RECOMMENDATIONS FOR 15% ABOVE-CODE ENERGY-EFFICIENCY MEASURES FOR COMMERCIAL OFFICE BUILDINGS

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ABSTRACT

This paper presents an overview of the recommendations for achieving 15% above code energy performance for commercial office buildings complying with ASHRAE Standard 90.1-1999. To accomplish the 15% annual energy consumption reductions, ten measures were considered. After energy savings were determined for each measure, they were then grouped in several groups to accomplish a minimum of 15% total annual energy consumption reduction.[1]

INTRODUCTION

Efforts to improve energy efficiency in new commercial buildings for hot and humid climates have been reported in several studies. Torcellini et al. (2004) reported an energy cost savings from 44% to 67% for six high-performance buildings when compared to ASHRAE 90.1-2001 specifications. Sylvester et al. (2002) reported a potential of reducing up to 46% in annual energy use for Robert E. Johnson building in Austin, Texas. Another study performed by Parker et al. (1997) presented the energy performance of the new Florida Solar Energy Center building. The optimized building with the implementation of several high performance systems showed an energy reduction of 62% and a cooling capacity decrease of 52% when compared to the energy use of the conventional building characteristics of Florida.

This paper presents an overview of the recommendations for achieving 15% above code energy performance for commercial office buildings complying with ASHRAE Standard 90.1-1999. The analysis was performed for a 6-story office building (89,304 ft^2) in Houston, Texas.[2] To accomplish the 15% annual energy consumption reductions, ten measures were considered, including: improved glazing U-value, decreasing lighting power density, window shading, reducing static pressure, improving chiller coefficient of performance (COP), improving boiler efficiency, cold deck reset, variable speed drives (VSDs) on chilled and hot water pumps, and occupancy sensors for lighting control[3]. After energy savings were determined for each measure, they were then grouped in several groups to accomplish a minimum of 15% total annual energy consumption reduction. Finally a cost analysis was performed and a simple payback calculated.

BASE-CASE BUILDING DESCRIPTION

The base-case building simulation model in this analysis is based on specifications in ASHRAE 90.1 1999. The simulation used the DOE-2 program and the TMY2 hourly weather data for Houston. Electricity costs were \$0.119/kWh, demand charges were \$5.00/kW, and costs for natural gas were \$8.00/MCF. Details of the base-case model are summarized in Table A.1. Additional details regarding the analysis can be found in the accompanying report (Cho et al. 2007).

Building Envelope, Lighting and Fenestration Characteristics

The analysis was performed for a 6-story office building (89,304 ft^2), with a 50% window-to-wall ratio that follows the prescriptive tables in ASHRAE 90.1-1999. Four perimeter zones and a central core zone were modeled for each floor.

Based on climate specific characteristics, the base-case was modeled with a wall insulation of R-13

[1] The analysis in this paper uses the total annual energy consumption of a simulated commercial building to determine the 15% above-code recommendations. The analysis also reports end-use energy use, including: heating, cooling, domestic hot water use, fans, heat rejection, equipment and lighting loads, and miscellaneous loads as defined by the BEPS and BEPU reports from the DOE-2 program. Since the 15% above code savings use annual energy cost savings, these same measures will report greater savings when compared against total heating and cooling loads, which has been used in other above-code programs.

[2] The complete analysis by Cho et al. (2007) includes recommendations for 15% above-code energy performance for all 41 non-attainment and affected counties in Texas.

[3] Selection of measures for this analysis is partly limited to the simulation capabilities of the DOE-2.1e program.

value and a roof insulation of R-15. The U-value of the windows in the base-case building was set at 1.22 Btu/hr °F ft^2.[4] As per ASHRAE 90.1 1999, the SHGC of the base-case building set at 0.44 for the north orientation and 0.17 for the other orientations.[5] Window overhangs or shading was not used. The base-case building was modeled with a lighting power density (LPD) of 1.3 W/ft^2, which is the maximum value for office applications, allowed by ASHRAE 90.1-1999.[6] The electric lighting profile was set to the recommended profile from ASHRAE's Diversity Factor Toolkit (RP-1093), as shown in Figure 1 (Abushakra et al. 2001).

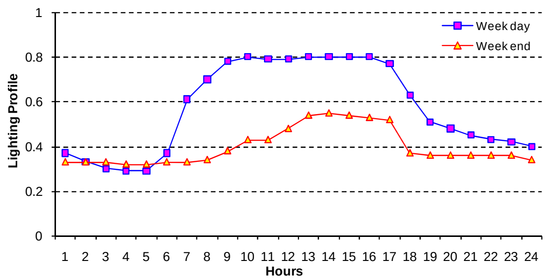


Figure 1: Base-case Lighting Profile for a large commercial building (Abushakra et al. 2001).

HVAC System Characteristics

The base-case building model used a variable air volume (VAV) system with terminal reheat that was set to have a total supply air static pressure of 2.5 inches of water (gauge), and has a constant supply air temperature of 55 °F.

Plant Characteristics

The base-case building has one 160 ton (1.926 MBtu/hr) screw chiller[7] with a COP of 4.9, and a constant speed chilled water pump. Two options for the heating fuel type were considered: a) natural gas (natural gas hot water boiler for space heating, and natural gas water heater for service water heating), and b) electricity (electric resistance hot water boiler for space heating, and electric water heater for service water heating).[8] For the electric/gas building, heating is provided by two 731 kBtu/hr hot water gas boilers[9] with an efficiency of 75%. For the all-electric building, heating was provided by an electric resistance boiler with an efficiency of 100%.

SUMMARY OF ENERGY EFFICIENCY MEASURES

A total of 10 measures were considered to achieve a 15% annual energy consumption reduction when compared to code for the electric/gas and the all-electric buildings. These measures included: improved glazing U-value, decreasing lighting power density, window shading, reducing static pressure, improving chiller COP, improving boiler efficiency, cold deck reset, VSDs on chilled and hot water pumps, and occupancy sensors for lighting control. After costs were determined for each measure, they were then grouped in several groups to accomplish a minimum of 15% total annual energy consumption reduction. A list of all measures is provided in Table 1. A brief description is provided in the following sections. Additional details are provided in the ESL report by Cho et al. (2007).

1) Decreased Glazing U-value (from 1.22 to 0.45).

To improve the glazing performance, the U-value was reduced to 0.45 Btu/hr ft^2 °F[10] from 1.22 Btu/hr ft^2 °F (ASHRAE 2004). The selection of this U-value was chosen to minimize winter-time heat loss using available commercial glazing products. The SHGC of the base-case building remained at 0.44 for the north orientation and 0.17 for the other orientations[11].

Table 1: Energy Efficiency Measures.

	NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM	ELECTRIC RESISTANCE HEATING / ELECTRIC DHW SYSTEM
A	**Envelope and Fenestration Measures**	
1	Improved Window Performance (U-factor = 0.45 Btu/hr-sqft C)	Improved Window Performance (U-factor = 0.45 Btu/hr-sqft C)
2	Improved lighting load (1W/sqft)	Improved lighting load (1W/sqft)
3	Occupancy sensors for lights	Occupancy sensors for lights (Using occupancy schedules)
4	Shading (ft) (From 0 ft to 2.5 ft)	Shading (ft) (From 0 ft to 2.5 ft)
B	**HVAC System Measures**	
5	Cold deck reset (Constant to variable)	Cold deck reset (From 55F to 60:55F; 55:85F)
6	Supply fan total pressure (From 2.5 inW.G. to 1.5 inW.G.)	Supply fan total pressure (From 2.5 inW.G. to 1.5 inW.G.)
C	**Plant Equipment Measures**	
7	Chiller COP (from 4.9 to 6.1)	Chiller COP (from 4.9 to 6.1)
8	Boiler efficiency (75% to 90%)	NA
9	VSD on chiller water loop	VSD on chiller water loop
10	VSD on hot water loop	VSD on hot water loop

2) Energy-Efficient Lighting (Decreasing Lighting Power Density from 1.3 W/ft^2 to 1.0 W/ ft^2)

The impact of energy-efficient lighting was determined by reducing the Lighting Power Density

[4] ASHRAE Standard 90.1-1999, Table B-5(Climate zone for Houston), p.95.
[5] ASHRAE Standard 90.1-1999, Table B-5(Climate zone for Houston), p.95.
[6] ASHRAE Standard 90.1-1999, Table 9.3.1.1, p.51.
[7] As required by ASHRAE 90.1-1999, Table 6.2.1C, p.29, for chiller sizes between 100 tons and 300 tons.
[8] In the remainder of this paper, these buildings will be referred to as (a) electric/gas building, and (b) all-electric building, respectively.
[9] As required by ASHRAE 90.1-1999, Table 6.2.1F, p.31.

[10] From Table for Climate Zone 2 from Advanced Energy Design Guide for Small Office Buildings. Although this guide was developed for small office buildings (i.e. up to 20,000 ft^2), its use in this study was deemed appropriate.
[11] As required by ASHRAE 90.1-1999, Table 5.3, p.24. (Derived from Table B-5, p.95.)

(LPD) from 1.3 W/ ft^2 to 1.0 W/ ft^2. [12] There are a number of lighting systems available to meet the LPD requirements described above. Some of these include changing the fixture type, fixture size, type of lens or louver, and mounting height. However, the cost analysis was simplified by only considering changing the lamp type and ballast type.

3) Window Shading (No Overhangs vs. 2.5 ft Width of Overhangs)

The impact of the addition of window shades was considered by adding window shades to all orientations (except north), using a projection factor of 0.5, as recommended by the ASHRAE Advanced Energy Design Guide for Small Office Buildings (ASHRAE 2004). Since the windows used in the base-case simulation was set to a height of 5 feet, this resulted in shade that projected 2.5 feet, which was attached at the top of the window.

4) Supply Fan Total Pressure (2.5 in W.G. to 1.5 in W.G.)

To improve the HVAC system's performance, the total supply fan static pressure was reduced to 1.5 inches of water (gauge) from the 2.5 inches of water (gauge) which was set for the base-case simulation.[13]

5) Chiller COP (COP 4.9 to COP 6.1)

To improve the performance of the building's chiller the COP was raised to 6.1[14] from 4.9, which was set for the base-case building.

6) Boiler Efficiency (75% to 95%)

The building's heating system efficiency was improved by increasing the natural gas boiler efficiency to 95% (condensing boiler) from 75% (conventional boiler), which was set for the base-case simulation.[15] For the all-electric system, the boiler efficiency was set at 100% for the base-case and hence no changes were made to the boiler efficiency in the all-electric case.

7) Cold Deck Reset (Constant to Variable)

To further improve the performance of the cooling system the cold deck schedule was changed from a constant 55 ºF to a schedule as shown in the graph in Figure 2. This saves cooling energy by maintaining the cold deck air temperature at 60 ºF when outdoor temperature is 55 ºF or lower and maintains the cold deck temperature at 55 ºF when outdoor temperature is 85 ºF or higher.[16] The cold deck temperature decreases linearly from 60 ºF to 55 ºF as the outdoor temperature increases from 55 ºF to 85 ºF.

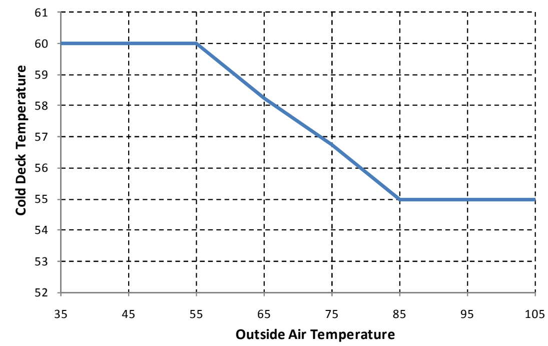


Figure 2: Cold Deck Temperature Schedule.

8) VSD on Chilled Water Pump

To improve the performance of the cooling system, variable speed drives were included for the chilled water pumps.

9) VSD on Hot Water Pump

To improve the performance of the heating system, variable speed drives were included for the hot water pumps.

10) Installation of Occupancy Sensors for Lighting

Finally, to improve the performance of the lighting systems occupancy sensors that control the general lighting were included in the simulation. In order to simulate the impact, the electric lighting profiles were modified using the occupancy schedules published in ASHRAE 90.1-1989 (Table 13-3, p.104). These modified lighting schedules were then used to represent the implementation of occupancy sensors (Figure 3).

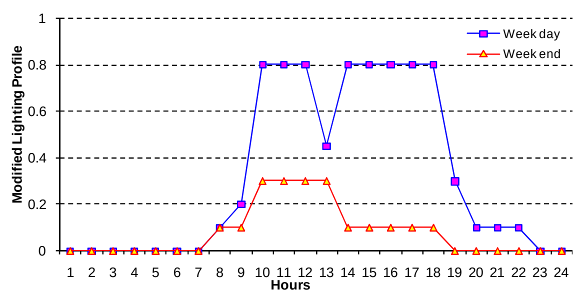


Figure 3: Modified Lighting Profile (ASHRAE Standard 90.1-1989).

[12] Recommended level in ASHRAE 90.1-2004 for general office space.

[13] The 1.5 inches of water (gauge) was a recommendation by the Laboratory's Continuous Commissioning ® (CC®) group (registered trademarks of the Texas A&M University System). This can be accomplished by: a larger sized ductwork, using low static filters and other such measures which reduce frictional losses in ducts. This pressure difference can also be achieved by slowing down the speed of the fans with no added first costs, assuming the indoor air quality conditions are met.

[14] To find currently available high COP screw chillers, a literature review was performed. The EE/RE website of DOE has a guide 'How to buy an energy-efficient water-cooled electric chiller'(www1.eere.energy.gov/femp/pdfs/wc_chillers.pdf, p.1).

[15] The 95% efficiency was based on communications with Mr. Jeff Leep at Rheem Corporation.

[16] This cold deck schedule was implemented based on settings revealed by a survey of the buildings at the Texas A&M campus that had received Continuous Commissioning ® (CC®).

Table 2: Specifications for an Electric/Gas Building.

EEM #	Energy Efficiency Measures	Glazing U-factor (Btu/hr-sqft-F)	Lighting Load (W/sqft)	Occupancy Sensors for Lights	Shading (ft)	Cold Deck Reset (F)	Supply Fan Total Pressure (in W.G.)	Chiller COP	Boiler Efficiency (%)	VSD on Chilled Water Loop	VSD on Hot Water Loop
	BaseCase	1.22	1.3	None	None	55	2.5	4.9	Efficiency	Constant Speed	Lighting Schedule
Envelope and fenestration measures											
1	Glazing U-factor (Btu/hr-sqft-F)	**0.45**	1.3	None	None	55	2.5	4.9	75	Constant Speed	Constant Speed
2	Lighting Load (W/sqft)	1.22	**1**	None	None	55	2.5	4.9	75	Constant Speed	Constant Speed
3	Occupancy Sensors for Lights	1.22	1.3	**Lit. Sch. = Occ. Sch.**	None	55	2.5	4.9	75	Constant Speed	Constant Speed
4	Shading (ft)	1.22	1.3	None	**2.5**	55	2.5	4.9	75	Constant Speed	Constant Speed
HVAC System Measures											
5	Cold Deck Reset (F)	1.22	1.3	None	None	**(60:55,55:85)**	2.5	4.9	75	Constant Speed	Constant Speed
6	Supply Fan Total Pressure (in W.G.)	1.22	1.3	None	None	55	**1.5**	4.9	75	Constant Speed	Constant Speed
Plant Equipment Measures											
7	Chiller COP	1.22	1.3	None	None	55	2.5	**6.1**	75	Constant Speed	Constant Speed
8	Boiler Efficiency (%)	1.22	1.3	None	None	55	2.5	4.9	**95**	Constant Speed	Constant Speed
9	VSD on Chilled Water Loop	1.22	1.3	None	None	55	2.5	4.9	75	**Variable Speed**	Constant Speed
10	VSD on Hot Water Loop	1.22	1.3	None	None	55	2.5	4.9	75	Constant Speed	**Variable Speed**

Table 3: Specifications for an All-Electric building.

EEM #	Energy Efficiency Measures	Glazing U-factor (Btu/hr-sqft-F)	Lighting Load (W/sqft)	Occupancy Sensors for Lights	Shading (ft)	Cold Deck Reset (F)	Supply Fan Total Pressure (in W.G.)	Chiller COP	Boiler Efficiency (%)	VSD on Chilled Water Loop	VSD on Hot Water Loop
	BaseCase	1.22	1.3	None	None	55	2.5	4.9	100	Constant Speed	Lighting Schedule
Envelope and fenestration measures											
1	Glazing U-factor (Btu/hr-sqft-F)	**0.45**	1.3	None	None	55	2.5	4.9	100	Constant Speed	Constant Speed
2	Lighting Load (W/sqft)	1.22	**1**	None	None	55	2.5	4.9	100	Constant Speed	Constant Speed
3	Occupancy Sensors for Lights	1.22	1.3	**Lit. Sch. = Occ. Sch.**	None	55	2.5	4.9	100	Constant Speed	Constant Speed
4	Shading (ft)	1.22	1.3	None	**2.5**	55	2.5	4.9	100	Constant Speed	Constant Speed
HVAC System Measures											
5	Cold Deck Reset (F)	1.22	1.3	None	None	**(60:55,55:85)**	2.5	4.9	100	Constant Speed	Constant Speed
6	Supply Fan Total Pressure (in W.G.)	1.22	1.3	None	None	55	**1.5**	4.9	100	Constant Speed	Constant Speed
Plant Equipment Measures											
7	Chiller COP	1.22	1.3	None	None	55	2.5	**6.1**	100	Constant Speed	Constant Speed
8	Boiler Efficiency (%)	1.22	1.3	None	None	55	2.5	4.9	100	Constant Speed	Constant Speed
9	VSD on Chilled Water Loop	1.22	1.3	None	None	55	2.5	4.9	100	**Variable Speed**	Constant Speed
10	VSD on Hot Water Loop	1.22	1.3	None	None	55	2.5	4.9	100	Constant Speed	**Variable Speed**

SIMULATION INPUT

Tables 2 and 3 list the inputs for simulating the energy efficiency measures in a representative office building located in Houston, Texas for an electric/gas building (Table 2) and an all-electric building (Table 3). Both systems had an electric chiller with a VAV air-handling unit. In the first row of each of the tables the values used for base-case are presented. The subsequent rows present information used in each of the individual energy efficiency measures. The shaded boxes in each row indicate changes in input values of the measures being simulated.

RESULTS

Tables 4 and 5 summarize the annual energy use, energy costs,[17] savings (both energy and dollars), implementation costs, and the calculated simple payback periods for the energy efficiency measures simulated for both the electric/gas building (Table 4), and the all-electric building (Table 5), for a building in Houston, Texas. In order to calculate the 15% above-code annual energy cost savings, the simulated electric and/or natural gas use was converted into total annual energy costs.[18]

Figures 4 through 9 graphically present the results of the simulations and cost analysis. Figure 4 and Figure 5 present the impact of energy efficiency measures on different energy uses; Figure 6a and Figure 6b present the first cost and the energy cost savings for different measures; Figure 7a and Figure 7b show the corresponding payback period in years; Figure 8 and Figure 9 present the 15% above code savings charts[19] for an electric/gas building and an all-electric building,[20] respectively.

[17] The energy use shown was obtained from DOE-2's BEPS and BEPU report.

[18] This is required when simulating a code-compliant building that follows ASHRAE Standard 90.1-1999. For this analysis, costs of $.119/kWh, $5/kW and $.80/therm were used.

[19] Based on the code-specified base-case building characteristics and the weather data for Houston, Texas, these charts are applicable to Brazoria, Fort Bend, Galveston, Harris and Montgomery counties. Cho et al. (2007) includes similar charts for other non-attainment and affected counties.

[20] The energy use shown was obtained from DOE-2's BEPS report.

Table 4: Summary of Annual Energy use, Energy Costs, Savings, Implementation Costs, and Payback Periods for Houston, Texas (Electric/Gas).

EEM #	Energy Efficiency Measures	Energy Use (MBtu/yr)					Energy Use (Utility Units)			Energy Savings					Increased First Year Cost ($)	Payback
		Cooling	Heating	DHW	Other	Total	kWh/yr	therms/yr	$/yr	MBtu/yr	%	kWh/yr	therms/yr	$/yr		(yrs)
Envelope and Fenestration Measures																
Basecase		1,126	590	43	3,899	5,658	1,472,338	6,325	$196,566							
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	1,125	68	43	3,815	5,051	1,447,640	1,106	$188,935	606	10.7%	24,698	5,219	$7,631	$95,130 - $174,150	12.5 - 22.8
2	Lighting Load (1.3 to 1.0 w/sq-ft)	1,064	702	43	3,460	5,268	1,325,451	7,447	$178,289	389	6.9%	146,887	-1,122	$18,277	$0 - $0	0.0 - 0.0
3	Occupancy Sensors Installation	976	879	43	3,024	4,922	1,172,190	9,211	$163,534	736	13.0%	300,148	-2,886	$33,032	$26,500 - $28,000	0.8 - 0.8
4	Shading (none to 2.5 ft overhangs)	1,058	590	43	3,859	5,549	1,440,495	6,331	$192,343	108	1.9%	31,843	-6	$4,223	$67,900 $110,000	16.1 - 26.0
HVAC System Measures																
Basecase		1,126	590	43	3,899	5,658	1,472,338	6,325	$196,566							
5	Cold Deck Reset	1,053	384	43	3,905	5,385	1,452,735	4,269	$192,679	273	4.8%	19,603	2,056	$3,887	$0 - $800	0.0 - 0.2
6	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1,109	591	43	3,841	5,583	1,450,195	6,333	$193,608	75	1.3%	22,143	-8	$2,958	$0 - $200	0.0 - 0.1
Plant Equipment Measures																
Basecase		1,126	590	43	3,899	5,658	1,472,338	6,325	$196,566							
7	Chiller COP (4.9 to 6.1)	905	590	43	3,899	5,436	1,407,487	6,325	$187,848	221	3.9%	64,851	0	$8,718	$16,000 - $18,000	1.8 - 2.1
8	Boiler Efficiency	1,126	466	43	3,899	5,533	1,472,338	5,084	$195,573	124	2.2%	-64,851	1,241	$993	$25,000 - $35,000	25.2 - 35.3
9	VSD on Chilled Water Pump (from Constant to VSD)	1,061	590	43	3,828	5,521	1,432,301	6,325	$191,681	137	2.4%	40,037	0	$4,885	$3,700 - $4,700	0.8 - 1.0
10	VSD on Hot Water Pump (from Constant to VSD)	1,126	444	43	3,868	5,481	1,463,265	4,871	$194,260	176	3.1%	9,073	1,454	$2,306	$4,000 - $5,000	1.7 - 2.2

Table 5: Summary of Annual Energy use, Energy Costs, Savings, Implementation Costs, and Payback Periods for Houston, Texas (All-Electric).

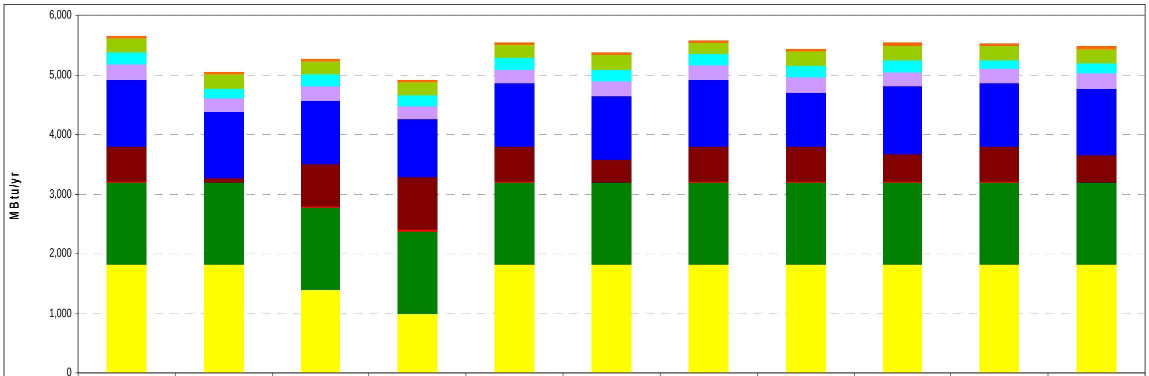
EEM #	Energy Efficiency Measures	Energy Use (MBtu/yr)					Energy Use (Utility Units)			Energy Savings					Increased First Year Cost ($)	Payback
		Cooling	Heating	DHW	Other	Total	kWh/yr	therms /yr	$/yr	MBtu/yr	%	kWh/yr	therms /yr	$/yr		(yrs)
Envelope and Fenestration Measures																
Basecase		1,126	513	36	3,879	5,554	1,627,216	0	$214,554							
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	1,125	87	36	3,812	5,061	1,482,815	0	$192,644	493	8.9%	144,401	0	$21,910	$95,130 - $174,150	4.3 - 7.9
2	Lighting Load (1.3 to 1.0 w/sq-ft)	1,064	594	36	3,436	5,130	1,503,067	0	$199,237	424	7.6%	124,149	0	$15,317	$0 - $0	0.0 - 0.0
3	Occupancy Sensors Installation	976	727	36	2,995	4,735	1,387,338	0	$187,476	819	14.7%	239,878	0	$27,078	$26,500 $0 $28,000	1.0 - 1.0
4	Shading (none to 2.5 ft overhangs)	1,058	511	36	3,838	5,443	1,594,868	0	$210,233	110	2.0%	32,348	0	$4,321	$67,900 $110,000	15.7 - 25.5
HVAC System Measures																
Basecase		1,126	513	36	3,879	5,554	1,627,216	0	$214,554							
5	Cold Deck Reset	1,053	0	36	4,252	5,341	1,564,931	0	$205,898	213	3.8%	62,285	0	$8,656	$0 - $800	0.0 - 0.1
6	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1,109	0	36	4,334	5,479	1,605,230	0	$211,638	75	1.4%	21,986	0	$2,916	$0 - $200	0.0 - 0.1
Plant Equipment Measures																
Basecase		1,126	513	36	3,879	5,554	1,627,216	0	$214,554							
7	Chiller COP (4.9 to 6.1)	905	0	36	4,392	5,332	1,562,366	0	$206,072	221	4.0%	64,850	0	$8,482	$16,000 - $18,000	1.8 - 2.1
8	Boiler Efficiency (Not Aplicable)	1,126	0	36	4,372	5,533	1,627,216	0	$214,554	0	0.0%	0	0	$0	NA - NA	0.0 - 0.0
9	VSD on Chilled Water Pump (from Constant to VSD)	1,061	0	36	4,320	5,417	1,587,179	0	$209,582	137	2.5%	40,037	0	$4,972	$3,700 - $4,700	0.7 - 0.9
10	VSD on Hot Water Pump (from Constant to VSD)	1,126	0	36	4,283	5,445	1,595,389	0	$210,594	109	2.0%	31,827	0	$3,960	$4,000 - $5,000	1.7 - 2.2

Base-case energy use

The total annual energy consumption for the base-case building in Houston, Texas, was 5,658 MBtu for the electric/gas building, and 5,554 MBtu for the all-electric building.

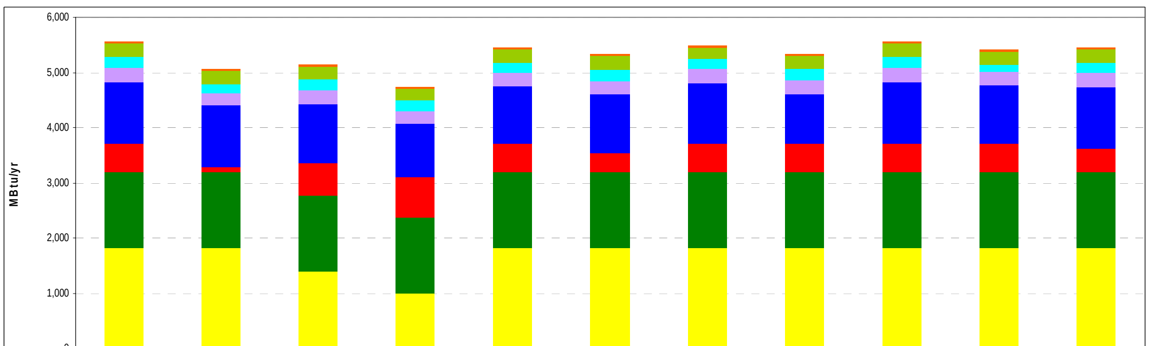
Energy Use and Cost Savings from Individual Measures

For both building types, the implementation of occupancy sensors for lighting and improved glazing U-factors had the greatest individual impact on the total annual energy consumption of the building. The implementation of occupancy sensors in the electric/gas building yields an annual energy consumption savings of 736 MBtu (13%). This same measure in the all-electric building yields a saving of 819 MBtu (14.7%). Surprisingly, the implementation of shading strategies and reduction of the supply fan static pressure resulted in comparatively small annual savings. For the electric/gas building, the implementation of shading strategies yields an annual energy saving of 108 MBtu (1.9%). This same measure in the all-electric building yields a saving of 110 MBtu (2%).



	New Baseline (L&E Schedule from RP-1093)	Glazing U-factor (Btu/hr-sqft-F)	Lighting Load (W/sqft)	Occupancy Sensors for Lights	Shading (ft)	Cold Deck Reset (F)	Supply Fan Total Pressure (in W.G.)	Chiller COP	Boiler Efficiency (%)	VSD on Chilled Water Loop	VSD on Hot Water Loop
Total	5,658	5,051	5,268	4,922	5,549	5,385	5,583	5,436	5,533	5,521	5,481
DHW	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.7
Fans	239	238	221	211	225	257	187	239	239	239	239
Misc.	201	157	200	189	191	195	199	201	201	130	178
HtRj.	250	229	245	219	234	251	246	250	250	250	250
Cooling	1,126	1,125	1,064	976	1,058	1,053	1,109	905	1,126	1,061	1,126
Heating-NG	589.9	67.9	702.1	878.5	590.4	384.2	590.6	589.9	465.8	589.9	444.4
Heating-Elec.	20.5	3.2	23.8	28.9	20.4	13.6	20.6	20.5	20.5	20.5	13.4
Equip.	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377
Lighting	1,811	1,811	1,393	999	1,811	1,811	1,811	1,811	1,811	1,811	1,811

Figure 4: Energy Use for Individual Energy Efficiency measures (Electric/Gas) for Houston, Texas.



	Baseline	Glazing U-factor (Btu/hr-sqft-F)	Lighting Load (W/sqft)	Occupancy Sensors for Lights	Shading (ft)	Cold Deck Reset (F)	Supply Fan Total Pressure (in W.G.)	Chiller COP	Boiler Efficiency (%)	VSD on Chilled Water Loop	VSD on Hot Water Loop
Total	5,554	5,061	5,130	4,735	5,443	5,341	5,479	5,332	5,554	5,417	5,445
DHW	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1
Fans	239	238	221	211	225	257	187	239	239	239	239
Misc.	201	157	200	189	191	195	199	201	201	130	178
HtRj.	250	229	245	219	234	251	246	250	250	250	250
Cooling	1,126	1,125	1,064	976	1,058	1,053	1,109	905	1,126	1,061	1,126
Heating-NG											
Heating-Elec.	513.1	87.2	593.9	727.1	511.2	360.5	513.6	513.1	513.1	513.1	428.3
Equip.	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377	1,377
Lighting	1,811	1,811	1,393	999	1,811	1,811	1,811	1,811	1,811	1,811	1,811

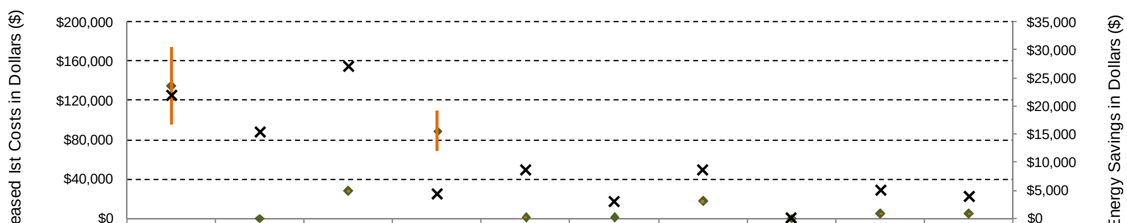
Figure 5: Energy Use for Individual Energy Efficiency measures (All-Electric) for Houston, Texas

<u>First Costs, Energy savings and Payback Periods for the Selected Energy Efficiency Measures</u>

Figure 6a (electric/gas) and Figure 6b (all-electric) show the increased costs and annual energy cost savings from the energy efficiency measures for lowered energy consumption for the different measures adopted. For example, in an electric/gas building with an improved glazing U-factor, the estimated first costs increased by $134,640 and saved $7,631, which represents a payback period of 12 years. In contrast, installing occupancy sensors cost $27,250, which saved $33,031, for a simple payback of less than one year. For both system types, four measures had very favorable paybacks of less than four years. These include: occupancy sensors, improved chiller COP, and VSDs on the hot and chilled water pumps. Figure 7a (electric/gas) and Figure 7b (all-electric) present the payback period in years for each of the measures implemented. Shading strategies did not perform well for both building types. The average first costs of installing shading strategies were $88,000 for both the building types. However, the energy savings obtained from implementing these strategies was $4,233 for the electric/gas building and $4,321 for the all-electric building. The resulting average payback periods were 21years for both the building types.

	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	Lighting Load (1.3 to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 ft overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency (Not Aplicable)	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min 1st costs	$95,130	$0	$26,500	$67,900	$0	$0	$16,000	$25,000	$3,700	$4,000
Max 1st costs	$174,150	$0	$28,000	$110,000	$800	$200	$18,000	$35,000	$4,700	$5,000
◆Av. 1st costs	$134,640	$0	$27,250	$88,950	$400	$100	$17,000	$30,000	$4,200	$4,500
×Energy Savings	$7,631	$18,277	$33,032	$4,223	$3,887	$2,958	$8,718	$993	$4,885	$2,306

Figure 6a: Increased First Costs and Energy Savings for the Selected Measures (Electric/Gas).

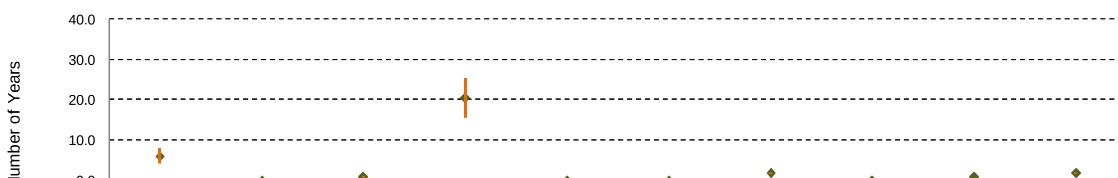


	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	Lighting Load (1.3 to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 ft overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency (Not Aplicable)	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min 1st costs	$95,130	$0	$26,500	$67,900	$0	$0	$16,000	$0	$3,700	$4,000
Max 1st costs	$174,150	$0	$28,000	$110,000	$800	$200	$18,000	$0	$4,700	$5,000
◆Av. 1st costs	$134,640	$0	$27,250	$88,950	$400	$100	$17,000	$0	$4,200	$4,500
×Energy Savings	$21,910	$15,317	$27,078	$4,321	$8,656	$2,916	$8,482	$0	$4,972	$3,960

Figure 6b: Increased First Costs and Energy Savings for the Selected Measures (All-Electric).

	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	Lighting Load (1.3 to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 ft overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min Years	12.5	0.0	0.8	16.1	0.0	0.0	1.8	25.2	0.8	1.7
Max Years	22.8	0.0	0.8	26.0	0.2	0.1	2.1	35.3	1.0	2.2
◆Av. Years	18	0	1	21	0	0	2	30	1	2

Figure 7a: Payback Periods for the Selected Measures (Electric/Gas).



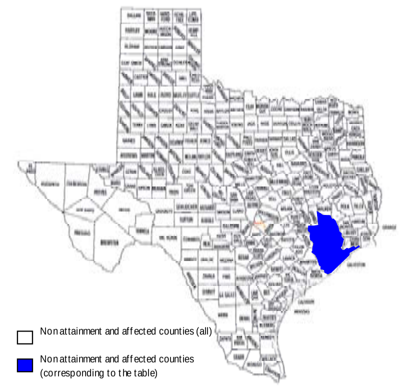
	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	Lighting Load (1.3 to 1.0 w/sq-ft)	Occupancy Sensors Installation	Shading (none to 2.5 ft overhangs)	Cold Deck Reset	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	Chiller COP (4.9 to 6.1)	Boiler Efficiency (Not Aplicable)	VSD on Chilled Water Pump (from Constant to VSD)	VSD on Hot Water Pump (from Constant to VSD)
Min Years	4.3	0.0	1.0	15.7	0.0	0.0	1.8	0.0	0.7	1.7
Max Years	7.9	0.0	1.0	25.5	0.1	0.1	2.1	0.0	0.9	2.2
◆Av Years	6	0	1	21	0	0	2	0	1	2

Figure 7b: Payback Periods for the Selected Measures (All-Electric).

Natural Gas Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)	Annual Energy Savings ($/year)	Annual Demand Savings (%)	Annual Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($)	
							Marginal Cost[1]	New System Cost[2]
A	Envelope and Fenestration Measures							
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	10.7%	$7,114	3.2%	$517	$7,631	$95,130 - $174,150	
2	Lighting Load (1.3 to 1.0 w/sq-ft)	6.9%	$16,582	10.4%	$1,695	$18,277	$0 - $0	
3	Occupancy Sensors Installation	13.0%	$33,409	-2.3%	-$377	$33,032		$26,500 - $28,000
4	Shading (none to 2.5 ft overhangs)	1.9%	$3,785	2.7%	$438	$4,223		$67,900 - $110,000
B	HVAC System Measures							
5	Cold Deck Reset	4.8%	$3,978	-0.6%	-$91	$3,887	$0 - $800	
6	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1.3%	$2,629	2.0%	$329	$2,958	$0 - $200	
C	Plant Equipment Measures							
7	Chiller COP (4.9 to 6.1)	3.9%	$7,717	6.1%	$1,000	$8,718	$16,000 - $18,000	
8	Boiler Efficiency (75% to 95%)	2.2%	$993	0.0%	$0	$993	$25,000 - $35,000	
9	VSD on Chilled Water Pump (from Constant to VSD)	2.4%	$4,764	0.7%	$121	$4,885	$3,700 - $4,700	
10	VSD on Hot Water Pump (from Constant to VSD)	3.1%	$2,243	0.4%	$63	$2,306	$4,000 - $5,000	



Description of Combined Measures to Achieve 15% Above Code Savings

	Combination of Measures[3]	Combined Energy Savings (%)	Combined Energy Savings ($/year)	Combined Demand Savings (%)	Combined Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($)		Combined Annual NOx Emissions Savings (lbs/year)	Combined Ozone Season Period NOx Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
							Marginal Cost[1]	New System Cost[2]			
	Combination 1										
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	20.1%	$26,160	13.6%	$2,214	$28,374	$95,130 - $174,150		258	0.95	3.6 - 6.7
2	Lighting Load (1.3 to 1.0 w/sq-ft)						$0 - $0				
	Combination 2										
3	Occupancy Sensors Installation	19.6%	$38,856	-3.4%	-$558	$38,299		$26,500 - $28,000	371	1.37	0.7 - 0.7
5	Cold Deck Reset						$0 - $800				
	Combination 3										
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	16.8%	$18,719	9.5%	$1,554	$20,273	$95,130 - $174,150		187	0.71	7.5 12.4
7	Chiller COP (4.9 to 6.1)						$16,000 - $18,000				
8	Boiler Efficiency (75% to 95%)						$25,000 - $35,000				
9	VSD on Chilled Water Pump (from Constant to VSD)						$3,700 - $4,700				

Note:
1. Marginal cost = new system cost - original system cost
2. New system cost = new system cost only
3. See individual measures above for specific savings
   * Energy Cost: Electricity cost = $0.119/kWh
   Demand cost = $5.00/kW
   (Yearly demand cost = Sum of monthly demand cost for 12 months
   Natural gas cost = $0.80/therm

(Building Description)
Building type: Office
Gross area: 89,340 sq-ft
Building dimension: 122ft x 122ft x 78ft (WxLxH)
Number of floors: 6
Floor-to-floor height: 13ft
Window-to-wall ratio: 50%

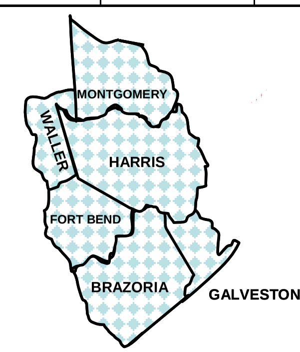


Table 5a: 15% Above Code Savings (Commercial – Natural Gas Heating) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties

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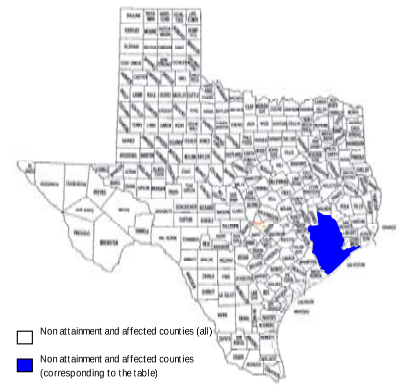
Figure 8: 15% Above-Code Savings (Commercial – Electric/Gas) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties.

Electric Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)

Description of Individual Measures

	Individual Measures	Annual Energy Savings (%)	Annual Energy Savings ($/year)	Annual Demand Savings (%)	Annual Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Estimated Cost ($) Marginal Cost[1]	Estimated Cost ($) New System Cost[2]
A	**Envelope and Fenestration Measures**							
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	8.9%	$17,184	22.6%	$4,726	$21,910	$95,130 - $174,150	
2	Lighting Load (1.3 to 1.0 w/sq-ft)	7.6%	$14,774	2.6%	$543	$15,317	$0 - $0	
3	Occupancy Sensors Installation	14.7%	$28,545	-7.0%	-$1,468	$27,078		$26,500 - $28,000
4	Shading (none to 2.5 ft overhangs)	2.0%	$3,849	2.3%	$471	$4,321		$67,900 - $110,000
B	**HVAC System Measures**							
5	Cold Deck Reset	3.8%	$7,412	5.9%	$1,244	$8,656	$0 - $800	
6	Supply Fan Total Pressure (2.5 to 1.5 in-H2O)	1.4%	$2,616	1.4%	$299	$2,916	$0 - $200	
C	**Plant Equipment Measures**							
7	Chiller COP (4.9 to 6.1)	4.0%	$7,717	3.7%	$765	$8,482	$16,000 - $18,000	
8	Boiler Efficiency (Not Aplicable)	n/a	n/a	n/a	n/a	n/a	n/a - n/a	
9	VSD on Chilled Water Pump (from Constant to VSD)	2.5%	$4,764	1.0%	$208	$4,972	$3,700 - $4,700	
10	VSD on Hot Water Pump (from Constant to VSD)	2.0%	$3,787	0.8%	$172	$3,960	$4,000 - $5,000	



Description of Combined Measures to Achieve 15% Above Code Savings

	Combination of Measures[3]	Combined Energy Savings (%)	Combined Energy Savings ($/year)	Combined Demand Savings (%)	Combined Demand Savings ($/year)	Combined Savings (Energy+Demand) ($/year)	Combined Estimated Cost ($) Marginal Cost[1]	Combined Estimated Cost ($) New System Cost[2]	Combined Annual NOx Emissions Savings (lbs/year)	Combined Ozone Season Period NOx Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
	Combination 1										
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	18.5%	$35,763	29.8%	$6,237	$42,000	$95,130 - $174,150		341	1.08	2.7 - 4.9
2	Lighting Load (1.3 to 1.0 w/sq-ft)						$0 - $0				
	Combination 2										
3	Occupancy Sensors Installation	19.8%	$38,343	0.0%	$5	$38,348		$26,500 - $28,000	366	1.36	0.7 - 0.8
5	Cold Deck Reset						$0 - $800				
	Combination 3										
1	Glazing U Factor (1.22 to 0.45 Btu/hr-sf-F)	15.5%	$30,066	27.7%	$5,793	$35,859	$95,130 - $174,150		287	0.90	4.0 - 6.7
7	Chiller COP (4.9 to 6.1)						$16,000 - $18,000				
9	VSD on Chilled Water Pump (from Constant to VSD)						$3,700 - $4,700				
10	VSD on Hot Water Pump (from Constant to VSD)						$4,000 - $5,000				

Note:
1. Marginal cost = new system cost - original system cost
2. New system cost = new system cost only
3. See individual measures above for specific savings
 * Energy Cost: Electricity cost = $0.119/kWh
 Demand cost = $5.00/kW
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 Natural gas cost = $0.80/therm

(Building Description)
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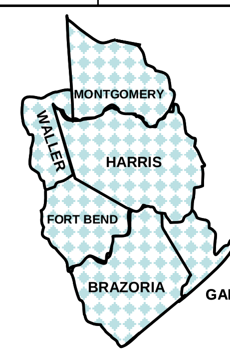

Table 5b: 15% Above Code Savings (Commercial – Electric Heating) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties

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Figure 9: 15% Above-Code Savings (Commercial – All-Electric) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties.

<u>Figures Containing 15% above Code Savings Charts</u>

Figures 8 and 9 present the 15% above-code saving charts for an electric/gas building (Figure 8), and an all-electric building (Figure 9). These charts represent the final summary presentation of the detailed information previously shown in Tables 1 to 5 and Figures 4 to 7. In Figures 8 and 9, the results are presented for Houston, Texas, which are also applicable for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller counties. Similar results for other non-attainment[21] counties in Texas can be found on the Laboratory's Senate Bill 5 website (eslsb5.tamu.edu).

In these figures, the upper table summarizes the results for individual measures in terms of annual energy savings (% and dollars/year), annual demand savings (% and dollars/year), combined savings (energy and demand in dollars/year) and the estimated costs for each measure.[22] The second table in each figure summarizes the results obtained by implementing combinations of measures. Results are presented in terms of combined energy savings (% and dollars/year), combined demand savings (% and dollars/year), combined savings (energy + demand in dollars/year), combined implementation costs (marginal and new system costs) and simple payback periods (years). NOx emissions reductions for each of the combinations are also presented in terms of annual NOx emission savings (lbs/year) and savings during the ozone season period (lbs/day).[23] The maps of all the non-attainment and near non-attainment counties and specific counties for each page are included in the upper and lower figures.

For the case of an electric/gas building, combining the measures of a glazing U-value of 0.45 Btu/hr-ft^2-°F and lighting load of 1 W/ft^2 in combination 1yields a combined energy saving of 20%. Combining the measures of installing occupancy sensors and cold deck reset in combination 2 yields a combined energy saving of 19.6%. Combination 3 consisting of implementing a low glazing U-value of 0.45 Btu/hr-ft^2-°F, a chiller COP of 6.1, a boiler efficiency of 95% and a VSD on the chilled water pump yields a combined energy saving of 16.8%.

For the case of an all-electric building, combining the measures of a glazing U-value of 0.45 Btu/hr-ft^2-°F and lighting load of 1 W/ft^2 in combination 1 yields a combined energy saving of 18.5%. Combining the measures of installing occupancy sensors and cold deck reset in combination 2 yields a combined energy saving of 19.8%. Combination 3 consisting of implementing a low glazing U-value of 0.45 Btu/hr-ft^2-°F, a chiller COP of 6.1 and VSDs on the chilled water pump and hot water pump yields a combined energy saving of 15.5%.

SUMMARY

This paper presented an overview of the recommendations for achieving 15% above-code energy performance for commercial office buildings complying with ASHRAE Standard 90.1-1999. In the paper an analysis was performed for an 89,304 ft^2, 6-story office building in Houston, Texas, with 50% window-to-wall ratio. To accomplish the 15% annual energy consumption reductions, ten measures were considered, including: improved glazing U-value, decreasing lighting power density, window shading, reducing static pressure, improving chiller COP, improving boiler efficiency, cold deck reset, VSDs on chilled and hot water pumps, and occupancy sensors for lighting control. After savings were determined for each measure, they were then grouped into several groups to accomplish a 15% total annual energy consumption reduction. The 15% above code energy performance accounted for the energy use of the building. If only the HVAC and lighting energy consumption were considered, the range of savings from implementing these measures would increase up to 20-30%.

For Houston, reducing lighting loads and implementing occupancy sensors were the most effective individual measures for both electric/gas and all-electric buildings. The strategy which combined lowering the glazing U factor and lighting loads proved to be most effective for the electric/gas building with savings of up to 20%. For the all-electric building the combination of implementing occupancy sensors and cold deck reset proved to be most effective with savings up to 20%. It is to be noted that the energy cost savings and cost-effectiveness for individual and combined measures were not of the same order as the energy use savings, since these depend on the fuel type used, demand savings, and the first cost vs. energy cost savings.

[21] The Clean Air Act and Amendments of 1990 define a "nonattainment area" as a locality where air pollution levels persistently exceed National Ambient Air Quality Standards, or that contributes to ambient air quality in a nearby area that fails to meet standards(http://www.scorecard.org/env-releases/def/cap_naa.html).

[22] The costs for measures are presented as marginal costs and new systems costs, where marginal costs represent the incremental costs to implement the measure by modifying an existing system. New system costs represent costs for newly installed measures.

[23] The Ozone Season Period (OSP) represents average daily savings during the hottest period of the year from mid-July to mid-September as defined by the U.S.E.P.A.

ACKNOWLEDGEMENTS

Funding for this work was provided by the Texas State Legislature, as part of the Laboratory's SB5 effort. This work would not have been possible without the help from numerous individuals from several Texas state agencies, including: Steve Anderson (TCEQ), Alfred Reyes (TCEQ), Art Diem (US EPA), Julie Rosenberg (US EPA), Jay Zarnikau (Frontier and Associates), Theresa Gross (PUC), Jess Totten (PUC), Glenn Jennings (SECO), Warren Lasher (ERCOT), Dan Woodfin (ERCOT), and David Hitchcock (HARC).

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APPENDIX

Table A.1 Base-case Summary.

CHARACTERISTIC	BASECASE ASSUMPTIONS	SOURCES
Building		
Building type	Office	
Gross area (sq-ft)	89,304	Prototypical office building size and number of floors (Huang & Franconi, 1999, p.31)
Dimension (ft x ft)	122 x 122	
Number of floors	6	
Floor to floor height (ft)	13	ASHRAE 90.1-1989-13.7.1 (p.105)
Construction		
Roof absorptance	0.7	ASHRAE 90.1-1999-11.4.2(b) (p.58)
Roof insulation R-value (hr-sq.ft-F/Btu)	15	ASHRAE 90.1-1999, Table B-5 (11.4.2(a)), (p.95)
Wall absorptance	0.7	ASHRAE 90.1-1989-13.7.3.3 (p.106)
Wall insulation R-value (hr-sq.ft-F/Btu)	13	ASHRAE 90.1-1999, Table B-5 (11.4.2(a)), (p.95)
Ground reflectance	0.2	ASHRAE 90.1-1989-13.7.3.3 (p.106)
U-Factor of glazing (Btu/hr-sq.ft-F)	1.22	ASHRAE 90.1-1999, Table B-5 (11.4.2(c)), (p.95)
Solar Heat Gain Coefficient (SHGC)	0.17	ASHRAE 90.1-1999, Table B-5 (11.4.2(c)), (p.95)
Window-to-wall ratio (%)	50	Average WWR of new construction (Huang & Franconi, 1999, p.31[1])
Space		
Area per person (ft^2/person) for office	275 (325 occupants)	ASHRAE 90.1-1989, Table 13-2, (p.103)
Occupancy schedule	8am-10pm (Monday - Saturday)	ASHRAE 90.1-1989, Table 13-3, (p.104)
Space temperature setpoint	70F Heating / 75F Cooling	ASHRAE 90.1-1989-13.7.6.2 (p.110)
Lighting load (W/ft2) for Office	1.3	ASHRAE 90.1-1999, Table 9.3.1.1, (p.51)
Lighting schedule	24 hours (Monday - Saturday)	Abushakra et al., 2001, (ASHRAE RP-1093, p.61)
Equipment load (W/ft2) for office	0.75	ASHRAE 90.1-1989, Table 13-4, (p.106)
Equipment schedule	24 hours (Monday - Saturday)	Abushakra et al., 2001, (ASHRAE RP-1093, p.62)
HVAC Systems		
HVAC system type	VAV with terminal reheat	ASHRAE 90.1-1999, Table 11.4.3A, (p.59, System2)
Number of HVAC units	5	Serving 5 thermal zones
Supply motor efficiency (%)	90	Kavanaugh, 2003 (p.38)
Supply fan efficiency (%)	61	ASHRAE 90.1-1989, Table 13-6, (p.108, System #5)
Supply fan total pressure (in W.G)	2.5	Info. by ESL CC engineers
Plant Equipment		
Chiller type	Screw	ASHRAE 90.1-1999, Table 6.2.1C, (p.29)
Chiller COP	4.9	ASHRAE 90.1-1999, Table 6.2.1C, (p.29)
Boiler type	Hot water boiler	ASHRAE 90.1-1999, Table 11.4.3A, (p.59, System2)
Boiler fuel type	Natural gas	ASHRAE 90.1-1999, Table 11.4.3A, (p.59, System2)
Boiler thermal efficiency (%)	75	ASHRAE 90.1-1999, Table 6.2.1F, (p.31)
DHW fuel type	Natural gas	ASHRAE 90.1-1999, Table 7.2.2, (p.47)
DHW heater thermal efficiency (%)	80	ASHRAE 90.1-1999, Table 7.2.2, (p.47)