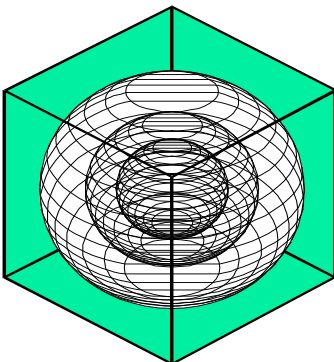


**RECOMMENDATIONS FOR 15% ABOVE ASHRAE 90.1-2007
CODE-COMPLIANT BUILDING ENERGY EFFICIENCY MEASURES
FOR SMALL OFFICE BUILDINGS**

**A Project for
Texas' Senate Bill 5 Legislation
For Reducing Pollution in
Nonattainment and Affected Areas**

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ENERGY SYSTEMS LABORATORY

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

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EXECUTIVE SUMMARY

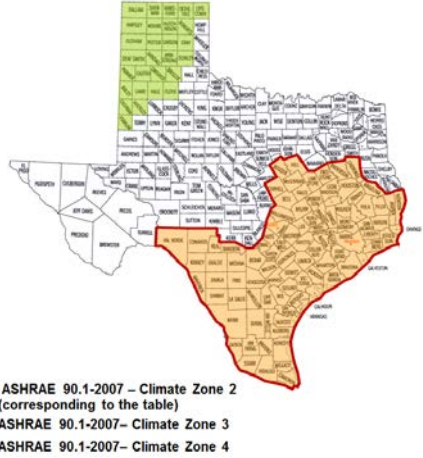
In the 79th Legislature (2005) the Energy Systems Laboratory was required to develop three alternative methods for achieving 15% above-code energy savings in new residential, commercial and industrial construction. The Laboratory continues to work closely with code officials, energy raters, manufacturers, state officials and other stakeholders to develop cost effective energy efficiency measures. This report 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, 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.

The analysis was performed using an ESL simulation model based on the DOE-2.1e simulation of a ASHRAE Standard 90.1-2007 code-compliant, small office building and the appropriate TMY2 weather files. According to the ASHRAE Standard 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. The ASHRAE 90.1-2007 code-compliant, small office base-case models were then constructed for each climate zone.

A total of 16 recommendations based on the energy savings above the base-case building were selected. These measures include building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. The implementation costs of each individual measure were also calculated along with simple payback calculations. 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 building. As a result, three example combinations were proposed for each climate zone. Each combination was formed to have a different payback period. Figures 1 to 3 present a description of the individual measures and combinations of these measures which achieve 15% source energy savings above the ASHRAE 90.1-2007 code-compliant building. Annual energy savings, estimated costs, simple payback, and NO_x, SO₂, and CO₂ emissions reduction are provided.

Description of Individual Measures

| Individual Measures | Annual Energy Savings (%) | | 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%, E/W=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 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 13.3% | 16.4% | \$2,920 | 18.2% | \$586 | \$3,507 | \$6,052 - \$9,079 | | 8.2 - 12.3 | 48.8 | 31.5 | 20.3 |
| 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.) | | | | | | | \$6,052 - \$9,079 | | | | | |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 13.7% | 15.7% | \$2,769 | 17.5% | \$564 | \$3,333 | \$12,288 - \$18,432 | | 8.2 - 12.3 | 45.4 | 28.7 | 19.1 |
| 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 | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 14.6% | 16.2% | \$2,849 | 20.6% | \$664 | \$3,512 | \$12,288 - \$18,432 | | 12.2 - 18.3 | 46.6 | 29.2 | 19.7 |
| 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 | | | | | |

- Notes:
- 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 = \$0.63/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%
 - * HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
 - * DHW: 80% Et Gas Water heater

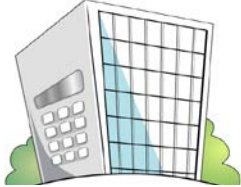
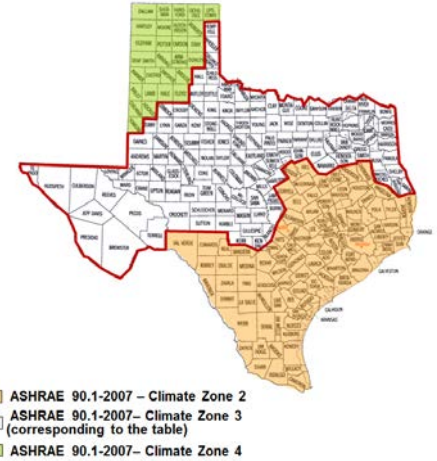


Figure 1. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 2

Description of Individual Measures

| Individual Measures | Annual Energy Savings (%) | | 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) | 1.7% | 0.9% | \$112 | 0.4% | \$14 | \$126 | \$9,092 - \$13,639 | | 72.1 - 108 |
| 2 Decreased Glazing U-Value (from 0.65 to 0.35) | 4.5% | 1.5% | \$146 | 0.0% | \$1 | \$147 | \$7,039 - \$10,558 | | 48.0 - 72.0 |
| 3 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 0.1% | 0.9% | \$178 | 1.1% | \$33 | \$211 | | \$14,159 - \$21,238 | 67.2 - 101 |
| 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% | 1.1% | \$216 | 1.2% | \$38 | \$253 | | \$14,159 - \$21,238 | 55.9 - 83.8 |
| B HVAC System Measures | | | | | | | | | |
| 5 CO ₂ Based Demand-Controlled Ventilation (DCV) | 2.0% | 1.2% | \$168 | 0.4% | \$14 | \$182 | | \$7,367 - \$11,051 | 40.5 - 60.8 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 3.6% | 4.2% | \$729 | 6.6% | \$205 | \$934 | \$12,288 - \$18,432 | | 13.1 - 19.7 |
| 7 Improved Furnace Efficiency (from 80% to 90% Et) | 1.7% | 0.7% | \$76 | 0.0% | \$0 | \$76 | \$7,900 - \$11,850 | | 104 - 156 |
| 8 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 | | | | | | | | | |
| 9 Improved SHW Heater Efficiency (from 80% to 95% Et) | 1.0% | 0.4% | \$48 | 0.0% | \$0 | \$48 | \$3,456 - \$5,184 | | 72.4 - 109 |
| 10 Tankless Gas Water Heater | 1.8% | 1.6% | \$265 | 0.6% | \$18 | \$282 | \$1,414 - \$2,120 | | 5.0 - 7.5 |
| 11 Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 3.6% | 1.4% | \$145 | -0.2% | -\$6 | \$139 | | \$2,880 - \$4,320 | 20.7 - 31.1 |
| 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.) | 1.9% | 2.6% | \$476 | 3.1% | \$97 | \$573 | \$4,913 - \$7,369 | | 8.6 - 12.9 |
| 13 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 |
| 14 Daylight Dimming Control | 5.7% | 7.5% | \$1,342 | 10.4% | \$325 | \$1,666 | | \$15,723 - \$23,584 | 9.4 - 14.2 |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | 1.9% | 2.6% | \$462 | 3.6% | \$112 | \$574 | | \$7,587 - \$11,380 | 13.2 - 19.8 |
| E Renewable Power Measure | | | | | | | | | |
| 16 40 kW Photovoltaic Array | 29.3% | 34.1% | \$5,979 | 25.6% | \$800 | \$6,779 | | \$200,000 - \$300,000 | 29.5 - 44.3 |



Description of Combined Measures

| Combination of Measures ⁶ | Combined Annual Energy Savings (%) ¹ | | Combined Energy Savings (\$/year) ² | Combined Demand Savings (%) | Combined Demand Savings (\$/year) ³ | Combined Savings (Energy+Demand) (\$/year) | Combined Estimated Cost (\$) | | Simple Estimated Payback (yrs) | NOx Emissions Savings 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 11.2% | 15.6% | \$2,810 | 18.6% | \$582 | \$3,392 | \$6,052 - \$9,079 | | 8.4 - 12.7 | 47.1 | 31.0 | 19.4 |
| 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.) | | | | | | | \$6,052 - \$9,079 | | | | | |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 12.2% | 16.3% | \$2,932 | 20.3% | \$635 | \$3,567 | \$12,288 - \$18,432 | | 9.2 - 13.8 | 49.1 | 32.0 | 20.3 |
| 8 Improved Fan Efficiency (from 55% to 65%) | | | | | | | \$6,869 - \$10,303 | | | | | |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | | | | | | | | \$7,587 - \$11,380 | | | | |
| Combination 3 | | | | | | | | | | | | |
| 14 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 13.0% | 15.1% | \$2,654 | 20.3% | \$633 | \$3,287 | \$12,288 - \$18,432 | | 13.1 - 19.6 | 44.2 | 27.8 | 18.6 |
| 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:
- 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 = \$0.63/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%
 - * HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
 - * DHW: 80% Et Gas Water heater

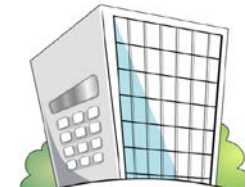
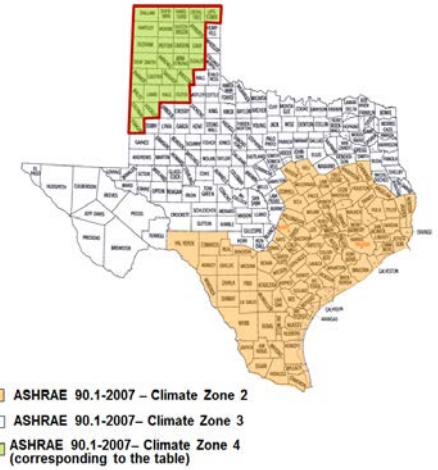


Figure 2. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 3

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) | 2.9% | 1.5% | \$181 | 0.4% | \$11 | \$192 | \$9,092 - \$13,639 | | 47.3 - 70.9 |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | 5.9% | 2.6% | \$289 | -0.2% | -\$5 | \$285 | \$6,223 - \$9,335 | | 21.9 - 32.8 |
| 3 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/EW) | -1.1% | 0.7% | \$195 | 2.0% | \$60 | \$255 | | \$14,159 - \$21,238 | 55.4 - 83.1 |
| 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/EW) | -0.4% | 1.1% | \$244 | 2.4% | \$70 | \$314 | | \$14,159 - \$21,238 | 45.0 - 67.5 |
| B HVAC System Measures | | | | | | | | | |
| 5 CO ₂ Based Demand-Controlled Ventilation (DCV) | 3.2% | 1.6% | \$202 | 0.3% | \$9 | \$211 | | \$7,367 - \$11,051 | 34.9 - 52.3 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 2.1% | 2.7% | \$496 | 6.1% | \$181 | \$676 | \$12,288 - \$18,432 | | 18.2 - 27.3 |
| 7 Improved Furnace Efficiency (from 80% to 90% Et) | 3.5% | 1.6% | \$191 | 0.0% | \$0 | \$191 | \$7,900 - \$11,850 | | 41.3 - 61.9 |
| 8 Improved Fan Efficiency (from 55% to 65%) | 1.3% | 3.0% | \$576 | 3.1% | \$92 | \$668 | \$6,869 - \$10,303 | | 10.3 - 15.4 |
| C Service Hot Water Measures | | | | | | | | | |
| 9 Improved SHW Heater Efficiency (from 80% to 95% Et) | 1.0% | 0.5% | \$53 | 0.0% | \$0 | \$53 | \$3,456 - \$5,184 | | 64.8 - 97.2 |
| 10 Tankless Gas Water Heater | 1.6% | 1.6% | \$273 | 0.6% | \$17 | \$290 | \$1,414 - \$2,120 | | 4.9 - 7.3 |
| 11 Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 3.2% | 1.4% | \$151 | -0.2% | -\$6 | \$146 | | \$2,880 - \$4,320 | 19.8 - 29.6 |
| 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.) | 1.2% | 2.3% | \$436 | 3.2% | \$95 | \$531 | \$4,913 - \$7,369 | | 9.3 - 13.9 |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 3.0% | 5.7% | \$1,087 | 8.0% | \$236 | \$1,324 | \$6,052 - \$9,079 | | 4.6 - 6.9 |
| 14 Daylight Dimming Control | 4.1% | 6.8% | \$1,275 | 11.1% | \$328 | \$1,603 | \$15,723 - \$23,584 | | 9.8 - 14.7 |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | 1.3% | 2.3% | \$429 | 3.6% | \$108 | \$537 | \$7,587 - \$11,380 | | 14.1 - 21.2 |
| E Renewable Power Measure | | | | | | | | | |
| 16 40 kW Photovoltaic Array | 27.1% | 36.1% | \$6,528 | 21.8% | \$648 | \$7,176 | \$200,000 - \$300,000 | | 27.9 - 41.8 |



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 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 8.8% | 15.2% | \$2,878 | 20.1% | \$582 | \$3,460 | | \$6,052 - \$9,079 | 8.7 - 13.0 | 48.4 | 32.5 | 19.7 |
| 8 Improved Fan Efficiency (from 55% to 65%) | | | | | | | | \$6,869 - \$10,303 | | | | |
| 10 Tankless Gas Water Heater | | | | | | | | \$1,414 - \$2,120 | | | | |
| Combination 2 | | | | | | | | | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 14.0% | 15.0% | \$2,580 | 17.9% | \$635 | \$3,215 | | \$6,052 - \$9,079 | 10.4 - 15.7 | 42.5 | 24.6 | 18.7 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | | | | | | | | \$12,288 - \$18,432 | | | | |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | | | | | | | | \$6,223 - \$9,335 | | | | |
| 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 | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 16.4% | 15.9% | \$2,666 | 20.1% | \$633 | \$3,299 | | \$12,288 - \$18,432 | 14.9 - 22.4 | 43.7 | 24.0 | 19.6 |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | | | | | | | | \$6,223 - \$9,335 | | | | |
| 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:
- 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 = \$0.63/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%
 - * HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
 - * DHW: 80% Et Gas Water heater

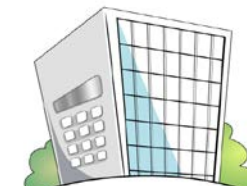


Figure 3. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 4

TABLE OF CONTENTS

1 INTRODUCTION..... 1
 1.1 Organization of the Report..... 1
 2 METHODOLOGY..... 2
 2.1 Overview 2
 2.2 Base-Case Building Description 4
 2.3 Assumptions for Cost Analysis..... 4
 3 PROPOSED ENERGY EFFICIENCY MEASURES FOR SMALL OFFICE BUILDINGS..... 6
 3.1 Individual EEMs 6
 3.2 Simulation Input for Individual EEMs..... 6
 4 RESULTS 10
 4.1 Results of Simulation and Cost Analysis..... 10
 4.1.1 Base-Case Energy Use 10
 4.1.2 Energy Savings from Various Individual EEMs..... 11
 4.1.3 Cost Effectiveness of Various Individual EEMs 13
 4.2 Combined EEMs: 15% Source Energy Savings Above ASHRAE 90.1-2007 Code-Compliant Building..... 14
 5 SUMMARY 24
 REFERENCES 25
 APPENDIX A..... 27

LIST OF TABLES

Table 1. Base-Case Building Description..... 5

Table 2. Energy Efficiency Measures..... 6

Table 3. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)..... 7

Table 4. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)..... 8

Table 5. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)..... 9

Table 6. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)..... 15

Table 7. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)..... 16

Table 8. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)..... 17

Table A-1. Summary of the Cost Information for an ASHRAE 90.1-2007 Code-Compliant Base Case .. 27

Table A-2. Cost Information for Envelope and Fenestration Measures..... 28

Table A-3. Cost Information for HVAC System Measures..... 31

Table A-4 Cost Information for Service Hot Water Measures..... 35

Table A-5. Cost Information for Lighting and Receptacle Measures..... 37

Table A-6. Cost Information for Renewable Power Measure 40

LIST OF FIGURES

| | |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| Figure 1. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 2..... | iii |
| Figure 2. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 3..... | iv |
| Figure 3. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 4..... | v |
| Figure 4. Climate Zones in ASHRAE Standard 90.1-2004/2007 and Three Selected Counties..... | 3 |
| Figure 5. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2) | 18 |
| Figure 6. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3) | 18 |
| Figure 7. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)..... | 19 |
| Figure 8. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2) | 19 |
| Figure 9. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3) | 20 |
| Figure 10. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4) | 20 |
| Figure 11. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 2..... | 21 |
| Figure 12. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 3..... | 22 |
| Figure 13. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 4..... | 23 |

1 INTRODUCTION

This report 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, for small office buildings across the State of Texas. To estimate savings (%) above the ASHRAE 90.1-2007 code-compliant building from energy efficiency measures, total source energy savings from heating, cooling, lighting, equipment, and DHW were considered. The recommendations were developed for three ASHRAE 90.1-2007 climate zones in Texas along with simple payback calculations¹. This information is useful to builders, utility demand side energy managers, building owners and others who wish to construct small office buildings that exceed the minimum national energy code requirements. The analysis was performed using an ESL simulation model based on the DOE-2.1e simulation of a ASHRAE 90.1-2007 code-compliant, small office building and the appropriate TMY2 weather files.

1.1 Organization of the Report

The report is organized in the following order:

- Section 1 presents the introduction and purpose of the report.
- Section 2 presents the methodology that was used.
- Section 3 gives a brief description of 16 individual energy efficiency measures and simulation input.
- Section 4 provides the results of simulation and cost analysis, including savings from individual measures along with the simple payback calculations and group measures to achieve 15% above the base-case ASHRAE Standard 90.1-2007 code-compliant building.
- Section 5 is a summary which is followed by references.

¹ 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.

2 METHODOLOGY

This section describes the methodology and assumptions that were used in this analysis to develop the cost-effective recommendations for achieving energy performance better than ASHRAE 90.1-2007 code-compliant building for small offices across the State of Texas. Section 2.1 presents an overall approach used in this analysis. Section 2.2 describes the base-case building characteristics. Section 2.3 presents assumptions used in cost analysis.

2.1 Overview

The analysis was performed using an ESL simulation model based on the DOE-2.1e simulation of a ASHRAE 90.1-2007 code-compliant, small office building and the appropriate TMY2 weather files. According to the ASHRAE Standard 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 4). 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 DHW 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. 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 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 example 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 (NO_x, SO₂, and CO₂) of each combination were calculated based on the eGrid for Texas.

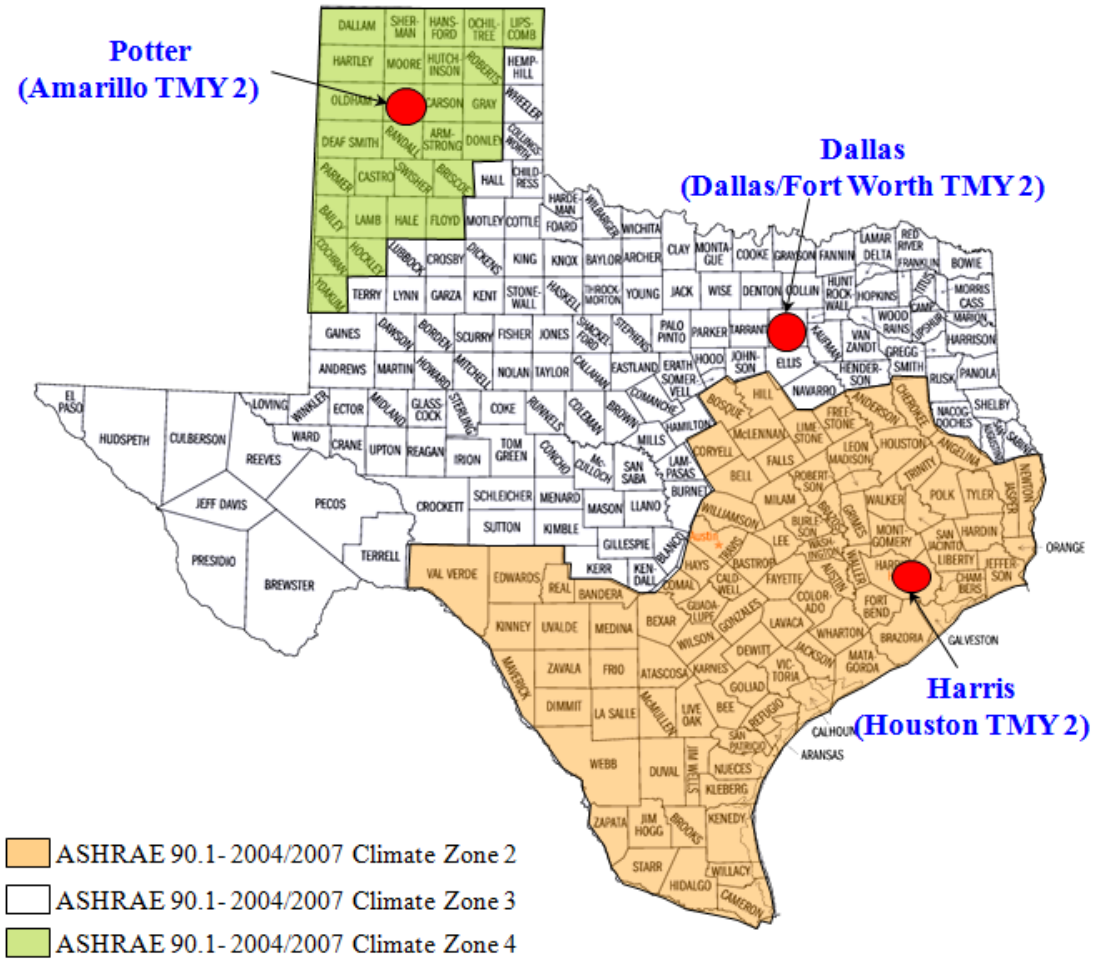


Figure 4. Climate Zones in ASHRAE Standard 90.1-2004/2007 and Three Selected Counties

2.2 Base-Case Building Description

The base-case building simulation model in this analysis is based on the *standard* design as defined in the ASHRAE 90.1-2007² and certain assumptions, which are described throughout this document. The base-case building is a 20,000 sq. ft., square-shape, two story, wood-frame building oriented N, S, E, W, with a 20% window-to-wall ratio. Four perimeter zones and a central core zone were modeled for each floor with a floor-to-ceiling height of 13 feet. The other envelope and system characteristics were determined from the general characteristics and the climate-specific characteristics as specified in the ASHRAE 90.1-2007. Table 1 summarizes the base-case, ASHRAE 90.1-2007 code-compliance building characteristics used in the DOE-2 simulation tool in this analysis.

2.3 Assumptions for Cost Analysis

The cost analysis for different measures was carried out based on utility costs of \$0.095/kWh for electricity, \$5.00/kW for demand charge, and \$0.63/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), and 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).

² per 2009 IECC Section 501.2

Table 1. Base-Case Building Description

| Characteristics | Information Source | ASHRAE 90.1-2007 Code-Compliant Small Office | | | Comments |
|----------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------------|------------------------|-----------------------|-----------------------------------------------------------------------------|
| | | Harris County (CZ 2A) | Tarrant County (CZ 3A) | Potter County (CZ 4B) | |
| Building | | | | | |
| Building Type | | Small office | | | Number of occupants = 73 |
| Gross Area (sq. ft.) | PNNL-19341 (Thornton et al. 2010) | 20,000 | | | |
| Aspect Ratio | PNNL-19341 (Thornton et al. 2010) | 1:1 | | | Square shape |
| Number of Floors | PNNL-19341 (Thornton et al. 2010) | 2 | | | |
| Floor-to-Floor Height (ft.) | ASHRAE 90.1-1989 13.7.1 | 13 | | | Floor-to-Ceiling Height = 9 ft |
| Orientation | PNNL-19341 (Thornton et al. 2010) | South facing | | | |
| Construction | | | | | |
| Wall Construction | CoA small office analysis (Kim et al. 2011) | Wood frame with 2x4 studs spaced at 16" on center | | | |
| Roof Configuration | PNNL-19341 (Thornton et al. 2010) | Flat built-up, Insulation entirely above deck | | | |
| Foundation Construction | PNNL-19341 (Thornton et al. 2010) | 6" concrete slab-on-grade floor | | | |
| Wall Absorptance | DOE 2.1E BDL SUMMARY, Page 12 | 0.75 | | | Assuming gray, light oil paint |
| Wall Insulation (hr-sq.ft.-°F/Btu) | ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4 | R-13 | | | |
| Roof Absorptance | ASHRAE 90.1-2007 Sec. 5.5.3.1.1 | 0.3 | | | Roof reflectance = 0.7 |
| Roof Insulation (hr-sq.ft.-°F/Btu) | ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4 | R-20 ci | | | |
| Slab Perimeter Insulation | ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4 | 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 90.1-2007 Table 5.5-2 to 5.5-4 | 0.75 | 0.65 | 0.55 | Fixed fenestration |
| Solar Heat Gain Coefficient (SHGC) | ASHRAE 90.1-2007 Table 5.5-2 to 5.5-4 | 0.25 | | 0.40 | |
| Window Area | PNNL-19341 (Thornton et al. 2010) | 20% Window to wall ratio | | | |
| Exterior Shading | ASHRAE 90.1-2007 Table 11.3.1 No.5 | None | | | |
| Space Conditions | | | | | |
| Space Heating Set point | PNNL-19341 (Thornton et al. 2010) | 70 F(Occupied), 5 F setback | | | |
| Space Cooling Set point | | 75 F(Occupied), 5 F setup | | | |
| Lighting Power Density (W/ft²) | ASHRAE 90.1-2007 Table 9.5.1 | 1.0 | | | |
| Equipment Power Density (W/ft²) | PNNL-19341 (Thornton et al. 2010) | 0.75 | | | |
| Mechanical Systems | | | | | |
| HVAC System Type | ASHRAE 90.1-2007 11.3.2 | Packaged rooftop air conditioner (CAV, DX, gas furnace) | | | |
| Air Conditioning System Efficiency | FEDERAL MINIMUM EFFICIENCY STANDARDS (effective as of 1/1/2010) | 13 SEER (<65,000 Btu/h) 11 EER (≥135,000 Btu/h and <240,000 Btu/h) | | | |
| Heating System Efficiency (%) | ASHRAE 90.1-2007 Table 6.8.1E | 80% Et | | | Gas-fired furnace Capacity < 225,000 Btu/h |
| Cooling Capacity (Btu/hr) | ASHRAE 90.1-2007 Appendix G and ASHRAE HOF-2009 | Autosized | | | |
| Heating Capacity (Btu/hr) | ASHRAE 90.1-2007 Appendix G and ASHRAE HOF-2009 | Autosized | | | |
| Economizer | ASHRAE 90.1-2007 Table 6.5.1 | No | Yes (≥65,000 Btu/h) | | |
| Ventilation (cfm/sq.ft) | ASHRAE 62.1-2004 | 0.08 | | | Total = 1,565 cfm based on 5 cfm/person & 0.06 cfm.sq.ft (ASHRAE 62.1-2004) |
| Supply Air Flow (cfm/sq.ft) | | 1.00 | | | |
| SHW System Type | PNNL-19341 (Thornton et al. 2010) | Gas-fired storage water heater (75 gallon, 75,100 Btu/hr) | | | |
| SHW Heater Efficiency (%) | ASHRAE 90.1-2007 Table 7.8 | 80 % Et (SL=1046.5 Btu/hr) | | | |
| SHW Temperature Setpoint (F) | PNNL-19341 (Thornton et al. 2010) | 120 F | | | |

3 PROPOSED ENERGY EFFICIENCY MEASURES FOR SMALL OFFICE BUILDINGS

This section documents 16 energy efficiency measures (EEMs) for small office buildings to achieve above-code energy performance based on the ASHRAE 90.1- 2007 code-compliant small office building in Texas. Section 3.1 gives a brief description of 16 individual EEMs. Section 3.2 provides input parameters used in the simulation of each EEM.

3.1 Individual EEMs

Table 2 lists 16 energy efficiency measures considered in this analysis. These include measures for the building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. These measures were simulated by modifying the selected parameters used for the DOE-2 simulation tool.

3.2 Simulation Input for Individual EEMs

Tables 3 to 5 list the input parameters used for the base case and individual EEMs for each climate zone. The entire row of shaded cells presents the parameters used in the base-case runs. The remaining rows show the parameters used in the simulation of the individual energy efficiency measures. The shaded cells in each row indicate the change in the value of the parameter used to simulate the measure.

Table 2. Energy Efficiency Measures

| | EEM No. | EEM Description |
|------------------------------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 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) |
| | 2 | Decreased Glazing U-Value (from 0.75 (CZ2), 0.65 (CZ3), and 0.55 (CZ4) 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) |
| HVAC System Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) |
| | 8 | Improved Fan Efficiency (from 55% to 65%) |
| Service Hot Water Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) |
| | 10 | Tankless Gas Water Heater |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) |
| | 14 | Daylight Dimming Control |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors |
| Renewable Power Measure | 16 | 40 kW Photovoltaic Array |

Table 3. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)

| EEM # | Energy Efficiency Measure | Roof Insulation R-Value | Wall c.i. R-Value | U-Value | SHGC | Shading (ft) | | | | WWR (%) | | | | OA Demand Control | EER for Perimeter Zone | EER for Core Zone | Furnace Eff. for PSZ (%) | Fan Eff. (%) | DHW Eff. Et(%) | DHW Tank Heat Loss | DHW Pump Electric Power | Lighting Power Density (W/ft ²) | Daylight Dimming Control | Auto. Receptacle Control | |
|--------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------|------------|-------------|--------------|------------|------------|------|------------|-----------|-----------|-----------|-------------------|------------------------|-------------------|--------------------------|--------------|----------------|--------------------|-------------------------|---------------------------------------------|--------------------------|--------------------------|----------|
| | | | | | | Front | Right | Back | Left | Front | Right | Back | Left | | | | | | | | | | | | |
| 90.1-2007 Base case (Harris County) | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N | |
| 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) | 25 | 3.8 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 2 | Decreased Glazing U-Value (from 0.75 to 0.35) | 20 | 0 | 0.35 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 3 | 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 20 | 0 | 0.75 | 0.25 | 2.5 | 2.5 | 0 | 2.5 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 4 | Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W) | 20 | 0 | 0.75 | 0.25 | 2.5 | 2.5 | 0 | 2.5 | 36 | 12 | 20 | 12 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| HVAC Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | Y | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 17.19 | 15.05 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 90 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 8 | Improved Fan Efficiency (from 55% to 65%) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 65 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| SHW Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 95 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 10 | Tankless Gas Water Heater | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0017 | 0 | 1.0 | N | N |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.9 | N | N |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.75 | N | N |
| | 14 | Daylight Dimming Control | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | Y | N |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | Y |
| Renewable Measure | 16 | 40 kW Photovoltaic Array | 20 | 0 | 0.75 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |

Table 4. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)

| EEM # | Energy Efficiency Measure | Roof Insulation R-Value | Wall c.i. R-Value | U-Value | SHGC | Shading (ft) | | | | WWR (%) | | | | OA Demand Control | EER for Perimeter Zone | EER for Core Zone | Furnace Eff. for PSZ (%) | Fan Eff. (%) | DHW Eff. Et(%) | DHW Tank Heat Loss | DHW Pump Electric Power | Lighting Power Density (W/ft ²) | Daylight Dimming Control | Auto. Receptacle Control | |
|---------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------|---------|------|--------------|-------|------|------|---------|-------|------|------|-------------------|------------------------|-------------------|--------------------------|--------------|----------------|--------------------|-------------------------|---------------------------------------------|--------------------------|--------------------------|---|
| | | | | | | Front | Right | Back | Left | Front | Right | Back | Left | | | | | | | | | | | | |
| 90.1-2007 Base case (Tarrant County) | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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) | 25 | 3.8 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 2 | Decreased Glazing U-Value (from 0.65 to 0.35) | 20 | 0 | 0.35 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 3 | 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 20 | 0 | 0.65 | 0.25 | 2.5 | 2.5 | 0 | 2.5 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 4 | Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W) | 20 | 0 | 0.65 | 0.25 | 2.5 | 2.5 | 0 | 2.5 | 36 | 12 | 20 | 12 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| HVAC Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | Y | 13.29 | 12.55 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 17.19 | 15.05 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 90 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 8 | Improved Fan Efficiency (from 55% to 65%) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 65 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| SHW Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 95 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 10 | Tankless Gas Water Heater | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0017 | 0 | 1.0 | N | N |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.9 | N | N |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.75 | N | N |
| | 14 | Daylight Dimming Control | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | Y | N |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | Y |
| Renewable Measure | 16 | 40 kW Photovoltaic Array | 20 | 0 | 0.65 | 0.25 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |

Table 5. Simulation Input Parameters of Individual EEMs for ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)

| EEM # | Energy Efficiency Measure | Roof Insulation R-Value | Wall c.i. R-Value | U-Value | SHGC | Shading (ft) | | | | WWR (%) | | | | OA Demand Control | EER for Perimeter Zone | EER for Core Zone | Furnace Eff. for PSZ (%) | Fan Eff. (%) | DHW Eff. Et(%) | DHW Tank Heat Loss | DHW Pump Electric Power | Lighting Power Density (W/ft ²) | Daylight Dimming Control | Auto. Receptacle Control | |
|--------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------|------------|-------------|--------------|------------|------------|------|------------|-----------|-----------|-----------|-------------------|------------------------|-------------------|--------------------------|--------------|----------------|--------------------|-------------------------|---------------------------------------------|--------------------------|--------------------------|----------|
| | | | | | | Front | Right | Back | Left | Front | Right | Back | Left | | | | | | | | | | | | |
| 90.1-2007 Base case (Potter County) | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N | |
| 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) | 25 | 3.8 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 2 | Decreased Glazing U-Value (from 0.55 to 0.35) | 20 | 0 | 0.35 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 3 | 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 20 | 0 | 0.55 | 0.4 | 2.5 | 2.5 | 0 | 2.5 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 4 | Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W) | 20 | 0 | 0.55 | 0.4 | 2.5 | 2.5 | 0 | 2.5 | 36 | 12 | 20 | 12 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| HVAC Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | Y | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 17.19 | 15.05 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 90 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 8 | Improved Fan Efficiency (from 55% to 65%) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 65 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| SHW Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 95 | 0.0139 | 0.0038 | 1.0 | N | N |
| | 10 | Tankless Gas Water Heater | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0017 | 0 | 1.0 | N | N |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.9 | N | N |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 0.75 | N | N |
| | 14 | Daylight Dimming Control | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | Y | N |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | Y |
| Renewable Measure | 16 | 40 kW Photovoltaic Array | 20 | 0 | 0.55 | 0.4 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | N | 13.29 | 12.82 | 80 | 55 | 80 | 0.0139 | 0.0038 | 1.0 | N | N |

4 RESULTS

This section presents the results of simulation and cost analysis. Section 4.1 provides the detailed results for three representative counties in each climate zone such as Harris County for Climate Zone 2, Tarrant County for Climate Zone 3 and Potter County for Climate Zone 4. Section 4.2 presents the group measures which are the combinations of individual measures for achieving 15% savings above the base-case, ASHRAE 90.1-2007 code-compliant building.

4.1 Results of Simulation and Cost Analysis

Tables 6 to 8 summarize the results of simulation and cost analysis for Harris, Tarrant, and Potter Counties, including:

- Annual site energy consumption for different end-uses and total;
- Annual source energy consumption for different fuel types and total;
- Above-code savings (%) for site and source;
- Annual energy and demand cost savings;
- Increased cost of implementation (obtained from various resources listed in Appendix A³); and
- Simple payback period.

The annual site energy use was obtained from the BEPS report of the DOE-2 output and then converted to source energy⁴. Figures 5 to 10 provide a graphical representation of the site/source energy consumption of the EEMs for the ASHRAE 90.1- 2007 code-compliant base-case small office building for Harris, Tarrant, and Potter Counties.

4.1.1 Base-Case Energy Use

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

- a) Site energy use by end-uses: 704 MMBtu/yr, including
 - 21.9% for cooling;
 - 9.4% for heating;
 - 42.6% for lighting and equipment;
 - 19.4% for fans and pumps; and
 - 6.6% for service water heating.
- b) Source energy use by fuel type: 1,992 MMBtu/yr, including
 - 93.7% for electricity; and
 - 6.3% for natural gas.

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

- a) Site energy use by end-uses: 732 MMBtu/yr, including
 - 18.4% for cooling;
 - 14.9% for heating;
 - 41.0% for lighting and equipment;
 - 19.1% for fans and pumps; and
 - 6.6% for service water heating.

³ The ranges of total implementation cost for some measures were modified according to the recommendations of stakeholders.

⁴ The source energy multipliers used in this analysis were 3.16 for electricity and 1.1 for natural gas based on Section 405.3 of the 2009 IECC.

- b) Source energy use by fuel type: 1,989 MMBtu/yr, including
 - 91.3% for electricity; and
 - 8.7% for natural gas.

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

- a) Site energy use by end-uses: 865 MMBtu/yr, including
 - 10.2% for cooling;
 - 31.8% for heating;
 - 34.7% for lighting and equipment;
 - 17.1% for fans and pumps; and
 - 6.2% for service water heating.
- b) Source energy use by fuel type: 2,055 MMBtu/yr, including
 - 82.4% for electricity; and
 - 17.6% for natural gas.

These results suggest that the measures that reduce the lighting and equipment energy use would have the highest impact on the total energy use for small office buildings in Texas, and 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.

4.1.2 Energy Savings from Various Individual EEMs

The savings results are:

- a) Increased Roof and Wall Insulation R-Value:
 - Harris County: 1.2% (site energy savings) and 0.6% (source energy savings);
 - Tarrant County: 1.7% (site energy savings) and 0.9% (source energy savings); and
 - Potter County: 2.9% (site energy savings) and 1.5% (source energy savings).
- b) Decreased Glazing U-Value:
 - Harris County: 3.5% (site energy savings) and 1.0% (source energy savings);
 - Tarrant County: 4.5% (site energy savings) and 1.5% (source energy savings); and
 - Potter County: 5.9% (site energy savings) and 2.6% (source energy savings).
- c) 0.5 PF Window Shading:
 - Harris County: 0.8% (site energy savings) and 1.3% (source energy savings);
 - Tarrant County: 0.1% (site energy savings) and 0.9% (source energy savings); and
 - Potter County: -1.1% (site energy savings) and 0.7% (source energy savings).
- d) Window Shading and Redistribution:
 - Harris County: 1.2% (site energy savings) and 1.5% (source energy savings);
 - Tarrant County: 0.6% (site energy savings) and 1.1% (source energy savings); and
 - Potter County: -0.4% (site energy savings) and 1.1% (source energy savings).
- e) CO₂-Based Demand-Controlled Ventilation:
 - Harris County: 2.1% (site energy savings) and 1.6% (source energy savings);

- Tarrant County: 2.0% (site energy savings) and 1.2% (source energy savings); and
 - Potter County: 3.2% (site energy savings) and 1.6% (source energy savings).
- f) Improved Air Conditioner Efficiency:
- Harris County: 4.2% (site energy savings) and 4.7% (source energy savings);
 - Tarrant County: 3.6% (site energy savings) and 4.2% (source energy savings); and
 - Potter County: 2.1% (site energy savings) and 2.7% (source energy savings).
- g) Improved Furnace Efficiency:
- Harris County: 1.1% (site energy savings) and 0.4% (source energy savings);
 - Tarrant County: 1.7% (site energy savings) and 0.7% (source energy savings); and
 - Potter County: 3.5% (site energy savings) and 1.6% (source energy savings).
- h) Improved Fan Efficiency:
- Harris County: 2.9% (site energy savings) and 3.6% (source energy savings);
 - Tarrant County: 2.4% (site energy savings) and 3.4% (source energy savings); and
 - Potter County: 1.3% (site energy savings) and 3.0% (source energy savings).
- i) Improved SHW Heater Efficiency:
- Harris County: 1.1% (site energy savings) and 0.4% (source energy savings);
 - Tarrant County: 1.0% (site energy savings) and 0.4% (source energy savings); and
 - Potter County: 1.0% (site energy savings) and 0.5% (source energy savings).
- j) Tankless Gas Water Heater:
- Harris County: 1.8% (site energy savings) and 1.6% (source energy savings);
 - Tarrant County: 1.8% (site energy savings) and 1.6% (source energy savings); and
 - Potter County: 1.6% (site energy savings) and 1.6% (source energy savings).
- k) Solar SHW System (64 sq. ft. collector, 80 gal tank):
- Harris County: 3.3% (site energy savings) and 1.2% (source energy savings);
 - Tarrant County: 3.6% (site energy savings) and 1.4% (source energy savings); and
 - Potter County: 3.2% (site energy savings) and 1.4% (source energy savings).
- l) Decreased Lighting Power Density to 0.9 W/sq.ft.:
- Harris County: 2.3% (site energy savings) and 2.8% (source energy savings);
 - Tarrant County: 1.9% (site energy savings) and 2.6% (source energy savings); and
 - Potter County: 1.2% (site energy savings) and 2.3% (source energy savings).
- m) Decreased Lighting Power Density to 0.75 W/sq.ft.:
- Harris County: 5.7% (site energy savings) and 7.0% (source energy savings);
 - Tarrant County: 4.8% (site energy savings) and 6.6% (source energy savings); and
 - Potter County: 3.0% (site energy savings) and 5.7% (source energy savings).
- n) Daylight Dimming Control:
- Harris County: 6.5% (site energy savings) and 7.8% (source energy savings);
 - Tarrant County: 5.7% (site energy savings) and 7.5% (source energy savings); and
 - Potter County: 4.1% (site energy savings) and 6.8% (source energy savings).

- o) Automatic Receptacle Control for Offices using Occupancy Sensors:
 - Harris County: 2.3% (site energy savings) and 2.7% (source energy savings);
 - Tarrant County: 1.9% (site energy savings) and 2.6% (source energy savings); and
 - Potter County: 1.3% (site energy savings) and 2.3% (source energy savings).

- p) 40 kW Photovoltaic Array:
 - Harris County: 20.6% (site energy savings) and 23.1% (source energy savings);
 - Tarrant County: 29.3% (site energy savings) and 34.1% (source energy savings); and
 - Potter County: 27.1% (site energy savings) and 36.1% (source energy savings).

Of 16 measures, a solar PV measure presents the most savings (23.1%, 34.1%, and 36.1% source energy savings) across the counties. A daylight dimming control and decreased lighting power density to 0.75 W/sq.ft measures also resulted in considerable savings (7.8%, 7.5%, and 6.8% source energy savings with daylight dimming control measure; and 7.0%, 6.6%, and 5.7% source energy savings with decreased lighting power density to 0.75 W/sq.ft measure). Among the envelope and fenestration measures, a decreased glazing u-value measure shows a high site energy savings (3.5%, 4.5%, and 5.9% site energy savings), while the source energy savings becomes lower (1.0%, 1.5%, and 2.6% source energy savings) due to a high savings in natural gas and the increased cooling energy penalty. Among the HVAC system measures, an improved air conditioner efficiency measure results in high source energy savings across the counties (4.7%, 4.2%, and 2.7% source energy savings), and an improved fan efficiency measure yields 3.6%, 3.4%, and 3.0% source energy savings. In service hot water measures, the solar SHW system measure with 64 ft² collector and 80 gallon tank is found to be effective only for site energy savings (3.3%, 3.6%, and 3.2% site energy savings and 1.2%, 1.4%, and 1.4% source energy savings). Finally, an automatic receptacle control measure presents a source energy savings of 2.7%, 2.6% and 2.3%.

4.1.3 Cost Effectiveness of Various Individual EEMs

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

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

To estimate the cost-effectiveness of measures, the implementation costs of each measure (obtained from various resources listed in Appendix A), were surveyed along with simple payback calculations. The cost-effectiveness of a measure depends upon the energy cost savings versus the cost of implementation. The most cost-effective measure is a decreased lighting power density to 0.75 W/sq.ft. measure (EEM 13) with the shortest payback periods of 4.1 to 6.1 years for Harris County, 4.2 to 6.3 years for Tarrant County, and 4.6 to 6.9 years for Potter County. The other two lighting measures (EEM 12 and EEM 14) yield relatively short payback periods: 8.2 to 12.4 years (Harris County), 8.6 to 12.9 years (Tarrant County), and 9.3 to 13.9 years (Potter County) for EEM 12; and 9.1 to 13.7 years (Harris County), 9.4 to

14.2 years (Tarrant County), and 9.8 to 14.7 years (Potter County) for EEM 14. Tankless gas water heater and improved fan efficiency also yield relatively short payback periods.

4.2 **Combined EEMs: 15% Source Energy Savings Above ASHRAE 90.1-2007 Code-Compliant Building**

Grouped measures are the combination of individual measures. The results from individual measures and cost analysis were used to guide the selection of measures for this group analysis. The measures were combined to achieve the total source energy savings⁵ of the group is 15% above the base-case simulation of ASHRAE 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 a similar fashion as the analysis of the individual measures, the group measures were simulated by modifying all the parameters of combined individual measures.

As shown in Figures 11 and 13, three group measures were proposed for each base case. In each figure, the first table summarizes the results obtained from individual measures in terms of annual site energy savings, annual source energy savings, annual demand savings, energy cost savings, estimated costs for each measure implemented individually, and payback period. The second table summarizes the results obtained by implementing combined measures to achieve 15% or more total source energy savings, and includes: energy savings, energy cost savings, estimated costs, payback period for each combination, and annual NO_x, SO₂, and CO₂ emission savings.

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

- a) Harris County: 8.2 to 12.3 years;
- b) Tarrant County: 8.4 to 12.7 years; and
- c) Potter County: 8.7 to 13.0 years.

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

- a) Harris County: 12.2 to 18.3 years;
- b) Tarrant County: 13.1 to 19.6 years; and
- c) Potter County: 14.9 to 22.4 years.

⁵ The estimated total source energy savings include heating, cooling, lighting, equipment, and SHW.

Table 6. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)

| EEM # | Energy Efficiency Measure | Site Energy Use by End-Uses (MMBtu/yr) | | | | | Source Energy Use by Fuel Type (MMBtu/yr) | | | Savings Above Base case (%) | | Annual Energy Savings (\$/yr) | Annual Demand Savings (\$/yr) | Increased Marginal Cost (\$) | Increased New System Cost (\$) | Payback (yrs) |
|--------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------------|-----|-------------------------------------------|--------|-------|-----------------------------|------|-------------------------------|-------------------------------|------------------------------|--------------------------------|---------------|
| | | Cooling | Heating | Ltg & Equip | Fans & Pumps | DHW | Total | Total | Elec. | Gas | Site | | | | | |
| 90.1-2007 Base case (Harris County) | | | | | | | | | | | | | | | | |
| | | 154 | 67 | 300 | 137 | 47 | 704.2 | 1991.9 | 1867 | 125 | 0.0% | 0.0% | \$0 | \$0 | | |
| 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) | | | | | | | | | | | | | | |
| | 2 | Decreased Glazing U-Value (from 0.75 to 0.35) | | | | | | | | | | | | | | |
| | 3 | 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | | | | | | | | | | | | | | |
| | 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) | | | | | | | | | | | | | | |
| HVAC Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) | | | | | | | | | | | | | | |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | | | | | | | | | | | | | | |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) | | | | | | | | | | | | | | |
| | 8 | Improved Fan Efficiency (from 55% to 65%) | | | | | | | | | | | | | | |
| SHW Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | | | | | | | | | | | | | | |
| | 10 | Tankless Gas Water Heater | | | | | | | | | | | | | | |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | | | | | | | | | | | | | | |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | | | | | | | | | | | | | | |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | | | | | | | | | | | | | | |
| | 14 | Daylight Dimming Control | | | | | | | | | | | | | | |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors | | | | | | | | | | | | | | |
| Renewable Measure | 16 | 40 kW Photovoltaic Array | | | | | | | | | | | | | | |

Table 7. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)

| EEM # | Energy Efficiency Measure | Site Energy Use by End-Uses (MMBtu/yr) | | | | | Source Energy Use by Fuel Type (MMBtu/yr) | | | Savings Above Base case (%) | | Annual Energy Savings (\$/yr) | Annual Demand Savings (\$/yr) | Increased Marginal Cost (\$) | Increased New System Cost (\$) | Payback (yrs) |
|---------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|---------|-------------|--------------|-----|-------------------------------------------|--------|-------|-----------------------------|-------|-------------------------------|-------------------------------|------------------------------|--------------------------------|---------------|
| | | Cooling | Heating | Ltg & Equip | Fans & Pumps | DHW | Total | Total | Elec. | Gas | Site | | | | | |
| 90.1-2007 Base case (Tarrant County) | | 135 | 109 | 300 | 140 | 48 | 732.0 | 1988.9 | 1816 | 173 | 0.0% | 0.0% | \$0 | \$0 | | |
| 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) | 134 | 98 | 300 | 139 | 48 | 719 | 1972 | 1811 | 161 | 1.7% | 0.9% | \$112 | \$14 | \$9,092 - \$13,639 | 72.1 - 108 |
| | 2 Decreased Glazing U-Value (from 0.65 to 0.35) | 139 | 73 | 300 | 138 | 48 | 699 | 1958 | 1825 | 134 | 4.5% | 1.5% | \$146 | \$1 | \$7,039 - \$10,558 | 48.0 - 72.0 |
| | 3 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 127 | 116 | 300 | 140 | 48 | 731 | 1972 | 1790 | 181 | 0.1% | 0.9% | \$178 | \$33 | \$14,159 - \$21,238 | 67.2 - 101 |
| | 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) | 127 | 113 | 300 | 139 | 48 | 728 | 1966 | 1788 | 178 | 0.6% | 1.1% | \$216 | \$38 | \$14,159 - \$21,238 | 55.9 - 83.8 |
| HVAC Measures | 5 CO ₂ -Based Demand-Controlled Ventilation (DCV) | 132 | 98 | 300 | 140 | 48 | 717 | 1965 | 1805 | 161 | 2.0% | 1.2% | \$168 | \$14 | \$7,367 - \$11,051 | 40.5 - 60.8 |
| | 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 109 | 109 | 300 | 140 | 48 | 706 | 1906 | 1733 | 173 | 3.6% | 4.2% | \$729 | \$205 | \$12,288 - \$18,432 | 13.1 - 19.7 |
| | 7 Improved Furnace Efficiency (from 80% to 90% Et) | 135 | 97 | 300 | 140 | 48 | 720 | 1976 | 1816 | 160 | 1.7% | 0.7% | \$76 | \$0 | \$7,900 - \$11,850 | 104 - 156 |
| | 8 Improved Fan Efficiency (from 55% to 65%) | 131 | 115 | 300 | 120 | 48 | 715 | 1921 | 1741 | 180 | 2.4% | 3.4% | \$615 | \$93 | \$6,869 - \$10,303 | 9.7 - 14.5 |
| SHW Measures | 9 Improved SHW Heater Efficiency (from 80% to 95% Et) | 135 | 109 | 300 | 140 | 41 | 724 | 1981 | 1816 | 165 | 1.0% | 0.4% | \$48 | \$0 | \$3,456 - \$5,184 | 72.4 - 109 |
| | 10 Tankless Gas Water Heater | 135 | 109 | 300 | 131 | 44 | 719 | 1957 | 1789 | 168 | 1.8% | 1.6% | \$265 | \$18 | \$1,414 - \$2,120 | 5.0 - 7.5 |
| | 11 Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 135 | 109 | 300 | 141 | 21 | 706 | 1962 | 1819 | 143 | 3.6% | 1.4% | \$145 | -\$6 | \$2,880 - \$4,320 | 20.7 - 31.1 |
| Lighting and Receptacle Measures | 12 Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | 132 | 113 | 284 | 140 | 48 | 718 | 1936 | 1759 | 178 | 1.9% | 2.6% | \$476 | \$97 | \$4,913 - \$7,369 | 8.6 - 12.9 |
| | 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 128 | 119 | 261 | 140 | 48 | 697 | 1857 | 1673 | 184 | 4.8% | 6.6% | \$1,196 | \$243 | \$6,052 - \$9,079 | 4.2 - 6.3 |
| | 14 Daylight Dimming Control | 127 | 118 | 257 | 140 | 48 | 690 | 1840 | 1657 | 182 | 5.7% | 7.5% | \$1,342 | \$325 | \$15,723 - \$23,584 | 9.4 - 14.2 |
| | 15 Automatic Receptacle Control for Offices using Occupancy Sensors | 132 | 113 | 285 | 140 | 48 | 718 | 1938 | 1761 | 177 | 1.9% | 2.6% | \$462 | \$112 | \$7,587 - \$11,380 | 13.2 - 19.8 |
| Renewable Measure | 16 40 kW Photovoltaic Array | 85 | 109 | 188 | 88 | 48 | 517 | 1310 | 1137 | 173 | 29.3% | 34.1% | \$5,979 | \$800 | \$200,000 - \$300,000 | 29.5 - 44.3 |

Table 8. Simulation Results of Individual EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)

| EEM # | Energy Efficiency Measure | Site Energy Use by End-Uses (MMBtu/yr) | | | | | Source Energy Use by Fuel Type (MMBtu/yr) | | | Savings Above Base case (%) | | Annual Energy Savings (\$/yr) | Annual Demand Savings (\$/yr) | Increased Marginal Cost (\$) | Increased New System Cost (\$) | Payback (yrs) | |
|--------------------------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------------|-----|-------------------------------------------|--------|-------|-----------------------------|------|-------------------------------|-------------------------------|------------------------------|--------------------------------|-----------------------|-------------|
| | | Cooling | Heating | Ltg & Equip | Fans & Pumps | DHW | Total | Total | Elec. | Gas | Site | | | | | | Source |
| 90.1-2007 Base case (Potter County) | | | | | | | | | | | | | | | | | |
| | | 88 | 275 | 300 | 148 | 54 | 864.6 | 2054.8 | 1693 | 362 | 0.0% | 0.0% | \$0 | \$0 | | | |
| 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) | 88 | 251 | 300 | 147 | 54 | 840 | 2025 | 1690 | 335 | 2.9% | 1.5% | \$181 | \$11 | \$9,092 - \$13,639 | 47.3 - 70.9 |
| | 2 | Decreased Glazing U-Value (from 0.55 to 0.35) | 92 | 222 | 300 | 146 | 54 | 813 | 2002 | 1698 | 304 | 5.9% | 2.6% | \$289 | -\$5 | \$6,223 - \$9,335 | 21.9 - 32.8 |
| | 3 | 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 76 | 296 | 300 | 148 | 54 | 874 | 2041 | 1656 | 385 | -1.1% | 0.7% | \$195 | \$60 | \$14,159 - \$21,238 | 55.4 - 83.1 |
| | 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) | 76 | 291 | 300 | 147 | 54 | 868 | 2033 | 1654 | 379 | -0.4% | 1.1% | \$244 | \$70 | \$14,159 - \$21,238 | 45.0 - 67.5 |
| HVAC Measures | 5 | CO ₂ -Based Demand-Controlled Ventilation (DCV) | 87 | 248 | 300 | 148 | 54 | 837 | 2022 | 1689 | 332 | 3.2% | 1.6% | \$202 | \$9 | \$7,367 - \$11,051 | 34.9 - 52.3 |
| | 6 | Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 71 | 275 | 300 | 148 | 54 | 847 | 1999 | 1637 | 362 | 2.1% | 2.7% | \$496 | \$181 | \$12,288 - \$18,432 | 18.2 - 27.3 |
| | 7 | Improved Furnace Efficiency (from 80% to 90% Et) | 88 | 244 | 300 | 148 | 54 | 834 | 2021 | 1693 | 328 | 3.5% | 1.6% | \$191 | \$0 | \$7,900 - \$11,850 | 41.3 - 61.9 |
| | 8 | Improved Fan Efficiency (from 55% to 65%) | 85 | 287 | 300 | 127 | 54 | 853 | 1994 | 1619 | 375 | 1.3% | 3.0% | \$576 | \$92 | \$6,869 - \$10,303 | 10.3 - 15.4 |
| SHW Measures | 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | 88 | 275 | 300 | 148 | 45 | 856 | 2045 | 1693 | 352 | 1.0% | 0.5% | \$53 | \$0 | \$3,456 - \$5,184 | 64.8 - 97.2 |
| | 10 | Tankless Gas Water Heater | 88 | 275 | 300 | 139 | 49 | 851 | 2022 | 1666 | 356 | 1.6% | 1.6% | \$273 | \$17 | \$1,414 - \$2,120 | 4.9 - 7.3 |
| | 11 | Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 88 | 275 | 300 | 149 | 26 | 837 | 2027 | 1696 | 331 | 3.2% | 1.4% | \$151 | -\$6 | \$2,880 - \$4,320 | 19.8 - 29.6 |
| Lighting and Receptacle Measures | 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | 87 | 281 | 284 | 148 | 54 | 854 | 2008 | 1639 | 369 | 1.2% | 2.3% | \$436 | \$95 | \$4,913 - \$7,369 | 9.3 - 13.9 |
| | 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 84 | 292 | 261 | 148 | 54 | 838 | 1938 | 1558 | 380 | 3.0% | 5.7% | \$1,087 | \$236 | \$6,052 - \$9,079 | 4.6 - 6.9 |
| | 14 | Daylight Dimming Control | 82 | 289 | 257 | 148 | 54 | 830 | 1915 | 1539 | 377 | 4.1% | 6.8% | \$1,275 | \$328 | \$15,723 - \$23,584 | 9.8 - 14.7 |
| | 15 | Automatic Receptacle Control for Offices using Occupancy Sensors | 87 | 281 | 285 | 148 | 54 | 854 | 2008 | 1640 | 368 | 1.3% | 2.3% | \$429 | \$108 | \$7,587 - \$11,380 | 14.1 - 21.2 |
| Renewable Measure | 16 | 40 kW Photovoltaic Array | 50 | 275 | 169 | 83 | 54 | 630 | 1314 | 952 | 362 | 27.1% | 36.1% | \$6,528 | \$648 | \$200,000 - \$300,000 | 27.9 - 41.8 |

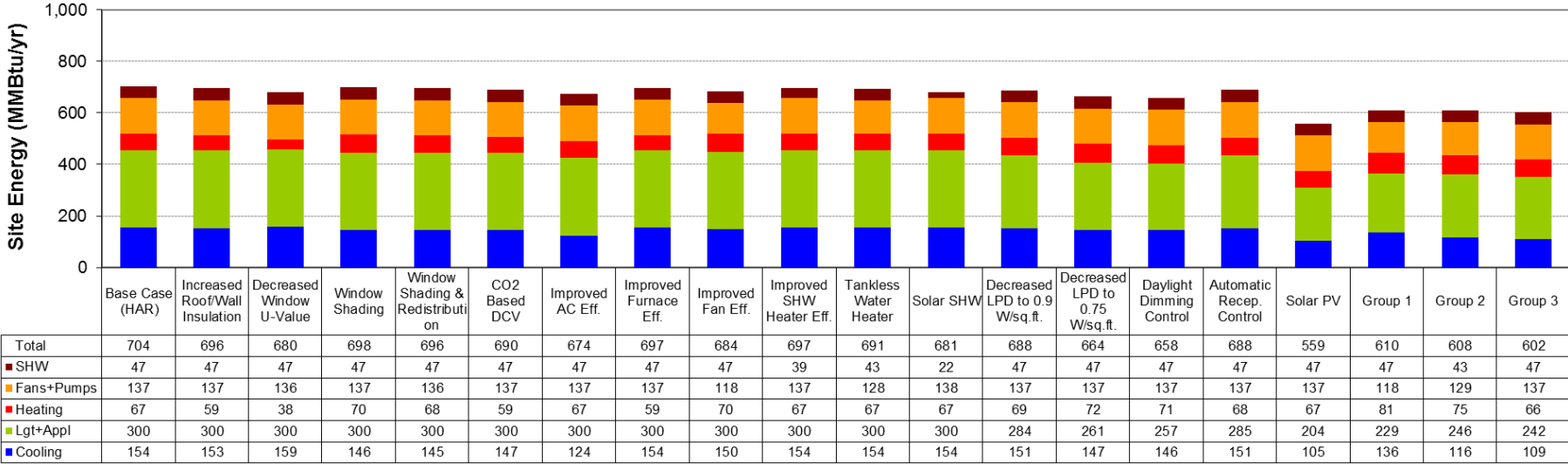


Figure 5. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)

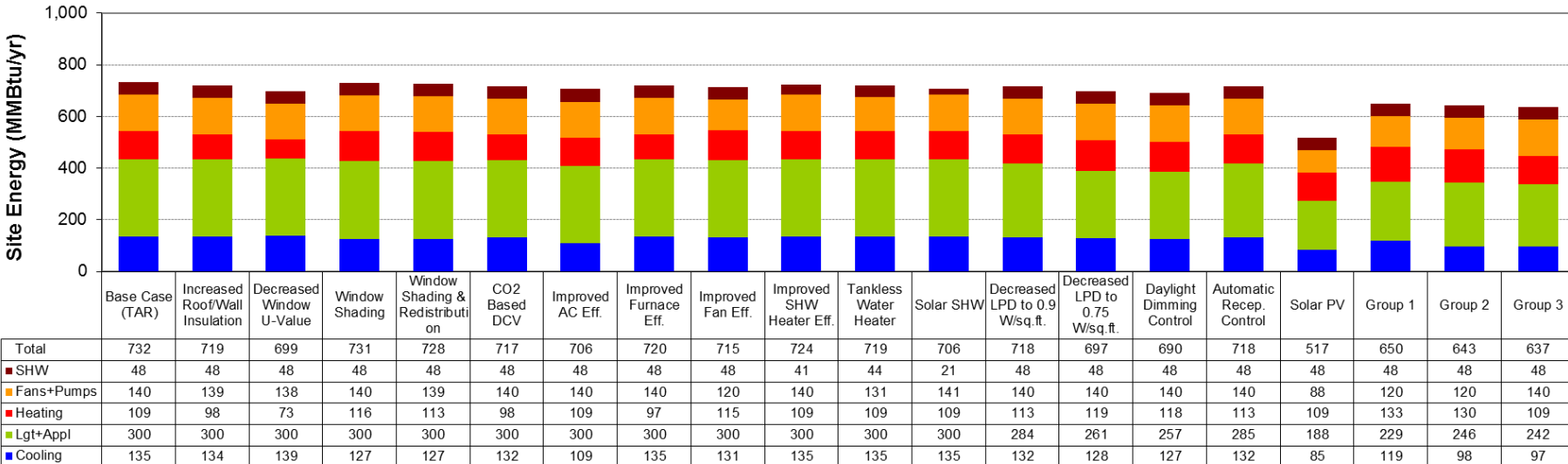


Figure 6. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)

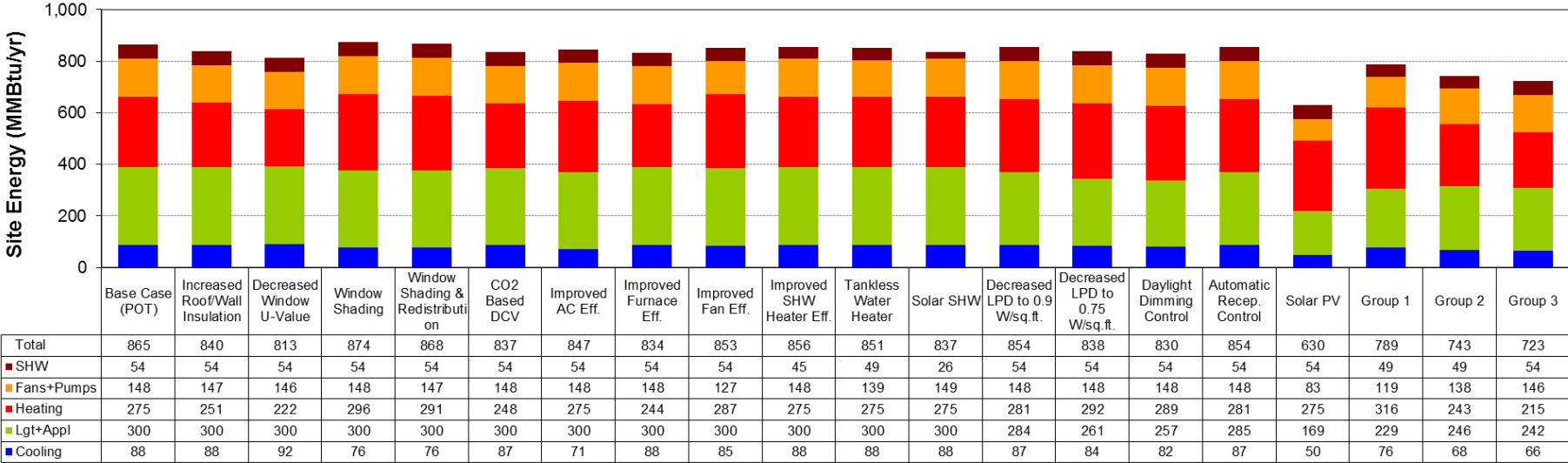


Figure 7. Site Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)

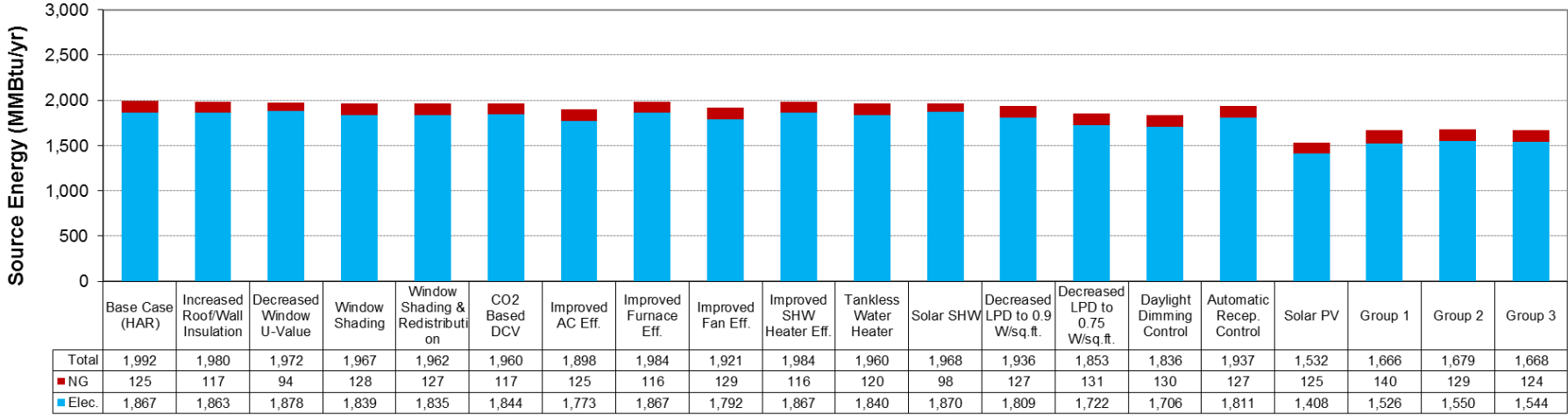


Figure 8. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Harris County (Climate Zone 2)

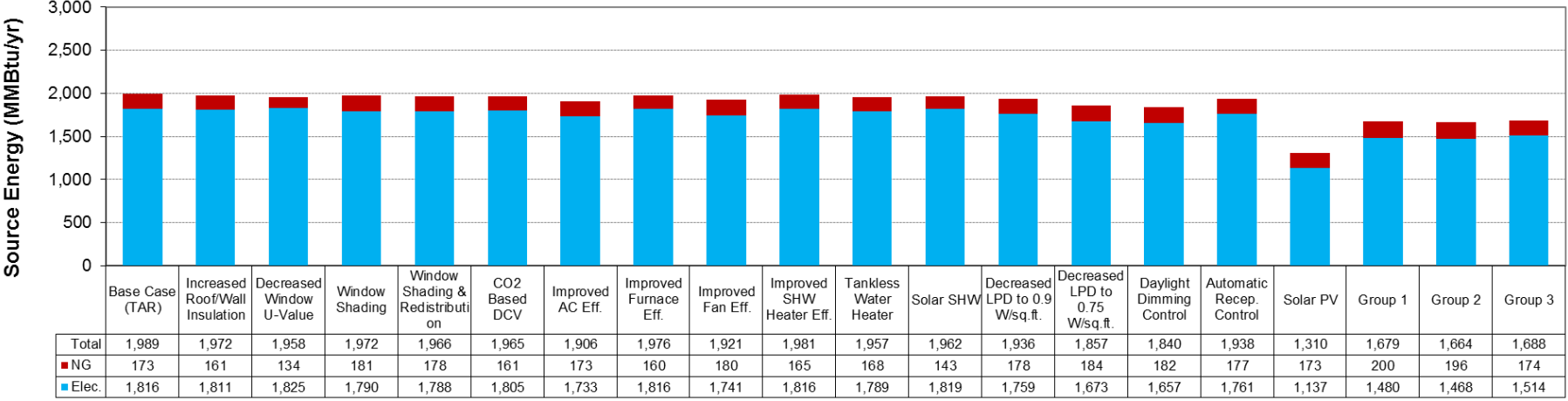


Figure 9. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Tarrant County (Climate Zone 3)

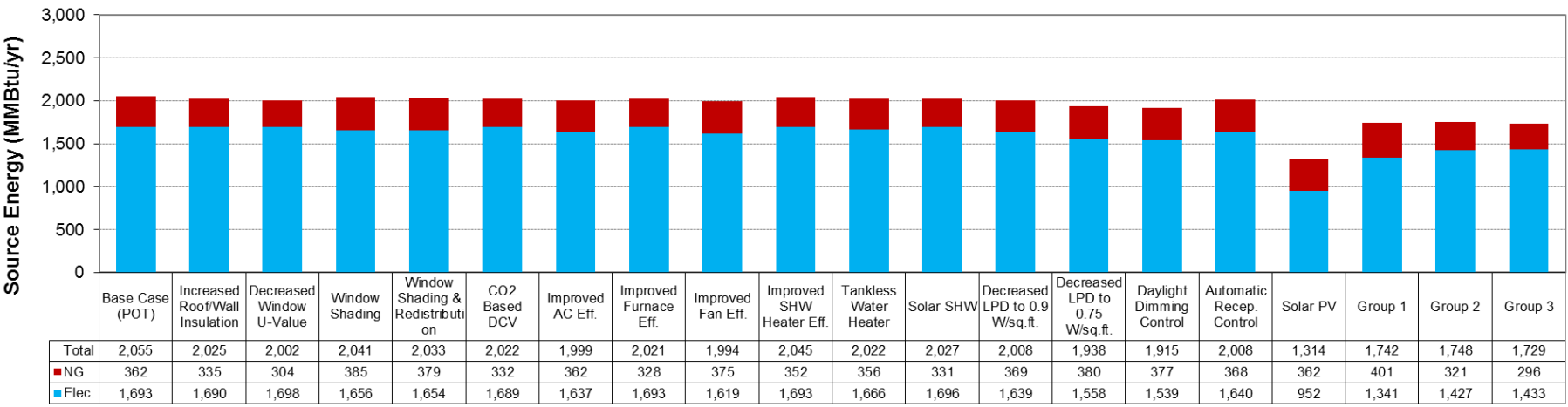
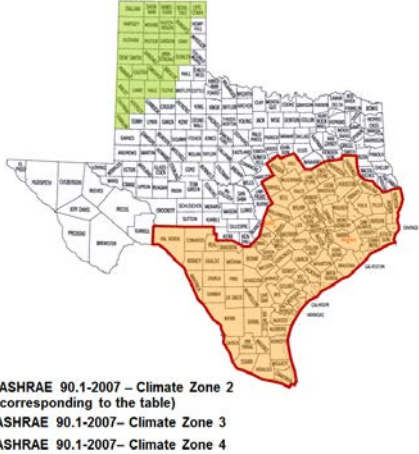


Figure 10. Source Energy Use of Various EEMs for an ASHRAE 90.1-2007 Code-Compliant Small Office Building in Potter County (Climate Zone 4)

Description of Individual Measures

| Individual Measures | Annual Energy Savings (%) | | 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%, E/W=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 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 13.3% | 16.4% | \$2,920 | 18.2% | \$586 | \$3,507 | \$6,052 - \$9,079 | | 8.2 - 12.3 | 48.8 | 31.5 | 20.3 |
| 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.) | | | | | | | \$6,052 - \$9,079 | | | | | |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 13.7% | 15.7% | \$2,769 | 17.5% | \$564 | \$3,333 | \$12,288 - \$18,432 | | 8.2 - 12.3 | 45.4 | 28.7 | 19.1 |
| 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 | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 14.6% | 16.2% | \$2,849 | 20.6% | \$664 | \$3,512 | \$12,288 - \$18,432 | | 12.2 - 18.3 | 46.6 | 29.2 | 19.7 |
| 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:
- 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 = \$0.63/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%
 - * HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
 - * DHW: 80% Et Gas Water heater

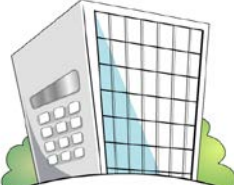
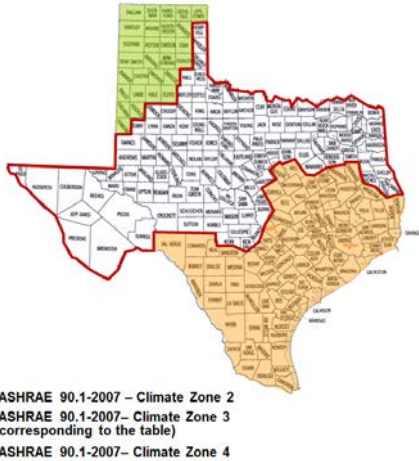


Figure 11. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 2

Description of Individual Measures

| Individual Measures | Annual Energy Savings (%) | | 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) | 1.7% | 0.9% | \$112 | 0.4% | \$14 | \$126 | \$9,092 - \$13,639 | | 72.1 - 108 |
| 2 Decreased Glazing U-Value (from 0.65 to 0.35) | 4.5% | 1.5% | \$146 | 0.0% | \$1 | \$147 | \$7,039 - \$10,558 | | 48.0 - 72.0 |
| 3 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | 0.1% | 0.9% | \$178 | 1.1% | \$33 | \$211 | | \$14,159 - \$21,238 | 67.2 - 101 |
| 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% | 1.1% | \$216 | 1.2% | \$38 | \$253 | | \$14,159 - \$21,238 | 55.9 - 83.8 |
| B HVAC System Measures | | | | | | | | | |
| 5 CO ₂ Based Demand-Controlled Ventilation (DCV) | 2.0% | 1.2% | \$168 | 0.4% | \$14 | \$182 | | \$7,367 - \$11,051 | 40.5 - 60.8 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 3.6% | 4.2% | \$729 | 6.6% | \$205 | \$934 | \$12,288 - \$18,432 | | 13.1 - 19.7 |
| 7 Improved Furnace Efficiency (from 80% to 90% Et) | 1.7% | 0.7% | \$76 | 0.0% | \$0 | \$76 | \$7,900 - \$11,850 | | 104 - 156 |
| 8 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 | | | | | | | | | |
| 9 Improved SHW Heater Efficiency (from 80% to 95% Et) | 1.0% | 0.4% | \$48 | 0.0% | \$0 | \$48 | \$3,456 - \$5,184 | | 72.4 - 109 |
| 10 Tankless Gas Water Heater | 1.8% | 1.6% | \$265 | 0.6% | \$18 | \$282 | \$1,414 - \$2,120 | | 5.0 - 7.5 |
| 11 Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 3.6% | 1.4% | \$145 | -0.2% | -\$6 | \$139 | | \$2,880 - \$4,320 | 20.7 - 31.1 |
| 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.) | 1.9% | 2.6% | \$476 | 3.1% | \$97 | \$573 | \$4,913 - \$7,369 | | 8.6 - 12.9 |
| 13 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 |
| 14 Daylight Dimming Control | 5.7% | 7.5% | \$1,342 | 10.4% | \$325 | \$1,666 | | \$15,723 - \$23,584 | 9.4 - 14.2 |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | 1.9% | 2.6% | \$462 | 3.6% | \$112 | \$574 | | \$7,587 - \$11,380 | 13.2 - 19.8 |
| E Renewable Power Measure | | | | | | | | | |
| 16 40 kW Photovoltaic Array | 29.3% | 34.1% | \$5,979 | 25.6% | \$800 | \$6,779 | | \$200,000 - \$300,000 | 29.5 - 44.3 |



Description of Combined Measures

| Combination of Measures ⁶ | Combined Annual Energy Savings (%) ¹ | | Combined Energy Savings (\$/year) ² | Combined Demand Savings (%) | Combined Demand Savings (\$/year) ³ | Combined Savings (Energy+Demand) (\$/year) | Combined Estimated Cost (\$) | | Simple Estimated Payback (yrs) | NOx Emissions Savings 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 11.2% | 15.6% | \$2,810 | 18.6% | \$582 | \$3,392 | \$6,052 - \$9,079 | | 8.4 - 12.7 | 47.1 | 31.0 | 19.4 |
| 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.) | | | | | | | \$6,052 - \$9,079 | | | | | |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 12.2% | 16.3% | \$2,932 | 20.3% | \$635 | \$3,567 | \$12,288 - \$18,432 | | 9.2 - 13.8 | 49.1 | 32.0 | 20.3 |
| 8 Improved Fan Efficiency (from 55% to 65%) | | | | | | | \$6,869 - \$10,303 | | | | | |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | | | | | | | | \$7,587 - \$11,380 | | | | |
| Combination 3 | | | | | | | | | | | | |
| 14 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 13.0% | 15.1% | \$2,654 | 20.3% | \$633 | \$3,287 | \$12,288 - \$18,432 | | 13.1 - 19.6 | 44.2 | 27.8 | 18.6 |
| 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:
- 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 = \$0.63/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%
 - * HVAC system: SEER 13 or EER 11 Rooftop PSZ & 80% Et Furnace
 - * DHW: 80% Et Gas Water heater

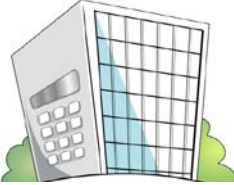
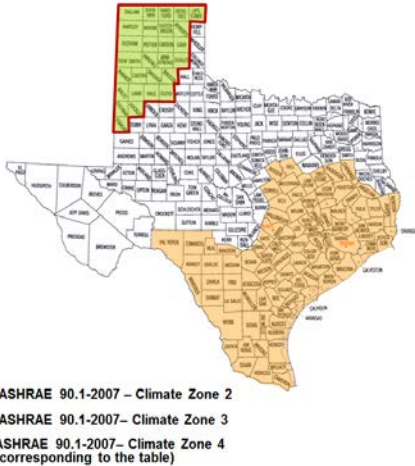


Figure 12. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 3

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) | 2.9% | 1.5% | \$181 | 0.4% | \$11 | \$192 | \$9,092 - \$13,639 | | 47.3 - 70.9 |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | 5.9% | 2.6% | \$289 | -0.2% | -\$5 | \$285 | \$6,223 - \$9,335 | | 21.9 - 32.8 |
| 3 0.5 PF Window Shading (None to 2.5 ft. Overhang for S/E/W) | -1.1% | 0.7% | \$195 | 2.0% | \$60 | \$255 | | \$14,159 - \$21,238 | 55.4 - 83.1 |
| 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) | -0.4% | 1.1% | \$244 | 2.4% | \$70 | \$314 | | \$14,159 - \$21,238 | 45.0 - 67.5 |
| B HVAC System Measures | | | | | | | | | |
| 5 CO ₂ Based Demand-Controlled Ventilation (DCV) | 3.2% | 1.6% | \$202 | 0.3% | \$9 | \$211 | | \$7,367 - \$11,051 | 34.9 - 52.3 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 2.1% | 2.7% | \$496 | 6.1% | \$181 | \$676 | \$12,288 - \$18,432 | | 18.2 - 27.3 |
| 7 Improved Furnace Efficiency (from 80% to 90% Et) | 3.5% | 1.6% | \$191 | 0.0% | \$0 | \$191 | \$7,900 - \$11,850 | | 41.3 - 61.9 |
| 8 Improved Fan Efficiency (from 55% to 65%) | 1.3% | 3.0% | \$576 | 3.1% | \$92 | \$668 | \$6,869 - \$10,303 | | 10.3 - 15.4 |
| C Service Hot Water Measures | | | | | | | | | |
| 9 Improved SHW Heater Efficiency (from 80% to 95% Et) | 1.0% | 0.5% | \$53 | 0.0% | \$0 | \$53 | \$3,456 - \$5,184 | | 64.8 - 97.2 |
| 10 Tankless Gas Water Heater | 1.6% | 1.6% | \$273 | 0.6% | \$17 | \$290 | \$1,414 - \$2,120 | | 4.9 - 7.3 |
| 11 Solar Service Hot Water System (64 sq.ft. collector, 80 gal tank) | 3.2% | 1.4% | \$151 | -0.2% | -\$6 | \$146 | | \$2,880 - \$4,320 | 19.8 - 29.6 |
| 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.) | 1.2% | 2.3% | \$436 | 3.2% | \$95 | \$531 | \$4,913 - \$7,369 | | 9.3 - 13.9 |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 3.0% | 5.7% | \$1,087 | 8.0% | \$236 | \$1,324 | \$6,052 - \$9,079 | | 4.6 - 6.9 |
| 14 Daylight Dimming Control | 4.1% | 6.8% | \$1,275 | 11.1% | \$328 | \$1,603 | \$15,723 - \$23,584 | | 9.8 - 14.7 |
| 15 Automatic Receptacle Control for Offices using Occupancy Sensors | 1.3% | 2.3% | \$429 | 3.6% | \$108 | \$537 | \$7,587 - \$11,380 | | 14.1 - 21.2 |
| E Renewable Power Measure | | | | | | | | | |
| 16 40 kW Photovoltaic Array | 27.1% | 36.1% | \$6,528 | 21.8% | \$648 | \$7,176 | \$200,000 - \$300,000 | | 27.9 - 41.8 |



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 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 Daylight Dimming Control | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 8.8% | 15.2% | \$2,878 | 20.1% | \$582 | \$3,460 | | \$6,052 - \$9,079 | 8.7 - 13.0 | 48.4 | 32.5 | 19.7 |
| 8 Improved Fan Efficiency (from 55% to 65%) | | | | | | | | \$6,869 - \$10,303 | | | | |
| 10 Tankless Gas Water Heater | | | | | | | | \$1,414 - \$2,120 | | | | |
| Combination 2 | | | | | | | | | | | | |
| 13 Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | 14.0% | 15.0% | \$2,580 | 17.9% | \$635 | \$3,215 | | \$6,052 - \$9,079 | 10.4 - 15.7 | 42.5 | 24.6 | 18.7 |
| 6 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | | | | | | | | \$12,288 - \$18,432 | | | | |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | | | | | | | | \$6,223 - \$9,335 | | | | |
| 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 | | | | | | | | \$15,723 - \$23,584 | | | | |
| 13 Improved Air Conditioner Efficiency (from 13 SEER & 11 EER to 18 SEER & 12.6 EER) | 16.4% | 15.9% | \$2,666 | 20.1% | \$633 | \$3,299 | | \$12,288 - \$18,432 | 14.9 - 22.4 | 43.7 | 24.0 | 19.6 |
| 2 Decreased Glazing U-Value (from 0.55 to 0.35) | | | | | | | | \$6,223 - \$9,335 | | | | |
| 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:
- 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 = \$0.63/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]
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 - * 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

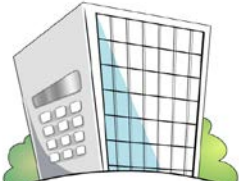


Figure 13. Individual and Combined Energy Efficiency Measures for an ASHRAE 90.1-2007 Code-Compliant Small Office Building for Climate Zone 4

5 SUMMARY

This report presents cost-effective recommendations to maximize energy savings for small office buildings across the State of Texas. A total of 16 recommendations based on the energy savings above the base-case building were selected. These measures include building envelope and fenestration, HVAC system, service hot water (SHW) system, lighting and receptacle, and renewable options. The implementation costs of each individual measure were also calculated along with simple payback calculations. 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. As a result, three combinations were proposed for each base case. Each combination was formed to have a different payback period. Finally, the corresponding emissions savings (NO_x, SO₂, and CO₂) of each combination were calculated based on the eGrid for Texas.

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APPENDIX A

Appendix A provides the implementation cost of each EEM obtained from various resources. Table A-1 summarizes the cost information for all measures, and the detailed product information and resources are listed in Table A-2 to Table A-6.

Table A-1. Summary of the Cost Information for an ASHRAE 90.1-2007 Code-Compliant Base Case

| | EEMs for ASHRAE 90.1-2007 Base Case | Description of EEM | | | Increased Cost per Unit | | Number of units/Total Area | | | Avg. Total Cost | Implementation Costs for Whole Building | | | References |
|----|-----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-------------------------|-------------------------------------|-------------------------|------------------|----------------------------|-------------|-------------|-----------------|-----------------------------------------|-----------|-----------|---------------------------------------------------|
| | | Unit/Category | Base Case | EEM | Unit | \$/Unit | Unit (#) | Length (ft) | Area (sqft) | | -20% | (Avg) | +20% | |
| 1 | Increased Roof and Wall Insulation R-Value (from 20 to 25 for roof and 13 to 13+3.8c.i. for walls) | hr-sq.ft.-°F/Btu | 20 | 25 | sqft | \$0.55 | | | 10,000 | \$5,500 | | | | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| | | hr-sq.ft.-°F/Btu | 0 c.i. | 3.8c.i. | sqft | \$0.71 | | | 8,320 | \$5,866 | \$9,092 | \$11,366 | \$13,639 | |
| 2 | Decreased Glazing U-Value (from 0.75 (CZ2), 0.65 (CZ3), and 0.55 (CZ4) to 0.35) | U-Value | 0.75 | 0.35 | sqft | \$6.2 | | | 2,080 | \$12,854 | \$10,284 | \$12,854 | \$15,425 | PNNL AEDG TSD-Small Office (Jarnagin et al. 2006) |
| | | | 0.65 | 0.35 | sqft | \$4.2 | | | 2,080 | \$8,798 | \$7,039 | \$8,798 | \$10,558 | |
| | | | 0.55 | 0.35 | sqft | \$3.7 | | | 2,080 | \$7,779 | \$6,223 | \$7,779 | \$9,335 | |
| 3 | Window Shading (None to 2.5 ft. Overhang for S/E/W) | Depth (ft) | 0 | 2.5 | length feet | \$42.5 | | 416 | | \$17,698 | \$14,159 | \$17,698 | \$21,238 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 4 | Window Shading and Redistribution (20% Equal Windows on All Sides with No Shadings to S=36%, N=20%, E/W=12% with 2.5 ft. Overhangs for S/E/W) | Depth (ft) WWR Front/ Back/ Right/ Left | 0 20%, 20%, 20%, 20% | 2.5 36%, 20%, 12%, 12% | length feet | \$42.5 | | 416 | | \$17,698 | \$14,159 | \$17,698 | \$21,238 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 5 | Outside Air Demand Control | OA Demand Control | No | Yes | each | \$921 | 10 | | | \$9,209 | \$7,367 | \$9,209 | \$11,051 | E source. 2006 |
| 6 | Improved Air Conditioner Efficiency | SEER (<65 kBtu/h) EER (≥135 and <240 kBtu/h) | 13 SEER 11 EER | 18 SEER 12.6 EER | each | \$1,536 | 10 | | | \$15,360 | \$12,288 | \$15,360 | \$18,432 | Kim et al. 2010 |
| 7 | Improved Furnace Efficiency (from 80% to 90% Et) | Et (%) | 80% | 90% | each | \$988 | 10 | | | \$9,875 | \$7,900 | \$9,875 | \$11,850 | Kim et al. 2010 |
| 8 | Improved Fan Efficiency (from 55% to 65%) | Fan Efficiency (%) | 55% | 65% | each | \$761 \$1,249 | 8 2 | | | \$8,586 | \$6,869 | \$8,586 | \$10,303 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 9 | Improved SHW Heater Efficiency (from 80% to 95% Et) | Et (%) | 80% | 95% | each | \$4,320 | 1 | | | \$4,320 | \$3,456 | \$4,320 | \$5,184 | PexSupply.com. 2011 |
| 10 | Tankless Gas Water Heater | tank heat loss Pump Electric Power (kW/100 gal) | 0.74% 0.00381 | 0.13% 0 | each | \$1,767 | 1 | | | \$1,767 | \$1,414 | \$1,767 | \$2,120 | PexSupply.com. 2011 |
| 11 | Solar SHW System (64 sq.ft. collector, 80 gal tank) | Solar SHW system | No | 64 sq.ft. collector, 80 gal tank | each | \$3,600 | 1 | | | \$3,600 | \$2,880 | \$3,600 | \$4,320 | Kim et al. 2010 |
| 12 | Decreased Lighting Power Density based on ASHRAE 90.1-2010 (from 1.0 to 0.9 W/sq.ft.) | W/ft ² | 1.0 | 0.9 | each | \$18.9 | 325 | | | \$6,141 | \$4,913 | \$6,141 | \$7,369 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 13 | Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.0 to 0.75 W/sq.ft.) | W/ft ² | 1.0 | 0.75 | each | \$23.3 | 325 | | | \$7,566 | \$6,052 | \$7,566 | \$9,079 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 14 | Daylight Dimming Control | Daylight Dimming Controls | No | Yes | each | \$1,228 | 16 | | | \$19,653 | \$15,723 | \$19,653 | \$23,584 | RSMMeans CostWorks ver. 4.7.0 (RCD 2011) |
| 15 | Automatic Receptacle Control for Offices | Automatic Receptacle Control | No | Yes | sqft | \$0.47 | | | 20,000 | \$9,483 | \$7,587 | \$9,483 | \$11,380 | C&S Program 2011 |
| 16 | 40 kW Photovoltaic Array | PV | No | 40 kW Photovoltaic Array | \$/watt | \$6.25 | 40 | | | \$250,000 | \$200,000 | \$250,000 | \$300,000 | Kim et al. 2010 |

Table A-2. Cost Information for Envelope and Fenestration Measures

EEM 1:
Increased Roof and Wall Insulation R-Value

| | Description | Total Roof/Wall Area (sq.ft.) | Increased Unit Cost (\$/sq.ft.) | Total Increased Cost (\$) | | | Remarks |
|----------------|--------------------------------------------|-------------------------------|---------------------------------|---------------------------|----------|----------|-----------------------------------------------------------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | Roof Insulation R-Value: R = 20 | 10,000 | \$ - | \$ - | \$ - | \$ - | Table <i>Increased Roof Insulation R-Value (1)</i> and <i>Increased Wall Insulation R-Value (1)</i> |
| | Wall Insulation R-Value: R = 13 | 8,320 | \$ - | \$ - | \$ - | \$ - | |
| EEM | Roof Insulation R-Value: R = 25 | 10,000 | \$ 0.55 | \$ 4,400 | \$ 5,500 | \$ 6,600 | |
| | Wall Insulation R-Value: R = 13 + 3.8 c.i. | 8,320 | \$ 0.71 | \$ 4,692 | \$ 5,866 | \$ 7,039 | |

References:
Increased Roof Insulation R-Value (1)

| | Description | Mat. Cost (\$/sq.ft.) | Labor Cost (\$/sq.ft.) | Bare Total (\$/sq.ft.) | Total O&P (\$/sq.ft.) | Total Roof Area (sq.ft.) | Total Roof Cost (\$) | Total Increased Cost | Source |
|----------------|---------------------------------------------------------------------------------------------|-----------------------|------------------------|------------------------|-----------------------|--------------------------|----------------------|----------------------|----------------------------------------|
| Base Case_2007 | Extruded polystyrene insulation, for roof decks, 3" thick, R15, 15 PSI compressive strength | \$ 1.04 | \$ 0.19 | \$ 1.23 | \$ 1.47 | 10,000 | \$ 14,700 | \$ - | RSMeans-CostWorks for Dallas Year 2011 |
| | Roof Deck Insulation, extruded polystyrene, 3" thick, R15, 25 PSI compressive strength | \$ 1.58 | \$ 0.19 | \$ 1.77 | \$ 2.06 | 10,000 | \$ 20,600 | | |
| EEM_2007 | Roof Deck Insulation, extruded polystyrene, 4" thick, R20, 25 PSI compressive strength | \$ 2.26 | \$ 0.19 | \$ 2.45 | \$ 2.80 | 10,000 | \$ 28,000 | | |

Increased Wall Insulation R-Value (1)

| | Description | Mat. Cost (\$/sq.ft.) | Labor Cost (\$/sq.ft.) | Bare Total (\$/sq.ft.) | Total O&P (\$/sq.ft.) | Total Wall Area (sq.ft.) | Total Wall Cost (\$) | Total Increased Cost | Source |
|-----|-----------------------------------------------------------------------|-----------------------|------------------------|------------------------|-----------------------|--------------------------|----------------------|----------------------|----------------------------------------|
| EEM | Wood fiber insulation, rigid, for walls, 1" thick, R3.85, low density | \$ 0.32 | \$ 0.22 | \$ 0.54 | \$ 0.69 | 8,320 | \$ 5,741 | \$ 5,866 | RSMeans-CostWorks for Dallas Year 2011 |
| | Wall Insulation, Rigid, expanded polystyrene, 1" thick, R3.85 | \$ 0.26 | \$ 0.28 | \$ 0.54 | \$ 0.72 | 8,320 | \$ 5,990 | | |

EEM 2:
Decreased Glazing U-value

| | Description | Total Glass Area (sq.ft.) | Increased Unit Cost (\$/sq.ft.) | Total Increased Cost (\$) | | | Remarks |
|-------------------------------|------------------------------------------|---------------------------|---------------------------------|---------------------------|-----------|-----------|--------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 (Harris, CZ2) | Clear single pane windows: U = 0.75 | 2,080 | \$ - | \$ - | \$ - | \$ - | Table Decreased Glazing U-Value (2) |
| EEM | Double pane with low-e coating: U = 0.35 | 2,080 | \$ 6.18 | \$ 10,284 | \$ 12,854 | \$ 15,425 | |
| Base Case_2007 (Tarrant, CZ3) | Double pane windows: U = 0.65 | 2,080 | \$ - | \$ - | \$ - | \$ - | |
| EEM | Double pane with low-e coating: U = 0.35 | 2,080 | \$ 4.23 | \$ 7,039 | \$ 8,798 | \$ 10,558 | |
| Base Case_2007 (Potter, CZ4) | Double pane windows: U = 0.55 | 2,080 | \$ - | \$ - | \$ - | \$ - | |
| EEM | Double pane with low-e coating: U = 0.35 | 2,080 | \$ 3.74 | \$ 6,223 | \$ 7,779 | \$ 9,335 | |

References:
Decreased Glazing U-Value (1)

| | Description | Mat. Cost (\$/sq.ft.) | Labor Cost (\$/sq.ft.) | Bare Total (\$/sq.ft.) | Total O&P (\$/sq.ft.) | Total Glass Area (sq.ft.) | Total Glazing Cost (\$) | Total Increased Cost | Source |
|-------------------------------|----------------------------------------------------------------------------------|-----------------------|------------------------|------------------------|-----------------------|---------------------------|-------------------------|----------------------|----------------------------------------|
| Base Case_2007 (Tarrant, CZ3) | Insulating Glass, double glazed, 5/8" thick unit, 3/16" float, 15-30 S.F., clear | \$ 13.4 | \$ 3.32 | \$ 16.7 | \$ 19.7 | 2,080 | \$ 40,914 | \$ - | RSMeans-CostWorks for Dallas Year 2011 |
| | Spectrally selective film, on ext, blocks solar gain/allows 70% of light | \$ 10.1 | \$ 3.15 | \$ 13.3 | \$ 15.9 | 2,080 | \$ 32,968 | | |
| EEM_2007 | Code_2007 with spectrally selective film (low-e coating) | \$ 23.5 | \$ 6.47 | \$ 29.9 | \$ 35.5 | 2,080 | \$ 73,882 | | |

Decreased Glazing U-value (2)

| | Description | Increased Unit Cost (\$/sq.ft.) | Total Glass Area (sq.ft.) | Total Increased Cost (\$) | Source |
|-------------------------------|---------------------------------|---------------------------------|---------------------------|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Base Case_2007 (Harris, CZ2) | U-value (Btu/hr-sq.ft.-F): 0.72 | \$ 3.90 | 2,080 | \$ - | PNNL AEDG TSD-Small Office Buildings: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-16250.pdf |
| Base Case_2007 (Tarrant, CZ3) | U-value (Btu/hr-sq.ft.-F): 0.60 | \$ 5.85 | 2,080 | \$ - | |
| Base Case_2007 (Potter, CZ4) | U-value (Btu/hr-sq.ft.-F): 0.57 | \$ 6.34 | 2,080 | \$ - | |
| EEM(Harris, CZ2) | U-value (Btu/hr-sq.ft.-F): 0.36 | \$ 9.56 | 2,080 | \$ 12,854 | |
| EEM(Tarrant, CZ3) | U-value (Btu/hr-sq.ft.-F): 0.34 | \$ 10.6 | 2,080 | \$ 8,798 | |
| EEM(Potter, CZ4) | U-value (Btu/hr-sq.ft.-F): 0.34 | \$ 10.1 | 2,080 | \$ 7,779 | |

**EEM 3 & 4:
2.5' Overhang**

| | Description | Total Overhang Length (ft.) | Increased Unit Cost (\$/ft.) | Total Increased Cost (\$) | | | Remarks |
|----------------|-------------------|-----------------------------|------------------------------|---------------------------|-----------|-----------|---------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No window shading | 416 | \$ - | \$ - | \$ - | \$ - | Table <i>Overhang (1)</i> |
| EEM | 2.5' overhang | 416 | \$ 42.5 | \$ 14,159 | \$ 17,698 | \$ 21,238 | |

**References:
Overhang (1)**

| | Description | Mat. Cost (\$/sq.ft. or ft.) | Labor Cost (\$/sq.ft. or ft.) | Bare Equipment (\$/sq.ft. or ft.) | Bare Total (\$/sq.ft.) | Total O&P (\$/sq.ft.) | Total Overhang Area(sq.ft.) or Length (ft.) | Total Overhang Cost (\$) | Total Increased Cost (\$) | Source |
|-----|-----------------------------------------------------------------|------------------------------|-------------------------------|-----------------------------------|------------------------|-----------------------|---------------------------------------------|--------------------------|---------------------------|---------------------------------------|
| EEM | Metal canopies, wall hung, .032", aluminum, prefinished, 8'X10' | \$ 26.9 | \$ 8.33 | \$ 2.05 | \$ 37.3 | \$ 45.9 | 1,040 | \$ 47,784 | \$ 44,245 | RSMean-CostWorks for Dallas Year 2011 |
| | Metal canopies, wall hung, .032", aluminum, prefinished, 8'X20' | \$ 26.7 | \$ 4.93 | \$ 1.21 | \$ 32.9 | \$ 39.1 | 1,040 | \$ 40,707 | | |

Table A-3. Cost Information for HVAC System Measures

**EEM 5:
Outside Air Demand Control**

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|-----------------------|-------------------------------|------|-------------------------------|---------------------------|----------|-----------|--------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No Outside Air Demand Control | 10 | \$ - | \$ - | \$ - | \$ - | Table <i>Outside Air Demand Control(1)</i> |
| EEM | Outside Air Demand Control | 10 | \$ 921 | \$ 7,367 | \$ 9,209 | \$ 11,051 | |

**References:
Outside Air Demand Control (1)**

| | Company | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|--------------------------|-----------------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| EEM: Sensor | Digital Control Systems Inc. | \$ 262 | 10 | \$ 321 | \$ 3,209 | esource: http://www.esource.com/BEA/hotbed/Xcel/PA_53.html |
| | Honeywell Control Products | \$ 350 | 10 | | | |
| | Johnson Controls Inc. | \$ 630 | 10 | | | |
| | Telaire Systems Inc. | \$ 150 to \$ 200 | 10 | | | |
| | Texas Instruments Inc. | \$ 265 to \$ 318 | 10 | | | |
| | Vaisala Inc. | \$ 335 | 10 | | | |
| | Veris Industries Inc. | \$ 378 | 10 | | | |
| EEM: Implementing | Implementing DCV on a newer DCV-ready RTU with an existing economizer | \$ 300 to \$ 900 | 10 | \$ 600 | \$ 6,000 | |

EEM 6:
Improved Air Conditioner Efficiency

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|---------------------------------------------------------------------------------------|------|-------------------------------|---------------------------|-----------|-----------|------------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | SEER (<65,000 Btu/h): 13 SEER EER (≥135,000 Btu/h and <240,000 Btu/h): 11 EER | 10 | \$ - | \$ - | \$ - | \$ - | Table <i>Improved Air Conditioner Efficiency (1)</i> |
| EEM | SEER (<65,000 Btu/h): 18 SEER EER (≥135,000 Btu/h and <240,000 Btu/h): 12.6 EER | 10 | \$ 1,536 | \$ 12,288 | \$ 15,360 | \$ 18,432 | |

References:
Improved Air Conditioner Efficiency (1)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|----------------|-----------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|---------------------------|
| Base Case_2007 | R-22 phase out refrigerant: Pilot-free PowerHeat™ ignition | \$ 5,100 | 10 | \$ - | \$ - | Residential Cost Analysis |
| | R-410A EPA complain refrigerant: Pilot-free PowerHeat™ ignition | \$ 5,100 | 10 | | | |
| | Ref. Type: R-22, Gas Furnace: 135000 Btu/hr | \$ 3,987 | 10 | | | |
| | \$12,000 includes duct work | \$ 4,500 | 10 | | | |
| EEM | R-22 phase out refrigerant: Pilot-free PowerHeat™ ignition | \$ 6,400 | 10 | \$ 1,536 | \$ 15,360 | |
| | R-410A EPA complain refrigerant: Pilot-free PowerHeat™ ignition | \$ 6,400 | 10 | | | |
| | Ref. Type: R-410A, Gas Furnace: 135000 Btu/hr | \$ 6,295 | 10 | | | |
| | \$13,000 includes duct work | \$ 5,500 | 10 | | | |

EEM 7:
Improved Furnace Efficiency

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|-------------|------|-------------------------------|---------------------------|----------|-----------|----------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | 80% | 10 | \$ - | \$ - | \$ - | \$ - | Table <i>Improved Furnace Efficiency (1)</i> |
| EEM | 90% | 10 | \$ 988 | \$ 7,900 | \$ 9,875 | \$ 11,850 | |

References:
Improved Furnace Efficiency (1)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|---------------------------|
| Base Case_2007 | Performance 80 Gas Furnace; Induced-combustion; Enhanced comfort control with dual stages of heating; 4-5 speed blower; Pilot-free PowerHeat™ ignition | \$ 2,700 | 10 | \$ - | \$ - | Residential Cost Analysis |
| | Up/Horiz | \$ 827 | 10 | | | |
| EEM | Performance 93 Gas Furnace; Multipoise condensing; direct vent/non direct vent; 4-5 speed blower; Pilot-free PowerHeat™ ignition | \$ 3,460 | 10 | \$ 988 | \$ 9,875 | |
| | Lennox Signature® Collection G61 94.1%AFUE Two-Stage, Multi-Speed Furnaces. Up/Horiz./Down | \$ 2,042 | 10 | | | |

EEM 8:
Improved Fan Efficiency

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|-------------|------|-------------------------------|---------------------------|----------|-----------|------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | 55% | 8 | \$ - | \$ - | \$ - | \$ - | Table <i>Improved Fan Efficiency (1)</i> |
| | | 2 | \$ - | | | | |
| EEM | 65% | 8 | \$ 761 | \$ 6,869 | \$ 8,586 | \$ 10,303 | |
| | | 2 | \$ 1,249 | | | | |

References:
Improved Fan Efficiency (1)

| | Description | Mat. Cost (\$/sq.ft.) | Labor Cost (\$/sq.ft.) | Bare Total (\$/sq.ft.) | Total O&P (\$/sq.ft.) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost | Source |
|----------------|------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------------|------------------------|-----------------------|------|-------------------------------|----------------------|----------------------------------------|
| Base Case_2007 | Axial Flow, constant speed; Direct drive, 1/8" S.P.; 12", 1060 CFM, 1/6 HP | \$ 560 | \$ 195 | \$ 755 | \$ 910 | 8 | | | RSMeans-CostWorks for Dallas Year 2011 |
| | Axial Flow, constant speed; Direct drive, 1/8" S.P.; 22", 4700 CFM, 3/4 HP | \$ 1,175 | \$ 226 | \$ 1,401 | \$ 1,613 | 2 | | | |
| EEM | In-line centrifugal, supply/exhaust booster; aluminum wheel/hub, disconnect switch; 1,380 CFM, 12" diameter connection | \$ 1,225 | \$ 291 | \$ 1,516 | \$ 1,790 | 8 | \$ 761 | \$ 8,586 | |
| | In-line centrifugal, supply/exhaust booster; aluminum wheel/hub, disconnect switch; 5,080 CFM, 20" diameter connection | \$ 1,875 | \$ 775 | \$ 2,650 | \$ 3,228 | 2 | \$ 1,249 | | |

Table A-4 Cost Information for Service Hot Water Measures

EEM 9:
Improved SHW Heater Efficiency

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|-------------|------|-------------------------------|---------------------------|----------|----------|-------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | 85% | 1 | \$ - | \$ - | \$ - | \$ - | Table <i>Improved SHW Heater Efficiency (1)</i> |
| EEM | 95% | 1 | \$ 4,320 | \$ 3,456 | \$ 4,320 | \$ 5,184 | |

References:
Improve SHW Heater Efficiency (1)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|----------------|--------------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|----------|
| Base Case_2007 | 98 Gallon-75,100 Btu Commercial Gas Water Heater | \$ 2,085 | 1 | \$ - | \$ - | AO Smith |
| | 98 Gallon-90,000 Btu Conservationist Commercial Gas Water Heater | \$ 2,650 | 1 | | | |
| EEM | 100 Gallon-150,000 Btu Cyclone Xi Commercial Gas Water Heater | \$ 5,633 | 1 | \$ 4,320 | \$ 4,320 | |
| | 100 Gallon-250,000 Btu Cyclone Xi ASME Commercial Gas Water Heater | \$ 7,742 | 1 | | | |

EEM 10:
Tankless Gas Water Heater

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|---------------------------------------------------------------|------|-------------------------------|---------------------------|----------|----------|--------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | DHW Tank Heat Loss: 0.74% DHW Pump Electric Power: 0.00381 | 1 | \$ - | \$ - | \$ - | \$ - | Table <i>Tankless Gas Water Heater (1)</i> |
| EEM | DHW Tank Heat Loss: 0.13% DHW Pump Electric Power: 0 | 1 | \$ 1,767 | \$ 1,414 | \$ 1,767 | \$ 2,120 | |

References:
Tankless Gas Water Heater (1)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|-----|-------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|----------|
| EEM | T-M32 Takagi Tankless Water Heater (Natural Gas) | \$ 1,589 | 1 | \$ 1,767 | \$ 1,767 | AO Smith |
| | T-M32 Takagi ASME Tankless Water Heater (Natural Gas) | \$ 1,945 | 1 | | | |

EEM 11:
Solar Service Hot Water System

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|-----------------------------------|------|-------------------------------|---------------------------|----------|----------|-------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No Solar Service Hot Water System | | \$ - | \$ - | \$ - | \$ - | Table <i>Solar Service Hot Water System (1)</i> |
| EEM | 64 sq.ft. collector, 80 gal tank | 1 | \$ 3,600 | \$ 2,880 | \$ 3,600 | \$ 4,320 | |

References:
Solar Service Hot Water System (1)

| | Description | 2010 Equipment Cost (\$) | Installation Cost (\$) | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|-----|----------------------------------|--------------------------|------------------------|-------------------------|------|-------------------------------|---------------------------|---------------------------|
| EEM | 64 sq. ft collector 80 Gallon | \$3200-\$4000 | n/a | \$ 3,200 to \$ 4,000 | 1 | \$ 3,600 | \$ 3,600 | Residential Cost Analysis |

Table A-5. Cost Information for Lighting and Receptacle Measures

EEM 12:
Decreased Lighting Power Density based on ASHRAE 90.1-2010

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|--------------|------|-------------------------------|---------------------------|----------|----------|---------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | 1.0 W/sq.ft. | 325 | \$ - | \$ - | \$ - | \$ - | Table <i>Decreased Lighting Power Density (1)</i> |
| EEM | 0.9 W/sq.ft. | 325 | \$ 18.9 | \$ 4,913 | \$ 6,141 | \$ 7,369 | |

References:
Decreased Lighting Power Density (1)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|----------------------|-------------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|-----------------------------------------|
| Base Case_2007: Lamp | Fluorescentlamp, energy saver, 32 watt, 4' long, T8 | \$ 16.0 | 325 | \$ - | \$ - | RSMMeans-CostWorks for Dallas Year 2011 |
| EEM: Lamp | Fluorescentlamp, high out put, energy saver, 28 watt, 4' long, T5 | \$ 34.9 | 325 | \$ 18.9 | \$ 6,141 | |

EEM 13:
Decreased Lighting Power Density based on AEDG-SMO-2011 (from 1.3 to 0.75 W/sq.ft.)

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|---------------|------|-------------------------------|---------------------------|----------|----------|---------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | 1.0 W/sq.ft. | 325 | \$ - | \$ - | \$ - | \$ - | Table <i>Decreased Lighting Power Density (2)</i> |
| EEM | 0.75 W/sq.ft. | 325 | \$ 23.3 | \$ 6,052 | \$ 7,566 | \$ 9,079 | |

References:
Decreased Lighting Power Density (2)

| | Description | Cost Per Unit (\$/unit) | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source |
|----------------------|-------------------------------------------------------------------|-------------------------|------|-------------------------------|---------------------------|-----------------------------------------|
| Base Case_2007: Lamp | Fluorescentlamp, energy saver, 32 watt, 4' long, T8 | \$ 16.0 | 325 | \$ - | \$ - | RSMMeans-CostWorks for Dallas Year 2011 |
| EEM: Lamp | Fluorescentlamp, high out put, energy saver, 21 watt, 3' long, T5 | \$ 39.3 | 325 | \$ 23.3 | \$ 7,566 | |

**EEM 14:
Daylight Dimming Control**

| | Description | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | | | Remarks |
|----------------|-----------------------------|------|-------------------------------|---------------------------|-----------|-----------|---------------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No daylight dimming control | 16 | \$ - | \$ - | \$ - | \$ - | Table <i>Decreased Lighting Power Density (2)</i> |
| EEM | Daylight dimming control | 16 | \$ 1,228 | \$ 15,723 | \$ 19,653 | \$ 23,584 | |

**References:
Daylight Dimming Control (1)**

| | Description | Cost Per Unit (\$/unit) | | Unit | Increased Unit Cost (\$/unit) | Total Increased Cost (\$) | Source | |
|------------------------------|----------------------------------|-------------------------|------------------------------|----------|-------------------------------|---------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------|
| | | | | | | | | |
| EEM (WattStopper) | Dimming Ballasts | \$ 50 | \$ 100 | \$ 1,032 | 16 | | http://www.wattstopper.com/ | |
| | Dimming photocell | \$ 140 | | | | | | |
| | Handheld programming remote | \$ 25 | | | | | | |
| | OCC sensor | \$ 140 | | | | | | |
| | PowerPack | \$ 27 | | | | | | |
| EEM (CW Lighting) | Ballasts | \$ 50 | \$ 100 | \$ 1,230 | 16 | \$ 1,228 | \$ 19,653 | http://www.cwlighting.com/ |
| | Dimming control module | \$ 300 | | | | | | |
| | Lighting Sensors | \$ 150 | | | | | | |
| | Wiring | \$ 5 | | | | | | |
| | PowerPack | \$ 75 | | | | | | |
| EEM (RS Means) | Daylight dimming control module | \$ 615 | included in unit costs | \$ 1,423 | 16 | | RSMMeans-CostWorks for Dallas Year 2011 | |
| | Daylight Sensor, ceiling mounted | \$ 208 | | | | | | |

EEM 15:
Automatic Receptacle Control for Offices

| | Description | Total Glass Area (sq.ft.) | Increased Unit Cost (\$/sq.ft.) | Total Increased Cost (\$) | | | Remarks |
|----------------|---------------------------------|---------------------------|---------------------------------|---------------------------|----------|-----------|-----------------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No automatic receptacle control | 20,000 | \$ - | \$ - | \$ - | \$ - | Table Automatic Receptacle Control (1) |
| EEM | Automatic receptacle control | 20,000 | \$ 0.47 | \$ 7,587 | \$ 9,483 | \$ 11,380 | |

References:
Automatic Receptacle Control (1)

| | Description | sq.ft. Cost (\$/sq.ft.) | Total Floor Area (sq.ft.) | Total Increased Cost (\$) | Source |
|-----|-----------------------------------------|-------------------------|---------------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| EEM | High Voltage OC Sensor for Small Office | \$ 0.55 | 20,000 | \$ 9,483 | Draft Measure Information Template – Office Task Lighting Plug Load Circuit Control - 2013 California building Energy Efficiency Standards (March 2011) |
| | Low Voltage OC Sensor for Small Office | \$ 0.40 | 20,000 | | |

Table A-6. Cost Information for Renewable Power Measure

EEM 16:
Photovoltaic Array

| | Description | Unit | Increased Unit Cost (\$/watt) | Total Increased Cost (\$) | | | Remarks |
|----------------|---------------|------|-------------------------------|---------------------------|------------|------------|-------------------------------------|
| | | | | -20% | (AVG) | 20% | |
| Base Case_2007 | No PV Array | | \$ - | \$ - | \$ - | \$ - | Table <i>Photovoltaic Array (1)</i> |
| EEM | 40kW PV Array | 40 | \$ 6.25 | \$ 200,000 | \$ 250,000 | \$ 300,000 | |

References:
Photovoltaic Array (1)

| | Description | Capacity | Equipment Cost (\$) | Installation Cost (\$) | Total Increased Cost (\$) | Source |
|-----|---------------|----------|---------------------|------------------------|---------------------------|---------------------------|
| EEM | 4 kW PV Array | 4 kW | \$10,000-\$20,000 | \$10,000 | \$20,000-\$30,000 | Residential Cost Analysis |