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ENERGY EFFICIENCY, COST-EFFECTIVENESS, AND AIR POLLUTANT REDUCTION ANALYSIS FROM ENERGY EFFICIENCY AND RENEWABLE ENERGY (EE/RE) PROJECTS IN TEXAS PUBLIC SCHOOLS

A Report to the U.S. EPA
Through the Laboratory's Center of Excellence
on Displaced Emission Reduction (CEDER)

Jeff S. Haberl, Ph.D., P.E.
Charles Culp, Ph.D., P.E.
Bahman Yazdani, P.E.
Hyojin Kim
Zi Liu, Ph.D.
Jaya Mukhopadhyay
Sunglok Do
Keehan Kim
Juan-Carlos Baltazar, Ph.D.

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ENERGY SYSTEMS LABORATORY

Texas Engineering Experiment Station
Texas A&M University System

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EXECUTIVE SUMMARY

The purpose of this report is to provide the preliminary results from an analysis of the potential energy savings, and resultant air pollution reductions associated with the energy savings from the application of cost-effective energy efficiency and renewable energy (EE/RE) projects applied to new and existing Texas Independent School Districts (ISDs). The final report from this analysis would be used in a marketing outreach program to school districts through the Texas Education Agency (TEA), Texas Association of School Boards (TASB), and others. This outreach program would be designed in concert with State agencies such as the State Energy Conservation Office (SECO), Public Utility Commission of Texas (PUCT), and Texas General Land Office (GLO); NGOs, and other federal agencies as appropriate.

The analysis was performed using a K-12 ESL simulation model based on the DOE-2.1e program that uses ASHRAE Standard 90.1 code-compliant, school buildings for three climate zones in Texas. A representative county in each climate zone was selected such as Harris County for Climate Zone 2, Dallas County for climate zone 3, and Potter County for Climate Zone 4. For each representative county, four base cases of each school group based on the year the school was built (Group 1: schools built before 2000; Group 2: schools built between 2000 and 2007; Group 3: schools built between 2007 and 2010; Group 4: new schools that will be built in 2011) that complies with the corresponding requirements of ASHRAE 90.1-1989, 1999, 2004, and 2007 were simulated.

A total of eighteen EE/RE measures were considered. These include measures for the building envelope, lighting, HVAC system, DHW system, and renewable energy systems. The proposed EE/RE measures were then applied to the base-case school model to examine the energy saving potential for Texas ISDs. Renewable energy options such as solar PV and GSHP had the largest annual total energy savings for all cases. Lighting measures such as daylight dimming controls and decreased lighting power density also resulted in high energy savings. However, for Potter County in Climate Zone 4, the savings from the lighting measures were not as large as the other counties because of the increased heating energy penalty. Among HVAC measures, OA demand control and PVAVS with VFD showed a good energy saving potential. Some measures such as improved AC efficiency and decreased supply fan power consumption resulted in higher savings for older school groups.

To examine the energy saving potential from the combination of individual EE/RE measures, a single group measure was simulated using the recommendations in the ASHRAE advance energy design guide (AEDG) for K-12 schools (ASHRAE 2008)[1]. The analysis demonstrates that 20.2% to 24.6% of a combined savings above 1999 base case (schools that built between 2000 and 2007) can be achieved by applying the recommendations in the AEDG for K-12 schools. Since the AEDG does not include any renewable measures, an energy saving potential would increase by implementing solar PV or GSHP measures.

Finally, to estimate the total state-wide potential energy and emissions savings of all Texas ISDs from the application of the AEDG measures, the total floor areas of each school group (Group 1: schools built before 2000; Group 2: schools built between 2000 and 2007; and Group 3: schools built between 2007 and 2010) was surveyed. For Group 4 (new schools that will be built in 2011), using the enrollment growth rate in Texas public schools (TEA 2009), the total floor area (sq. ft.) was estimated. Using the surveyed total floor area (sq.ft.) and simulated energy savings (kBtu/sq. ft.) of each school group in each climate zone, the total energy and emissions savings of the new and existing Texas ISDs from the application of the AEDG measures were estimated: 10,520,419 MMBtu/yr, 2,743 tons/yr for NOx, 1,772 tons/yr for SO_2, and 2,286,012 tons/yr for CO_2.

[1] The ASHRAE AEDG provides recommendations to achieve 30% energy savings over ASHRAE Standard 90.1-1999 for each climate zone.

A cost analysis was performed to determine the payback for each of the 18 energy efficiency measures implemented. The paybacks are based on the ASHRAE 90.1 1999 code. Best payback periods were obtained from decreasing the infiltration, improving the supply fan power and using tankless water heaters.

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1. INTRODUCTION

The purpose of this report is to provide the preliminary results from an analysis of the potential energy savings, and resultant air pollution reductions associated with the energy savings from the application of cost-effective energy efficiency and renewable energy (EE/RE) projects applied to new and existing Texas Independent School Districts (ISDs). The final report from this analysis would be used in a marketing outreach program to school districts through the Texas Education Agency (TEA), Texas Association of School Boards (TASB), and others. This outreach program would be designed in concert with State agencies such as the State Energy Conservation Office (SECO), Public Utility Commission of Texas (PUCT), and Texas General Land Office (GLO); NGOs, and other federal agencies as appropriate.

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1.1 Organization of the Report

The report is organized in the following order. Section 2 presents the methodology, including overview as well as developments of base-case model and EE/RE measures. Section 3 describes the base-case school model used for simulation, including building envelope characteristics, assumed space conditions, and HVAC and DHW system characteristics. Section 4 gives a description of 18 individual EE/RE measures. Section 5 presents the simulation results for the base case, individual EE/RE measures, and ASHRAE AEDG combination measure. And lastly Section 6 provides the estimation results of the total state-wide potential energy and emissions savings of all Texas ISDs from the application of the AEDG measures.

2. METHODOLOGY

2.1 Overview

Figure 1 shows the detailed procedure for calculating the potential energy savings for existing K-12 schools in Texas. The analysis considered the location of the school, type and year of construction. The schools were grouped according to the climate zones (CZ) given in ASHRAE 90.1 2004 and 2007 standards. Total number of schools and square footage was gathered for each type of school; elementary, middle and high schools[2]. The existing K-12 schools were also classified in four school groups according to the year of construction as Group 1: schools built before 2000; Group 2: schools built between 2000 and 2007; Group 3: schools built between 2007 and 2010; and Group 4: schools built after 2010. To assess the potential energy savings for new high performance K-12 schools in Texas, new schools that will be constructed in 2011 will be used and the total floor area (sq. ft.) of new schools will be estimated using the enrollment growth rate. For the baseline of new schools, ASHRAE Standard 90.1-2007 requirements will be referenced.

To estimate the total potential savings from implementing energy efficiency and renewable energy measures on all the schools of Texas, simulations for every school in each county should be carried out, which would lead to an extraordinary number of simulations. To simplify the calculation procedure a base-case simulation model was constructed for each group defined by the Climate Zones (CZ), Texas has three climate zones – the CZ2, CZ3 and CZ4. For each climate zone a representative county in each climate zone was selected such as Harris County for Climate Zone 2, Dallas County for climate zone 3, and Potter County for Climate Zone 4 (Figure 2). For each representative county, four base cases of each school group (based on the year the school was built) that complies with the corresponding requirements of ASHRAE 90.1-1989, 1999, 2004, and 2007 were simulated.[3] A total of eighteen energy efficient and renewal energy (EE/RE) measures and ASHRAE AEDG combination measure were then applied to the base-case school model to examine the energy saving potential for Texas ISDs. Finally, the total state-wide potential energy savings of all Texas ISDs from the application of the AEDG measures were estimated using the surveyed total floor area (sq. ft.) and simulated energy savings (kBtu/sq.ft.) of each school group in each climate zone. The corresponding emissions were calculated based on the eGrid for Texas.

[2] Information such as the total square footage of the schools and the average square footage per student in each group were provided by agencies such as the Texas Education agency, Energy star school and SECO K-12 energy audit.

[3] Other information for the base-case models were taken from the EPlus benchmark models, AEDG baseline models for schools and from surveys of schools conducted in the Bryan College Station area.

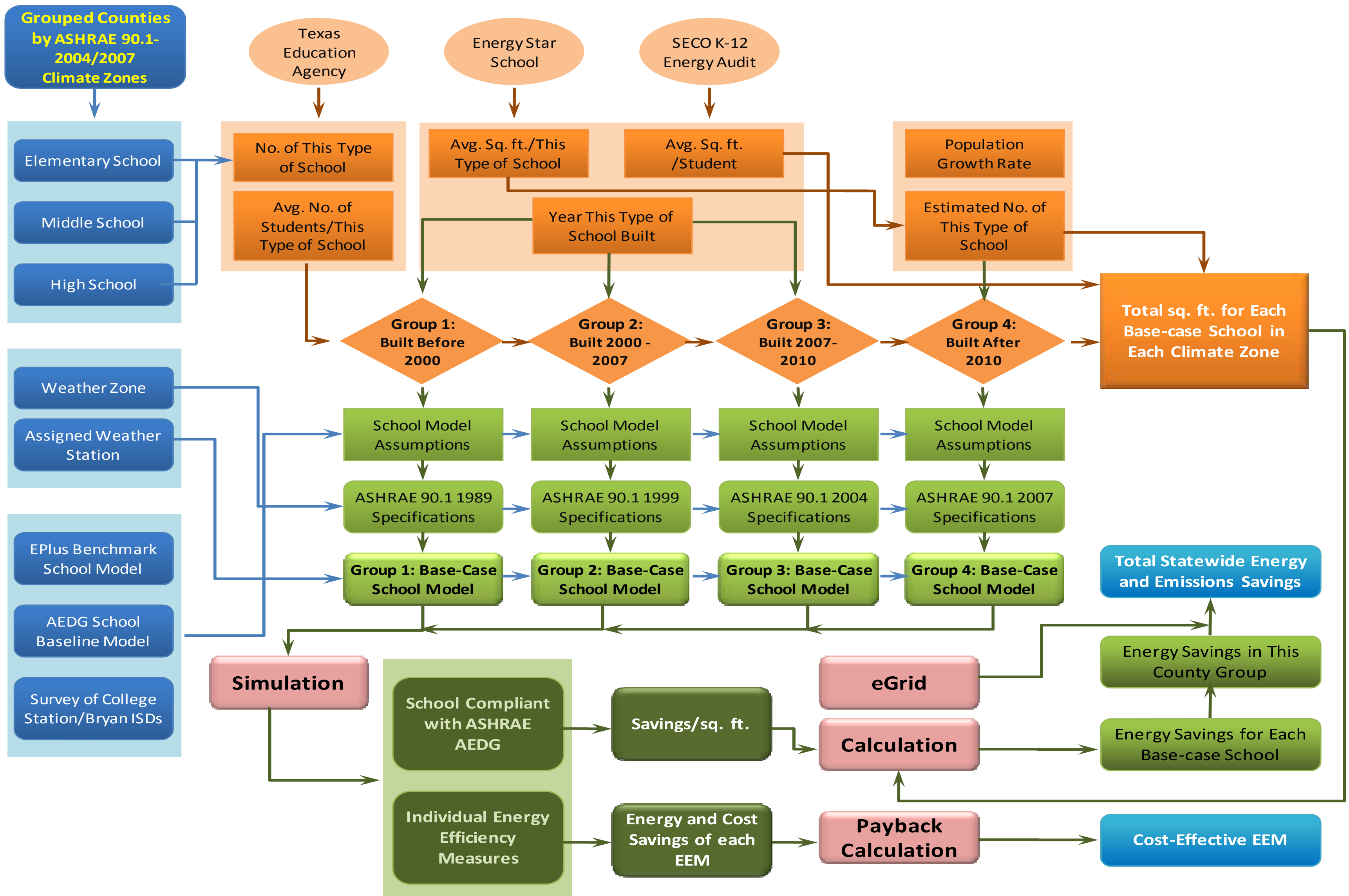


Figure 1. Flow Chart for Calculating Potential Energy Savings for Existing K-12 Schools

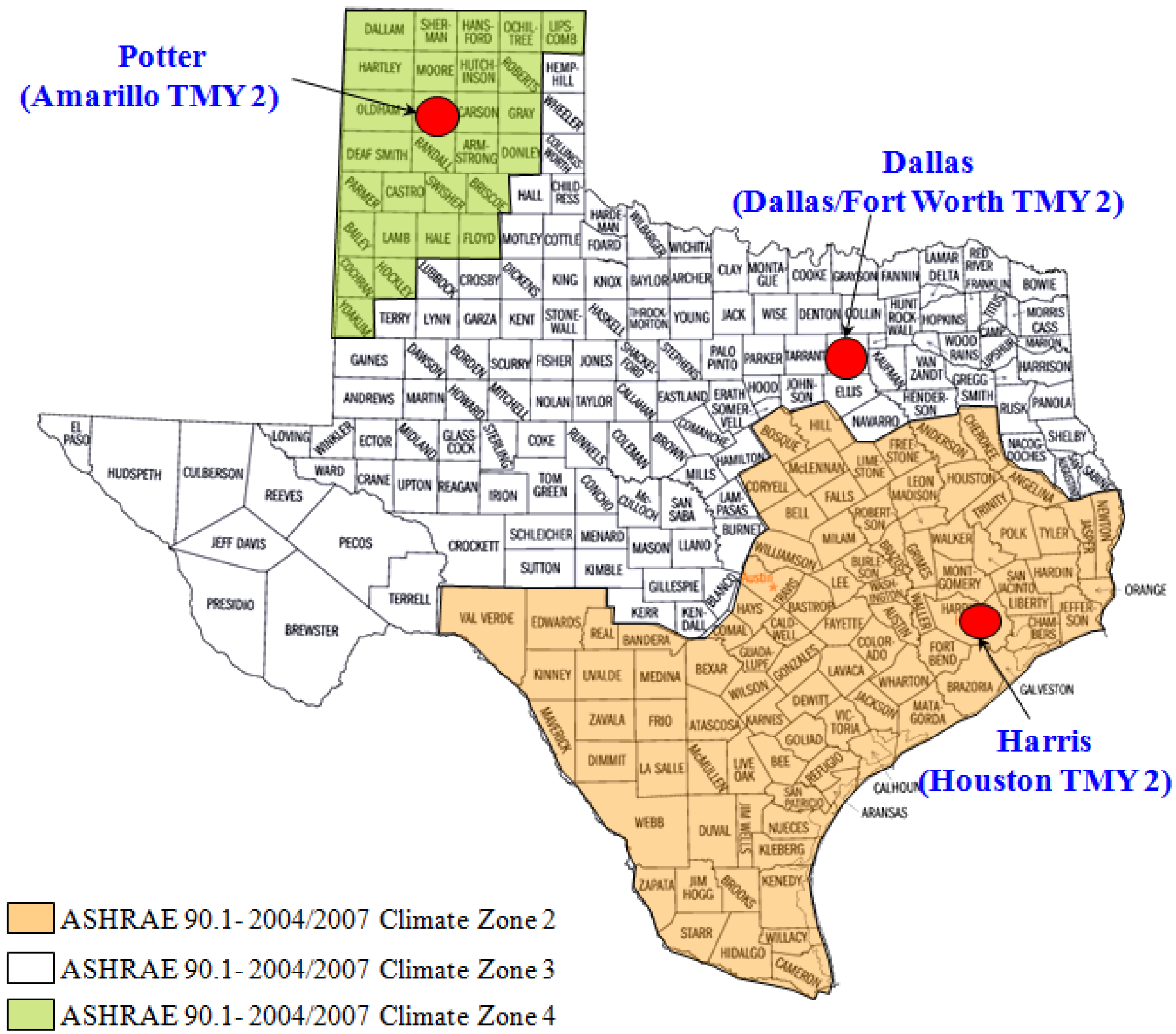


Figure 2. Climate Zones in ASHRAE Standard 90.1-2004/2007 and Three Selected Counties

2.2 Development of Base-Case Model

To develop a base-case school model, the following sources were reviewed: the ASHRAE Standard 90.1-1989, 1999, 2004, and 2007, the U.S. EPA Energy Star, the Texas Education Agency (TEA), and the EnergyPlus Benchmark school models. The floor area of the base-case model was determined based on the information from the TEA's K-12 school survey results and the Energy Star Labeled schools in Texas (Table 1). The TEA (2010) provides information of K-12 schools in Texas, including the number of schools and students. Using this information the average number of students per school was calculated. Then using the information from the Energy Star labeled schools in Texas (EPA 2010), the average floor area per student was calculated. Finally, using these two numbers, the average floor area per school was estimated for each school type: elementary, middle, and high school. This average floor area for an elementary school was then used for the base-case school model.

To determine a typical window area for K-12 schools in Texas, a field survey of elementary schools in Bryan and College Station school district was conducted (Table **2**). Six schools were selected based on the shape and geometry of the school. The selected schools were built between 1966 and 2009. The window-to-wall ratio (WWR) of each school was calculated and averaged, and the averaged WWR was used for the base-case model.

For the occupancy, lighting, equipment, and DHW schedules, space heating and cooling set back temperatures, and the type of HVAC and DHW system, the EnergyPlus Benchmark primary school model (EE/RE 2010) and the NREL's technical support document of the Advanced Energy Design Guide (AEDG) for K-12 schools (Pless et al. 2007) were used as references. Additional characteristics were then determined to comply with the ASHRAE Standard 90.1, including the building envelope construction, and HVAC and DHW system efficiency and controls.

2.3 Development of Energy Efficiency and Renewable Energy (EE/RE) Measures

To develop energy efficiency and renewable energy (EE/RE) measures for high performance schools, ASHRAE AEDG for K-12 Schools (ASHRAE 2008), the Collaborative for High Performance Schools (CHPS) Best Practices Manual (CHPS 2006) and the U.S. EPA Energy Star Building Upgrade Manual (EPA 2008) were reviewed. To determine the feasibility of these measures, an interview was conducted with a maintenance manager of College Station school district. Finally a total of 18 individual EE/RE measures[4] were considered.

[4] The selection of measures for this analysis is limited to the simulation capabilities of the DOE-2.1e program.

Table 1. K-12 School description from the Texas Education Agency (2010) and the U.S. EPA Energy Star (2010)

K-12 School	Texas Education Agency (TEA)			Energy Star				Estimated Avg. sq.ft./school
	No. of Schools	No. of Student	Avg. No. of Student/school	No. of Schools	No. of Student	Total Floor Area (sq.ft.)	Avg. sq.ft. per student	
Elementary	3,919	2,169,097	553	105	59,969	8,578,253	143	79,173
Middle	1,613	1,002,912	622	31	24,105	4,473,684	186	115,395
High	1,226	1,214,495	991	15	24,708	4,711,418	191	188,894
Total	8,276	4,710,935		160	110,202	19,059,308		

Table 2. Window Area of the Six Elementary Schools in Bryan and College Station School District

	Bryan				College Station	
	School 1	School 2	School 3	School 4	School 5	School 6
Year Built	2009	1999	1990	1996	1999	2007
Total Window Area (sq.ft.)	2,352	1,453	2,594	2,929	3,443	2,065
Total Wall Area (sq.ft.)	17,942	19,724	22,541	22,403	30,979	32,517
WWR (%)	13.1%	7.4%	11.5%	13.1%	11.1%	6.4%

3. BASE-CASE MODEL DESCRIPTION

The base-case school model is a one-story primary school with a 79,430 sq.ft of floor area. Figure 3 shows the shape and geometry of the base-case model. In this model, modified spine plan geometry was selected based on the study by Im (2009). The space usage includes classrooms, administration, cafeteria, and gymnasium activities.

3.1 Building Envelope Characteristics

The building was assumed to have a steel frame construction with 4” studs at 16” on center, a 4” concrete slab-on-grade floor, and flat built-up roofing with insulation entirely above the structural deck. The window area is equal to 10% of the WWR as surveyed from the Bryan and College Station schools and distributed equally with no exterior shading as specified in the ASHRAE Standard 90.1. Other climate-specific envelope characteristics such as wall and roof insulation and glazing U-value and solar heat gain coefficient (SHGC) were determined differently for each school group in each climate zone according to the corresponding requirements of the ASHRAE 90.1-1989, 1999, 2004, and 2007. Table 3 shows the specification of the base-case school model built between 2000 and 2007, which is compliant with ASHRAE 90.1-1999 requirement.

3.2 Space Conditions

The heating and cooling set-points were assumed to be 70°F for winter and 77°F for summer, with a 9.2°F setback and a 10.8°F setup (for winter and summer, respectively) during unoccupied hours. The equipment power density was assumed as 1.06 W/sq.ft. The lighting power density was determined differently for each school group to comply with the corresponding requirement of the ASHRAE 90.1-1989, 1999, 2004, and 2007: 1.57 W/sq.ft. for 1989 base case, 1.5 W/ sq.ft. for 1999 base cases, and 1.2 W/ sq.ft. for 2004 and 2007 base cases.

3.3 HVAC System Characteristics

The base-case HVAC system includes two different types of packaged rooftop units: packaged variable-air-volume systems (PVAVS) with two hot- water boilers for the classrooms and packaged single zone (PSZ) systems with furnaces for the common areas (administration, cafeteria, and gymnasium). The capacities of PVAVS and PSZ systems were assumed to be 30-ton and 10-ton, respectively. To determine the system efficiency and fan power consumption of each school group, the ASHRAE 90.1-1989, 1999, 2004, and 2007 were referenced: 8.5 energy efficiency ratio (EER) of PVAVS and 8.9 EER of PSZ for 1989 base case, 9.5 EER of PVAVS and 10.3 EER of PSZ for 1999 base case, 9.3 EER of PVAVS and 10.1 EER of PSZ for 2004 base case, and 9.8 EER of PVAVS and 11.0 EER of PSZ for 2007 base case. The supply fan power consumption were 1.7 hp/1,000 cfm of PVAVS and 1.2 hp/1,000 cfm of PSZ for 1989, 1999, and 2004 base cases and 1.5 hp/1,000 cfm of PVAVS and 1.1 hp/1,000 cfm of PSZ for 2007 base case. The ventilation rate was assumed to be 15% of design flow, and the supply air flow was determined based on the study of Im (2009) as follows: 1.0 cfm/sq. ft. for classroom, 1.03 cfm/sq. ft. for administration, 1.69 cfm/sq. ft. for cafeteria, and 1.72 cfm/sq. ft. for gymnasium.

3.4 DHW System Characteristics

For the base-case DHW system, two gas storage water heaters were assumed. The DHW heater thermal efficiency was determined based on the ASHRAE 90.1-1989, 1999, 2004, and 2007: 77% for 1989 base case and 80% for 1999, 2004, and 2007 base cases. The daily hot-water use was assumed to be 0.8 gallons/student/day according to the NREL's technical support document of the AEDG for K-12 schools (Pless et al. 2007)[5].

[5] The hot-water use assumption of 0.8 gal/student/day is the most appropriate for the K-4 schools. Table 7 in the ASHRAE Handbook HVAC Applications Chapter 49 (2007) specified the average daily hot-water demands of elementary schools and of junior/senior high schools as 0.6 gal/student and 1.8 gal/student, respectively.

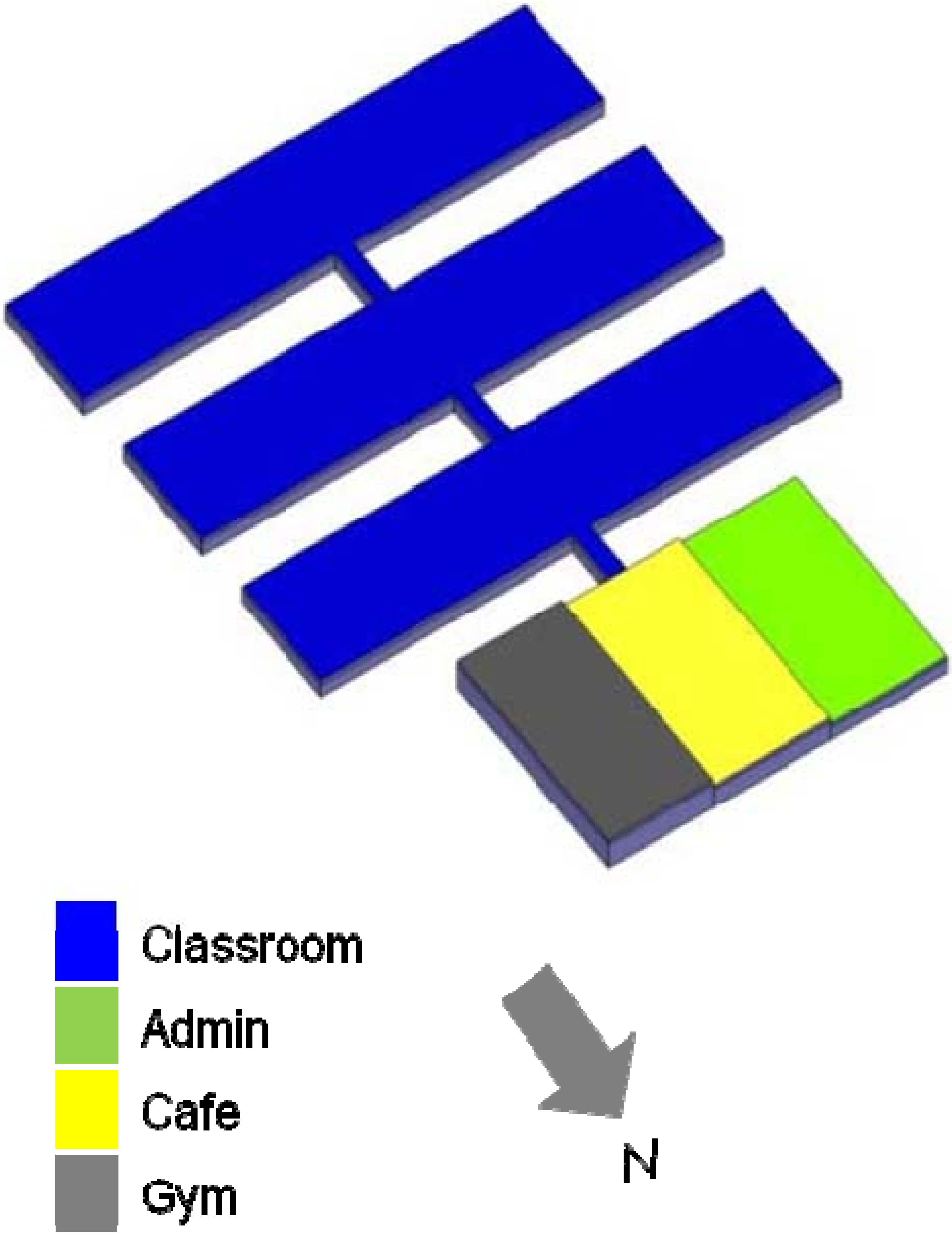


Figure 3. Shape and Geometry of Base-Case School Model (Im 2009)

Table 3. Characteristics of the ASHRAE 90.1-1999 Compliant Base-Case School Model for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4)

<table>
<tr><th rowspan="2">Characteristics</th><th colspan="3">Assumptions</th><th rowspan="2">Information Source</th></tr>
<tr><th>Harris County (Climate Zone 2)</th><th>Dallas county (Climate Zone 3)</th><th>Potter county (Climate Zone 4)</th></tr>
<tr><td colspan="5">Building</td></tr>
<tr><td>Building Type</td><td colspan="3">Primary School</td><td></td></tr>
<tr><td>Gross Area (sq. ft.)</td><td colspan="3">79,430</td><td>TEA Survey: Primary School</td></tr>
<tr><td>Number of Floors</td><td colspan="3">1</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Ceiling-to-Floor Height (ft.)</td><td colspan="3">10 ft (Classroom, Admin, Café, Gym)</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Orientation</td><td colspan="3">South facing</td><td></td></tr>
<tr><td colspan="5">Construction</td></tr>
<tr><td>Wall Construction</td><td colspan="3">Steel-Framed with
4" studs spaced at 16” on center</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Roof Configuration</td><td colspan="3">Flat built-up, Insulation entirely above deck</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Foundation Construction</td><td colspan="3">4" Concrete slab-on-grade floor</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Wall Absorptance</td><td colspan="3">0.55</td><td>DOE 2.1E BDL SUMMARY, Page 12</td></tr>
<tr><td>Wall Insulation (hr-sq.ft.-°F/Btu)</td><td colspan="3">R-13</td><td>ASHRAE 90.1-1999 Appendix B</td></tr>
<tr><td>Roof Absorptance</td><td colspan="3">0.7</td><td>ASHRAE 90.1-1999 11.4.2</td></tr>
<tr><td>Roof Insulation (hr-sq.ft.-°F/Btu)</td><td colspan="3">R-15 ci</td><td>ASHRAE 90.1-1999 Appendix B</td></tr>
<tr><td>Slab Perimeter Insulation</td><td colspan="3">None</td><td>ASHRAE 90.1-1999 Appendix B</td></tr>
<tr><td>Ground Reflectance</td><td colspan="3">0.24</td><td>DOE 2.1E BDL SUMMARY, Page 20</td></tr>
<tr><td>U-Factor of Glazing (Btu/hr-sq.ft.-°F)</td><td colspan="2">1.22</td><td>0.57</td><td>ASHRAE 90.1-1999 Appendix B</td></tr>
<tr><td>Solar Heat Gain Coefficient (SHGC)</td><td>0.25</td><td colspan="2">0.39</td><td>ASHRAE 90.1-1999 Appendix B</td></tr>
<tr><td>Window Area</td><td colspan="3">10% Window to wall ratio</td><td>Bryan/College Station School Survey</td></tr>
<tr><td>Exterior Shading</td><td colspan="3">None</td><td>ASHRAE 90.1-1999 11.4.2</td></tr>
<tr><td colspan="5">Space Conditions</td></tr>
<tr><td>Space Heating Set point</td><td colspan="3">70 F(Occupied), 60.8 F(Unoccupied)</td><td rowspan="2">EnergyPlus Benchmark</td></tr>
<tr><td>Space Cooling Set point</td><td colspan="3">77 F(Occupied), 87.8 F(Unoccupied)</td></tr>
<tr><td>Lighting Power Density (W/ft^2)</td><td colspan="3">1.5</td><td>ASHRAE 90.1-1999 Table 9.3.1.1</td></tr>
<tr><td>Equipment Power Density (W/ft^2)</td><td colspan="3">1.06</td><td>AEDG</td></tr>
<tr><td colspan="5">Mechanical Systems</td></tr>
<tr><td>HVAC System Type</td><td colspan="3">PVAVS: Classroom
PSZ: Admin/Café/Gym</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>Air Conditioning System Efficiency</td><td colspan="3">PVAVS: 9.5 EER
PSZ: 10.3 EER</td><td>ASHRAE 90.1-1999 Table 6.2.1A</td></tr>
<tr><td>Heating System Efficiency (%)</td><td colspan="3">80%</td><td>ASHRAE 90.1-1999 Table 6.2.1F</td></tr>
<tr><td>Cooling Capacity (Btu/hr)</td><td colspan="3">Autosized</td><td></td></tr>
<tr><td>Heating Capacity (Btu/hr)</td><td colspan="3">Autosized</td><td></td></tr>
<tr><td>Economizer</td><td colspan="3">No</td><td>ASHRAE 90.1-1999 6.3.1</td></tr>
<tr><td>Ventilation</td><td colspan="3">15 % of design flow</td><td></td></tr>
<tr><td>Supply Air Flow (cfm/sq.ft)</td><td colspan="3">Classroom: 1.00 cfm/sq.ft.
Admin: 1.03 cfm/sq.ft.
Cafe: 1.69 cfm/sq.ft.
Gym: 1.72 cfm/sq.ft.</td><td>Simplified School Model (Im 2009)</td></tr>
<tr><td>Supply Fan Power (hp/1000cfm)</td><td colspan="3">PVAVS: 1.7 hp/1000cfm
PSZ: 1.2 hp/1000cfm</td><td>ASHRAE 90.1-1999Table 6.3.3.1</td></tr>
<tr><td>DHW System Type</td><td colspan="3">Two gas storage water heaters (125 gallon, 199,000 Btu/hr)</td><td>EnergyPlus Benchmark</td></tr>
<tr><td>DHW Heater Efficiency (%)</td><td colspan="3">80 % Et</td><td>ASHRAE 90.1-1999Table 7.2.2</td></tr>
<tr><td>DHW Temperature Setpoint (F)</td><td colspan="3">140 F</td><td>EnergyPlus Benchmark</td></tr>
</table>

4. ENERGY EFFICIENCY AND RENEWABLE ENERGY (EE/RE) MEASURES

Table 4 lists a summary of the 18 individual EE/RE measures that were simulated for High Performance Schools. These include measures for the building envelope, lighting, HVAC system, DHW system, and renewable energy systems. Of 18 measures, three measures including Daylight Dimming Control, Skylights, and Ground Source Heat Pump were simulated using the eQuest 3.6 simulation software (JJH. 2009), and two 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 description of each measure is provided in the following section.

4.1 Description of Individual Measures

1) Increased Roof Insulation

This measure was simulated by specifying a roof insulation of R-25 according to the recommendations of the AEDG.

2) Decreased Glazing U-value

This measure was simulated by specifying a 0.45 Btu/h-sq.ft.-°F glazing U-value. The frame type and SHGC remained the same as the base case.

3) Decreased Infiltration

This measure analyzed the energy savings that would occur if the air leakage of the building decreased by using more airtight construction. This measure was simulated by reducing the fixed infiltration rates of the base cases (0.085 cfm sq.ft. for classroom, 0.083 cfm/ sq.ft. for administration, 0.087 cfm/ sq.ft. for cafeteria, and 0.07 cfm/ sq.ft. for gym) by 40%.

4) Decreased Lighting Power Density

This measure analyzed the energy savings that would occur if old lighting was replaced by energy efficient lighting. This measure was simulated by specifying a fixed lighting power density of 1.1 W/sq.ft., which is recommended by the AEDG for Climate Zone 2.

5) Occupancy Sensor for Lighting Control

This measure analyzed the energy savings that would occur by installing occupancy sensors for lighting control. This measure was simulated by adjusting the lighting power (i.e., 10% reduction) based on the methods in the Appendix G of ASHRAE 90.1-2007.

6) Daylight Dimming Controls

For this measure, continuous daylight dimming control systems were simulated using eQuest 3.6 simulation software (JJH. 2009). The sensors were assumed to be located 10 ft apart from side windows.

7) Skylights

For this measure, horizontal skylights were simulated in the cafeteria and gymnasium using eQuest 3.6 simulation software. Each skylight window has four by four feet dimension. A total of 20 skylights for the cafeteria and 18 skylights for the gymnasium were simulated to cover 4% of its roof area.

8) OA Demand Control

This measure analyzed the energy savings that would occur by installing CO_2 sensors for outside air demand control. This measure was simulated by changing the fixed ventilation ratio of the base cases (15% of design flow) to 15 cfm/person for classrooms and administration and 20 cfm/person for cafeteria and gymnasium.

9) Improved AC Efficiency
This measure was simulated by specifying the EER of the PVAVS and PSZ systems as 10.6 EER and 12.2 EER, respectively.

10) Improved Heating System Efficiency
This measure was simulated by increasing the heating system thermal efficiency from 80% to 90%.

11) Decreased Supply Fan Power Consumption
This measure was simulated by specifying the supply fan power consumption of the PVAVS and PSZ systems as 1.3 hp/1,000 cfm and 1.0 hp/1,000 cfm, respectively.

12) PVAVS with VFD for Fan Control
This measure was simulated by installing a variable frequency drive (VFD) for fan control of the PVAVS system instead of inlet vanes.

13) PVAVS with Variable Speed for HW Pump
This measure was simulated by installing variable speed hot-water (HW) pumps for PVAVS systems.

14) Improved DHW Heater Efficiency
This measure was simulated by increasing the DHW system thermal efficiency from 77%-80% to 95%.

15) Tankless Water Heater
To simulate this measure, the standby loss (SL) of DHW system decreased from 2% to 0.3%, and the circulation pump electricity use was minimized.

16) Renewable Energy-Solar PV
For this measure, solar PV systems with 16% efficiency that comprise 20% of roof area (16,000 sq.ft.) were simulated using the PV F-Chart program (Klein and Beckman 1994). The PV array tilt was assumed to be the same as the latitude of that location.

17) Renewable Energy-Solar DHW
For this measure, two solar thermal DHW systems were simulated using the F-Chart program (Klein and Beckman 1983). Each DHW system comprises of four 32 sq.ft. of flat plate solar collectors. The collector tilt was assumed to be the same as the latitude of that location. A constant hot-water use of 447 gallons/day was assumed year around. Additional electricity use was taken into account for operating the pump.

18) Ground Source Heat Pump (GSHP)
For this measure, conventional water source heat pumps with ground heat exchanger (GHX) units were simulated using eQuest 3.6 simulation software. The specification of the GHX units was decided based on the Geothermal Heat Pumps in K-12 Schools (Shonder et al. 2000). The GHX units consist of 120 vertical boreholes with 240 ft depth. Borehole spacing is 20 ft to reduce thermal interference between individual bores.

Table 4. Energy Efficient Measures for High Performance Schools for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4)

EEM #	Individual Energy Efficiency Measure (EEM)	Base Case Input												EEM Input	EEM Source
		Climate Zone 2 (Harris County)				Climate Zone 3 (Dallas County)				Climate Zone 4 (Potter County)					
		ASHRAE 90.1-1989	ASHRAE 90.1-1999	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-1989	ASHRAE 90.1-1999	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-1989	ASHRAE 90.1-1999	ASHRAE 90.1-2004	ASHRAE 90.1-2007		
Envelope Measures															
1	Increased Roof Insulation	R-14	R-15		R-20	R-16	R-15		R-20	R-16	R-15		R-20	R-25	AEDG
2	Decreased Glazing U-Value	U-1.15	U-1.22		U-0.75	U-1.15	U-1.22	U-0.57	U-0.65	U-0.81	U-0.57	U-0.57	U-0.40	U-0.45	AEDG
3	Decreased Infiltration	Classroom: 0.085 cfm/ft^2; Admin 0.083 cfm/ft^2; Café: 0.087 cfm/ft^2; Gym: 0.07 cfm/ft^2				Classroom: 0.085 cfm/ft^2; Admin 0.083 cfm/ft^2; Café: 0.087 cfm/ft^2; Gym: 0.07 cfm/ft^2				Classroom: 0.085 cfm/ft^2; Admin 0.083 cfm/ft^2; Café: 0.087 cfm/ft^2; Gym: 0.07 cfm/ft^2				40% Reduction	
Lighting Measures															
4	Decreased Lighting Power Density	1.57 W/ft^2	1.5 W/ft^2	1.2 W/ft^2		1.57 W/ft^2	1.5 W/ft^2	1.2 W/ft^2		1.57 W/ft^2	1.5 W/ft^2	1.2 W/ft^2		1.1 W/ft^2	AEDG
5	Occupancy Sensor for Lighting Control	No Occupancy Sensor				No Occupancy Sensor				No Occupancy Sensor				Occupancy Sensor	AEDG
6	Daylight Dimming Controls[2]	No Daylight Dimming Controls				No Daylight Dimming Controls				No Daylight Dimming Controls				Daylight Continuous Dimming Controls	AEDG
7	Skylights[2]	0% SRR				0% SRR				0% SRR				4% SRR for Gym and Café	
HVAC System Measures															
8	OA Demand Control	15% of design flow				15% of design flow				15% of design flow				Classroom/Admin: 15 cfm/person Café/Gym: 20 cfm/person	AEDG
9	Improved AC Efficiency (EER)	PVAVS:8.5 PSZ:8.9	PVAVS:9.5 PSZ:10.3	PVAVS:9.3 PSZ:10.1	PVAVS:9.8 PSZ:11.0	PVAVS:8.5 PSZ:8.9	PVAVS:9.5 PSZ:10.3	PVAVS:9.3 PSZ:10.1	PVAVS:9.8 PSZ:11.0	PVAVS:8.5 PSZ:8.9	PVAVS:9.5 PSZ:10.3	PVAVS:9.3 PSZ:10.1	PVAVS:9.8 PSZ:11.0	PVAVS:10.6 EER PSZ:12.2 EER	AEDG
10	Improved Heating System Efficiency	80%				80%				80%				90%	AEDG
11	Decreased Supply Fan Power Consumption	PVAVS:1.7 hp/1000 cfm PSZ 1.2 hp/1000 cfm			PVAVS:1.5 PSZ 1.1	PVAVS:1.7 hp/1000 cfm PSZ 1.2 hp/1000 cfm			PVAVS:1.5 PSZ 1.1	PVAVS:1.7 hp/1000 cfm PSZ 1.2 hp/1000 cfm			PVAVS:1.5 PSZ 1.1	PVAVS:1.3 hp/1000 cfm PSZ 1.0 hp/1000 cfm	AEDG
12	PVAVS with VFD for Fan Control	Inlet Vanes				Inlet Vanes				Inlet Vanes				VFD	
13	PVAVS with Variable Speed for HW Pump	Constant				Constant				Constant				Variable	
DHW Measures															
14	Improved DHW Heater Efficiency	77%	80%			77%	80%			77%	80%			95%	AEDG
15	Tankless Water Heater	DHW SL: 2%[1] DHW pump electric power: 0.00381 W/Btuh				DHW SL: 2%[1] DHW pump electric power: 0.00381 W/Btuh				DHW SL: 2%[1] DHW pump electric power: 0.00381 W/Btuh				DHW SL: 0.3% DHW pump electric power: 0 W/Btuh	
Renewable Measures															
16	Renewable Energy - Solar PV	No PV				No PV				No PV				200 kW PV (20% of Roof Area)	
17	Renewable Energy - Solar DHW	No SDHW				No SDHW				No SDHW				Two SDHW (One unit: 128 sq.ft., 120 gallon)	
18	Ground Source Heat Pump[2]	No GSHP				No GSHP				No GSHP				Vertical GSHP (120 Boreholes, 240 depth)	Geothermal Heat Pumps in K-12 Schools

NOTE:
1. Standby Loss (SL) based on a 70°F temperature difference between stored water and ambient requirements
2. EEM #6, #7 and #18 were modeled using eQuest 3.6 software.

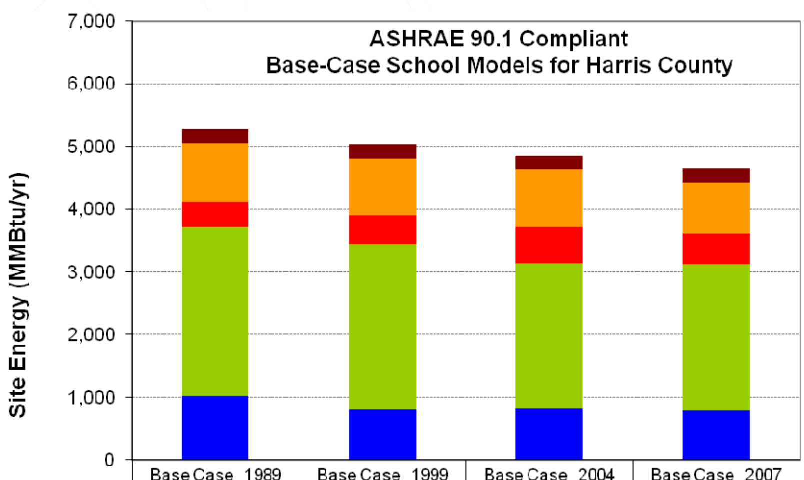
5. RESULTS

5.1 Base Case Energy Use

An analysis was performed for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4). Four base cases which are compliant with ASHRAE 90.1-1989, 1999, 2004, and 2007 were developed for each county. Figure 4 shows the annual site energy consumption for different end-uses and total for Harris, Dallas, and Potter County, respectively. The annual site energy use was obtained from the BEPS report of the DOE-2 output file.

Not surprisingly, the annual total energy consumption of base-case schools increased as the schools became older. The 1989 base case consumed the largest energy while the 2007 base case consumed the least energy. There was only one exception in Potter County, where the 1989 base case consumed less energy than 1999 base case due to more stringent code requirements of the ASHRAE 90.1-1989 for Potter County.

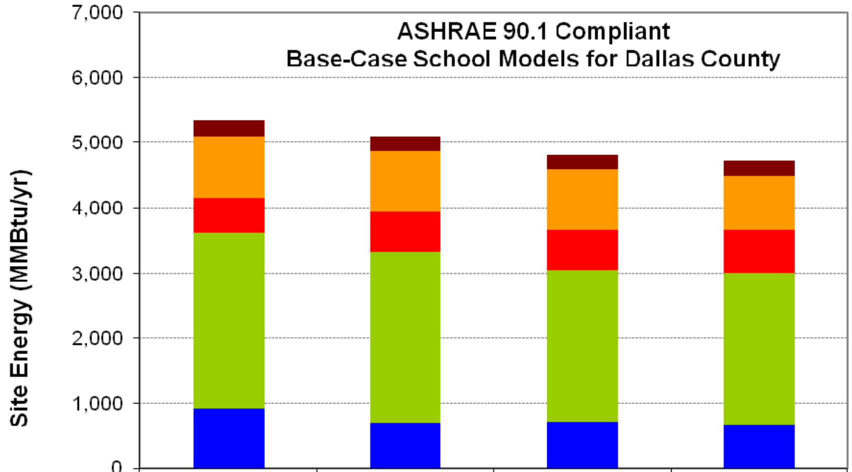
The annual total energy consumption of the Standard 90.1-1999 base case was 5,030 MMBtu/yr (63.3 kBtu/sq.ft.-yr) for Harris County, 5,101 MMBtu/yr (64.2 kBtu/sq.ft.-yr for Dallas County, and 5,875 MMBtu/yr (74.0 kBtu/sq.ft.-yr) for Potter County. By end-use category, the 1999 base-case consumption includes: 52.2% for lighting and equipment, 18.1% for fans and pumps, and 16.0% for cooling, 9.2% for heating, and 4.5% for domestic water heating for Harris County; 51.5% for lighting and equipment, 18.4% for fans and pumps, and 13.7% for cooling, 12.0% for heating, and 4.5% for domestic water heating for Dallas County; and 44.7% for lighting and equipment, 17.0% for fans and pumps, and 7.6% for cooling, 26.7% for heating, and 4.1% for domestic water heating for Potter County. This suggested that the measures that reduce lighting energy use would have the highest impact on the total energy use of school building, and for Potter County, the measures that reduce the heating energy use would have higher impact on the total energy use.



	Base Case_1989	Base Case_1999	Base Case_2004	Base Case_2007
Total	5,276	5,030	4,851	4,648
DHW	232	225	225	225
Fans+Pumps	933	913	913	816
Heating	394	460	575	493
Lgt+Appl	2,694	2,625	2,328	2,328
Cooling	1,023	807	811	786

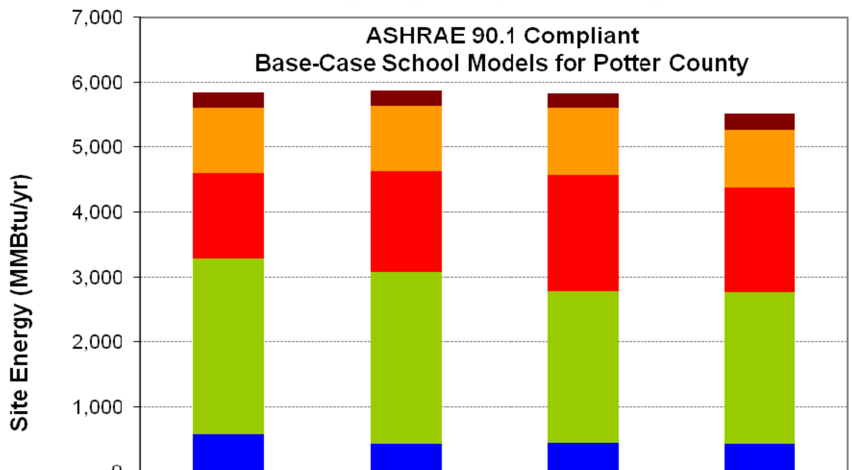
(a) Harris County (Climate Zone 2)

Figure 4. ASHRAE 90.1 Compliant Base-Case School Models



	Base Case_1989	Base Case_1999	Base Case_2004	Base Case_2007
Total	5,343	5,101	4,815	4,717
DHW	236	229	229	229
Fans+Pumps	948	938	928	829
Heating	552	610	617	655
Lgt+Appl	2,694	2,625	2,328	2,328
Cooling	912	700	712	676

(b) Dallas County (Climate Zone 3)



	Base Case_1989	Base Case_1999	Base Case_2004	Base Case_2007
Total	5,844	5,875	5,329	5,503
DHW	248	240	240	240
Fans+Pumps	989	998	1,010	891
Heating	1,329	1,566	1,803	1,605
Lgt+Appl	2,694	2,625	2,328	2,328
Cooling	583	445	448	439

(c) Potter County (Climate Zone 4)

Figure 4. ASHRAE 90.1 Compliant Base-Case School Models (continued)

5.2 Energy and Cost Savings from Individual EE/RE measures

Table 5 shows the annual site energy savings (%) above the base case achieved by each EE/RE measure for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4). The calculated cost savings ($/yr) are also presented in the Table 5. To show the impact of individual EE/RE measures on site energy consumption for different end-uses and total, these results were graphically represented in Figure 5 to 16 for Harris, Dallas, and Potter County.

5.2.1 Energy Savings

Renewable energy options such as solar PV and GSHP had the largest annual total energy savings for all cases. The savings above the base case from solar PV ranged from 17.9% to 22.8% across the climate zones. For the GSHP measure, it ranged from 6.4% to 28.3% (i.e, 6.4% to 11.2% for Harris County, 10.5% to 14.2% for Dallas County, and 21.0% to 28.3% for Potter County). Not surprisingly, the estimated savings from GSHP were larger in colder climate zones.

Daylight dimming controls also resulted in large energy savings ranging from 4.9% to 9.6% for Harris County, from 3.5% to 11.2% for Dallas County, and from 1.6% to 3.5% for Potter County. For Potter County, the savings from lighting measures were reduced due to the heating energy penalty. Larger savings were expected for older school groups due to their higher base-case lighting power density than new school groups. Likewise, decreasing the lighting power density measure by installing energy efficient lamps yields higher savings for older school groups in Harris and Dallas County: 7.1% for 1989 Harris case and 6.1% for 1989 Dallas case. The savings from occupancy sensors and skylights were less than 2% for all cases. For Potter County, a negative savings were estimated from skylights.

Among HVAC system measures, OA demand control showed a high energy saving potential in Potter County. The expected savings from OA demand control measure were 4.5% to 5.1% for Harris County, 4.4% to 4.7% for Dallas County, and 8.5% to 9.9% for Potter County. PVAVS with VFD measure also showed a promising energy saving potential with 5.3% to 5.8% savings for Harris County, 5.2% to 5.8% savings for Dallas County, and 3.9% to 4.5% savings for Potter County. Improved AC efficiency resulted in high savings for older school groups (1989 cases). The savings of 1989 cases were 6.8% for Harris County, 6.0% for Dallas County, and 3.5% for Potter County. Decreased supply fan power consumption measure yields between 3.3% and 3.8% savings for the existing school groups (1989, 1999, and 2004 cases). However, for the new schools (2007 cases), the savings were less than 2% due to their smaller base-case, fan power consumption.

Among the envelope measures, decreased infiltration showed a high energy saving potential in Potter County with 5.6% to 6.4% savings. The savings from DHW measures were small, less than 2% because the base-case, end-use consumption of domestic water heating was only around 4.1% to 4.5% of the total. However, the savings from these measures may be higher for the K-5 to K-12 schools since the base-case daily hot-water use was assumed based on the K-4 schools' hot-water demands.

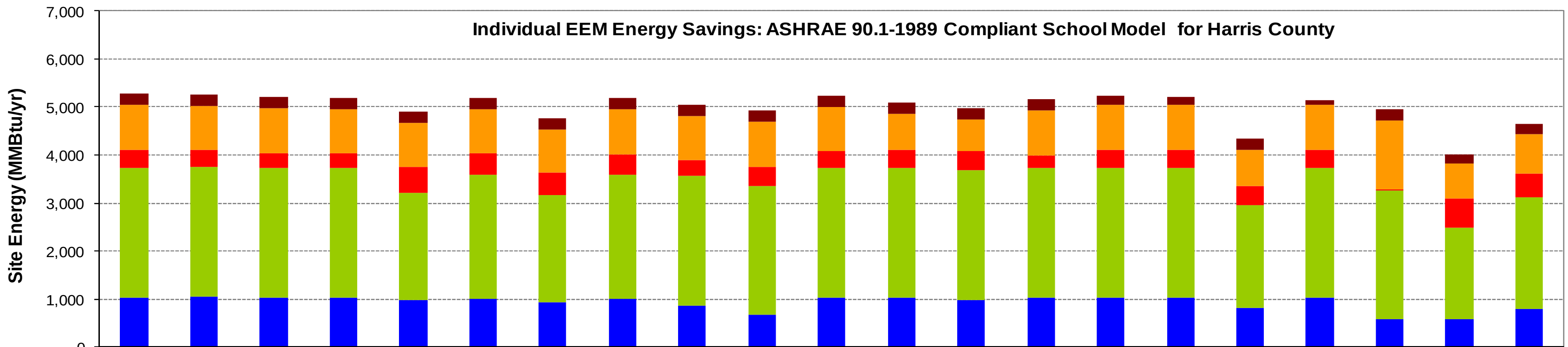
5.2.2 Cost Savings

First it should be noted that due to the difference in the unit cost of electricity and gas, the energy cost savings for a measure are not always of the same order as 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 result in large energy cost savings compared to the measures that reduce only gas use. For example, the savings from the GSHP measure is mainly from heating. Thus the estimated energy cost savings were small compared to other measures that reduce electricity use such as daylight dimming control or improved AC efficiency. To justify the cost-effectiveness of these proposed measures, a detailed cost analysis such as a payback period calculation will be performed and reported in a forthcoming report.

Table 5. Annual Total Site Energy and Cost Savings from Individual EE/RE Measures for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4)

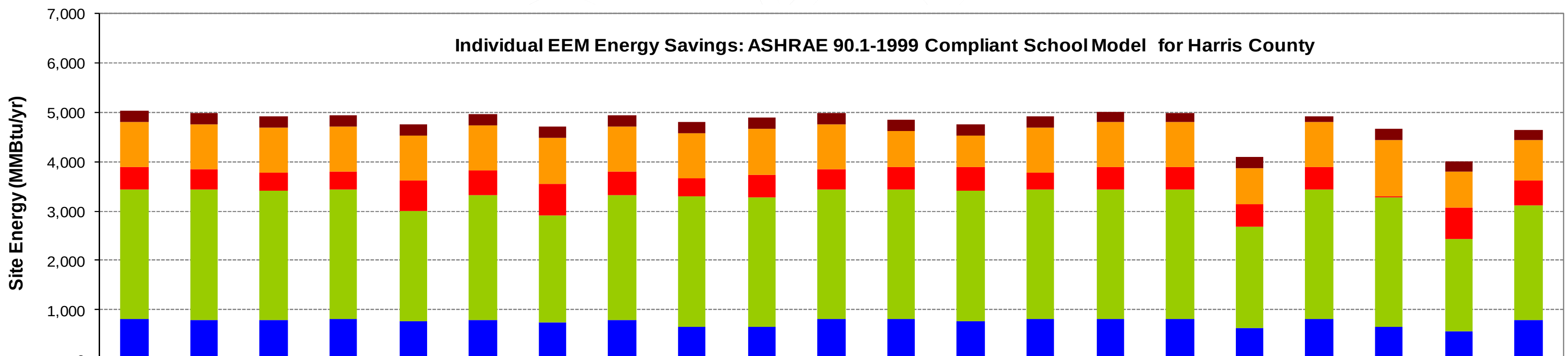
EEM #	Individual Energy Efficiency Measure (EEM)	Harris County (Climate Zone 2)								Dallas County (Climate Zone 3)								Potter County (Climate Zone 4)							
		ASHRAE 90.1-1989		ASHRAE 90.1-1999		ASHRAE 90.1-2004		ASHRAE 90.1-2007		ASHRAE 90.1-1989		ASHRAE 90.1-1999		ASHRAE 90.1-2004		ASHRAE 90.1-2007		ASHRAE 90.1-1989		ASHRAE 90.1-1999		ASHRAE 90.1-2004		ASHRAE 90.1-2007	
		Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]	Savings (%)[1]	Cost Savings ($/year)[2]
Envelope Measures																									
1	Increased Roof Insulation	0.5%	-$308	0.9%	$841	1.0%	$863	0.4%	$256	1.0%	$765	1.2%	$960	1.4%	$1,244	0.6%	$481	2.4%	$1,948	2.8%	$2,323	2.8%	$2,247	1.2%	$884
2	Decreased Glazing U-Value	1.4%	$556	2.4%	$2,141	2.9%	$2,503	0.9%	$404	2.2%	$1,108	2.5%	$1,126	0.5%	$256	1.0%	$479	3.3%	$2,294	1.2%	$880	1.2%	$889	-	-
3	Decreased Infiltration	1.6%	$974	1.8%	$1,130	2.1%	$1,343	2.0%	$1,124	2.3%	$1,465	2.4%	$1,269	2.7%	$1,495	2.8%	$1,586	5.6%	$4,123	5.8%	$4,453	6.1%	$4,758	6.4%	$4,617
Lighting Measures																									
4	Decreased Lighting Power Density	7.1%	$21,446	5.4%	$17,100	1.3%	$4,211	1.3%	$4,144	6.1%	$20,575	5.0%	$16,941	1.3%	$4,195	1.2%	$4,144	2.3%	$17,437	1.4%	$14,182	0.3%	$3,472	0.3%	$3,478
5	Occupancy Sensor for Lighting Control	1.7%	$5,249	1.5%	$4,705	1.1%	$3,661	1.1%	$3,616	1.4%	$4,996	1.3%	$4,676	1.1%	$3,659	1.0%	$3,595	0.6%	$4,398	0.4%	$3,994	0.2%	$3,108	0.2%	$3,102
6	Daylight Dimming Controls[3]	9.6%	$24,913	6.6%	$20,081	4.9%	$15,820	5.0%	$15,391	11.2%	$28,249	6.0%	$19,550	3.9%	$14,205	3.5%	$13,338	3.5%	$18,467	2.5%	$16,649	1.4%	$12,725	1.6%	$12,743
7	Skylights[3]	1.9%	$5,251	1.9%	$5,111	1.4%	$3,943	1.6%	$3,962	1.6%	$4,997	1.1%	$4,483	0.8%	$3,101	0.9%	$3,362	-0.8%	$3,440	-0.9%	$3,085	-1.3%	$1,977	-1.2%	$2,132
HVAC System Measures																									
8	OA Demand Control	4.5%	$8,078	4.6%	$7,499	5.1%	$7,789	4.8%	$7,381	4.7%	$7,076	4.4%	$5,969	4.7%	$6,265	4.7%	$5,963	8.5%	$5,137	9.2%	$5,599	9.9%	$5,805	9.6%	$5,433
9	Improved AC Efficiency	6.8%	$15,826	3.0%	$6,709	3.6%	$7,680	3.2%	$6,608	6.0%	$14,156	2.6%	$5,790	3.2%	$6,726	2.7%	$5,693	3.5%	$9,100	1.4%	$3,640	1.6%	$4,190	1.5%	$3,706
10	Improved Heating System Efficiency	0.8%	$397	1.0%	$474	1.3%	$596	1.1%	$506	1.1%	$567	1.3%	$632	1.4%	$632	1.5%	$677	2.4%	$1,383	2.9%	$1,633	3.3%	$1,886	3.1%	$1,675
11	Decreased Supply Fan Power Consumption	3.5%	$8,058	3.6%	$7,900	3.7%	$7,891	1.9%	$3,917	3.5%	$8,212	3.6%	$8,124	3.8%	$8,036	1.9%	$3,983	3.3%	$8,516	3.3%	$8,608	3.4%	$8,700	1.8%	$4,260
12	PVAVS with VFD for Fan Control	5.6%	$13,609	5.6%	$12,969	5.8%	$13,037	5.3%	$11,538	5.4%	$13,631	5.5%	$13,200	5.8%	$13,079	5.2%	$11,568	4.5%	$13,667	4.3%	$13,578	4.3%	$13,714	3.9%	$11,886
13	PVAVS with Variable Speed for HW Pump	2.4%	$1,773	2.4%	$1,728	2.6%	$1,816	2.5%	$1,681	2.1%	$1,615	2.2%	$1,605	2.3%	$1,568	2.3%	$1,559	2.8%	$2,301	2.7%	$2,295	2.8%	$2,344	2.9%	$2,269
DHW Measures[4]																									
14	Improved DHW Heater Efficiency	0.7%	$340	0.6%	$279	0.6%	$279	0.6%	$279	0.7%	$355	0.6%	$285	0.6%	$281	0.6%	$281	0.7%	$374	0.5%	$299	0.5%	$299	0.6%	$299
15	Tankless Water Heater	1.1%	$2,093	1.1%	$2,091	1.1%	$2,091	1.2%	$2,091	1.1%	$2,102	1.1%	$2,096	1.2%	$2,092	1.2%	$2,096	1.0%	$2,112	1.0%	$2,109	1.0%	$2,104	1.0%	$2,109
Renewable Measures																									
16	Renewable Energy - Solar PV	17.9%	$41,592	18.8%	$41,592	19.5%	$41,592	20.4%	$41,592	20.1%	$47,202	21.0%	$47,202	22.3%	$47,202	22.8%	$47,202	20.1%	$51,537	20.0%	$51,537	20.1%	$51,537	21.3%	$51,537
17	Renewable Energy - Solar DHW	2.4%	$1,171	2.4%	$1,100	2.5%	$1,100	2.6%	$1,100	2.7%	$1,338	2.7%	$1,265	2.8%	$1,265	2.9%	$1,265	2.7%	$1,482	2.6%	$1,405	2.6%	$1,405	2.7%	$1,405
18	Ground Source Heat Pump[3]	6.4%	$1,806	7.6%	$1,509	11.2%	$4,811	10.0%	$4,080	10.5%	$6,431	11.2%	$4,892	12.6%	$6,278	14.2%	$7,695	21.0%	$9,860	24.2%	$10,342	28.3%	$12,568	26.9%	$11,672
Combinations																									
1	AEDG	23.8%	$61,598	20.2%	$49,970	17.4%	$38,430	13.7%	$32,304	25.0%	$67,009	21.5%	$55,083	16.7%	$42,104	14.9%	$36,734	23.9%	$60,492	24.6%	$54,415	23.9%	$44,349	19.4%	$36,976
2	ASHRAE 90.1 2007	11.9%	$30,663	7.6%	$17,880	4.2%	$6,205	-	-	11.7%	$30,726	7.5%	$18,419	2.0%	$5,590	-	-	5.8%	$23,997	6.3%	$17,644	5.6%	$7,661	-	-

NOTE:
1. Annual total site energy savings from heating, cooling, lighting, equipment and DHW.
2. Savings depend on fuel mix used.
* Energy Cost: Electricity = $0.15/kWh
Natural gas = $1.00/therm
3. EEM #6, #7 and #18 were modeled using eQuest 3.6 software.
4. These DHW measures are applicable to K-4 schools. The savings from measures impacting DHW consumption will be different for the K-5 to K-12 schools.



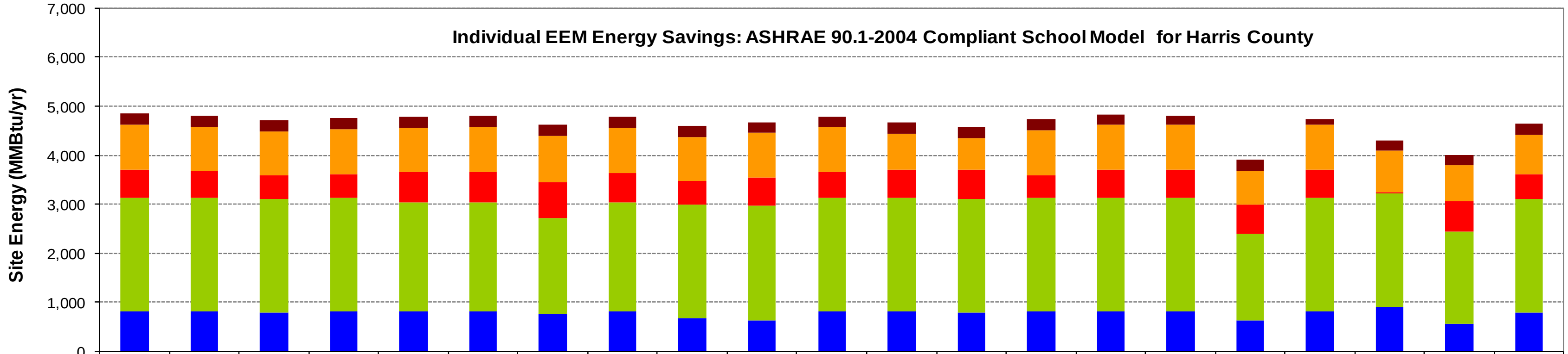
	Base Case (1989)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,276	5,251	5,201	5,189	4,901	5,186	4,768	5,174	5,036	4,916	5,235	5,093	4,981	5,151	5,240	5,220	4,330	5,149	4,940	4,022	4,648
DHW	232	232	232	232	232	232	232	232	232	232	232	232	232	232	197	177	232	105	232	205	225
Fans+Pumps	933	923	929	930	926	931	908	934	921	933	933	749	658	922	933	933	743	933	1,424	726	816
Heating	394	352	312	308	542	433	470	416	318	394	352	394	412	279	394	394	394	394	15	611	493
Lgt+Appl	2,694	2,694	2,694	2,694	2,229	2,581	2,215	2,581	2,694	2,694	2,694	2,694	2,694	2,694	2,694	2,694	2,146	2,694	2,694	1,899	2,328
Cooling	1,023	1,049	1,034	1,024	972	1,009	944	1,010	870	663	1,023	1,023	983	1,023	1,023	1,023	815	1,023	574	581	786

Figure 5. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1989 Compliance Base-Case School: Harris County (Climate Zone 2)



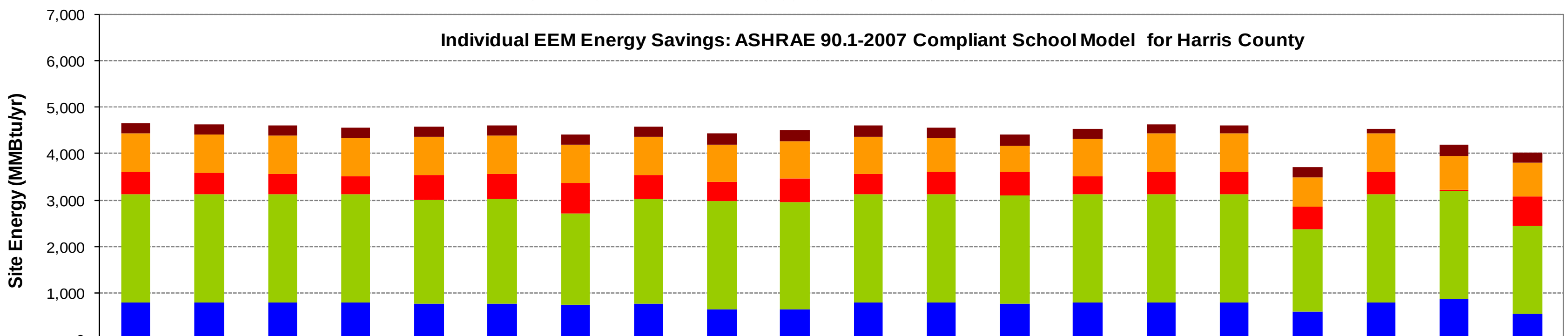
	Base Case (1999)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,030	4,985	4,907	4,938	4,757	4,957	4,700	4,934	4,798	4,877	4,981	4,850	4,750	4,909	5,002	4,975	4,084	4,910	4,650	4,012	4,648
DHW	225	225	225	225	225	225	225	225	225	225	225	225	225	225	197	170	225	105	225	205	225
Fans+Pumps	913	907	909	909	913	913	932	914	906	913	913	733	639	902	913	913	714	913	1,136	734	816
Heating	460	427	363	373	612	505	623	487	379	460	412	460	480	350	460	460	460	460	17	632	493
Lgt+Appl	2,625	2,625	2,625	2,625	2,229	2,516	2,170	2,515	2,625	2,625	2,625	2,625	2,625	2,625	2,625	2,625	2,053	2,625	2,625	1,885	2,328
Cooling	807	801	785	806	778	798	750	793	664	654	807	807	781	807	807	807	631	807	647	556	786

Figure 6. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1999 Compliance Base-Case School: Harris County (Climate Zone 2)



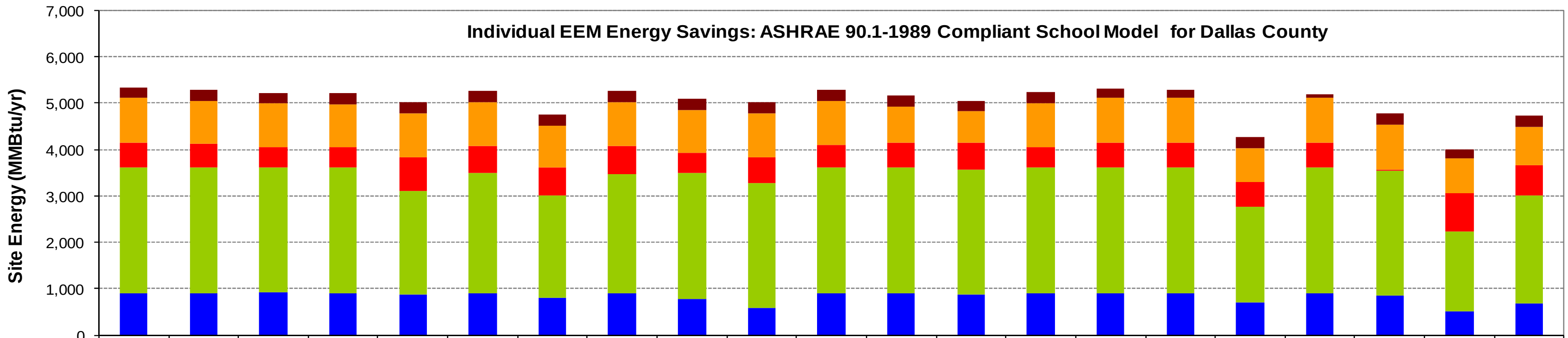
	Base Case (2004)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	4,851	4,804	4,713	4,751	4,787	4,799	4,613	4,781	4,603	4,677	4,790	4,672	4,571	4,724	4,823	4,796	3,905	4,731	4,309	4,006	4,648
DHW	225	225	225	225	225	225	225	225	225	225	225	225	225	225	197	170	225	105	225	205	225
Fans+Pumps	913	907	906	905	913	913	930	914	906	913	913	733	637	901	913	913	700	913	844	732	816
Heating	575	538	468	484	615	615	731	600	480	575	514	575	596	459	575	575	575	575	20	629	493
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,971	2,241	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,784	2,328	2,328	1,887	2,328
Cooling	811	806	786	809	804	804	756	802	664	636	811	811	785	811	811	811	622	811	893	554	786

Figure 7. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-2004 Compliance Base-Case School: Harris County (Climate Zone 2)



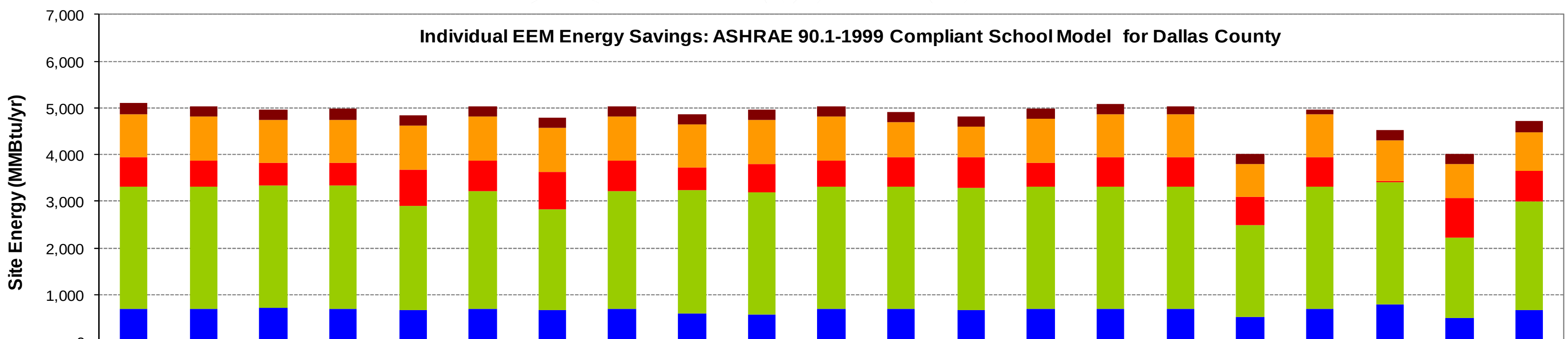
	Base Case (2007)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG
Total	4,648	4,631	4,606	4,555	4,587	4,598	4,415	4,576	4,423	4,498	4,596	4,559	4,400	4,530	4,620	4,593	3,702	4,528	4,185	4,012
DHW	225	225	225	225	225	225	225	225	225	225	225	225	225	225	197	170	225	105	225	205
Fans+Pumps	816	814	814	812	817	817	833	817	810	816	816	727	575	806	816	816	620	816	737	734
Heating	493	479	451	405	536	536	643	516	416	493	441	493	512	385	493	493	493	493	18	639
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,973	2,241	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,768	2,328	2,328	1,879
Cooling	786	785	789	785	779	779	740	777	643	636	786	786	760	786	786	786	597	786	877	556

Figure 8. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-2007 Compliance Base-Case School: Harris County (Climate Zone 2)



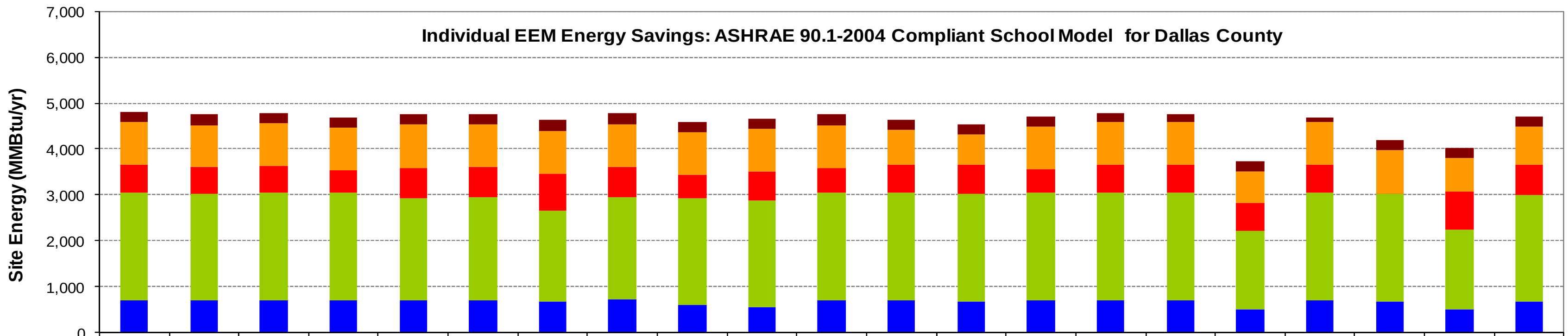
	Base Case (1989)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,343	5,291	5,224	5,218	5,018	5,266	4,743	5,258	5,093	5,021	5,284	5,156	5,053	5,230	5,307	5,287	4,269	5,198	4,781	4,007	4,717
DHW	236	236	236	236	236	236	236	236	236	236	236	236	236	236	200	180	236	92	236	209	229
Fans+Pumps	948	940	942	941	947	948	896	952	936	948	948	761	667	938	948	948	724	948	979	736	829
Heating	552	508	430	433	738	601	607	589	434	552	494	552	579	449	552	552	552	552	19	824	655
Lgt+Appl	2,694	2,694	2,694	2,694	2,229	2,581	2,210	2,580	2,694	2,694	2,694	2,694	2,694	2,694	2,694	2,694	2,059	2,694	2,694	1,729	2,328
Cooling	912	913	922	913	867	900	794	901	792	590	912	912	877	912	912	912	697	912	852	509	676

Figure 9. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1989 Compliance Base-Case School: Dallas County (Climate Zone 3)



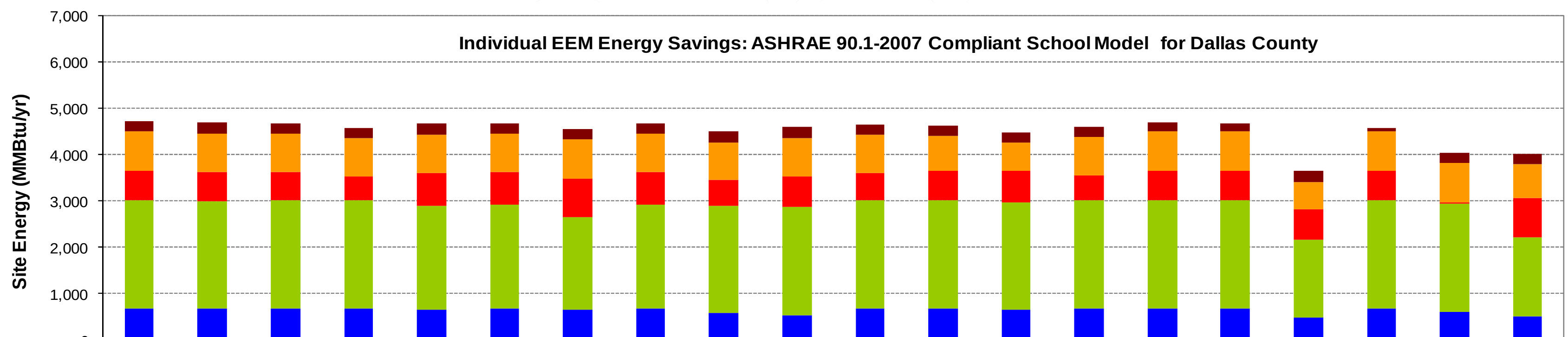
	Base Case (1999)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,101	5,039	4,972	4,980	4,847	5,033	4,795	5,044	4,874	4,969	5,036	4,916	4,821	4,989	5,072	5,045	4,027	4,964	4,530	4,005	4,717
DHW	229	229	229	229	229	229	229	229	229	229	229	229	229	229	200	173	229	92	229	208	229
Fans+Pumps	938	928	929	929	938	938	949	941	927	938	938	753	658	928	938	938	702	938	871	736	829
Heating	610	557	475	490	781	659	788	667	489	610	545	610	637	508	610	610	610	610	20	833	655
Lgt+Appl	2,625	2,625	2,625	2,625	2,229	2,516	2,166	2,513	2,625	2,625	2,625	2,625	2,625	2,625	2,625	2,625	1,964	2,625	2,625	1,715	2,328
Cooling	700	700	714	707	670	691	664	694	605	568	700	700	673	699	700	700	523	700	786	513	676

Figure 10. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1999 Compliance Base-Case School: Dallas County (Climate Zone 3)



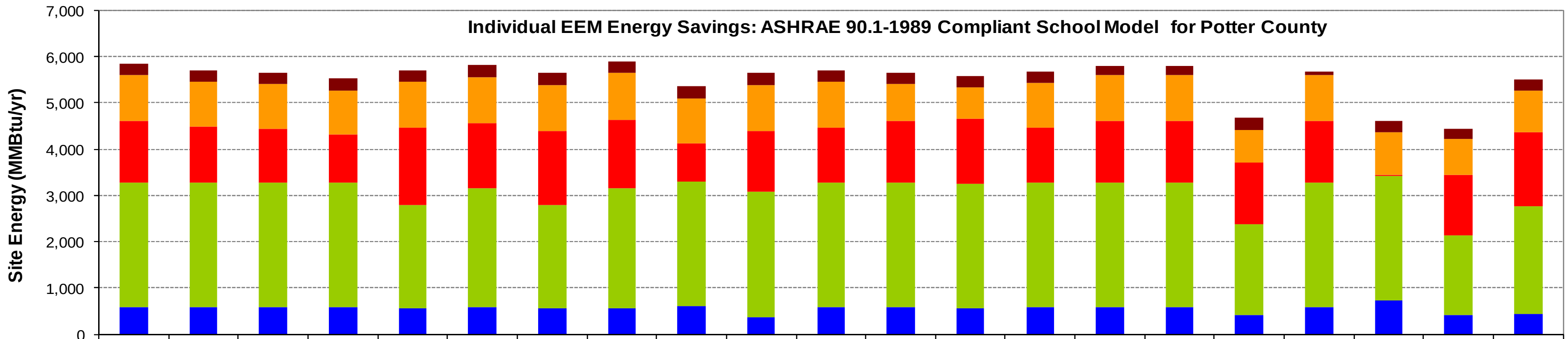
	Base Case (2004)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	4,815	4,745	4,789	4,687	4,754	4,764	4,628	4,775	4,587	4,662	4,749	4,632	4,537	4,705	4,786	4,759	3,741	4,678	4,207	4,012	4,717
DHW	229	229	229	229	229	229	229	229	229	229	229	229	229	229	200	173	229	92	229	208	229
Fans+Pumps	928	918	927	922	929	929	947	933	919	928	928	746	651	918	928	928	677	928	943	736	829
Heating	617	563	591	495	662	659	793	657	504	617	552	617	643	517	617	617	617	617	20	838	655
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,970	2,239	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,698	2,328	2,328	1,717	2,328
Cooling	712	707	714	713	705	706	690	717	608	559	712	712	686	713	712	712	520	712	687	513	676

Figure 11. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-2004 Compliance Base-Case School: Dallas County (Climate Zone 3)



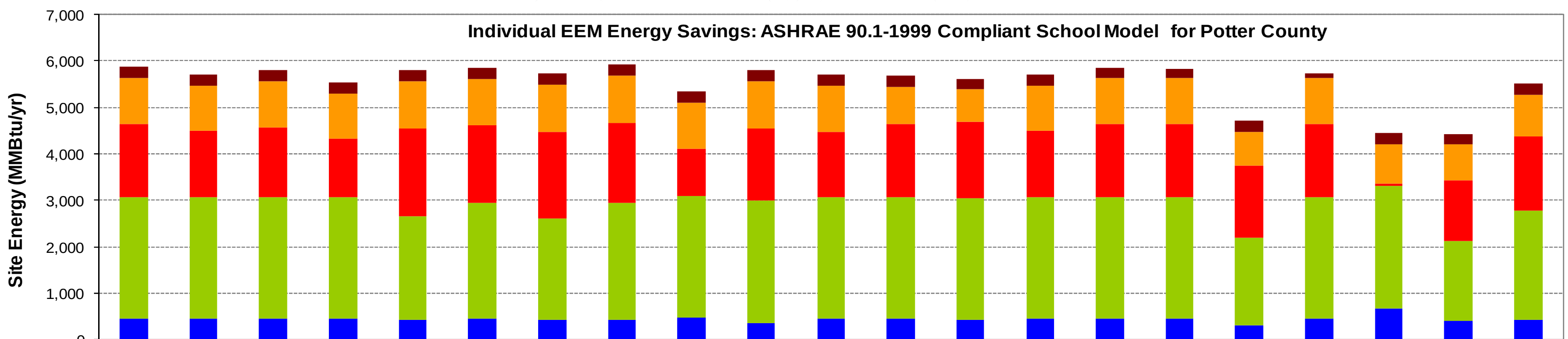
	Base Case (2007)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG
Total	4,717	4,689	4,671	4,584	4,658	4,670	4,553	4,674	4,495	4,587	4,647	4,626	4,473	4,607	4,688	4,661	3,643	4,580	4,047	4,012
DHW	229	229	229	229	229	229	229	229	229	229	229	229	229	229	200	173	229	92	229	208
Fans+Pumps	829	825	827	822	829	829	848	832	822	829	829	739	585	819	829	829	597	829	860	736
Heating	655	632	610	529	702	701	834	698	541	655	585	655	681	555	655	655	655	655	20	844
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,974	2,240	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,676	2,328	2,328	1,710
Cooling	676	674	678	676	669	670	668	675	576	547	676	676	651	676	676	676	487	676	610	514

Figure 12. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-2007 Compliance Base-Case School: Dallas County (Climate Zone 3)



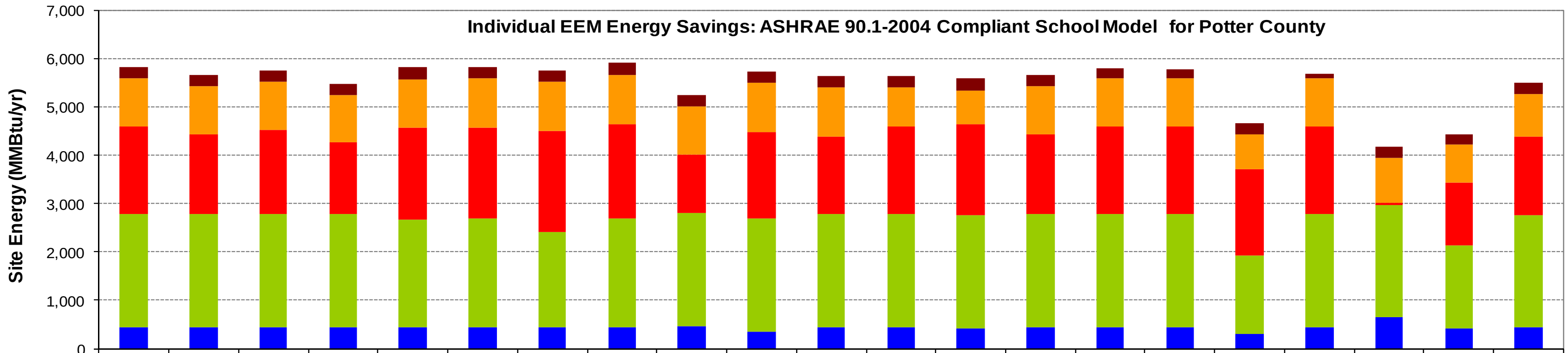
	Base Case (1989)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,844	5,701	5,654	5,518	5,707	5,807	5,643	5,893	5,349	5,637	5,702	5,651	5,584	5,684	5,806	5,787	4,672	5,685	4,616	4,446	5,503
DHW	248	248	248	248	248	248	248	248	248	248	248	248	248	248	210	191	248	89	248	219	240
Fans+Pumps	989	975	973	958	1,004	991	999	1,005	972	989	989	796	690	975	989	989	718	989	913	773	891
Heating	1,329	1,200	1,150	1,026	1,667	1,410	1,609	1,491	831	1,329	1,186	1,329	1,395	1,183	1,329	1,329	1,329	1,329	40	1,325	1,605
Lgt+Appl	2,694	2,694	2,694	2,694	2,229	2,581	2,231	2,575	2,694	2,694	2,694	2,694	2,694	2,694	2,694	2,694	1,954	2,694	2,694	1,723	2,328
Cooling	583	584	588	591	559	577	555	572	603	376	583	583	557	583	583	583	423	583	720	406	439

Figure 13. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1989 Compliance Base-Case School: Potter County (Climate Zone 4)



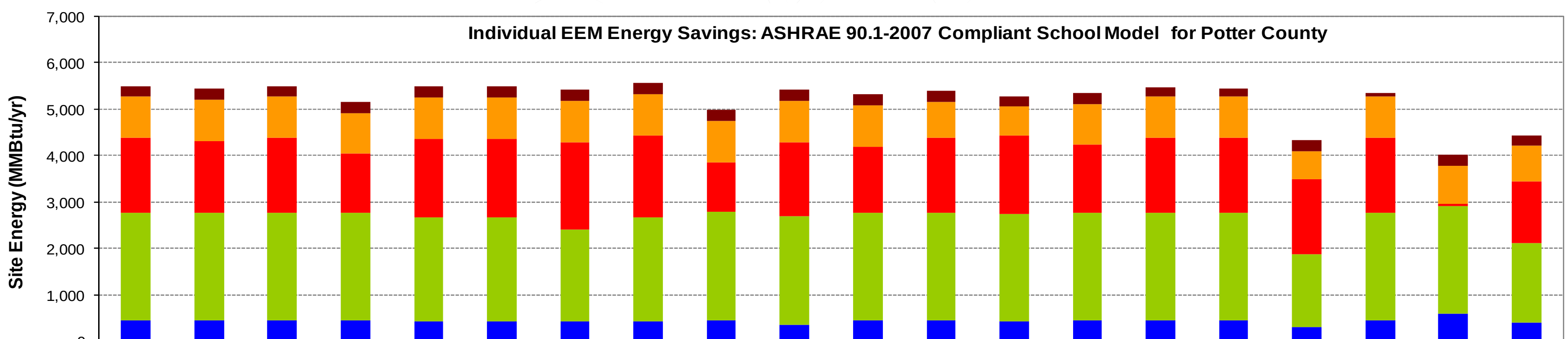
	Base Case (1999)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,875	5,709	5,805	5,536	5,793	5,850	5,728	5,928	5,334	5,792	5,707	5,679	5,619	5,715	5,844	5,818	4,702	5,723	4,454	4,430	5,503
DHW	240	240	240	240	240	240	240	240	240	240	240	240	240	240	210	183	240	89	240	219	240
Fans+Pumps	998	980	992	963	1,014	1,001	1,012	1,015	982	998	998	803	693	983	998	998	711	998	867	774	891
Heating	1,566	1,418	1,502	1,258	1,880	1,653	1,864	1,725	1,023	1,566	1,398	1,566	1,636	1,421	1,566	1,566	1,566	1,566	45	1,313	1,605
Lgt+Appl	2,625	2,625	2,625	2,625	2,229	2,516	2,185	2,512	2,625	2,625	2,625	2,625	2,625	2,625	2,625	2,625	1,869	2,625	2,625	1,716	2,328
Cooling	445	445	446	450	429	440	427	436	463	362	445	445	425	445	445	445	317	445	677	409	439

Figure 14. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1999 Compliance Base-Case School: Potter County (Climate Zone 4)



	Base Case (2004)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG	ASHRAE 90.1 2007
Total	5,829	5,667	5,759	5,475	5,813	5,816	5,748	5,903	5,249	5,733	5,634	5,631	5,575	5,665	5,798	5,772	4,656	5,677	4,177	4,433	5,503
DHW	240	240	240	240	240	240	240	240	240	240	240	240	240	240	210	183	240	89	240	219	240
Fans+Pumps	1,010	992	1,003	971	1,014	1,012	1,021	1,027	993	1,010	1,010	812	701	994	1,010	1,010	697	1,010	918	774	891
Heating	1,803	1,658	1,738	1,484	1,885	1,878	2,070	1,956	1,218	1,803	1,608	1,803	1,879	1,655	1,803	1,803	1,803	1,803	49	1,315	1,605
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,981	2,238	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,607	2,328	2,328	1,717	2,328
Cooling	448	448	449	452	444	444	435	443	470	353	448	448	427	448	448	448	309	448	641	409	439

Figure 15. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-2004 Compliance Base-Case School: Potter County (Climate Zone 4)



	Base Case (2007)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	Solar PV	Solar DHW	GSHP	AEDG
Total	5,503	5,438	5,503	5,149	5,488	5,491	5,417	5,569	4,975	5,419	5,331	5,406	5,287	5,345	5,472	5,446	4,331	5,352	4,023	4,436
DHW	240	240	240	240	240	240	240	240	240	240	240	240	240	240	210	183	240	89	240	219
Fans+Pumps	891	885	891	856	895	893	902	906	877	891	891	794	625	876	891	891	605	891	821	774
Heating	1,605	1,546	1,605	1,282	1,689	1,681	1,867	1,752	1,075	1,605	1,433	1,605	1,676	1,462	1,605	1,605	1,605	1,605	46	1,326
Lgt+Appl	2,328	2,328	2,328	2,328	2,229	2,241	1,982	2,238	2,328	2,328	2,328	2,328	2,328	2,328	2,328	2,328	1,582	2,328	2,328	1,708
Cooling	439	439	439	443	435	435	427	433	455	354	439	439	418	439	439	439	298	439	588	409

Figure 16. Energy Use of Individual EE/RE Measures for ASHRAE 90.1-1999 Compliance Base-Case School: Potter County (Climate Zone 4)

5.3 ASHRAE AEDG for K-12 Schools

To examine the energy saving potential from the combination of individual EE/RE meausres, a single group measure was simulated using the recommendations in the ASHRAE AEDG for K-12 schools (ASHRAE 2008). The AEDG provides recommendations to achieve 30% energy savings over ASHRAE Standard 90.1-1999 for each climate zone. The simulated measures for AEDG are presented in Table 6. The resultant energy and cost savings were presented in Table 5. The annual total energy savings ranged from 13.7% to 23.8% for Harris County, from 14.9% to 25.0% for Dallas County, and from 19.4% to 24.6% for Potter County. Since the ASHRAE AEDG does not include any renewable measures or GSHPs, the energy saving potential for a school would increase by implementing solar PV or GSHP measures.

Table 6. Simulated Measures for AEDG

EEM #	Individual Energy Efficiency Measure (EEM)	AEDG		
		Climate Zone 2	Climate Zone 3	Climate Zone 4
1	Increased Roof Insulation	R-25		
2	Decreased Glazing U-Value	U-0.45		U-0.42
4	Decreased Lighting Power Density	1.1 W/ft^2	0.9 W/ft^2	
5	Occupancy Sensor for Lighting Control	Occupancy Sensor		
6	Daylight Dimming Controls	Daylight Dimming Controls		
8	OA Demand Control	Classroom/Admin: 15 cfm/person; Café/Gym: 20 cfm/person		
9	Improved AC Efficiency	PVAVS: 10.6 EER; PSZ 11.3 EER		
10	Improved Heating System Efficiency	80%	85%	85%
11	Decreased Supply Fan Power Consumption	PVAVS:1.3 hp/1000 cfm; PSZ 1.0 hp/1000 cfm		
14	Improved DHW Heater Efficiency	90%		
-	Exterior Wall Insulation	Not Required	R-3.8 c.i.	R-7.5 c.i.
-	Window Shading	0.5 projection factor (2.5 ft) for East, West, and South		
-	High Albedo Roof	0.3	0.3	0.7
-	Glazing SEER	0.25	0.25	0.40

6. TOTAL STATE-WIDE POTENTIAL ENERGY AND EMISSIONS SAVINGS

Table 7 presents the total surveyed and estimated floor area of each school group in each climate zone. To estimate the total state-wide potential energy and emissions savings of all Texas ISDs from the application of the AEDG measures, the total floor areas of each school group (Group 1: schools built before 2000; Group 2: schools built between 2000 and 2007; and Group 3: schools built between 2007 and 2010) was surveyed. For Group 4 (new schools that will be built in 2011), using the enrollment growth rate in Texas public schools (TEA 2009), the total floor area (sq. ft.) was estimated.

Finally, using the surveyed total floor area (sq.ft.) as well as the simulated energy savings (kBtu/sq. ft.) from the application of the AEDG, the total annual energy savings of the new and existing Texas ISDs were estimated and presented in Table 8. The corresponding annual and ozone season daily (OSD) emissions savings were also calculated and presented in Table 9. The estimated annual energy and emissions savings were 10,520,419 MMBtu/yr for total energy, 2,743 tons/yr for NOx, 1,772 tons/yr for SO_2, and 2,286,012 tons/yr for CO_2, and the estimated OSD emissions savings were 6.0 tons/day for NOx, 2.5 tons/day for SO_2, and 5,041 tons/day for CO_2.

Table 7. Total Surveyed and Estimated Floor Area of Each School Group in Each Climate Zone

Climate Zone (ASHRAE 90.1 2004/2007)	Elementary School (thousand sq.ft.)				Middle School (thousand sq.ft.)				High School (thousand sq.ft.)			
	Existing Schools			New Schools (2011)	Existing Schools			New Schools (2011)	Existing Schools			New Schools (2011)
	Built before 2000	Built 2000-2007	Built 2007-2010		Built before 2000	Built 2000-2007	Built 2007-2010		Built before 2000	Built 2000-2007	Built 2007-2010	
2	111,844	49,308	7,216	3,046	66,519	29,326	4,292	1,812	86,005	37,916	5,549	2,342
3	78,050	34,409	5,036	2,126	43,816	19,317	2,827	1,193	61,321	27,034	3,956	1,670
4	3,913	1,725	252	107	2,343	1,033	151	64	3,153	1,390	203	86
Total	**193,807**	**85,442**	**12,504**	**5,278**	**112,678**	**49,675**	**7,270**	**3,069**	**150,478**	**66,340**	**9,708**	**4,098**

Table 8. Total Estimated Energy Savings of Each School Group in Each Climate Zone

Climate Zone (ASHRAE 90.1 2004/2007)	Elementary School (MMBtu/yr)				Middle School (MMBtu/yr)				High School (MMBtu/yr)				Total for Each Climate Zone (MMBtu/yr)
	Existing Schools			New Schools (2011)	Existing Schools			New Schools (2011)	Existing Schools			New Schools (2011)	
	Built before 2000	Built 2000-2007	Built 2007-2010		Built before 2000	Built 2000-2007	Built 2007-2010		Built before 2000	Built 2000-2007	Built 2007-2010		
2	1,765,446	632,186	76,750	24,370	1,049,996	375,992	45,647	14,494	1,357,573	486,132	59,018	18,740	**5,906,342**
3	1,312,594	474,863	50,881	18,844	736,872	266,581	28,564	10,579	1,031,244	373,078	39,975	14,805	**4,358,879**
4	68,908	31,367	4,434	1,432	41,252	18,778	2,655	857	55,517	25,272	3,573	1,154	**255,198**
Total (TX State)	**3,146,948**	**1,138,417**	**132,065**	**44,646**	**1,828,120**	**661,351**	**76,865**	**25,930**	**2,444,333**	**884,481**	**102,565**	**34,698**	**10,520,419**

Table 9. Annual and Ozone Season Daily Emissions Savings

	Annual Emissions Savings (tons/yr)			OSD Emissions Savings (tons/day)		
	NOx	SO_2	CO_2	NOx	SO_2	CO_2
Total (TX State)	2743.0	1772.4	2286012.1	6.0	2.5	5040.6

7. COST ANALYSIS

Table 10 presents the estimated initial costs for implementing the eighteen selected individual EE/ER measures in existing schools. Table 11 presents the paybacks associated with the installation of these measures for three counties. The paybacks are based on the ASHRAE 90.1 1999 analysis for Harris, Dallas and Potter Counties in Texas which has been discussed in the previous sections of this report. ASHRAE 90.1 1999 was considered over the other codes as it covers a greater number of buildings.

The measures have been grouped under envelope, lighting, HVAC system, domestic hot water and renewable systems. Most of the initial costs are obtained from local manufacturers and contractors. In addition, information from RSMeans was also used. The initial costs include material as well as installation costs. Several quotes were obtained for each measure and subsequently averaged out to establish a single quote for each measure. A range of ± 20% was then established for each quote. The implementation of measures is considered as part of retrofitting the school buildings. A simple payback was calculated for each measure using the $/year annual energy savings obtained from the implementation of the measure. Similar results for new schools cost analysis are found on Table 12 and 13 respectively.

It has been observed the best paybacks are provided by implementing various HVAC measures such as demand ventilation control and installation of variable frequency drives (VFD) on fans and pumps. Other viable measures include installation of occupancy and daylighting controls as well as tankless water heaters. In the case of renewable measures it is important to note that the paybacks associated with these measures can be heavily influenced by the incentives and tax credits provided by local and federal authorities. The impact of these incentives has not been considered by this study.

Table 10. Estimated Initial Costs for Selected Energy Efficiency Measures for Retrofitting Existing Schools

EEM #	Individual Energy Efficiency Measure (EEM)	Average Cost Range for Efficiency Measures for Whole Building			Average Cost/sqft of floor area covered				Average Cost / Unit				
		-20%	Average	+20%	Area Covered by Measure (Sqft)	-20%	Average	+20%	Unit Description	Unit Area	-20%	Average	+20%
	Envelope Measures												
1	Roof Insulation (Going from R-15 to R-25) Adding R-10 on existing roof	$52,953	$66,192	$79,430	79,431	$0.67	$0.83	$1.00	Sqft of Roof Ins.	79,430	$0.67	$0.83	$1.00
2	High Performance Glazing (Going from U-1.22 / 0.57 to U-0.45) Changing out the windows to U-0.45	$27,315	$34,143	$40,972	79,431	$0.34	$0.43	$0.52	Sqft of Glazing	1,120	$24.39	$30.49	$36.58
3	Decreased Infiltration (40% reduction)	$7,500	$16,250	$25,000	79,431	$0.16	$0.20	$0.25	Sqft of Total Area	79,430	$0.16	$0.20	$0.25
	Lighting Measures												
4	Interior Lighting (From 1.2W/sqft to 1.1W/sqft) Changing out fixtures and ballasts only from T12 to T8	$63,544	$79,430	$95,316	79,431	$0.80	$1.00	$1.20	Sqft of Total Area	79,430	$0.80	$1.00	$1.20
5	Occupancy Control (Implementing occupancy sensors)	$18,624	$23,280	$27,936	61,161	$0.30	$0.38	$0.46	Sqft of Classroom Area	61,161	$0.30	$0.38	$0.46
6	Daylighting Control (Implementing continious daylighting control)	$68,068	$85,085	$102,102	79,431	$0.86	$1.07	$1.29	Sqft of Total Area	79,431	$0.86	$1.07	$1.29
7	Skylights (4% SRR for gym and café)	$42,431	$53,039	$63,647	18,269	$2.32	$2.90	$3.48	Sqft of Gym+Cafe Area	18,269	$2.32	$2.90	$3.48
	HVAC System Measures												
8	Demand Control Ventilation	$29,888	$37,360	$44,832	61,161	$0.49	$0.61	$0.73	Sqft of Classroom Area	61,161	$0.49	$0.61	$0.73
9	Improved AC Efficiency (For PSZ 5 ton units: From EER11 to EER12.2) (For PVAV 15 ton units: From EER9.8 to EER10.6)	$106,161	$132,701	$159,241	79,431	$1.34	$1.67	$2.00	Per Ton of Capacity	320	$331.75	$414.69	$497.63
10	Efficient Boilers (From conventional to condensing)	$24,000	$30,000	$36,000	79,431	$0.30	$0.38	$0.45	Per kBtu/hr of Capacity	400	$60.00	$75.00	$90.00
11	Decreased Supply Fan Power Consumption (For PSZ: From 1.2hp/1000cfm to 1.0hp/1000cfm) (For PVAV: From 1.7hp/1000cfm to 1.3hp/1000cfm)	$10,000	$17,500	$25,000	79,431	$0.18	$0.22	$0.26	Per Ton	320	$43.75	$54.69	$65.63
12	PVAVS with VFD for Fan Control (Installing VFD)	$31,824	$39,780	$47,736	79,431	$0.40	$0.50	$0.60	Per Ton	320	$99.45	$124.31	$149.18
13	PVAVS with Variable Speed for HW Pump (Installing VFD)	$4,120	$5,150	$6,180	79,431	$0.05	$0.06	$0.08	Per Ton	320	$12.88	$16.09	$19.31
	DHW Measures												
14	Improved DHW Efficiency (From conventional to condensing)	$13,562	$16,952	$20,342	79,431	$0.17	$0.21	$0.26	Per Gallon	135	$100.46	$125.57	$150.68
15	Tankless Water Heater	$4,800	$6,000	$7,200	79,431	$0.06	$0.08	$0.09	Per kBtu/hr of Capacity	597	$8.04	$10.05	$12.06
	Renewable Measures												
16	Solar PV (Instaling 200kW PV (20% of roof area)	$1,343,467	$1,679,333	$2,015,200	79,431	$16.91	$21.14	$25.37	Collector Area (20% of Roof)	15,886	$84.57	$105.71	$126.85
17	Solar DHW (Two SDHW: One Unit:128sqft; 120 Gal)	$7,968	$9,960	$11,952	79,431	$0.10	$0.13	$0.15	Collector Area	256	$31.13	$38.91	$46.69
18	GSHP (120 Boreholes, 240 depth)	$96,000	$120,000	$144,000	79,431	$1.21	$1.51	$1.81	Per Ton	320	$300.00	$375.00	$450.00

Table 11. Estimated Payback Periods for Energy Efficiency Measures for Retrofitting Existing Schools (Harris, Dallas and Potter County)

EEM #	Individual Energy Efficiency Measure (EEM)	For Harris County									For Dallas County									For Potter County								
		Annual Energy Savings over ASHRAE 1999						Simple Estimated Payback (Years)			Annual Energy Savings over ASHRAE 1999						Simple Estimated Payback (Years)			Annual Energy Savings over ASHRAE 1999						Simple Estimated Payback (Years)		
		Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%	Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%	Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%
	Envelope Measures																											
1	Roof Insulation (Going from R-15 to R-25) Adding R-10 on existing roof	3,488	317	0.9%	$523	$317	$841	63	79	94	3,048	503	1.2%	$457	$503	$960	55	69	83	6,096	1,409	2.8%	$914	$1,409	$2,323	23	28	34
2	High Performance Glazing (Going from U-1.22 / 0.57 to U-0.45) Changing out the windows to U-0.45	8,089	927	2.4%	$1,213	$927	$2,141	13	16	19	-1,084	1,288	2.5%	($163)	$1,288	$1,126	24	30	36	1,758	617	1.2%	$264	$617	$880	31	39	47
3	Decreased Infiltration (40% reduction)	1,993	831	1.8%	$299	$831	$1,130	6.6	14	22	821	1,146	2.4%	$123	$1,146	$1,269	5.9	12.8	19.7	9,994	2,954	5.8%	$1,499	$2,954	$4,453	1.7	3.6	5.6
	Lighting Measures																											
4	Interior Lighting (From 1.2W/sqft to 1.1W/sqft) Changing out fixtures and ballasts only from T12 to T8	123,623	-1,444	5.4%	$18,543	($1,444)	$17,100	3.7	4.6	5.6	123,886	-1,642	5.0%	$18,583	($1,642)	$16,941	3.8	4.7	5.6	114,537	-2,999	1.4%	$17,181	($2,999)	$14,182	4.5	5.6	6.7
5	Occupancy Control (Implementing occupancy sensors)	34,174	-421	1.5%	$5,126	($421)	$4,705	4.0	4.9	5.9	34,349	-477	1.3%	$5,152	($477)	$4,676	4.0	5.0	6.0	32,151	-829	0.4%	$4,823	($829)	$3,994	4.7	5.8	7.0
6	Daylighting Control (Implementing continious daylighting control)	144,370	-1,575	6.6%	$21,656	($1,575)	$20,081	3.4	4.2	5.1	141,893	-1,734	6.0%	$21,284	($1,734)	$19,550	3.5	4.4	5.2	130,273	-2,892	2.5%	$19,541	($2,892)	$16,649	4.1	5.1	6.1
7	Skylights (4% SRR for gym and café)	35,786	-257	1.9%	$5,368	($257)	$5,111	8.3	10	12	33,625	-561	1.1%	$5,044	($561)	$4,483	9.5	12	14	30,822	-1,539	-0.9%	$4,623	($1,539)	$3,085	14	17	21
	HVAC System Measures																											
8	Demand Control Ventilation	44,930	759	4.6%	$6,739	$759	$7,499	4.0	5.0	6.0	32,268	1,129	4.4%	$4,840	$1,129	$5,969	5.0	6.3	7.5	2,960	5,155	9.2%	$444	$5,155	$5,599	5.3	6.7	8.0
9	Improved AC Efficiency (For PSZ 5 ton units: From EER11 to EER12.2) (For PVAV 15 ton units: From EER9.8 to EER10.6)	44,725	0	3.0%	$6,709	$0	$6,709	16	20	24	38,599	0	2.6%	$5,790	$0	$5,790	18	23	28	24,267	0	1.4%	$3,640	$0	$3,640	29	36	44
10	Efficient Boilers (From conventional to condensing)	29	470	1.0%	$4	$470	$474	51	63	76	29	627	1.3%	$4	$627	$632	38	47	57	0	1,633	2.9%	$0	$1,633	$1,633	15	18	22
11	Decreased Supply Fan Power Consumption (For PSZ: From 1.2hp/1000cfm to 1.0hp/1000cfm) (For PVAV: From 1.7hp/1000cfm to 1.3hp/1000cfm)	52,667	0	3.6%	$7,900	$0	$7,900	1.3	2.2	3.2	54,162	0	3.6%	$8,124	$0	$8,124	1.2	2.2	3.1	57,386	0	3.3%	$8,608	$0	$8,608	1.2	2.0	2.9
12	PVAVS with VFD for Fan Control (Installing VFD)	87,691	-184	5.6%	$13,154	($184)	$12,969	2.5	3.1	3.7	89,713	-257	5.5%	$13,457	($257)	$13,200	2.4	3.0	3.6	94,959	-666	4.3%	$14,244	($666)	$13,578	2.3	2.9	3.5
13	PVAVS with Variable Speed for HW Pump (Installing VFD)	4,719	1,020	2.4%	$708	$1,020	$1,728	2.4	3.0	3.6	4,426	941	2.2%	$664	$941	$1,605	2.6	3.2	3.9	6,331	1,346	2.7%	$950	$1,346	$2,295	1.8	2.2	2.7
	DHW Measures																											
14	Improved DHW Efficiency (From conventional to condensing)	29	275	0.6%	$4	$275	$279	49	61	73	29	281	0.6%	$4	$281	$285	48	59	71	0	299	0.5%	$0	$299	$299	45	57	68
15	Tankless Water Heater	13,306	95	1.1%	$1,996	$95	$2,091	2.3	2.9	3.4	13,306	100	1.1%	$1,996	$100	$2,096	2.3	2.9	3.4	13,306	113	1.0%	$1,996	$113	$2,109	2.3	2.8	3.4
	Renewable Measures																											
16	Solar PV (Instaling 200kW PV (20% of roof area)	277,280	0	18.8%	$41,592	$0	$41,592	32	40	48	314,682	0	21.0%	$47,202	$0	$47,202	28	36	43	343,577	0	20.0%	$51,537	$0	$51,537	26	33	39
17	Solar DHW (Two SDHW: One Unit:128sqft; 120 Gal)	-545	1,181	2.4%	($82)	$1,181	$1,100	7.2	9.1	11	-545	1,347	2.7%	($82)	$1,347	$1,265	6.3	7.9	9.4	-545	1,486	2.6%	($82)	$1,486	$1,405	5.7	7.1	8.5
18	GSHP (120 Boreholes, 240 depth)	-18,647	4,306	7.6%	($2,797)	$4,306	$1,509	64	80	95	-5,571	5,727	11.2%	($836)	$5,727	$4,892	20	25	29	-29,508	14,768	24.2%	($4,426)	$14,768	$10,342	9	12	14

Table 12. Estimated Initial Costs for Selected Energy Efficiency Measures for New School Buildings

EEM #	Individual Energy Efficiency Measure (EEM)	Average Cost Range for Efficiency Measures for Whole Building			Average Cost/sqft of floor area covered				Average Cost / Unit				
		-20%	Average	+20%	Area Covered by Measure (Sqft)	-20%	Average	+20%	Unit Description	Unit Area	-20%	Average	+20%
	Envelope Measures												
1	Roof Insulation (Going from R-15 to R-25) Adding R-10 on existing roof	$63,544	$79,430	$95,316	79,431	$0.80	$1.00	$1.20	Sqft of Roof Ins.	79,430	$0.80	$1.00	$1.20
2	High Performance Glazing (Going from U-0.75 to U-0.45) Changing out the windows to U-0.45	$17,759	$22,199	$26,639	79,431	$0.22	$0.28	$0.34	Sqft of Glazing	1,120	$15.86	$19.82	$23.78
3	Decreased Infiltration (40% reduction)	$7,500	$16,250	$25,000	79,431	$0.16	$0.20	$0.25	Sqft of Total Area	79,430	$0.16	$0.20	$0.25
	Lighting Measures												
4	Interior Lighting (From 1.2W/sqft to 1.1W/sqft) Changing out fixtures and ballasts only from T12 to T8	$10,266	$12,833	$15,399	79,431	$0.13	$0.16	$0.19	Sqft of Total Area	79,430	$0.13	$0.16	$0.19
5	Occupancy Control (Implementing occupancy sensors)	$18,624	$23,280	$27,936	61,161	$0.30	$0.38	$0.46	Sqft of Classroom Area	61,161	$0.30	$0.38	$0.46
6	Daylighting Control (Implementing continious daylighting control)	$68,068	$85,085	$102,102	79,431	$0.86	$1.07	$1.29	Sqft of Total Area	79,431	$0.86	$1.07	$1.29
7	Skylights (4% SRR for gym and café)	$42,431	$53,039	$63,647	18,269	$2.32	$2.90	$3.48	Sqft of Gym+Cafe Area	18,269	$2.32	$2.90	$3.48
	HVAC System Measures												
8	Demand Control Ventilation	$29,888	$37,360	$44,832	61,161	$0.49	$0.61	$0.73	Sqft of Classroom Area	61,161	$0.49	$0.61	$0.73
9	Improved AC Efficiency (For PSZ 5 ton units: From EER11 to EER12.2) (For PVAV 15 ton units: From EER9.8 to EER10.6)	$8,262	$10,328	$12,393	79,431	$0.10	$0.13	$0.16	Per Ton of Capacity	320	$25.82	$32.27	$38.73
10	Efficient Boilers (From conventional to condensing)	$10,400	$13,000	$15,600	79,431	$0.13	$0.16	$0.20	Per kBtu/hr of Capacity	400	$26.00	$32.50	$39.00
11	Decreased Supply Fan Power Consumption (For PSZ: From 1.2hp/1000cfm to 1.0hp/1000cfm) (For PVAV: From 1.7hp/1000cfm to 1.3hp/1000cfm)	$10,000	$17,500	$25,000	79,431	$0.18	$0.22	$0.26	Per Ton	320	$43.75	$54.69	$65.63
12	PVAVS with VFD for Fan Control (Installing VFD)	$31,824	$39,780	$47,736	79,431	$0.40	$0.50	$0.60	Per Ton	320	$99.45	$124.31	$149.18
13	PVAVS with Variable Speed for HW Pump (Installing VFD)	$4,120	$5,150	$6,180	79,431	$0.05	$0.06	$0.08	Per Ton	320	$12.88	$16.09	$19.31
	DHW Measures												
14	Improved DHW Efficiency (From conventional to condensing)	$13,562	$16,952	$20,342	79,431	$0.17	$0.21	$0.26	Per Gallon	135	$100.46	$125.57	$150.68
15	Tankless Water Heater	$4,800	$6,000	$7,200	79,431	$0.06	$0.08	$0.09	Per kBtu/hr of Capacity	597	$8.04	$10.05	$12.06
	Renewable Measures												
16	Solar PV (Instaling 200kW PV (20% of roof area)	$1,343,467	$1,679,333	$2,015,200	79,431	$16.91	$21.14	$25.37	Collector Area (20% of Roof)	15,886	$84.57	$105.71	$126.85
17	Solar DHW (Two SDHW: One Unit:128sqft; 120 Gal)	$7,968	$9,960	$11,952	79,431	$0.10	$0.13	$0.15	Collector Area	256	$31.13	$38.91	$46.69
18	GSHP (120 Boreholes, 240 depth)	$109,600	$137,000	$164,400	79,431	$1.38	$1.72	$2.07	Per Ton	320	$342.50	$428.13	$513.75

Table 13. Estimated Payback Periods for Energy Efficiency Measures for New School Buildings (Harris, Dallas and Potter County)

EEM #	Individual Energy Efficiency Measure (EEM)	For Harris County									For Dallas County									For Potter County								
		Annual Energy Savings over ASHRAE 2007						Simple Estimated Payback (Years)			Annual Energy Savings over ASHRAE 2007						Simple Estimated Payback (Years)			Annual Energy Savings over ASHRAE 2007						Simple Estimated Payback (Years)		
		Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%	Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%	Electricity kWh	Gas CCF	Total Energy Savings %	Electricity Costs $	Gas Costs $	($/year)	-20%		+20%
	Envelope Measures																											
1	Roof Insulation (Going from R-15 to R-25) Adding R-10 on existing roof	821	133	0.4%	$123	$133	$256	248	310	372	1,788	213	0.6%	$268	$213	$481	132	165	198	2,110	567	1.2%	$317	$567	$884	72	90	108
2	High Performance Glazing (Going from U-0.75 to U-0.45) Changing out the windows to U-0.45	0	404	0.9%	$0	$404	$404	44	55	66	352	426	1.0%	$53	$426	$479	37	46	56	0	0	-	$0	$0	-	-	-	-
3	Decreased Infiltration (40% reduction)	1,934	834	2.0%	$290	$834	$1,124	6.7	14	22	2,550	1,204	2.8%	$382	$1,204	$1,586	4.7	10	16	10,111	3,100	6.4%	$1,517	$3,100	$4,617	1.6	3.5	5.4
	Lighting Measures																											
4	Interior Lighting (From 1.2W/sqft to 1.1W/sqft) Changing out fixtures and ballasts only from T12 to T8	30,363	-411	1.3%	$4,555	($411)	$4,144	2.5	3.1	3.7	30,627	-450	1.2%	$4,594	($450)	$4,144	2.5	3.1	3.7	28,517	-800	0.3%	$4,278	($800)	$3,478	3.0	3.7	4.4
5	Occupancy Control (Implementing occupancy sensors)	26,817	-407	1.1%	$4,023	($407)	$3,616	5.2	6.4	7.7	26,905	-441	1.0%	$4,036	($441)	$3,595	5.2	6.5	7.8	25,528	-727	0.2%	$3,829	($727)	$3,102	6.0	7.5	9.0
6	Daylighting Control (Implementing continious daylighting control)	112,329	-1,459	5.0%	$16,849	($1,459)	$15,391	4.4	5.5	6.6	100,535	-1,742	3.5%	$15,080	($1,742)	$13,338	5.1	6.4	7.7	101,873	-2,538	1.6%	$15,281	($2,538)	$12,743	5.3	6.7	8.0
7	Skylights (4% SRR for gym and café)	27,901	-223	1.6%	$4,185	($223)	$3,962	11	13	16	25,229	-423	0.9%	$3,784	($423)	$3,362	13	16	19	23,704	-1,424	-1.2%	$3,556	($1,424)	$2,132	20	25	30
	HVAC System Measures																											
8	Demand Control Ventilation	44,431	717	4.8%	$6,665	$717	$7,381	4.0	5.1	6.1	32,620	1,070	4.7%	$4,893	$1,070	$5,963	5.0	6.3	7.5	2,608	5,042	9.6%	$391	$5,042	$5,433	5.5	6.9	8.3
9	Improved AC Efficiency (For PSZ 5 ton units: From EER11 to EER12.2) (For PVAV 15 ton units: From EER9.8 to EER10.6)	44,050	0	3.2%	$6,608	$0	$6,608	1.3	1.6	1.9	37,954	0	2.7%	$5,693	$0	$5,693	1.5	1.8	2.2	24,707	0	1.5%	$3,706	$0	$3,706	2.2	2.8	3.3
10	Efficient Boilers (From conventional to condensing)	0	506	1.1%	$0	$506	$506	21	26	31	0	677	1.5%	$0	$677	$677	15	19	23	0	1,675	3.1%	$0	$1,675	$1,675	6.2	7.8	9.3
11	Decreased Supply Fan Power Consumption (For PSZ: From 1.2hp/1000cfm to 1.0hp/1000cfm) (For PVAV: From 1.7hp/1000cfm to 1.3hp/1000cfm)	26,114	0	1.9%	$3,917	$0	$3,917	2.6	4.5	6.4	26,553	0	1.9%	$3,983	$0	$3,983	2.5	4.4	6.3	28,400	0	1.8%	$4,260	$0	$4,260	2.3	4.1	5.9
12	PVAVS with VFD for Fan Control (Installing VFD)	78,136	-183	5.3%	$11,720	($183)	$11,538	2.8	3.4	4.1	78,781	-250	5.2%	$11,817	($250)	$11,568	2.8	3.4	4.1	83,705	-670	3.9%	$12,556	($670)	$11,886	2.7	3.3	4.0
13	PVAVS with Variable Speed for HW Pump (Installing VFD)	4,572	995	2.5%	$686	$995	$1,681	2.5	3.1	3.7	4,279	917	2.3%	$642	$917	$1,559	2.6	3.3	4.0	6,272	1,328	2.9%	$941	$1,328	$2,269	1.8	2.3	2.7
	DHW Measures																											
14	Improved DHW Efficiency (From conventional to condensing)	29	275	0.6%	$4	$275	$279	49	61	73	0	281	0.6%	$0	$281	$281	48	60	73	0	299	0.6%	$0	$299	$299	45	57	68
15	Tankless Water Heater	13,306	95	1.2%	$1,996	$95	$2,091	2.3	2.9	3.4	13,306	100	1.2%	$1,996	$100	$2,096	2.3	2.9	3.4	13,306	113	1.0%	$1,996	$113	$2,109	2.3	2.8	3.4
	Renewable Measures																											
16	Solar PV (Instaling 200kW PV (20% of roof area)	277,280	0	20.4%	$41,592	$0	$41,592	32	40	48	314,682	0	22.8%	$47,202	$0	$47,202	28	36	43	343,577	0	21.3%	$51,537	$0	$51,537	26	33	39
17	Solar DHW (Two SDHW: One Unit:128sqft; 120 Gal)	-545	1,181	2.6%	($82)	$1,181	$1,100	7.2	9.1	10.9	-545	1,347	2.9%	($82)	$1,347	$1,265	6.3	7.9	9.4	-545	1,486	2.7%	($82)	$1,486	$1,405	5.7	7.1	8.5
18	GSHP (120 Boreholes, 240 depth)	-3,560	4,614	10.0%	($534)	$4,614	$4,080	27	34	40	10,236	6,159	14.2%	$1,535	$6,159	$7,695	14	18	21	-23,121	15,140	26.9%	($3,468)	$15,140	$11,672	9	12	14

8. SUMMARY

This report presents the preliminary results from an analysis of the potential energy savings, and resultant air pollution reductions associated with the energy savings from the application of EE/RE projects applied to new and existing Texas ISDs. The analysis was performed using a K-12 simulation model based on the DOE-2.1e program that uses ASHRAE Standard 90.1 code-compliant, 79,430 sq.ft., school buildings for three climate zones in Texas. Four base-case school models that are compliant with the ASHRAE Standard 90.1-1989, 1999, 2004, and 2007 were developed for each climate zone. A total of eighteen energy efficient measures were considered. These include measures for the building envelope, lighting, HVAC system, DHW system, and renewable energy systems.

This analysis identified the energy saving potential in new and existing school buildings in Texas from the applications of various high performance EE/RE measures. Renewable energy options such as solar PV and GSHP had the largest annual total energy savings for all cases. Lighting measures such as daylight dimming controls and decreased lighting power density also resulted in high energy savings. However, for Potter County in Climate Zone 4, the savings from the lighting measures were not as large as the other counties because of the increased heating energy penalty. Among HVAC measures, OA demand control and PVAVS with VFD showed a good energy saving potential. Some measures such as improved AC efficiency and decreased supply fan power consumption resulted in higher savings for older school groups.

In addition, the analysis demonstrates that 20.2% to 24.6% of a combined savings above 1999 base case (schools that built between 2000 and 2007) can be achieved by applying the recommendations in the ASHRAE AEDG for K-12 schools. Since the ASHRAE AEDG does not include any renewable measures, an energy saving potential would increase by implementing solar PV or GSHP measures. Finally, the state-wide total energy and emissions savings of the new and existing Texas ISDs from the application of the AEDG measures were estimated: 10,520,419 MMBtu/yr, 2,743 tons/yr for NOx, 1,772 tons/yr for SO_2, and 2,286,012 tons/yr for CO_2.

A cost analysis was performed to determine the payback for each of the 18 energy efficiency measures implemented. The paybacks are based on the ASHRAE 90.1 1999 code. Best payback periods were obtained from decreasing the infiltration, improving the supply fan power and using tankless water heaters.

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