Energy Efficiency/Renewable Energy (EERE) Projects in Texas Public Schools

Hyojin Kim
Graduate Research Assistant

Zi Liu
Asst. Research Engineer

Juan-Carlos Baltazar
Assc. Research Engineer

Jaya Mukhopadhyay
Research Associate

Jeff S. Haberl
Professor/Assc. Director

Sunglok Do
Graduate Research Assistant

Bahman Yazdani
Assc. Director

Charles Culp
Assc. Professor/Assc. Director

Energy Systems Laboratory, Texas A&M University System
College Station, TX.

ABSTRACT

This paper presents the preliminary results from an analysis of the energy saving potential in new and existing Texas Independent School Districts (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, school buildings for three climate zones in Texas. In this analysis, government and private data sources from the U.S. EPA Energy Star, the Texas Education Agency, and the EnergyPlus Benchmark school models were reviewed to determine the base-case K-12 school characteristics in Texas. Available guidelines and case-studies were reviewed to develop energy efficient measures for high performance school buildings. As a result, 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. In addition, 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. The proposed energy efficient measures were then applied to the base-case school model to examine the energy saving potential for Texas ISDs.

INTRODUCTION

Schools are one of the building types with a high energy saving potential from the application of high performance strategies. The most efficient schools use one third the energy than the least efficient schools (EPA 2010). Im and Haberl (2006) reviewed over fifty studies on existing high performance schools. From this review, the annual energy savings from the application of high performance strategies ranged from 20% to 40%. However, to maximize the savings from high performance applications, it is obvious that different strategies are needed for schools built in different years as well as different climate zones.

According to the survey of Texas Comptroller of Public Accounts (2006), the average age of Texas elementary, middle, and high schools is 35.2, 32.2, and 32.7 years old, respectively. In addition, the average enrollment of Texas public schools continuously increased over the past 10-year period by 20.1% (TEA 2009). This would indicate that there is a huge energy saving potential in both existing and new schools in Texas from the application of high performance retrofit strategies.

This paper presents the preliminary results from an analysis of the energy saving potential in new and existing Texas Independent School Districts (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, school buildings for three climate zones in Texas according to ASHRAE 90.1-2004 and 2007 climate zone classifications.

METHODOLOGY

Figure 1 shows the detailed procedure for calculating the potential energy savings for existing K-12 schools in Texas. In this analysis, the existing K-12 schools were classified as three school groups according to the year of construction as Group 1: schools built before 2000; Group 2: schools built between 2000 and 2007; and Group 3: schools built after 2007. To calculate potential energy savings for new high performance K-12 schools in Texas, new schools that will be constructed in 2011 were classified as Group 4, and the total floor area (sq. ft.) of new schools will be estimated using the population growth rate. For the baseline of new schools, ASHRAE Standard 90.1-2007 requirements were referenced.

To estimate the savings of 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, different counties in Texas were grouped according to ASHRAE 90.1-2004 and

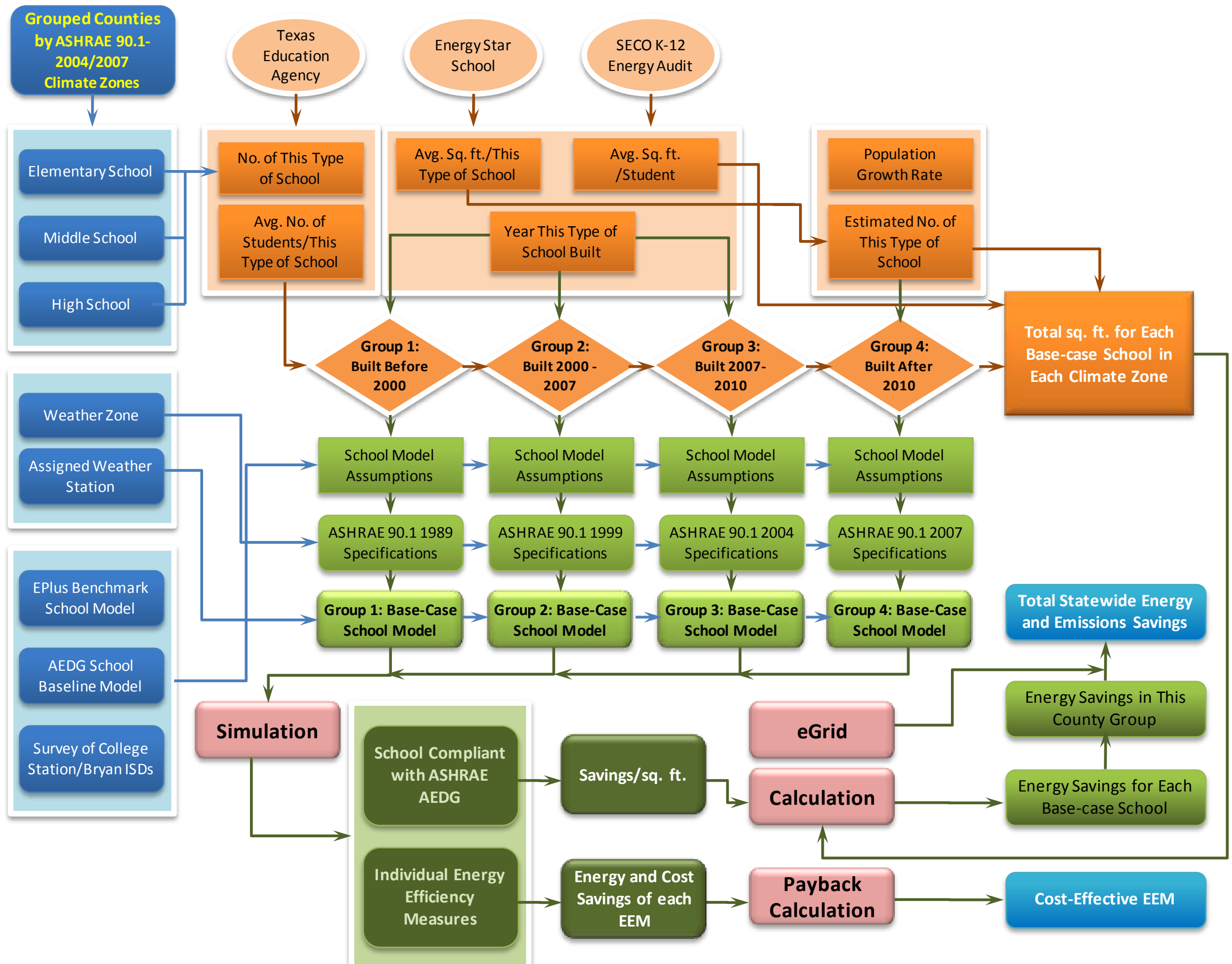


Figure 1. Flow Chart for Calculating Potential Energy Savings for Existing K-12 Schools

2007 Climate Zones. Then 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. Finally, the total energy consumption of the existing and new schools in Texas will be calculated using the simulated energy use intensity (kBtu/sq. ft.) and the surveyed total floor area (sq. ft.) of each school group in each climate zone.

<u>Development of Base-Case Model</u>

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

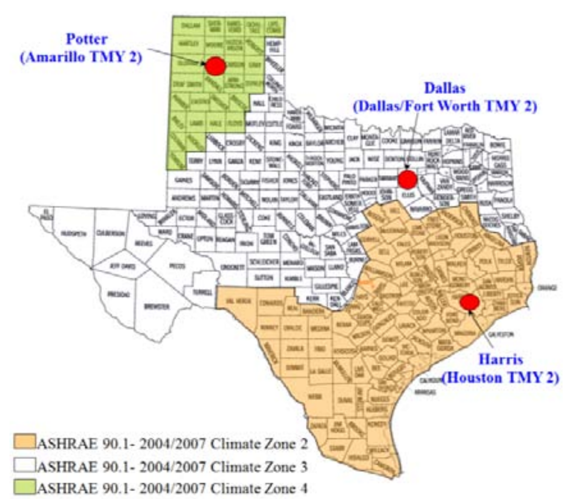


Figure 2. Climate Zones in ASHRAE Standard 90.1-2004/2007 and Three Selected Counties

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./student
	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%

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 (EERE 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.

Development of Energy Efficiency Measures

To develop energy efficiency measures for high performance schools, ASHRAE's 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 Energy Efficiency Measures (EEMs)[1] were considered for a preliminary analysis.

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.

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

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

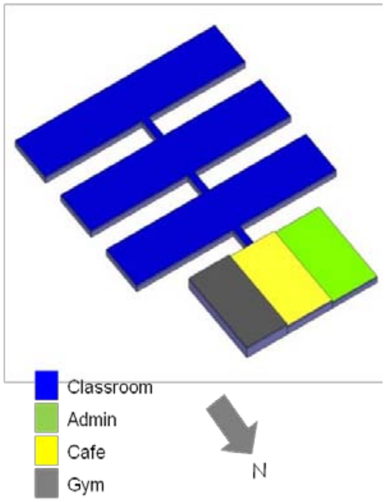


Figure 3. Shape and Geometry of Base-Case School Model (Im 2009)

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.

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/ft^2. 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.

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.

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)[2].

ENERGY EFFICIENCY MEASURES

Table 4 lists a summary of the 18 individual energy efficiency measures that were simulated for a preliminary analysis 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.

1) Increased Roof Insulation

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

[2] 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.

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 (Climate Zone 4) County

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

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)[3] 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)

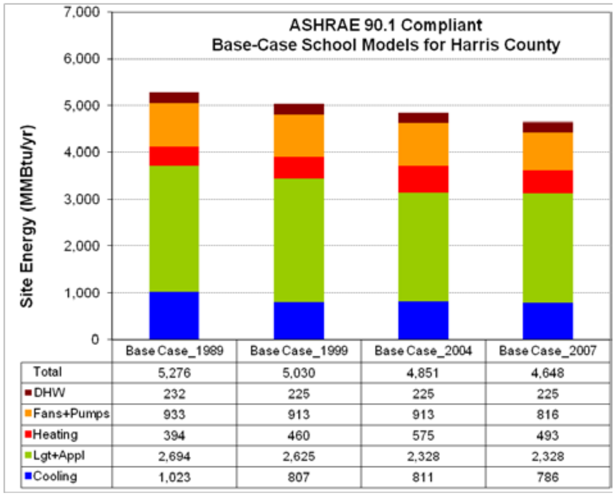
For this measure, conventional water source heat pumps with ground heat exchanger (GHX) units were simulated using eQuest 3.6 simulation software. The specification of the GHX units was decided based on the Geothermal Heat Pumps in K-12 Schools (Shonder et al. 2000). The GHX units consist of 120 vertical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

RESULTS

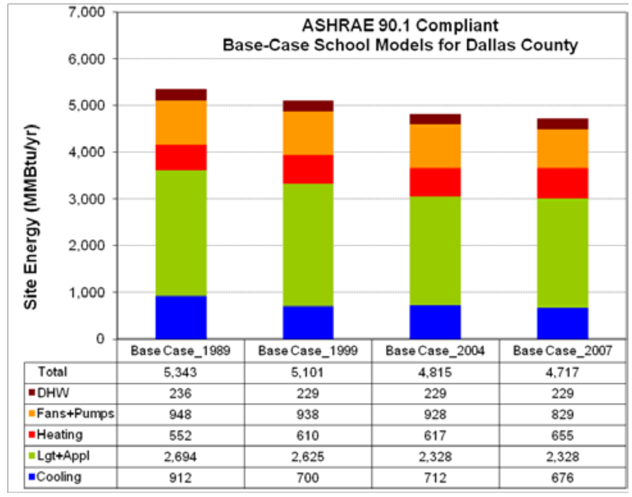
Base Case Energy Use

A preliminary 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

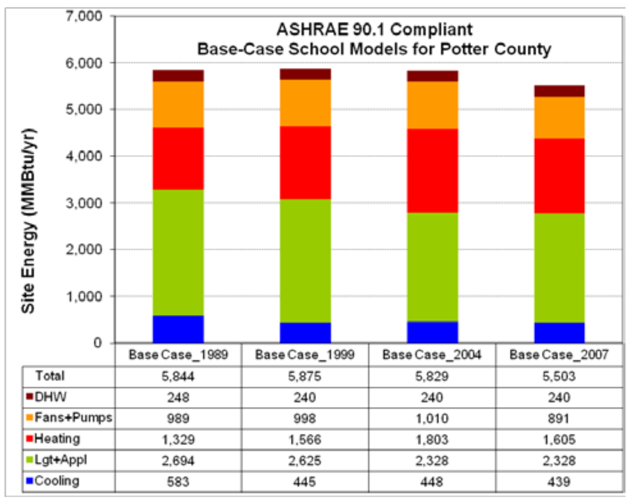
[3] Standby Loss (SL) based on a 70°F temperature difference between stored water and ambient requirements



(a) Harris County (Climate Zone 2)



(b) Dallas County (Climate Zone 3)



(c) Potter County (Climate Zone 4)

Figure 4. ASHRAE 90.1 Compliant Base-Case School Models

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[4].

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%

[4] Based on the requirements specified in Table 8A-23 of the ASHRAE Standard 90.1-1989, higher insulation are required for walls, roof, and slab-on-grade floor than are required in Table B-13 of the 90.1-1999.

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.

Energy Savings from Various EEMs

Table 5 shows the annual site energy savings (%) above the base case achieved by each EEM for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4). The calculated cost savings ($/year)[5] are also presented in the Table. To show the impact of individual EEMs on site energy consumption for different end-uses and total, these results were graphically represented in Figure 5 to 7 using the ASHRAE 90.1-1999 compliant base cases (schools that built between 2000 and 2007) for Harris, Dallas, and Potter County, respectively.

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.

Cost Savings from Various EEMs

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.

ASHRAE's AEDG for K-12 Schools

To examine the energy saving potential from the combination of individual EEMs, a single group measure was simulated using the recommendations in the ASHRAE's 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

[5] Savings depend on fuel mix used: electricity = $0.15/kWh and natural gas = $1.00/therm.

Table 4. 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

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.

SUMMARY

This paper presents the preliminary results from an analysis of the energy saving potential in 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 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, 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 (1989 base case).

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's 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.

FUTURE WORK

To estimate the total state-wide energy saving potential of all Texas ISDs, 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 after 2007) will be surveyed. For Group 4 (new schools that will be constructed in 2011), using the population growth rate, the total floor area (sq. ft.) will also be estimated. Finally, the total energy consumption of the existing and new schools in Texas will be estimated using the simulated energy use intensity (kBtu/sq. ft.) and the surveyed total floor area (sq. ft.) of each school group in each climate zone.

ACKNOWLEDGEMENT

Funding for this study was provided by the U.S. EPA through the Laboratory's Center for Excellence on Displaced Emission Reduction (CEDER) and by the Texas State Legislature through the Texas Emissions Reduction Program (TERP).

REFERENCES

ASHRAE. 2007. *ASHRAE Handbook HVAC Applications,* Ch. 49 Service Water Heating. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2008. *Advanced Energy Design Guide for K-12 School Buildings*. Atlanta, GA: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.

CHPS. 2006. *CHPS Best Practices Manual*. San Francisco, CA: Collaborative High Performance Schools.

EERE. 2010. *Commercial Building Initiative.* Washington, DC: United States Department of Energy Efficiency and Renewable Energy. Retrieved July 1, 2010, from http://www1.eere.energy.gov/buildings/commercial_initiative/reference_buildings.html

EPA. 2008. *ENERGY STAR Building Upgrade Manual*. Washington, DC: United States Environmental Protection Agency ENERGY STAR.

EPA. 2010. *ENERGY STAR for K-12 School Districts*. Washington, DC: United States Environmental Protection Agency ENERGY STAR. Retrieved July 1, 2010, from http://www.energystar.gov/index.cfm?c=k12_schools.bus_schoolsk12

JJH. 2009. *DOE2.com eQUEST*. Camarillo, CA: James J. Hirsch & Associates. Retrieved July 1, 2010, from http://www.doe2.com/equest/

Im, P and J. Haberl. 2006. A survey of high performance schools. *Proceedings of the Fifteenth Symposium on Improving Building Systems in Hot and Humid Climates,* Orlando, FL (July).

Im, P. 2009. Methodology for the Preliminary Design of High Performance Schools in Hot and Humid Climates. Ph.D. dissertation, Department of Architecutre, Texas A&M University.

Klein, S.A. and W.A. Beckman. 1983. *F-Chart SolarEnergy System Analysis: DOS Version 5.6.* F-Chart Software. Middleton, WI: www.fchart.com

Klein, S.A. and W.A Beckman. 1994. *PV F-Chart Photovoltaic Systems Analysis*. PV F-Chart Software. Middleton, WI: www.fchart.com

Shonder, J. A., M. A. Martin, P. J. Hughes, and J. Thornton, 2000. *Geothermal Heat Pumps in K-12 Schools: A Case Study of the Lincoln, Nebraska, Schools*. ORNL/TM-2000/80. Oak Ridge, TN: Oak Ridge National Laboratory.

Pless, S., P. Torcellini, and N. Long. 2007. *Technical Support Document of the Advanced Energy Design Guide for K-12 Schools-30% Energy Savings*. Technical report NREL/TP-550-42114. Golden, CO: National Renewable Energy Laboratory.

TEA. 2009. *Enrollment in Texas Public Schools, 2008-09*. Document No. GE10 601 02. Austin, TX: Texas Education Agency.

TEA. 2010. *School and District File*. Austin, TX: Texas Education Agency. Retrieved July 1, 2010, from http://mansfield.tea.state.tx.us/TEA.AskTED.Web/Forms/Home.aspx

Texas Comptroller of Public Accounts. 2006. *Current and Future Facilities Needs of Texas Public School Districts*. Austin, TX: Texas Comptroller of Public Accounts.

Table 5. Energy Efficient Measures for High Performance Schools
for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4)

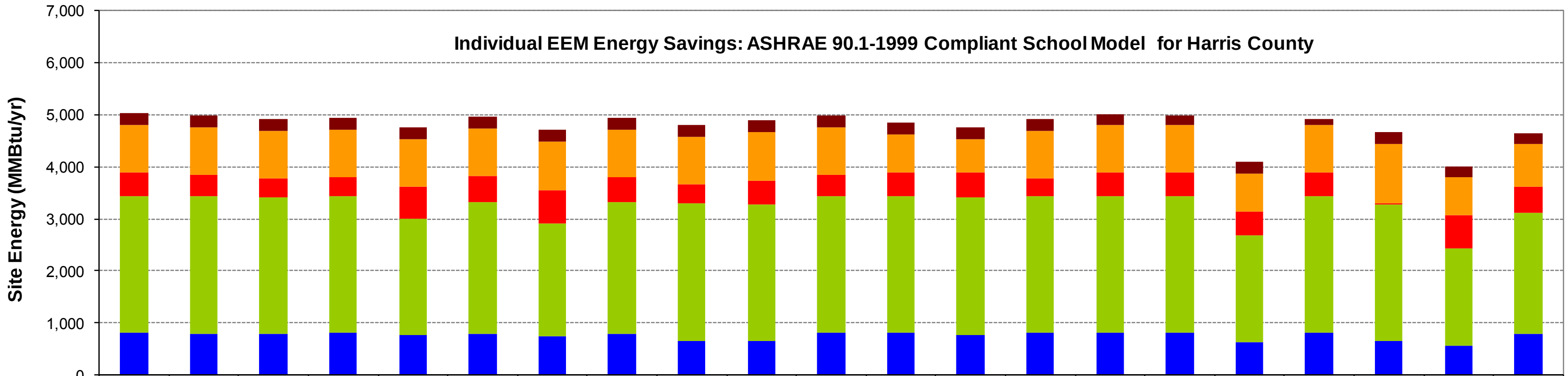
EEM #	Individual Energy Efficiency Measure (EEM)	Base Case Input												EEM Input	EEM Source
		Climate Zone 2 (Harris County)				Climate Zone 3 (Dallas County)				Climate Zone 4 (Potter County)					
		ASHRAE 90.1-1989	ASHRAE 90.1-1999	ASHRAE 90.1-2004	ASHRAE 90.1-2007	ASHRAE 90.1-1989	ASHRAE 90.1-1999	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.

Table 6. Annual Total Site Energy and Cost Savings from Individual EEMs for Harris County (Climate Zone 2), Dallas County (Climate Zone 3), and Potter County (Climate Zone 4)

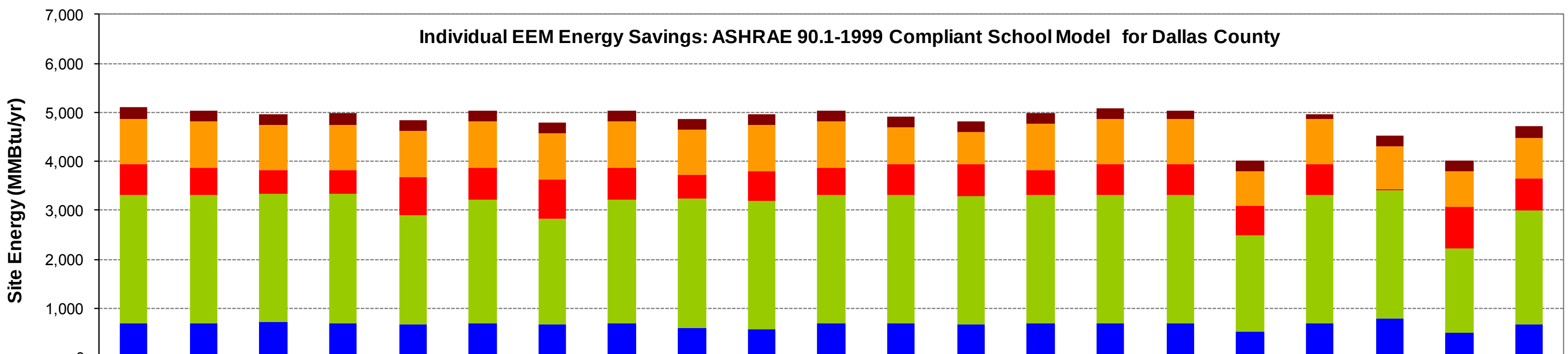
EEM #	Individual Energy Efficiency Measure (EEM)	Harris County (Climate Zone 2)								Dallas County (Climate Zone 3)								Potter County (Climate Zone 4)							
		ASHRAE 90.1-1989		ASHRAE 90.1-1999		ASHRAE 90.1-2004		ASHRAE 90.1-2007		ASHRAE 90.1-1989		ASHRAE 90.1-1999		ASHRAE 90.1-2004		ASHRAE 90.1-2007		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.



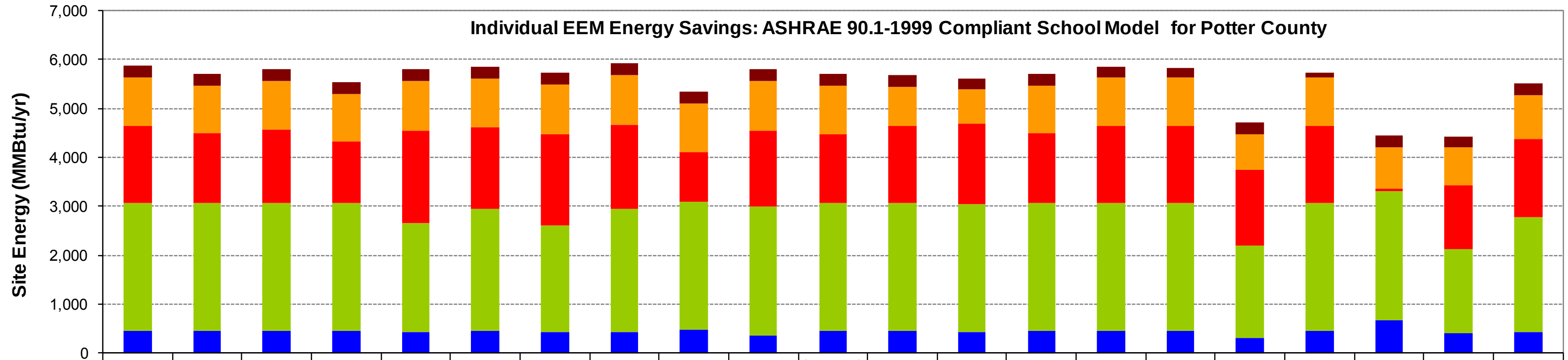
	Base Case (1999)	Increased Roof Insulation	Decreased U-Value	Decreased Infiltration	Decreased LPD	Occupancy Sensor	Daylight Dimming	Skylights	OA Demand Control	Improved AC Eff.	Improved Heating System Eff.	Decreased Fan Power	PVAVS with VFD	HW Pump with VSD	Improved DHW Heater Eff.	Tankless Water Heater	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 5. Energy Use of Individual EEMs for ASHRAE 90.1 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	5,101	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 6. Energy Use of Individual EEMs for ASHRAE 90.1 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	5,875	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 7. Energy Use of Individual EEMs for ASHRAE 90.1 Compliance Base-Case School: Potter County (Climate Zone 4)