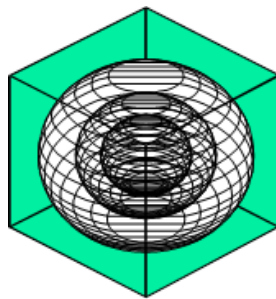


COST-EFFECTIVE ENERGY EFFICIENCY MEASURES FOR ABOVE CODE (ASHRAE 90.1-2001 and 2007) SMALL OFFICE BUILDINGS IN THE CITY OF ARLINGTON

A Research Project for the City of Arlington

**August 25, 2011
(Revised: January 5, 2012)**



ENERGY SYSTEMS LABORATORY

**Texas Engineering Experiment Station
Texas A&M University System**

Background

- ▶ Reviewed two years of building energy compliance reports from 2008 to 2010 for 11 commercial projects in the CoA.
 - ▶ Results of the review: Summary of above-code approaches that have been made in the CoA during the 2008-2010.
- ▶ Results of the current project: 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.

Methodology

- ▶ ESL simulation model based on the DOE-2.1e of ASHRAE 90.1-2001 and 2007 code-compliant, small office building for Tarrant County
- ▶ A total of 17 energy efficiency measures (EEMs)
- ▶ Solar measures using PV-F Chart and F-Chart programs
- ▶ Implementation costs of each measure with simple payback



Methodology

- ▶ 20,000 ft², square-shape, two-story, office building
- ▶ Wood frame construction
- ▶ 20% window-to-wall ratio
- ▶ Packaged rooftop air conditioner (CAV, DX, gas furnace)

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.)	NREL TSD: AEDG-SMO-2011 and CoA	20,000		
Aspect Ratio	NREL TSD: AEDG-SMO-2011	1:1		Square shape
Number of Floors	NREL TSD: AEDG-SMO-2011	2		
Floor-to-Floor Height (ft.)	ASHRAE 90.1-1989 13.7.1	13		Floor-to-Ceiling Height = 9 ft
Orientation	NREL TSD: AEDG-SMO-2011	South facing		
Construction				
Wall Construction	CoA	Wood frame with 2x4 studs spaced at 16" on center		
Roof Configuration	NREL TSD: AEDG-SMO-2011	Flat built-up, Insulation entirely above deck		
Foundation Construction	NREL TSD: AEDG-SMO-2011	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	NREL TSD: AEDG-SMO-2011	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		70 F(Occupied), 5 F setback		
Space Cooling Set point	NREL TSD: AEDG-SMO-2011	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)	NREL TSD: AEDG-SMO-2011	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	NREL TSD: AEDG-SMO-2011	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)	NREL TSD: AEDG-SMO-2011	120 F		



Methodology

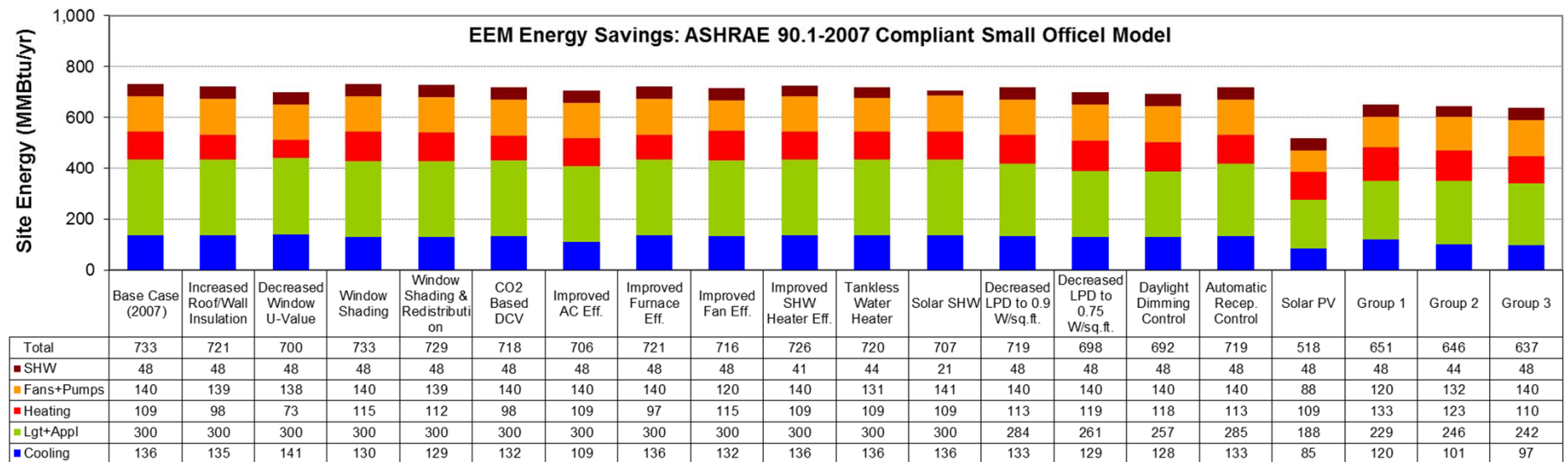
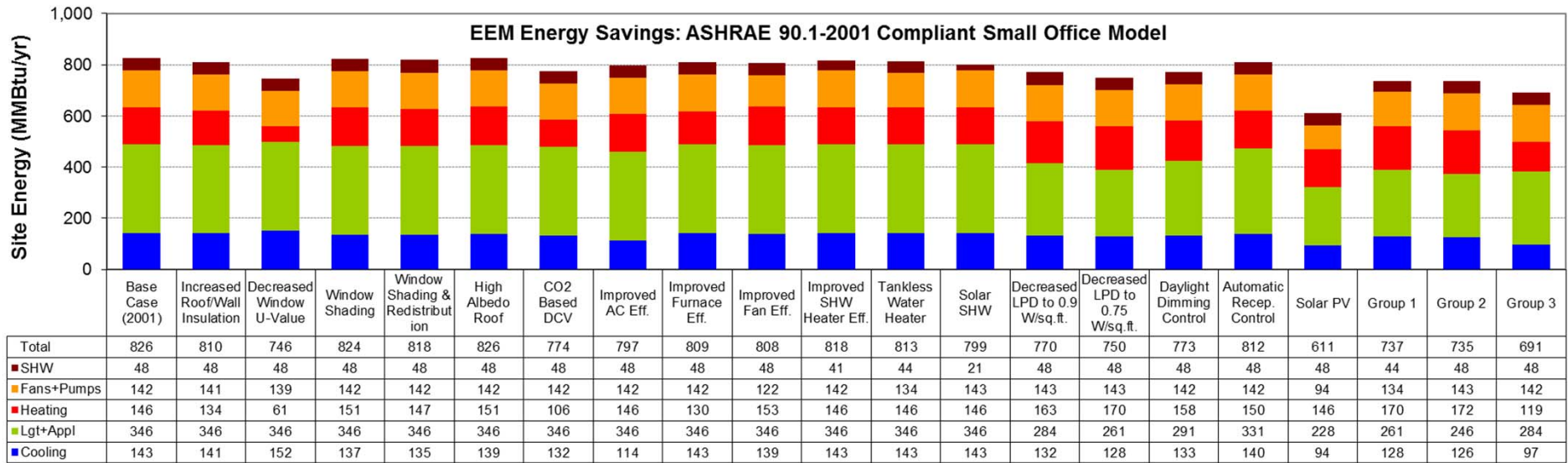
- ▶ 17 EEMs for envelope and fenestration, HVAC System, service hot water (SHW) system, lighting and receptacle, and renewable measures

	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



Energy Savings from EEMs

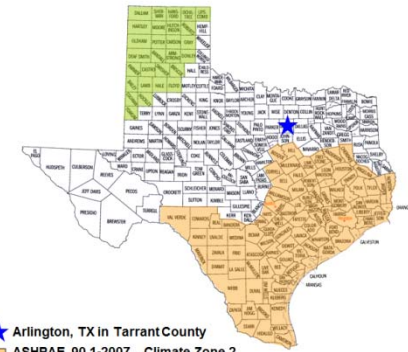
ASHRAE 90.1-2001/2007 Code-Compliant Small Office Building



Proposed Energy Efficiency Measures (EEMs) 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 Dem and Savings (%)	Annual Dem and Savings (\$/year) ³	Combined Savings (Energy+Dem and) (\$/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 FF 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% E)	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% E)	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



- ★ Arlington, TX in Tarrant County
- ASHRAE 90.1-2007 – Climate Zone 2
- ASHRAE 90.1-2007 – Climate Zone 3
- ASHRAE 90.1-2007 – Climate Zone 4

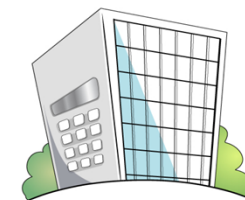
Description of Combined Measures

Combination of Measures ⁶	Combined Annual Energy Savings (%) ¹		Combined Energy Savings (\$/year) ²	Combined Dem and Savings (%)	Combined Dem and Savings (\$/year) ³	Combined Savings (Energy+Dem and) (\$/year)	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NOx Emissions Savings Annual (lbs/yr)	SO ₂ Emissions Savings Annual (lbs/yr)	CO ₂ Emissions Savings Annual (tons/yr)
	Site	Source					Marginal Cost ⁴	New System Cost ⁵				
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:
- Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
 - Savings depend on fuel mix used.
 - * Energy Cost: Electricity = \$0.095/kWh & Demand = \$5.00/kWh
 - Natural gas = \$0.65/therm
 - Yearly demand cost = Sum of monthly demand cost for 12 months
 - Marginal cost = new system cost - original system cost
 - New system cost = new system cost only
 - See individual measures above for specific savings

[ASHRAE 90.1-2001 Code-Compliant Building Description]

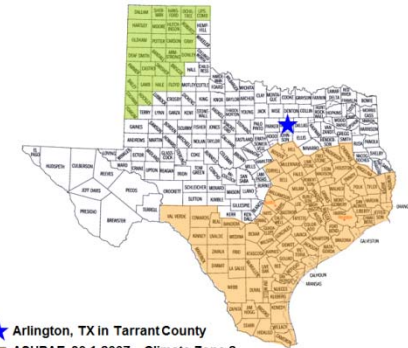
- * Building type: Small Office
- * Gross area: 20,000 sq-ft
- * Building dimension: 100 ft x 100 ft x 13 ft (WxLxH)
- * Number of floors: 2
- * Floor-to-floor height: 13 ft
- * Window-to-wall ratio: 20.0%
- * HVAC system: SEER 13 or EER 10.8 Rooftop PSZ & 80% E Furnace
- * DHW: 80% E Gas Water heater



Proposed Energy Efficiency Measures (EEMs) 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 Dem and Savings (%)	Annual Dem and Savings (\$/year) ³	Combined Savings (Energy+Dem and) (\$/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% E)	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% E)	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%	\$285	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 - \$7,389		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



- ★ Arlington, TX in Tarrant County
- ASHRAE 90.1-2007 – Climate Zone 2
- ASHRAE 90.1-2007 – Climate Zone 3
- ASHRAE 90.1-2007 – Climate Zone 4

Description of Combined Measures

Combination of Measures ⁶	Combined Annual Energy Savings (%) ¹		Combined Energy Savings (\$/year) ²	Combined Dem and Savings (%)	Combined Dem and Savings (\$/year) ³	Combined Savings (Energy+Dem and) (\$/year)	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NOx Emissions Savings Annual (lbs/yr)	SO ₂ Emissions Savings Annual (lbs/yr)	CO ₂ Emissions Savings Annual (tons/yr)
	Site	Source					Marginal Cost ⁴	New System Cost ⁵				
Combination 1												
15 Daylight Dimming Control								\$15,723 - \$23,584				
14 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	11.2%	15.5%	\$2,812	18.6%	\$583	\$3,395	\$6,052 - \$9,079		8.4 - 12.7	47.2	31.0	19.4
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.)							\$6,052 - \$9,079					
7 Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	11.9%	14.9%	\$2,639	18.3%	\$572	\$3,212	\$12,288 - \$18,432		8.5 - 12.8	44.1	28.2	18.4
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								\$15,723 - \$23,584				
14 Improved Air Conditioner Efficiency (from 13 SEER & 10.8 EER to 18 SEER & 12.6 EER)	13.1%	15.3%	\$2,682	20.5%	\$642	\$3,324	\$12,288 - \$18,432		12.9 - 19.4	44.7	28.1	18.9
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:
- Total energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
 - Savings depend on fuel mix used.
 - * Energy Cost: Electricity = \$0.095/kWh & Demand = \$5.00/kW
 - Natural gas = \$0.65/therm
 - Yearly demand cost = Sum of monthly demand cost for 12 months
 - Marginal cost = new system cost - original system cost
 - New system cost = new system cost only
 - 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% E/Furnace
 - * DHW: 80% E/Gas Water heater



Questions?