Analysis of the Energy Savings Potential in K-5 Schools in Hot and Humid Climates

Piljae Im
Graduate Student

Jeff S. Haberl, Ph.D., P.E.
Professor

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

ABSTRACT

This paper presents the analysis of the energy savings potential in K-5 schools in hot and humid climates. For the analysis, an existing K-5 school in Central Texas was selected as a case study school, and the building energy related data and information were collected. Based on the information, an hourly building energy simulation was developed using the DOE-2 program and calibrated with the measured building energy use. This final calibrated simulation was modified to be compliant to the ASHRAE Standard 90.1-1999 in order to be used as a base-case school. Then, several energy efficient measures that are appropriate for the school buildings in hot and humid climates were identified from previous studies and applied to the base-case school simulation to estimate the energy savings potential. The measures include high R-values for walls and roofs, high performance glazing, T-5 or T-8 fluorescent lamps, occupancy sensors for lighting control, and high efficient chillers and boilers.

BACKGROUND

According to the National Center for Education Statistics (NCES), U.S. Schools spent nearly $8 billion on energy costs in 2001, which is more than the cost of textbooks and supplies combined (Smith et al. 2003). In addition, about sixty-one percent of public school districts reported a shortfall in funding to pay their energy bills. As a result, most school districts need to reduce energy expenditures. Therefore, the application of energy efficient strategies to new and existing schools can be an effective solution for this problem. Furthermore, the average age of America's public schools is 42 years (Rowand 1999), which means the vast majority of existing schools could benefit greatly from the application of energy efficient strategies.

Several energy efficient measures for schools can be found in the literature. A previous study (Im and Haberl 2006) surveyed the common energy efficient measures found in recent high performance schools. The survey results showed that: 1) high performance glazing, 2) high R-values for walls and roofs, 3) high albedo roof, 4) T-5 or T-8 fluorescent lamps, 5) lighting occupancy sensor, and 6) high efficient chillers and boilers are the common energy efficient measures found in existing high performance schools.

In addition, ASHRAE's recently published Advanced Energy Design Guide (AEDG) for K-12 School Buildings (ASHRAE 2008) provides a number of energy efficient measures available for schools in each climate zone. This design guide was developed to achieve 30% more energy efficient schools compared to the ASHRAE Standard 90.1-1999 when the recommended energy efficient measures for each climate zone are applied.

Objectives

The paper analyzes energy savings potentials by applying the energy efficient measures recommended in the AEDG for K-12 School Buildings to an existing K-5 school building in hot and humid climates. In order to achieve this purpose, three objectives are defined as below:

1) A calibrated simulation for an existing K-5 school building is developed.
2) The calibrated simulation is modified to be compliant with the ASHRAE 90.1-1999.
3) Based on the simulated energy consumption of the ASHRAE 90.1-1999 compliant school, the energy savings potential is estimated by applying the energy saving measures recommended in the AEDG for K-12 School Buildings.

By applying the energy efficient measures recommended in the AEDG for K-12 School Buildings to an actually existing school building, this study demonstrates the application procedure of the AEDG's recommendations and how much energy could be saved compared to the code compliant school building.

CALIBRATED SIMULATION OF A CASE STUDY BUILDING

As a first step of the study, an existing case study building was selected and simulated. The detailed description of the case study building and the calibrated simulation results were previously presented in the paper by Im and Haberl (2008). The selected case study elementary school is one of six elementary schools in the same school district. As of 2006, about 600 students were enrolled. Total gross floor area is about 74,000 square feet. The building is served by eight Air Handling Units (AHUs) consisting of three different types of AHUs including: 1) four variable air volume systems for the classrooms and library, 2) three constant volume systems for a gym, cafeteria, and kitchen, and 3) one multi zone unit for administration offices. Table 1 and Figure 1 show the summary of the building description and the building geometry, respectively. The calibration simulation results are shown in Figure 2. The final Mean Biased Error (MBE) and the Coefficiency of Variation of the Root Mean Square Error (CV(RMSE)) [1] for whole building electricity were calculated as 1.4% and 16.6%, respectively. The Energy Usage Index (EUI) from the calibrated simulation is calculated as 49.3 kBtu/ ft^2-yr.

ASHRAE STANDARD 90.1-1999 COMPLIANT SIMULATION

One of the purposes of the ASHRAE 90.1-1999 compliant simulation in this study is to compare the energy consumptions of the case study school to the code compliant school. However, the Outside Air (OA) ventilation rate of the case study school is

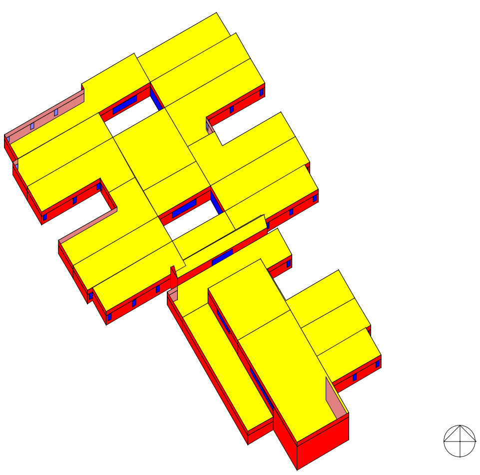

Figure 1: Building Geometry of the Case Study School

Description	Case Study School
General	
Location (Longitude & Latitude) (Degrees)	Longitude: 96.30 Latitude: 30.57
Floor Area (ft2)	74,905
Architectural Features	
Number of Floors	1
Window-to-Wall Ratio (%)	10%
Exterior Wall	
Calculated U-Factor (Btu/hr-ft2-F)	0.085
Roof	
Calculated U-Factor (Btu/hr-ft2-F)	0.053
Slab-On-Grade Floor	
Calculated U-Factor (Btu/hr-ft2-F)	0.043
Windows	
Structure	Sinlge Pane Glass
Calculated U-Factor (Btu/hr-ft2-F)	1.09
Solar Heat Gain Coefficient (SHGC)	0.59
Internal Loads	
Number of Student	600
Lighting Fixture	T-8 with Electronic Ballas
Lighting Density (W/ft2)	1.2
Equipment Density (W/ft2)	0.6
HVAC Systems	
System type and assigned spaces	4 VAV with reheat: Classrooms + library 3 CV with reheat: Common area 1 MZU: Administration office
Setpoint temperature for each space	Cooling: 72F Heating: 72F
Space T-stat setup/setback	Cooling: 80F Heating: 55F
Design Supply Air	55F
Plant	
Chiller	
Number of chiller(s)	2
Size (Tons)	95.7 each
Chiller COP	2.8
Boiler	
Number of Boiler(s)	1
Size (MBtu/hr)	2.05
Boiler Thermal Efficiency (%)	0.82
SWH	
Number of SWH	2
Size (gallons)	100
SWH Efficiency (Et, %)	78.6
Pump	
Number of Pump(s)	2 for Chiller, 1 for Boiler

Table 1: Building Description of the Case Study School

currently too low (i.e., approximately 5 CFM/person in classrooms) compared to the ASHRAE Standard 62-1999 requirement, 15 CFM/person. Therefore, the OA ventilation rate in the calibrated simulation was modified to be 15 CFM/person. The simulation result from this modification with the calibrated simulation result is shown in Figure 3. As shown, the cooling and heating energy increased due to the increased OA ventilation rate. The EUI for the calibrated simulation and the modified calibrated simulation are 49.3 kBtu/ ft^2-yr and 51.6 kBtu/ ft^2-yr, respectively (i.e., 4.7 % increase).

[1] The equation for the calculation of MBE (%) and the CV(RMSE) (%) is provided in Appendix of this paper.

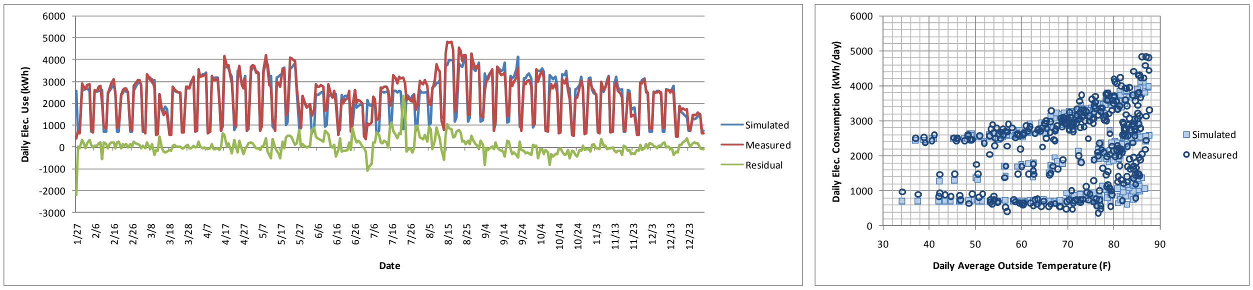

Figure 2: Calibrated Simulation vs. Measured Energy Uses

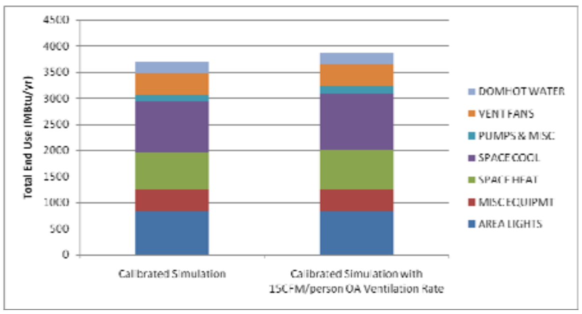

Figure 3: Calibrated Simulation vs. Modified Calibrated Simulation (with 15 CFM/Person OA Ventilation rate)

Measures	Case Study School	ASHRAE 90.1-1999
Roof Insulation (Btu/ft2-F-hr)	U-0.053	U-0.063
Wall Insulation (Btu/ft2-F-hr)	U-0.085	U-0.089
Glazing (U-Value and SHGC)	U-1.12 SHGC - 0.72	U-1.27 SHGC - 0.25
Lighting Power Density (W/ft2)	1.2	1.5
Occupancy Control	None	Scheduled On Off
HVAC Type (See Table 1)	VAV with Reheat Constant Air Volume Multi Zone Unit	Packaged Rooftop VAV system
Economizer	None	Yes
Cooling Efficiency (EER)	9.6 EER	10.1 EER
Boiler Efficiency (%)	82%	80%
SWH Efficiency (Et %)	78.6%	80%

Table 2: Simulation Input for the Case Study School vs. ASHRAE Standard 90.1-1999

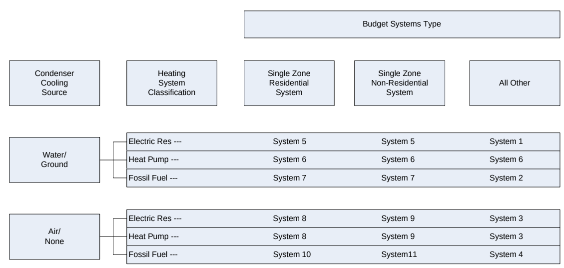

Figure 4: HVAC Systems Map (ASHRAE 1999)

ASHRAE 90.1-1999 Compliant Simulation

ASHRAE Standard 90.1-1999 provides three options for the code compliant path, including: 1) Prescriptive option, 2) Trade off option, and 3) Energy Cost Budget (ECB) option. There are also mandatory provisions in envelope, lighting, and mechanical systems required for all compliance options. In this study, the Energy Cost Budget method (ECB) was used to modify the case study school to be compliant to the 90.1-1999. Table 2 shows the summarized comparison for the simulation inputs of the case study school and the ECB simulation model. As shown, the requirements for the envelope systems for ECB model used 90.1-1999 values for the corresponding climate area (i.e., Table B-6 in ASHRAE 90.1-1999). The HVAC systems for ECB model was selected as instructed by 90.1-1999 (i.e., Section 11.4.3). First, based on the *HVAC Systems Map* (See Figure 4), the type of the system was selected. Since the case study building has air-cooled condensers, the type of heating system was classified as fossil fuel, and the building has multiple zones, system 4, *"Packaged variable air volume with reheat"* was selected from Figure 4.

The code-compliant simulation result is shown in Figure 5 compared with the previously modified calibrated simulation result. The most noticeable change in the end uses is the lighting energy use. The 834.7 MBtu of lighting energy use from the calibrated simulation increased to 1,043.3 MBtu in the code-compliant simulation (i.e., a 25% increase). This is because the lighting power density for the code-compliant school is 1.5 W/ ft^2, while the case study school has 1.2 W/ ft^2 of the lighting power density. Therefore, the total lighting energy use increased.

In addition, the space heating energy use decreased (i.e., a 48% decrease) in the code-compliant simulation as the internal heat gain increased due to the increased lighting power density. The space cooling energy also increased due to the increased internal load. The EUI for the as-built simulation and the code-compliant simulation were

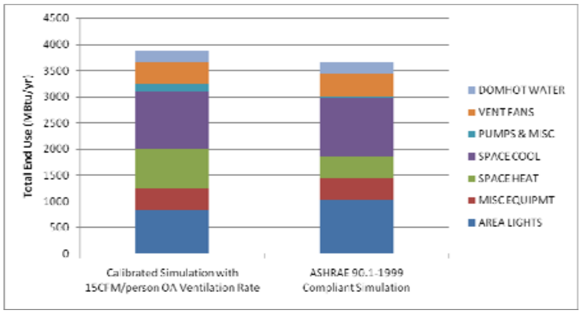

Figure 5: Modified Calibrated Simulation (with 15 CFM/Person OA Ventilation rate) vs. ASHRAE 90.1-1999 Compliant Simulation

51.6 kBtu/ ft^2-yr and 48.7 kBtu/ ft^2-yr, respectively (i.e., a 5.7 % decrease).

Since a code-complaint check requires total energy costs in the ECB method, the total energy costs for the two scenarios were calculated. The energy rate for the calculation used the average commercial price of electricity and natural gas by State in 2006. According to Energy Information Agency (EIA) (EIA 2008), the average commercial price of electricity for Texas in 2006 was \$0.0985/kWh. The same source showed that the average commercial natural gas rate for Texas in 2006 was \$1.025/ccf. The calculated total annual energy cost for two scenarios are shown in Table 3. The as-built building consumes \$94,400 annually, while the code compliant building consumes \$94,361 annually. As shown in this cost calculation, even though the code-compliant building consumes 5.7 % less energy than the case study school, the energy cost for the case study school is almost the same as the cost for the code compliant school (i.e., \$39 total annual increase, 0.04% of energy budget).

SIMULATION FOR THE AEDG FOR K-12 SCHOOL BUILDINGS

As a final step of this study, the energy saving measures recommended in the AEDG for K-12 school buildings are applied to the baseline simulation (i.e., code-compliant simulation). The location of the baseline school corresponds to the climate zone 2 in the AEDG for K-12 school buildings (See Figure 6). Table 4 shows the energy features that would be changed from the baseline school based on the recommendations from the AEDG for K-12 schools. To perform this analysis, eight separate changes were made to the simulation input. Each step of the modifications was separately simulated, and the result was compared to the baseline school energy use in order to verify the impact of each measure. In addition, the cumulative energy savings from the steps 1 to 8 were also simulated and compared to the baseline energy consumption.

Figure 7 and Table 5 present the energy savings from the application of the individual energy saving measures. As shown, the most effective energy saving measure in terms of energy consumption was step 5, which is the use of occupancy sensors. The installation of the occupancy sensor saved 8.7% of the total energy use compared to the base-case school that has the existing lighting schedule. The next largest savings was achieved by reducing the lighting power density from 1.5 W/ ft^2 to 1.1 W/ ft^2 (i.e., 6.7% of total energy savings). The first and the second largest energy savings were achieved by reducing the lighting energy use in the school.

Figure 6: Climate Zone 2 Defined in the AEDG for K-12 School Buildings

In order to estimate the total cumulative energy savings from the application of all the recommendations of the AEDG for K-12 schools, the cumulative savings were simulated as summarized in Table 4. By applying all 8 measures, the AEDG recommended school would reduce the total annual energy use by 22.8%. Table 6 and Figure 8 present the cumulative energy savings as steps increase. Converting these energy savings to the cost savings using the same energy rate used in the previous section, the AEDG recommended school will save \$28,131 annually, which is 27.1% less cost consumptive than the baseline school (See Table 6). The EUI for the school was reduced from 48.7 kBtu/ ft^2-yr to 37.6 kBtu/ ft^2-yr by applying all 8 measures.

Electricity Rate	0.0985 ($/kWh) =	28.87 ($/MBtu)
Natural Gas Rate	10.25 ($/kcf) =	10.25 ($/MBtu)

	Calibrated Simulation with 15CFM/person OA Ventilation Rate				ASHRAE 90.1-1999 Compliant Simulation				% Diff.			
	Electricity (MBtu)	N.G. (MBtu)	Total (MBtu)	EUI (kBtu/sqft-yr)	Electricity (MBtu)	N.G. (MBtu)	Total (MBtu)	EUI (kBtu/sqft-yr)	Electricity	N.G.	Total	EUI
TOTAL	2,938.8	932.7	3,871.5	51.6	3,058.7	591.2	3,649.9	48.7				**5.72%**
TOTAL COST	**$84,839**	**$9,561**	**$94,400**		**$88,301**	**$6,060**	**$94,361**		**-4.08%**	**36.61%**	**0.04%**	

Table 3: Energy Cost Calculation for the Case Study and Code Compliant School

Step	Measures	Baseline (ASHRAE 90.1-1999)	Recommendations from the AEDG for K-12 Schools
1	Roof R-Value (ft^2-F-hr/Btu)	R-15	R-25
2	Glazing U-value (Btu/ ft^2-F-hr) & SHGC	U-1.27	U-0.45
		SHGC - 0.287	SHGC - 0.25
3	Shading & Orientation	No Shading	Projection Factor = 0.5
4	Lighting Power Density (W/ ft^2)	1.5	1.1
5	Occupancy Control	Scheduled on off	Occupancy sensor
6	Cooling COP (EER)	10.1	10.6
7	SWH efficiency (%)	80%	90%
8	Fans (CFM)	1.7 hp/1000	1.3 hp/1000

Table 4: Input Measures for the Baseline and AEDG Recommended Simulations

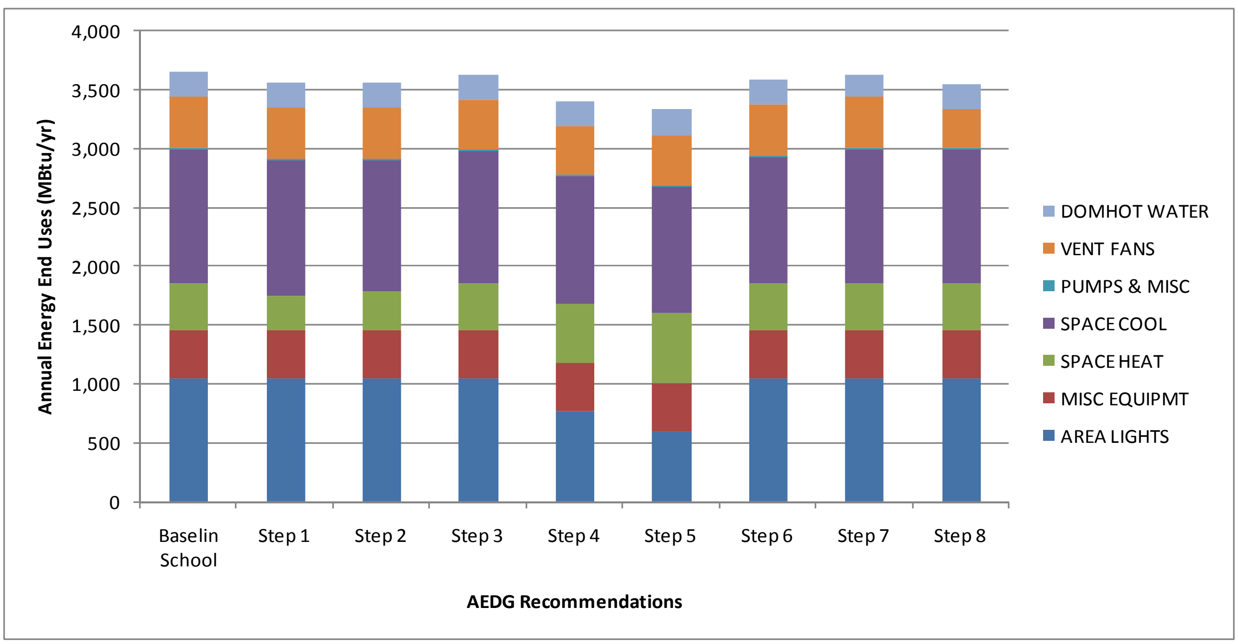

Figure 7: Individual Energy Savings from Energy Efficient Measures

	Baseline School (ASHRAE 90.1-1999)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
AREA LIGHTS (MBtu/yr)	1,043.3	1,043.3	1,043.3	1,043.3	765.1	595.2	1,043.3	1,043.3	1,043.3
MISC EQUIPMT (MBtu/yr)	417.3	417.3	417.3	417.3	417.3	417.3	417.3	417.3	417.3
SPACE HEAT (MBtu/yr)	392.6	287.4	325.0	395.6	499.2	593.8	392.6	392.6	392.6
SPACE COOL (MBtu/yr)	1,146.0	1,160.8	1,126.3	1,130.9	1,088.8	1,083.8	1,088.4	1,146.0	1,146.0
PUMPS & MISC (MBtu/yr)	4.4	4.2	4.3	4.4	4.7	5.0	4.4	4.4	4.4
VENT FANS (MBtu/yr)	434.0	437.4	428.4	429.8	419.2	423.8	434.0	434.0	331.9
DOMHOT WATER (MBtu/yr)	212.3	212.3	212.3	212.3	212.3	212.3	212.3	193.3	212.3
TOTAL (MBtu/yr)	3,649.9	3,562.7	3,556.8	3,633.7	3,406.7	3,331.3	3,592.3	3,630.9	3,547.8
% Diff (vs. Baseline)	-	**2.4%**	**2.5%**	**0.4%**	**6.7%**	**8.7%**	**1.6%**	**0.5%**	**2.8%**
$ Elec.	$88,301	$88,753	$87,529	$87,746	$78,254	$73,392	$86,637	$88,301	$85,354
$ N.G.	$6,060	$5,005	$5,381	$6,091	$7,134	$8,088	$6,060	$5,865	$6,060
$ Total	$94,361	$93,759	$92,909	$93,837	$85,388	$81,480	$92,697	$94,166	$91,414
% Diff (vs. Baseline $)	-	**0.0%**	**0.9%**	**-0.1%**	**8.9%**	**13.1%**	**1.1%**	**-0.4%**	**2.5%**

Table 5: Individual Energy Savings from Energy Efficient Measures

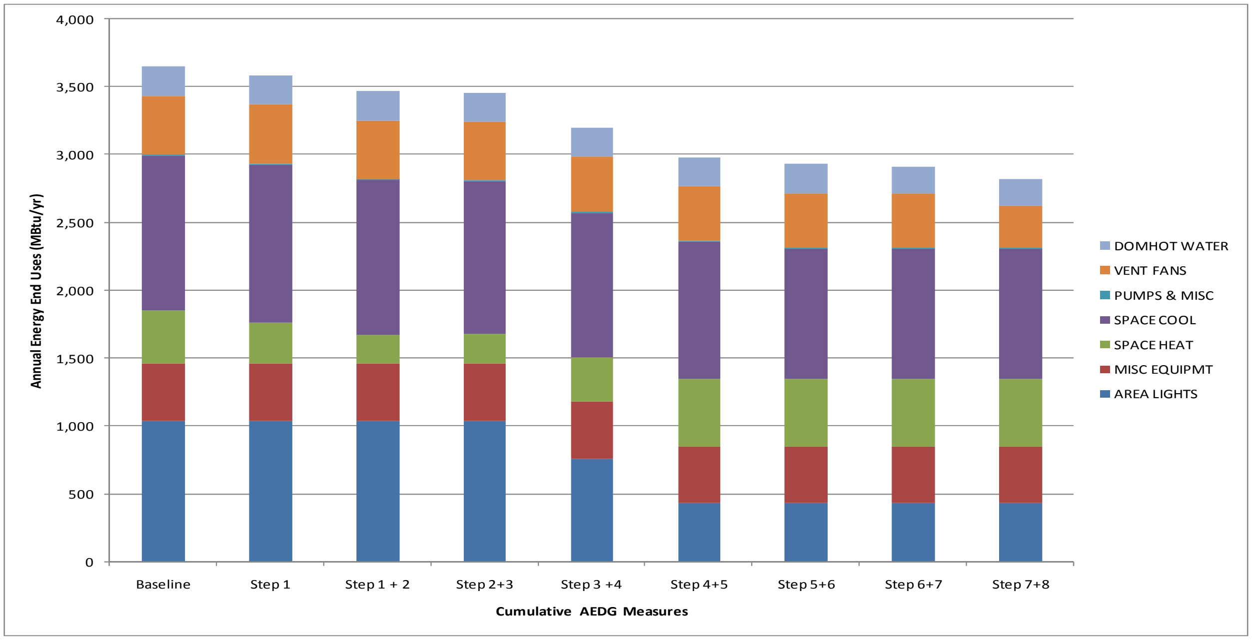

Figure 8: Cumulative Energy Savings from the Energy Efficient Measures

	Baseline School (ASHRAE 90.1-1999)	Step 1	Step 1 + 2	Step 2+3	Step 3 +4	Step 4+5	Step 5+6	Step 6+7	Step 7+8
AREA LIGHTS (MBtu/yr)	1,043.3	1,043.3	1,043.3	1,043.3	765.1	436.5	436.5	436.5	436.5
MISC EQUIPMT (MBtu/yr)	417.3	417.3	417.3	417.3	417.3	417.3	417.3	417.3	417.3
SPACE HEAT (MBtu/yr)	392.6	301.8	216.3	223.0	329.0	498.8	498.8	498.8	498.8
SPACE COOL (MBtu/yr)	1,146.0	1,166.2	1,142.4	1,126.2	1,062.7	1,011.4	960.6	960.6	960.6
PUMPS & MISC (MBtu/yr)	4.4	4.2	4.0	4.0	4.5	4.9	4.9	4.9	4.9
VENT FANS (MBtu/yr)	434.0	438.7	432.5	428.2	411.3	402.5	402.5	402.5	307.8
DOMHOT WATER (MBtu/yr)	212.3	212.3	212.3	212.3	212.3	212.3	212.3	193.3	193.3
TOTAL (MBtu/yr)	**3,649.9**	**3,583.9**	**3,468.1**	**3,454.4**	**3,202.2**	**2,983.7**	**2,932.9**	**2,913.9**	**2,819.2**
% Diff (vs. Baseline)	-	**1.8%**	**5.0%**	**5.4%**	**12.3%**	**18.3%**	**19.6%**	**20.2%**	**22.8%**
$ Elec.	$88,301	$88,960	$88,018	$87,434	$77,188	$66,075	$64,607	$64,607	$61,873
$ N.G.	$6,060	$5,150	$4,297	$4,364	$5,416	$7,123	$7,123	$6,927	$6,927
$ Total	$94,361	$94,110	$92,315	$91,797	$82,605	$73,199	$71,730	$71,534	$68,800
% Diff (vs. Baseline $)	-	**0.3%**	**2.2%**	**2.7%**	**12.5%**	**22.4%**	**24.0%**	**24.2%**	**27.1%**

Table 6: Cumulative Energy Savings by Step

CONCLUSION

The energy savings potential by applying the energy efficient measures recommended in the AEDG for K-12 School Buildings was presented in this paper. In order to estimate the energy savings, an existing case study school building in a hot and humid climate was selected and simulated. The EUI from the calibrated simulation was calculated as 49.3 KBtu/ ft^2-yr. After calibrating the initial simulation with the measured data and other information, the calibrated simulation was modified to be compliant with the ASHRAE Standard 90.1-1999 using the ECB option offered in the standard. The EUI for the code-compliant simulation was 48.7 kBtu/ ft^2-yr. As a final step of the study, the AEDG recommended energy efficient measures were applied to the code compliant school simulation. There were 8 steps of the applications. Of these, the application of the occupancy sensor was the most effective measure in terms of energy use, and the decreased lighting power density was the second most effective measure. The total energy saving by applying the 8 measures all together was 22.8% compared to the baseline school. When converting this energy savings to the cost savings using the same energy rate used in the previous section, the AEDG recommended school will save $25,561 annually, and this is 27.1% less consumptive than the baseline school costs.

ACKNOWLEDGEMENT

Funding for this study was provided by Texas State Legislature through the Texas Emissions Reduction Program. The author wants to acknowledge the support given by College Station Independent School District for providing the case school's building information and the utility bills for the analysis of this study.

APPENDIX

MBE (%) and CV(RMSE) (%) can be calculated as followings:

$$\text{MBE}\ (\%) = \frac{\dfrac{\sum_{i=1}^{n} \text{Residual}_i}{n-p}}{M} \times 100$$

$$\text{CV(RMSE)}\ (\%) = \frac{\sqrt{\dfrac{\sum_{i=1}^{n} \text{Residual}^2_i}{n-p}}}{M} \times 100$$

Where,

n is the number of data points,
p is the total number of regression parameters in the model,
M is the mean value of the dependent variable of the set.

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