COST-EFFECTIVE RECOMMENDATIONS FOR 15% ABOVE CODE ENERGY EFFICIENCY MEASURES BASED ON THE ASHRAE 90.1-2007 FOR SMALL OFFICE BUILDINGS IN TEXAS

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ABSTRACT

This paper presents cost-effective recommendations for achieving 15% above-code energy performance, which are based on the ASHRAE Standard 90.1-2007, for commercial small office buildings across the State of Texas. The recommendations were developed for three ASHRAE 90.1-2007 climate zones in Texas along with simple payback calculations. A total of 16 measures were selected, including 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 calculated along with simple payback calculations. These measures were then combined to achieve a total source energy savings for the group that is 15% above the base-case, ASHRAE 90.1-2007 code-compliant building. Three combinations were proposed in each climate zone with the corresponding payback periods and NOx, SOx, and CO_2 emissions savings.

INTRODUCTION

In the 79th Texas Legislature (2005) the Energy Systems Laboratory was required to develop three alternative methods for achieving 15% above-code energy savings in new residential, commercial and industrial construction. The Laboratory continues to work closely with code officials, energy raters, manufacturers, state officials and other stakeholders to develop cost effective energy efficiency measures. This paper presents detailed information about the recommendations for achieving 15% above code-compliant building energy performance, which are based on the ASHRAE Standard 90.1-2007 (ASHRAE 2007), for small office buildings across the State of Texas. The recommendations were developed for three ASHRAE Standard 90.1-2007 climate zones in Texas along with simple payback calculations.

METHODOLOGY

The analysis was performed using the Laboratory's simulation model, which is based on the DOE-2.1e simulation of an ASHRAE Standard 90.1-2007 code-compliant, small office building and the appropriate TMY2 weather files. According to the ASHRAE 90.1-2007 Climate Zone, a representative county was selected in each climate zone: Harris County for Climate Zone 2, Tarrant County for Climate Zone 3, and Potter County for Climate Zone 4 (Figure 1).

To begin, the ASHRAE 90.1-2007 code-compliant, small office base-case models were constructed for each climate zone. A total of 16 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 model. The solar measures including solar PV and solar service hot water (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. Cost information was obtained from various resources, including: Texas manufacturers, local contractors, online suppliers, and R.S.Means costWorks database (RCD 2011).

These measures were then combined to achieve a total source energy savings for the group that is 15% above the base-case ASHRAE 90.1-2007 code-compliant small office building. The results from individual measures and cost analysis were used to guide the selection of measures for this group analysis. Another set of simulations was performed with the selected measures applied in combination. As a result, three combinations were proposed for each base case in each climate zone. 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 US EPA's

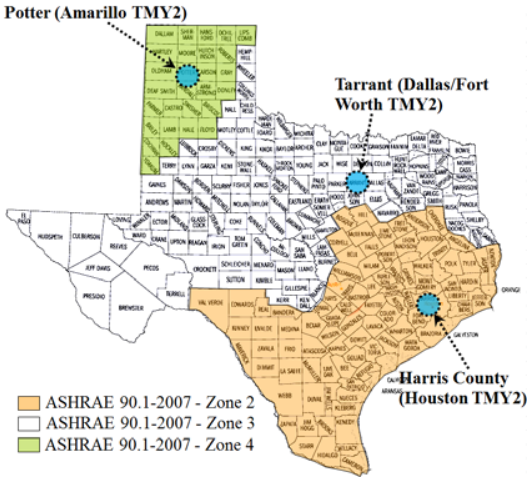


Figure 1: Climate Zones in ASHRAE Standard 90.1-2007 and Three Selected Counties

Emissions and Generation Resource Integrated Database (eGrid) for Texas[1].

Base-Case Building Description

The base-case building simulation model in this analysis is based on the standard design as defined in the ASHRAE Standard 90.1-2007 and certain assumptions. 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 90.1-2007. Table 1 summarizes the base-case, ASHRAE 90.1-2007 code-compliance building characteristics used in the DOE-2 simulation tool in this analysis.

Assumptions for the 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 $0.63/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). Demand charges were from the previous study by Cho et al. (2007). For natural gas rates, the annual average natural gas rates for 2011 were surveyed and averaged for the following five area categories in Texas: San Antonio, Dallas, all cities except Dallas in Mid-TX, Amarillo inside city limit, and Amarillo outside city limit (Atmos Energy 2011).

[1] The emissions savings were calculated using the 2007 eGRID which were specially prepared for Texas by Mr. Art Diem at the US EPA.

ENERGY EFFICIENCY MEASURES (EEMS) AND IMPLEMENTATION COSTS

A total of 16 energy efficiency measures were considered in this analysis. These measures include building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options.

1) Increased Roof and Wall Insulation

This measure was simulated by increasing roof insulation from R-20 to R-25 and by adding R-3.8c.i. wall insulation. It was estimated that this measure would increase the cost by $9,092 - $13,639.

2) Decreased Glazing U-value

In this option, the base-case U-Factor was taken as 0.75 Btu/h-sq.ft.-°F for Climate Zone 2, 0.65 Btu/h-sq.ft.-°F for Climate Zone 3, and 0.55 Btu/h-sq.ft.-°F for Climate Zone 4. For the EEM, a U-Factor of 0.35 Btu/h-sq.ft.-°F was used. The frame type and SHGC remained the same as the base case. In this analysis, it was estimated that improving the U-value of the fenestration system would increase the cost by $10,284 − $15,425 for Climate Zone 2; $7,039 − $10,558 for Climate Zone 3; and by $6,223 − $9,335 for Climate Zone 4.

3) 0.5 PF Window Shading

This measure was simulated by modeling a 2.5 foot window overhang with a projection factor (PF) of 0.5 on south, east and west sides. The gross window area, orientation, and other characteristics were kept the same as the base-case building. It was estimated that this measure would increase the cost by $14,159 − $21,238.

4) 0.5 PF Window Shading and Redistribution

For this measure, the building was simulated with the windows distributed 36% on the south, 20% on the north, 12% each on east and west orientations. A 2.5 foot window overhang was also included on south, east and west sides. Adding a 2.5 foot of window overhang is estimated to increase the cost by $14,159 − $21,238. However, window redistribution in a new construction would have no increased cost.

5) CO_2-Based Demand-Controlled Ventilation (DCV)

This measure analyzed the energy savings that would occur by installing CO_2 sensors for outside air demand control. This measure was simulated by changing the

Table 1: Characteristics of the ASHRAE 90.1-2007 Compliant Base-Case Small Office Model for Harris County (Climate Zone 2), Tarrant County (Climate Zone 3), and Potter County(Climate Zone 4)

Characteristics	ASHRAE 90.1-2007 Code-Compliant Small Office			Information Source
	Harris County (CZ 2A)	Tarrant County (CZ 3A)	Potter County (CZ 4B)	
Building				
Gross Area (sq.ft.)	20,000			PNNL-19341 (Thornton et al. 2010)
Aspect Ratio	1:1			PNNL-19341 (Thornton et al. 2010)
Number of Floors	2			PNNL-19341 (Thornton et al. 2010)
Floor-to-Floor Height (ft.)	13			ASHRAE 90.1-1989 13.7.1
Orientation	South facing			PNNL-19341 (Thornton et al. 2010)
Construction				
Wall Construction	Wood frame with 2x4 studs spaced at 16" on center			CoA small office analysis (Kim et al. 2011)
Roof Configuration	Flat built-up, Insulation entirely above deck			PNNL-19341 (Thornton et al. 2010)
Foundation Construction	6" concrete slab-on-grade floor			PNNL-19341 (Thornton et al. 2010)
Wall Absorptance	0.75			DOE 2.1E BDL SUMMARY, Page 12
Wall Insulation (hr-sq.ft.-°F/Btu)	R-13			ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4
Roof Absorptance	0.3			ASHRAE 90.1-2007 Sec. 5.5.3.1.1
Roof Insulation (hr-sq.ft.-°F/Btu)	R-20 ci			ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4
Slab Perimeter Insulation	None			ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4
U-Factor of Glazing (Btu/hr-sq.ft.-°F)	0.75	0.65	0.55	ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4
Solar Heat Gain Coefficient (SHGC)	0.25		0.40	ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4
Window Area	20% Window to wall ratio			PNNL-19341 (Thornton et al. 2010)
Exterior Shading	None			ASHRAE 90.1-2007 Table 11.3.1 No.5
Space Conditions				
Space Heating Set point	70 F(Occupied), 5 F setback			PNNL-19341 (Thornton et al. 2010)
Space Cooling Set point	75 F(Occupied), 5 F setup			
Lighting Power Density (W/sq.ft.)	1.0			ASHRAE 90.1-2007 Table 9.5.1
Equipment Power Density (W/sq.ft.)	0.75			PNNL-19341 (Thornton et al. 2010)
Mechanical Systems				
HVAC System Type	Packaged rooftop air conditioner (CAV, DX, gas furnace)			ASHRAE 90.1-2007 11.3.2
Air Conditioning System Efficiency	13 SEER (<65,000 Btu/h) 11 EER (≥135,000 Btu/h and <240,000 Btu/h)			FEDERAL MINIMUM EFFICIENCY STANDARDS (effective as of 1/1/2010)
Heating System Efficiency (%)	80% Et			ASHRAE 90.1-2007 Table 6.8.1E
Cooling Capacity (Btu/hr)	Autosized			ASHRAE 90.1-2007 Appendix G
Heating Capacity (Btu/hr)	Autosized			ASHRAE 90.1-2007 Appendix G
Economizer	No		Yes (≥65,000 Btu/h)	ASHRAE 90.1-2007 Table 6.5.1
Ventilation (cfm/sq.ft)	0.08			ASHRAE 62.1-2004
Supply Air Flow (cfm/sq.ft)	1.00			
SHW System Type	Gas-fired storage water heater (75 gallon, 75,100 Btu/hr)			PNNL-19341 (Thornton et al. 2010)
SHW Heater Efficiency (%)	80 % Et (SL=1046.5 Btu/h)			ASHRAE 90.1-2007 Table 7.8
SHW Temperature Setpoint (F)	120 F			PNNL-19341 (Thornton et al. 2010)

fixed ventilation ratio of the base cases[2] to be adjusted for varying occupancy: 5 cfm/person. This measure was estimated to increase the cost by $7,367 − $11,051.

6) Improved AC Efficiency

In this option, the Seasonal Energy Efficiency Ratio (SEER) 13[3] and EER (Energy Efficiency Ratio) 11[4] packaged single zone (PSZ) systems were replaced with a similarly sized SEER 18 and EER 12.6 units, respectively. This measure would increase the cost by $12,288 − $18,432.

7) Improved Heating System Efficiency

This measure was simulated by increasing the heating system thermal efficiency from 80% to 90%. This measure would increase the cost by $7,900 − $11,850.

[2] The base-case building was assumed to have a fixed ventilation ratio of 0.08 cfm/sq.ft. This ratio was calculated using 5 cfm/person and 0.06 cfm/sq.ft, which is based on Sec. 6.2.2.1 of the ASHRAE Standard 62.1-2004 (ASHRAE 2004) with an assumption of 275 sq.ft./person.

[3] for the units smaller than 5.4 ton (65,000 Btu/h).

[4] for the units between 11.3 ton (135,000 Btu/h) and 20.0 ton (240,000 Btu/h).

8) Improved Fan Efficiency

This measure was simulated by increasing the fan efficiency from 55% to 65%. Improving fan efficiency was estimated to increase the cost by $6,869 − $10,303.

9) Improved SHW Heater Efficiency

This measure was simulated by increasing the SHW system thermal efficiency from 80% to 95%. This measure would increase the cost by $3,456 − $5,184.

10) Tankless Gas Water Heater

To simulate this measure, the standby loss (SL)[5] of SHW system decreased from 2.4% to 0.3%, and the circulation pump electricity use was minimized. This measure is expected to increase the cost by $1,414 − $2,120.

11) Solar SHW System

For this measure, one solar thermal SHW system was simulated using the F-Chart program (Klein and Beckman 1983). The modeled SHW system is comprised of two 32 sq.ft. of flat plate solar collectors. The collector tilt was assumed to be the same as the latitude of that location. A constant hot-water use of 73 gallons/day was assumed year around. Any supplementary hot water heating was provided by the base-case water heating system. Additional electricity use was taken into account for operating the pump. This measure would increase the cost by $2,880 − $4,320.

12 & 13) Decreased Lighting Power Density (LPD)

These measures analyzed the energy savings that would occur if base-case lighting was replaced by energy efficient lighting. This measure was simulated by changing a fixed lighting power density (LPD) from 1.0 W/sq.ft. to 0.9 W/sq.ft as required in the ASHRAE Standard 90.1-2010 (ASHRAE 2010) for EEM 12; and to 0.75 W/sq.ft as recommended by the ASHRAE Advanced Energy Design Guide (AEDG) for small to medium office buildings (ASHRAE 2011) for EEM 13. The increased cost would be $4,913 − $7,369 for EEM 12 and $6,052 − $9,079 for EEM 13.

14) Daylight Dimming Controls

For this measure, continuous daylight dimming control systems were simulated. The sensors were assumed to be located 10 ft. from the side windows for the primary daylighted area which is an area closest to the window; and 15 ft. from the side windows for the secondary daylighted area which is an area beyond the primary daylighted area. The increased cost would be $15,723 − $23,584.

15) Automatic Receptacle Control for Offices using Occupancy Sensors

This measure was simulated by modifying the schedule for the plug load equipment based on the Section 8.4.2 of the ASHRAE Standard 90.1-2010[6]. This measure was estimated to increase the cost by $7,587 − $11,380.

16) 40 kW Photovoltaic (PV) array

For this measure, solar PV systems with 16% efficiency that comprise 16% of roof area (3,200 sq.ft.) were simulated using the PV F-Chart program (Klein and Beckman 1994). The PV array tilt was assumed to be the same as the latitude of that location. Installing a 40 kW PV array was estimated to increase the cost by $200,000 − $300,000.

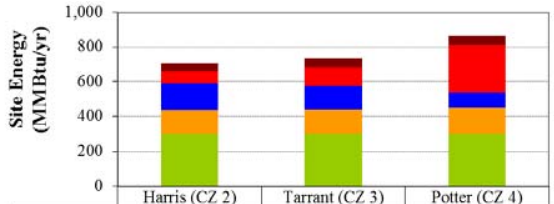
RESULTS FOR INDIVIDUAL MEASURES

Base-Case Energy Use

Figure 2 shows the annual site and source energy consumption of base-case small office buildings for three counties that represent each climate zone such as Harris County for Climate Zone 2, Tarrant County for Climate Zone 3 and Potter County for Climate Zone 4. The base-case total annual site energy consumption was 704 MMBtu/yr (35.2 kBtu/ sq.ft.-yr) for Harris County, 732 MMBtu/yr (36.6 kBtu/ sq.ft.-yr) for Tarrant County, and 865 MMBtu/yr (43.2 kBtu/ sq.ft.-yr) for Potter County. This includes: 1) Harris County: 22% for cooling, 9% for heating, 43% for lighting and equipment, 19% for fans and pumps, and 7% for service water heating; 2) Tarrant County: 18% for cooling, 15% for heating, 41% for lighting and equipment, 19% for fans and pumps, and 7% for service water heating; and 3) Potter County: 10% for cooling, 32% for heating, 35% for lighting and equipment, 17% for fans and pumps, and 6% for service water heating. The annual source energy consumption was then calculated using the multipliers of 3.16 for electricity and 1.1 for natural gas per Section 405.3 of the 2009 IECC (ICC 2009): 1,992 MMBtu/yr (94% for electricity and 6% for natural gas) for Harris County, 1,989 MMBtu/yr (91% for electricity and 9% for natural gas) for Tarrant County, and 2,055 MMBtu/yr (82% for electricity and 18% for natural gas) for Potter County.

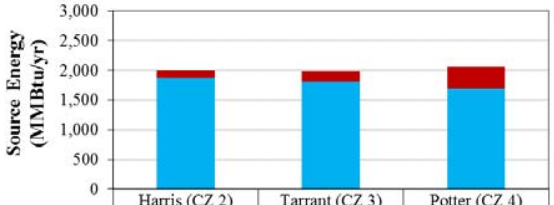
[5] Standby Loss (SL) based on a 70°F temperature difference between stored water and ambient requirements.

[6] About 22% of reduction was assumed in the schedule fraction during occupied hours (Thornton et al. 2011) for the 50% of receptacles in a building.



	Harris (CZ 2)	Tarrant (CZ 3)	Potter (CZ 4)
Total	704	732	865
SHW	47	48	54
Heating	67	109	275
Cooling	154	135	88
Fans+Pumps	137	140	148
Lgt+Appl	300	300	300

(a) Annual Site Energy Consumption



	Harris (CZ 2)	Tarrant (CZ 3)	Potter (CZ 4)
Total	1,992	1,989	2,055
NG	125	173	362
Elec.	1,867	1,816	1,693

(b) Annual Source Energy Consumption

Figure 2: Annual Site and Source Energy Consumption of ASHRAE 90.1-2007 Code-Compliant Small Office Base-Case Models in Texas

This suggests 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 Texas. For Potter County in Climate Zone 4, the measures that reduce the heating energy use would have higher impact on the total energy use compared to Climate Zone 2 and 3. It is also noted that 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.

Energy Savings from Various EEMs

Table 2 summarizes the detailed results of the simulations and cost analysis for three counties that represent each climate zone. Of the sixteen measures, a solar PV had the largest savings, ranging between 23.1% and 36.1% source energy savings across the counties. Daylight dimming control and decreased LPD to 0.75 W/sq.ft. measures also resulted in considerable savings (6.8% to 7.8% source energy savings with daylight dimming control measure; and 5.7% to 7.0% source energy savings with decreased LPD to 0.75 W/sq.ft. measure).

Among the envelope and fenestration measures, a decreased glazing u-value measure showed a relatively high site energy savings (3.5% to 5.9% site energy savings), while the source energy savings became lower (1.0% to 2.6% source energy savings) due to a high savings in natural gas and the increased cooling energy penalty. The savings from the three other envelope and fenestration measures were less than 1.5% for all cases.

Among the HVAC system measures, an improved air conditioner efficiency measure resulted in high source energy savings in Harris and Tarrant Counties: 4.2% and 4.7% source energy savings, respectively. For Potter County in climate Zone 4, the resultant savings were somewhat less at 2.7% source energy savings. An improved fan efficiency measure resulted in good savings across the counties: 3.0% to 3.6% source energy savings.

The savings from SHW measures were small, less than 1.6% of source energy savings because the base-case, end-use consumption of service water heating was only around 2.6% to 2.9% of the total source energy use of the building. The solar SHW system measure was found to be effective only for site energy savings (3.2% to 3.6% site energy savings and 1.2% to 1.4% source energy savings). Finally, an automatic receptacle control measure yielded a source energy savings between 2.3% and 2.7%.

Cost Effectiveness of Various EEMs

The cost savings depend on the fuel type associated with the end use affected by the measure. The measures that reduce electricity use as well as peak demand resulted in significant energy cost savings compared to the measures that reduce only gas use. Thus the solar PV and all three lighting measures that showed a significant reduction in electricity use were very effective in reducing the overall energy cost. The measures that reduce electricity use for cooling and fans and pumps also resulted in high energy cost savings. These measures include improved air conditioner efficiency and improved fan efficiency. An automatic receptacle control measure also showed good cost savings.

To estimate the cost-effectiveness of measures, a simple payback was calculated using the implementation costs obtained from various resources. The cost-effectiveness of a measure depends upon the energy cost savings versus the cost of implementation. The most cost-effective measure was a decreased LPD to 0.75 W/sq.ft. (EEM 13) with the shortest payback periods across the counties: 4.1 to 6.9 years. Tankless gas water heater yielded the second shortest payback periods: 4.9 to 7.6 years, although the energy savings

Table 2: Annual Total Site and Source Energy and Cost Savings from Individual EEMs for Harris County (Climate Zone 2), Tarrant County (Climate Zone 3), and Potter County(Climate Zone 4)

No.	EEM Description	Harris County (Climate Zone 2)					Tarrant County (Climate Zone 3)					Potter County (Climate Zone 4)				
		Energy Savings (%)		Cost Savings ($/year)		Simple Estimated Payback (yrs)	Energy Savings (%)		Cost Savings ($/year)		Simple Estimated Payback (yrs)	Energy Savings (%)		Cost Savings ($/year)		Simple Estimated Payback (yrs)
		Site	Source	Energy	Demand		Site	Source	Energy	Demand		Site	Source	Energy	Demand	
Envelope and Fenestration Measures																
1	Increased Roof/Wall R-Value	1.2%	0.6%	$79	$14	97.0 - 145	1.7%	0.9%	$112	$14	72.1 - 108	2.9%	1.5%	$181	$11	47.3 - 70.9
2	Decreased Glazing U-Value	3.5%	1.0%	$80	$16	107 - 161	4.5%	1.5%	$146	$1	48.0 - 72.0	5.9%	2.6%	$289	-$5	21.9 - 32.8
3	Window Shading	0.8%	1.3%	$231	$38	52.6 - 78.9	0.1%	0.9%	$178	$33	67.2 - 101	-1.1%	0.7%	$195	$60	55.4 - 83.1
4	Window Shading & Redistribution	1.2%	1.5%	$269	$45	45.0 - 67.5	0.6%	1.1%	$216	$38	55.9 - 83.8	-0.4%	1.1%	$244	$70	45.0 - 67.5
HVAC System Measures																
5	CO_2-Based Demand-Controlled Ventilation	2.1%	1.6%	$253	$43	24.9 - 37.3	2.0%	1.2%	$168	$14	40.5 - 60.8	3.2%	1.6%	$202	$9	34.9 - 52.3
6	Improved A/C Efficiency	4.2%	4.7%	$830	$224	11.7 - 17.5	3.6%	4.2%	$729	$205	13.1 - 19.7	2.1%	2.7%	$496	$181	18.2 - 27.3
7	Improved Furnace Efficiency	1.1%	0.4%	$46	$0	170 - 255	1.7%	0.7%	$76	$0	104 - 156	3.5%	1.6%	$191	$0	41.3 - 61.9
8	Improved Fan Efficiency	2.9%	3.6%	$640	$91	9.4 - 14.1	2.4%	3.4%	$615	$93	9.7 - 14.5	1.3%	3.0%	$576	$92	10.3 - 15.4
Service Hot Water Measures																
9	Improved SHW Heater Efficiency	1.1%	0.4%	$46	$0	74.4 - 112	1.0%	0.4%	$48	$0	72.4 - 109	1.0%	0.5%	$53	$0	64.8 - 97.2
10	Tankless Gas Water Heater	1.8%	1.6%	$264	$16	5.0 - 7.6	1.8%	1.6%	$265	$18	5.0 - 7.5	1.6%	1.6%	$273	$17	4.9 - 7.3
11	Solar SHW System	3.3%	1.2%	$127	-$6	23.7 - 35.6	3.6%	1.4%	$145	-$6	20.7 - 31.1	3.2%	1.4%	$151	-$6	19.8 - 29.6
Lighting and Receptacle Measures																
12	Decreased LPD to 0.9 W/sq.ft.	2.3%	2.8%	$501	$96	8.2 - 12.4	1.9%	2.6%	$476	$97	8.6 - 12.9	1.2%	2.3%	$436	$95	9.3 - 13.9
13	Decreased LPD to 0.75 W/sq.ft.	5.7%	7.0%	$1,247	$241	4.1 - 6.1	4.8%	6.6%	$1,196	$243	4.2 - 6.3	3.0%	5.7%	$1,087	$236	4.6 - 6.9
14	Daylihgt Dimming Control	6.5%	7.8%	$1,387	$334	9.1 - 13.7	5.7%	7.5%	$1,342	$325	9.4 - 14.2	4.1%	6.8%	$1,275	$328	9.8 - 14.7
15	Automatic Receptacle Control	2.3%	2.7%	$486	$109	12.7 - 19.1	1.9%	2.6%	$462	$112	13.2 - 19.8	1.3%	2.3%	$429	$108	14.1 - 21.2
Renewable Power Measure																
16	40 kW PV Array	20.6%	23.1%	$4,048	$760	41.6 - 62.4	29.3%	34.1%	$5,979	$800	29.5 - 44.3	27.1%	36.1%	$6,528	$648	27.9 - 41.8

was not significant (1.6% of source energy savings). The other two lighting measures, decreased LPD to 0.9 W/sq.ft. (EEM 12) and daylight dimming control (EEM 14), also yielded relatively short payback periods: 8.2 to 13.9 years for EEM 12 and 9.1 to 14.7 years for EEM 14.

15% ENERGY SAVINGS ABOVE ASHRAE 90.1-2007 CODE-COMPLIANT BUILDING

Grouped measures are the combination of individual measures that have been combined and re-simulated. The measures were combined to achieve a total source energy savings for the group that is 15% above the base-case simulation of ASHRAE Standard 90.1- 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 each climate zone, three combinations were developed. Figure 3 presents the results of analysis for Harris County in Climate Zone 2[7]. In the figure, the upper 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 lower 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

[7] The results for other counties are presented in Kim et al. (2012).

period for each combination, and annual NO_x, SO_2, and CO_2 emission savings.

The groups shown in the table represent several ways of grouping to achieve 15% savings above the base case. The most cost-effective combination (combination 1) has a payback period of: 8.2 to 12.3 years for Harris County in Climate Zone 2; 8.4 to 12.7 years for Tarrant county in Climate Zone 3; 8.7 to 13.0 years for Potter County in Climate Zone 4. On the other hand, a payback period of the least cost-effective combination (combination 3) is: 12.2 to 18.3 years for Harris County in Climate Zone 2; 13.1 to 19.6 years for Tarrant County in Climate Zone 3; and 14.9 to 22.4 years for Potter County in Climate Zone 4.

SUMMARY

This paper presents cost-effective recommendations to maximize energy savings for small office buildings across the State of Texas. A total of sixteen recommendations based on the energy savings above the base-case building were selected. The most cost-effective measure was a decreased LPD to 0.75 W/sq.ft. with the shortest payback periods across the counties: 4.1 to 6.9 years. Tankless gas water heater and the other two lighting measures (i.e., LPD to 0.9 W/sq.ft. and daylight dimming control) also yielded relatively short payback periods. These measures were then combined to achieve the total source energy savings of the group is 15% above the base-case, ASHRAE 90.1-2007 code-compliant small office buildings. The most cost-effective combination has a payback period of: 8.2 to 13.0 years across the three representative climate zones for Texas.

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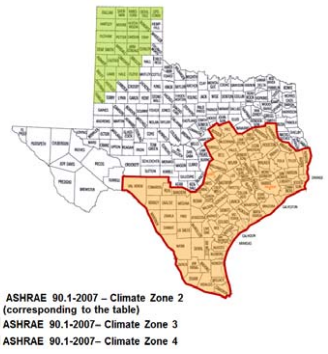
Description of Individual Measures

	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 20 to 25 for roof and 13 to 13+3.8c.i. for walls)	1.2%	0.6%	$79	0.5%	$14	$94	$9,092 - $13,639		97.0 - 145
2	Decreased Glazing U-Value (from 0.75 to 0.35)	3.5%	1.0%	$80	0.5%	$16	$96	$10,284 - $15,425		107 - 161
3	0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W)	0.8%	1.3%	$231	1.2%	$38	$269		$14,159 - $21,238	52.6 - 78.9
4	Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, EW=12% with 2.5 ft. Overhangs for S/E/W)	1.2%	1.5%	$269	1.4%	$45	$315		$14,159 - $21,238	45.0 - 67.5
B	**HVAC System Measures**									
5	CO_2 Based Demand-Controlled Ventilation (DCV)	2.1%	1.6%	$253	1.3%	$43	$296		$7,367 - $11,051	24.9 - 37.3
6	Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER)	4.2%	4.7%	$830	6.9%	$224	$1,053	$12,288 - $18,432		11.7 - 17.5
7	Improved Furnace Efficiency (from 80% to 90% Et)	1.1%	0.4%	$46	0.0%	$0	$46	$7,900 - $11,850		170 - 255
8	Improved Fan Efficiency (from 55% to 65%)	2.9%	3.6%	$640	2.8%	$91	$732	$6,869 - $10,303		9.4 - 14.1
C	**Service Hot Water Measures**									
9	Improved SHW Heater Efficiency (from 80% to 95% Et)	1.1%	0.4%	$46	0.0%	$0	$46	$3,456 - $5,184		74.4 - 112
10	Tankless Gas Water Heater	1.8%	1.6%	$264	0.5%	$16	$280	$1,414 - $2,120		5.0 - 7.6
11	Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank)	3.3%	1.2%	$127	-0.2%	-$6	$121		$2,880 - $4,320	23.7 - 35.6
D	**Lighting and Receptacle Measures**									
12	Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.)	2.3%	2.8%	$501	3.0%	$96	$597	$4,913 - $7,369		8.2 - 12.4
13	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	5.7%	7.0%	$1,247	7.5%	$241	$1,488	$6,052 - $9,079		4.1 - 6.1
14	Daylight Dimming Control	6.5%	7.8%	$1,387	10.4%	$334	$1,721		$15,723 - $23,584	9.1 - 13.7
15	Automatic Receptacle Control for Offices using Occupancy Sensors	2.3%	2.7%	$486	3.4%	$109	$596		$7,587 - $11,380	12.7 - 19.1
E	**Renewable Power Measure**									
16	40 kW Photovoltaic Array	20.6%	23.1%	$4,048	23.6%	$760	$4,808		$200,000 - $300,000	41.6 - 62.4



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	Daylight Dimming Control	13.3%	16.4%	$2,920	18.2%	$586	$3,507		$15,723 - $23,584	8.2 - 12.3	48.8	31.5	20.3
13	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)							$6,052 - $9,079					
8	Improved Fan Efficiency (from 55% to 65%)							$6,869 - $10,303					
	Combination 2												
13	Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.)	13.7%	15.7%	$2,769	17.5%	$564	$3,333	$6,052 - $9,079		8.2 - 12.3	45.4	28.7	19.1
6	Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
15	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
10	Tankless Gas Water Heater							$1,414 - $2,120					
	Combination 3												
14	Daylight Dimming Control	14.6%	16.2%	$2,849	20.6%	$664	$3,512		$15,723 - $23,584	12.2 - 18.3	46.6	29.2	19.7
13	Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER)							$12,288 - $18,432					
15	Automatic Receptacle Control for Offices using Occupancy Sensors								$7,587 - $11,380				
5	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 = $0.63/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%
* HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
* DHW: 80% Et Gas Water heater

Figure 3: Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 2