulation between Framing of All-Wood Joist/Truss (WWR 10-25%)

g. Roof R-Value for Continuous Insulation of All-Wood Joist/Truss (WWR 10-25%)

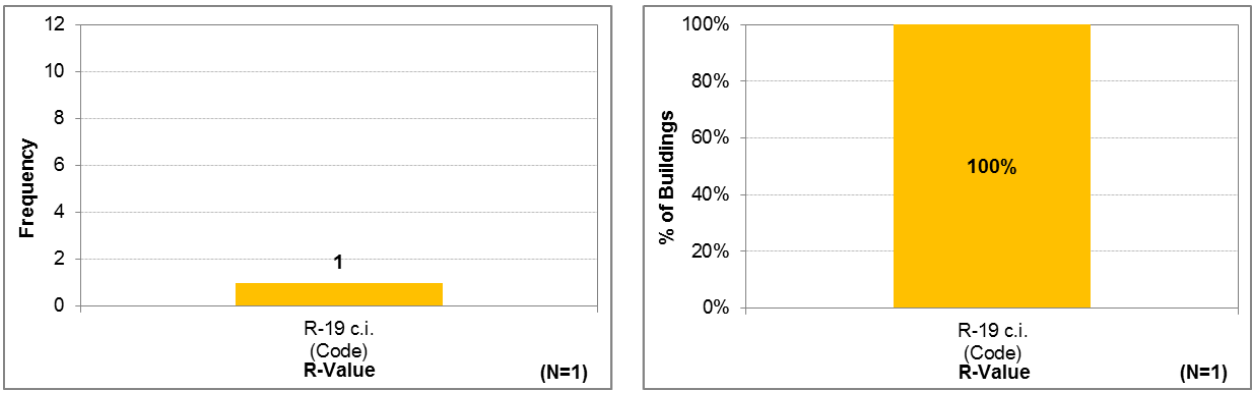


Figure A-16. Frequency and Percentage Distribution of Two Buildings by Roof R-Value, Continuous Insulation of All-Wood Joist/Truss (WWR 10-25%)

h. R Roof R-Value for Continuous Insulation of Metal Joist/Truss (WWR 10-25%)

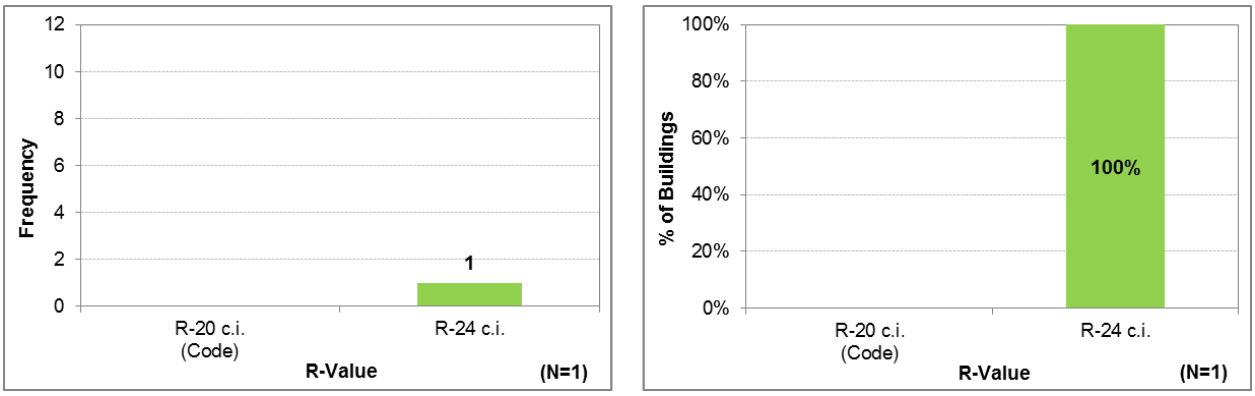


Figure A-17. Frequency and Percentage Distribution of One Building by Roof R-Value, Continuous Insulation of Metal Joist/Truss (WWR 10-25%)

6) Door
   a. Glass Door PF

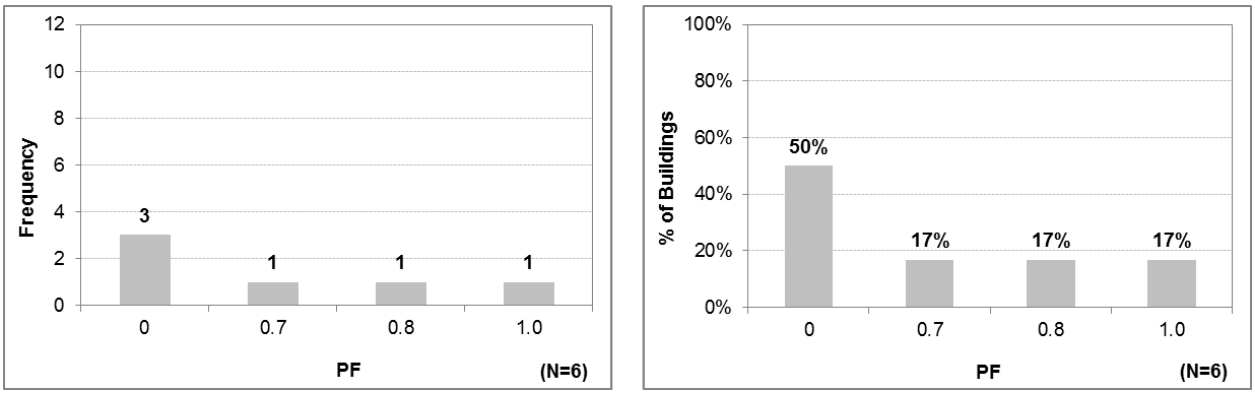


Figure A-18. Frequency and Percentage Distribution of Three Buildings by Glass Door PF

   b. Glass Door SHGC

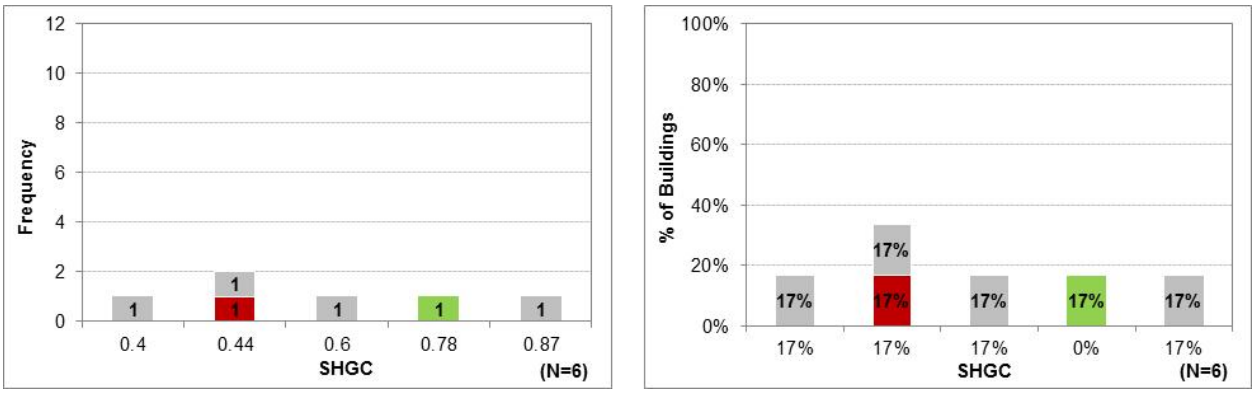


Figure A-19. Frequency and Percentage Distribution of Six Buildings by Glass Door SHGC

7) Interior Lighting
   a. Average Decreased Electricity Usage

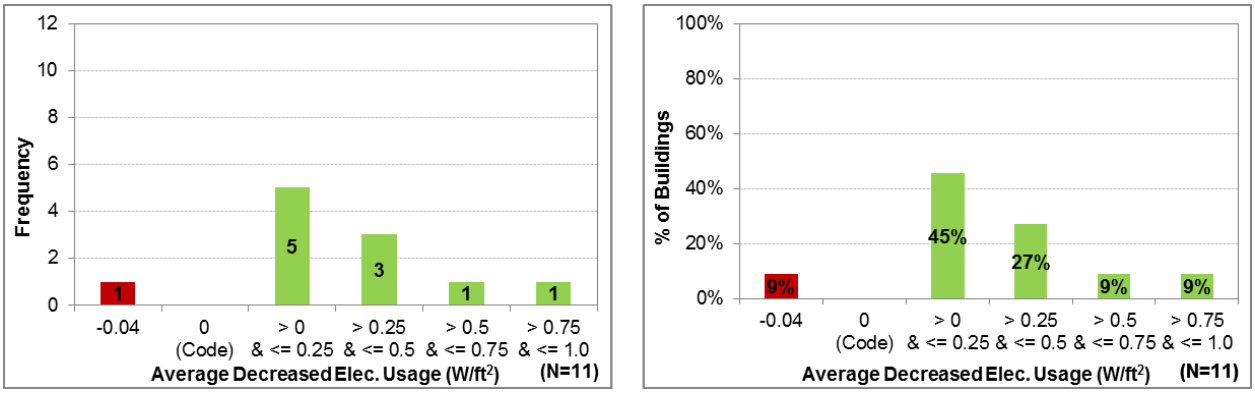


Figure A-20. Frequency and Percentage Distribution of Eleven Buildings by Average Decreased Electricity Usage

b. Electricity Usage for Restaurant

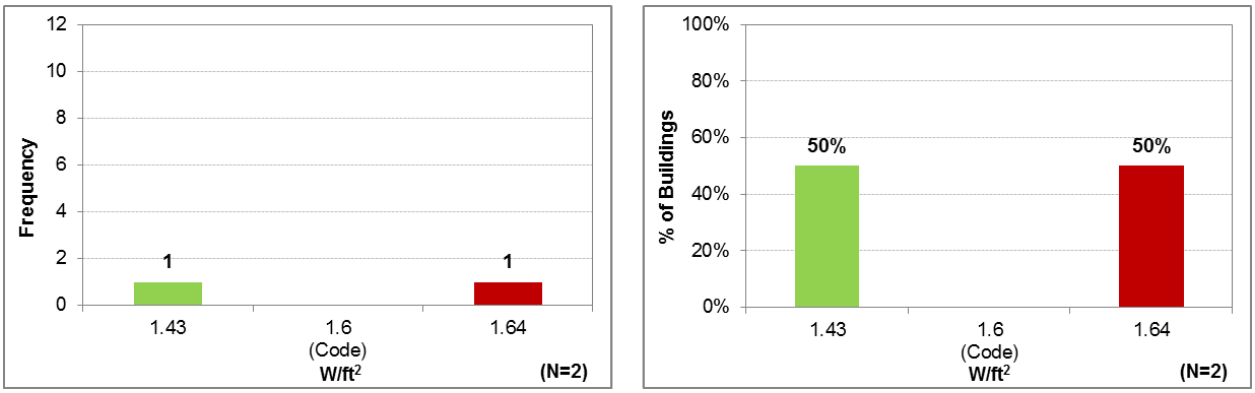
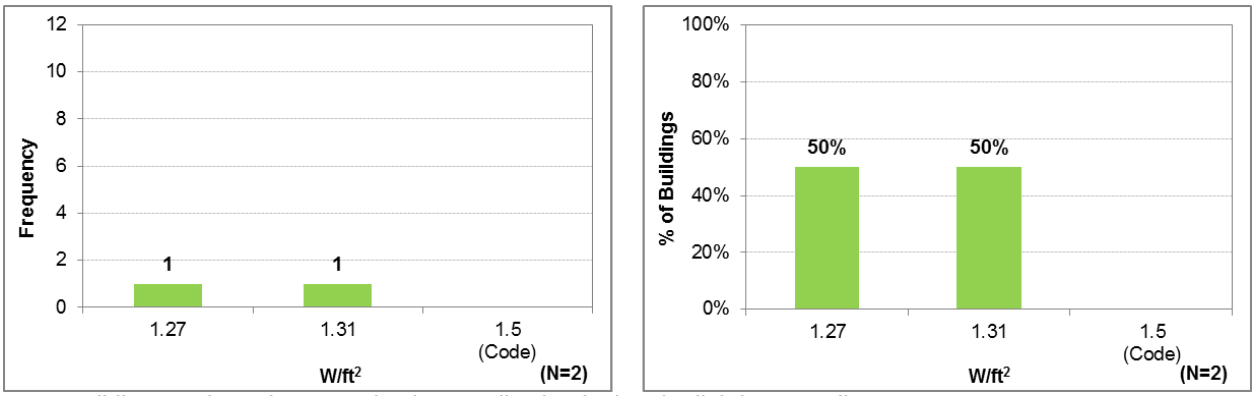


Figure A-21. Frequency and Percentage Distribution of Two Buildings by Restaurant Electricity Usage

c. Electricity Usage for Retail Sales



Note: Building number 1 is categorized as retail sales for interior lighting compliance.

Figure A-22. Frequency and Percentage Distribution of Two Buildings by Retail Sales Electricity Usage

d. Electricity Usage for Medical and Clinical Care

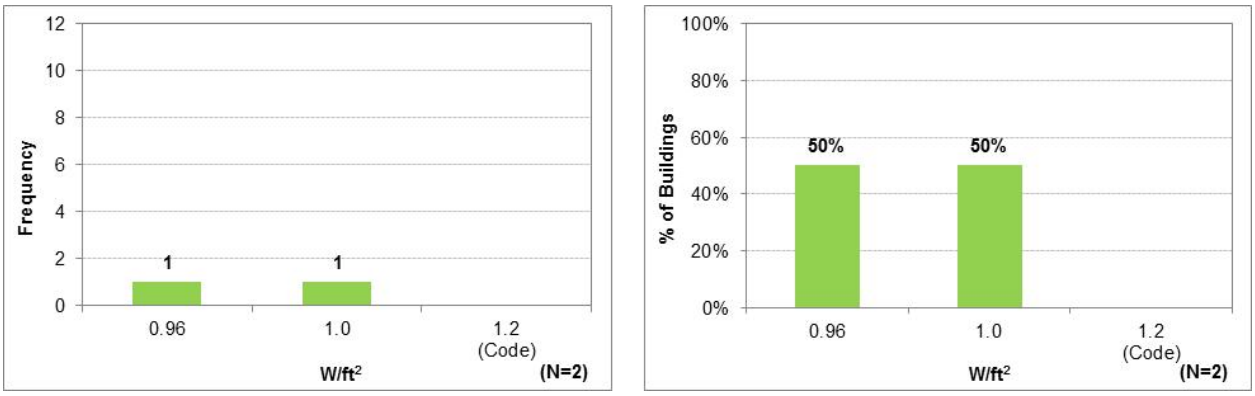
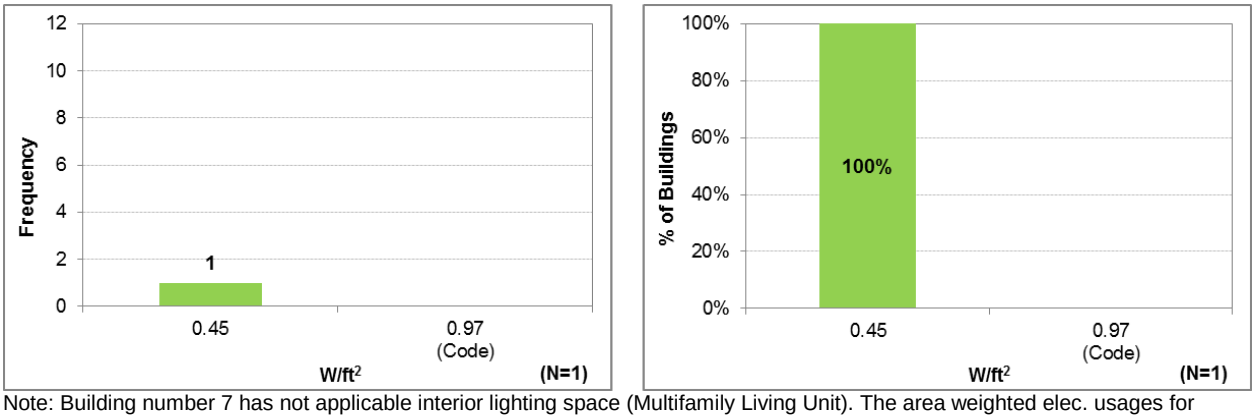


Figure A-23. Frequency and Percentage Distribution of Two Buildings by Medical and Clinical Care Electricity Usage

e. Electricity Usage for Multifamily



Note: Building number 7 has not applicable interior lighting space (Multifamily Living Unit). The area weighted elec. usages for allowed and proposed watts are calculated except of the multifamily living space.

Figure A-24. Frequency and Percentage Distribution of One Building by Multifamily Electricity Usage

f. Electricity Usage for School

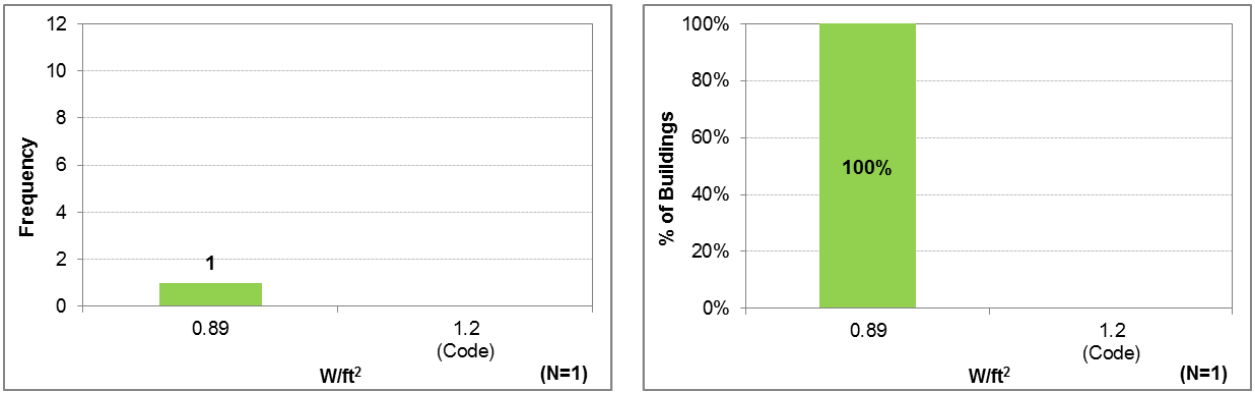


Figure A-25. Frequency and Percentage Distribution of One Building by School Electricity Usage

g. Electricity Usage for Office and Industrial Work

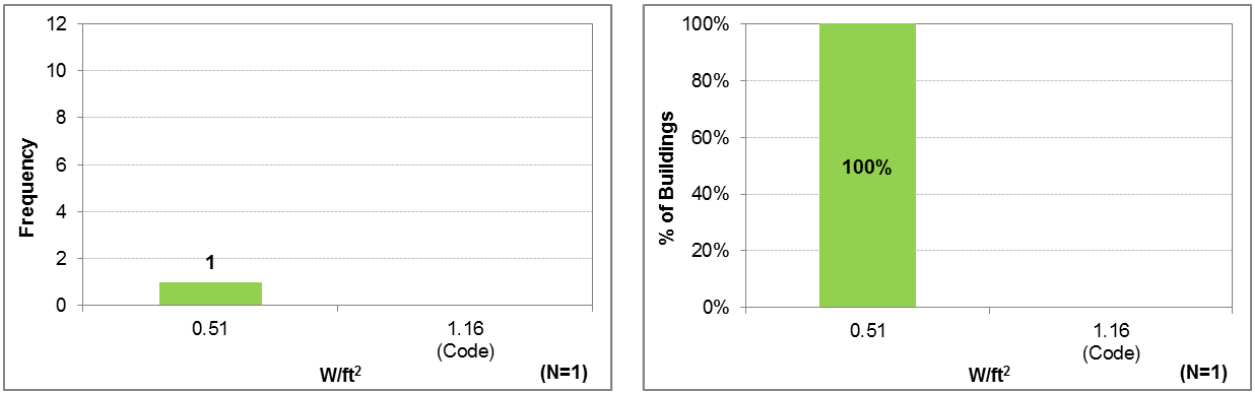


Figure A-26. Frequency and Percentage Distribution of One Building by Office and Industrial Work Electricity Usage

h. Electricity Usage for Industrial Work

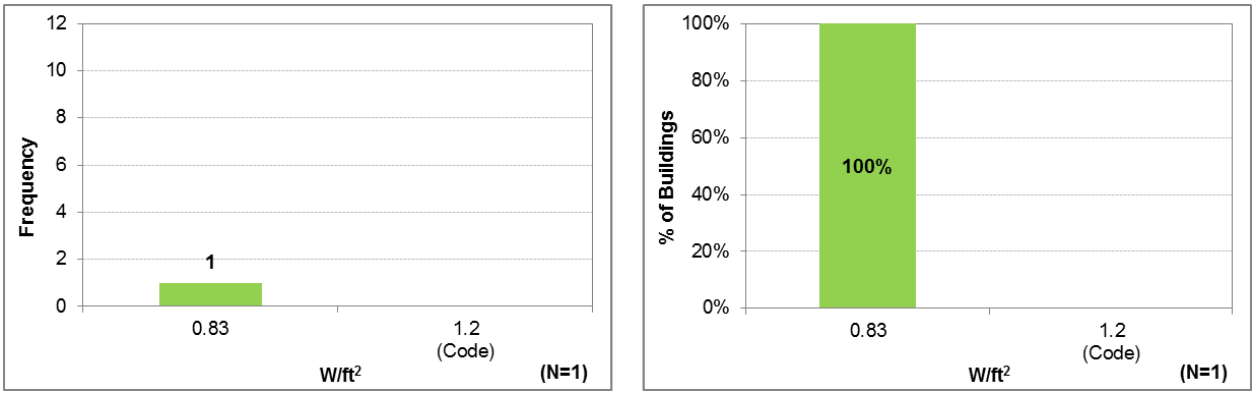


Figure A-27. Frequency and Percentage Distribution of One Building by Industrial Work Electricity Usage

i. Electricity Usage for Classroom and Lecture Hall

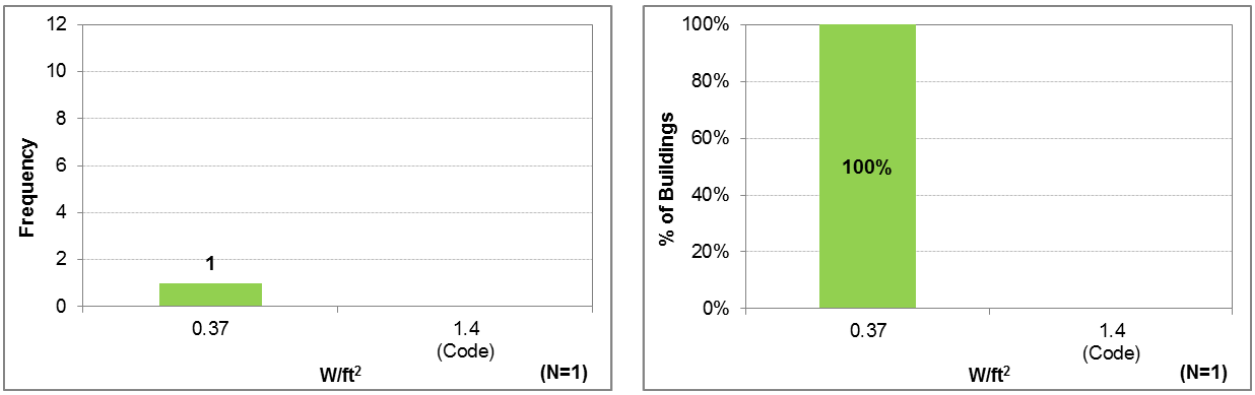


Figure A-28. Frequency and Percentage Distribution of One Building by Classroom and Lecture Hall Electricity Usage

8) Type of A/C Condenser

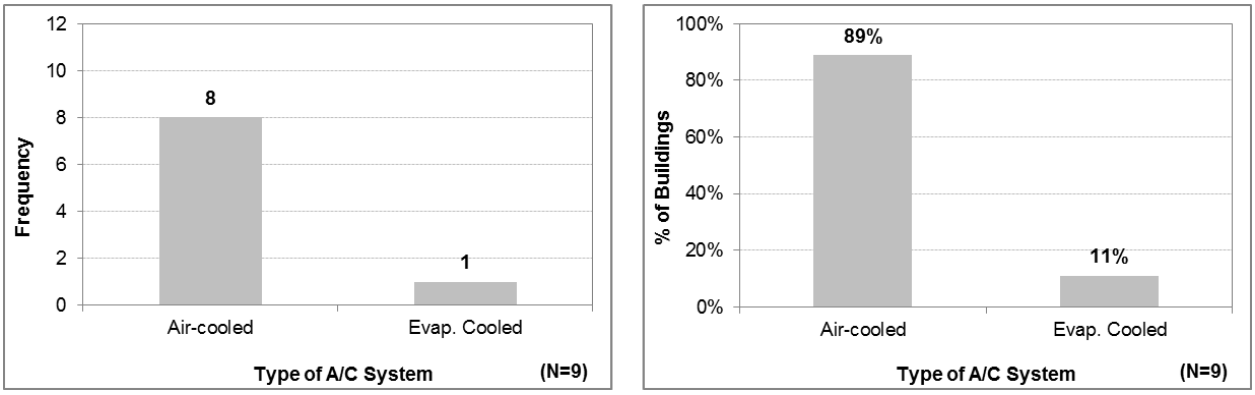


Figure A-29. Frequency and Percentage Distribution of Nine Buildings by Type of A/C Condenser

APPENDIX B

Appendix B provides the implementation cost of each EEM obtained from various resources. Table B-1 and B-2 summarize the cost information for all measures.

Table B-1. Summary of the Cost Information for an ASHRAE 90.1-2001 Code-Compliant Base Case

	EEMs for ASHRAE 90.1-2001 Base Case (CoA)	Description of EEM			Increased Cost per Unit		Number of units/Total Area			Avg. Total Increased Cost	Implementation Costs for Whole Building			References
		Unit/Category	Base Case	EEM	Unit	$/Unit	Unit (#)	Length (ft)	Area (sqft)		-20%	(Avg)	+20%	
1	Increased Roof and Wall Insulation R-Value (from 15 to 25 for roof and 13 to 13+3.8c.i. for walls)	hr-sq.ft.-°F/Btu	15	25	sqft	$1.21			10,000	$12,050	$14,332	$17,916	$21,499	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
		hr-sq.ft.-°F/Btu	0 c.i.	3.8c.i.	sqft	$0.71			8,320	$5,866				
2	Decreased Glazing U-Value (from 1.22 to 0.45)	U-Value	1.22	0.35	sqft	$10.1			2,080	$20,966	$16,773	$20,966	$25,160	PNNL AEDG TSD-Somall Office (Jarnagin et al. 2006)
3	Window Shading (None to 2.5 ft. Overhang for S/E/W)	Depth (ft)	0	2.5	length feet	$42.5		416		$17,698	$14,159	$17,698	$21,238	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	Depth (ft) WWR Front/ Back/ Right/ Left	0 20%, 20%, 20%, 20%	2.5 36%, 20%, 12%, 12%	length feet	$42.5		416		$17,698	$14,159	$17,698	$21,238	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
5	High Albedo Roof (Roof Absorptance from 0.7 to 0.3)	Roof Absorptance	0.7	0.3	sqft	$0.55			10,000	$5,500	$4,400	$5,500	$6,600	Thornton et al. 2010
6	Outside Air Demand Control	OA Demand Control	No	Yes	each	$921	10			$9,209	$7,367	$9,209	$11,051	E source. 2006
7	Improved Air Conditioner Efficiency	SEER (<65 kBtu/h) EER (≥135 and <240 kBtu/h)	13 SEER 10.8 EER	15 SEER 12.2 EER	each	$1,536	10			$15,360	$12,288	$15,360	$18,432	Kim et al. 2010
8	Improved Furnace Efficiency (from 80% to 90% Et)	Et (%)	80%	90%	each	$988	10			$9,875	$7,900	$9,875	$11,850	Kim et al. 2010
9	Improved Fan Efficiency (from 55% to 65%)	Fan Efficiency (%)	55%	65%	each	$761 $1,249	8 2			$8,586	$6,869	$8,586	$10,303	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	Et (%)	80%	95%	each	$4,320	1			$4,320	$3,456	$4,320	$5,184	PexSupply.com. 2011
11	Tankless Gas Water Heater	Tank Heat Loss Pump Electric Power (W/Btu/h)	0.74% 0.00381	0.13% 0	each	$1,767	1			$1,767	$1,414	$1,767	$2,120	PexSupply.com. 2011
12	Solar SHW System (64 sq.ft. collector, 80 gal tank)	Solar SHW system	No	64 sq.ft. collector, 80 gal tank	each	$3,600	1			$3,600	$2,880	$3,600	$4,320	Kim et al. 2010
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.3 to 0.9 W/sq.ft.)	W/ft^2	1.3	0.9	each	$35.9	325			$11,680	$9,344	$11,680	$14,016	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)	W/ft^3	1.3	0.75	each	$40.3	325			$13,105	$10,484	$13,105	$15,726	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
15	Daylight Dimming Control	Daylight Dimming Controls	No	Yes	each	$1,228	16			$19,653	$15,723	$19,653	$23,584	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
16	Automatic Receptacle Control for Offices	Automatic Receptacle Control	No	Yes	sqft	$0.47			20,000	$9,483	$7,587	$9,483	$11,380	C&S Program 2011
17	40 kW Photovoltaic Array	PV	No	40 kW Photovoltaic Array	$/watt	$6.25	40			$ 250,000	$200,000	$250,000	$300,000	Kim et al. 2010

Table B-2. Summary of the Cost Information for an ASHRAE 90.1-2007 Code-Compliant Base Case

	EEMs for ASHRAE 90.1-2007 Base Case (CoA)	Description of EEM			Increased Cost per Unit		Number of units/Total Area			Avg. Total Cost	Implementation Costs for Whole Building			References
		Unit/Category	Base Case	EEM	Unit	$/Unit	Unit (#)	Length (ft)	Area (sqft)		-20%	(Avg)	+20%	
1	Increased Roof and Wall Insulation R-Value (from 20 to 25 for roof and 13 to 13+3.8c.i. for walls)	hr-sq.ft.-°F/Btu	20	25	sqft	$0.55			10,000	$5,500	$9,092	$11,366	$13,639	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
		hr-sq.ft.-°F/Btu	0 c.i.	3.8c.i.	sqft	$0.71			8,320	$5,866				
2	Decreased Glazing U-Value (from 0.65 to 0.45)	U-Value	0.65	0.35	sqft	$4.2			2,080	$8,798	$7,039	$8,798	$10,558	PNNL AEDG TSD-Somall Office (Jarnagin et al. 2006)
3	Window Shading (None to 2.5 ft. Overhang for S/E/W)	Depth (ft)	0	2.5	length feet	$42.5		416		$17,698	$14,159	$17,698	$21,238	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W)	Depth (ft) WWR Front/ Back/ Right/ Left	0 20%, 20%, 20%, 20%	2.5 36%, 20%, 12%, 12%	length feet	$42.5		416		$17,698	$14,159	$17,698	$21,238	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
6	Outside Air Demand Control	OA Demand Control	No	Yes	each	$921	10			$9,209	$7,367	$9,209	$11,051	E source. 2006
7	Improved Air Conditioner Efficiency	SEER (<65 kBtu/h) EER (≥135 and <240 kBtu/h)	13 SEER 10.8 EER	18 SEER 12.6 EER	each	$1,536	10			$15,360	$12,288	$15,360	$18,432	Kim et al. 2010
8	Improved Furnace Efficiency (from 80% to 90% Et)	Et (%)	80%	90%	each	$988	10			$9,875	$7,900	$9,875	$11,850	Kim et al. 2010
9	Improved Fan Efficiency (from 55% to 65%)	Fan Efficiency (%)	55%	65%	each	$761 $1,249	8 2			$8,586	$6,869	$8,586	$10,303	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
10	Improved SHW Heater Efficiency (from 80% to 95% Et)	Et (%)	80%	95%	each	$4,320	1			$4,320	$3,456	$4,320	$5,184	PexSupply.com. 2011
11	Tankless Gas Water Heater	Tank Heat Loss Pump Electric Power W/Btu/h)	0.74% 0.00381	0.13% 0	each	$1,767	1			$1,767	$1,414	$1,767	$2,120	PexSupply.com. 2011
12	Solar SHW System (64 sq.ft. collector, 80 gal tank)	Solar SHW system	No	64 sq.ft. collector, 80 gal tank	each	$3,600	1			$3,600	$2,880	$3,600	$4,320	Kim et al. 2010
13	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	W/ft^2	1.0	0.9	each	$18.9	325			$6,141	$4,913	$6,141	$7,369	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
14	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	W/ft^3	1.0	0.75	each	$23.3	325			$7,566	$6,052	$7,566	$9,079	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
15	Daylight Dimming Control	Daylight Dimming Controls	No	Yes	each	$1,228	16			$19,653	$15,723	$19,653	$23,584	RSMeans CostWorks ver. 4.7.0 (RCD 2011)
16	Automatic Receptacle Control for Offices	Automatic Receptacle Control	No	Yes	sqft	$0.47			20,000	$9,483	$7,587	$9,483	$11,380	C&S Program 2011
17	40 kW Photovoltaic Array	PV	No	40 kW Photovoltaic Array	$/watt	$6.25	40			$250,000	$200,000	$250,000	$300,000	Kim et al. 2010