ANALYSIS OF THE ENERGY SAVINGS POTENTIAL IN K-5 SCHOOLS IN HOT AND HUMID CLIMATES: APPLICATION OF HIGH PERFORMANCE MEASURES AND RENEWABLE ENERGY SYSTEMS[1]

Piljae Im[1], and Jeff S. Haberl[2]
[1]Oak Ridge National Laboratory, Oak Ridge, TN
[2]Texas A&M University, College Station, TX

ABSTRACT

This paper presents the analysis of the energy savings potential in an existing K-5 school in hot and humid climates. Previous paper (Im and Haberl 2008b) presented a calibrated simulation procedure for an existing K-5 school in hot and humid area, and the first step of the energy savings potential analysis by applying the energy savings measures recommended as in the ASHRAE Advanced Energy Design Guides for K-12 Schools. As an effort to investigate more energy savings potential for the school building, several other energy savings measures and renewable energy measures were applied to the target building. Those measures include: increased glazing U-value, VFD application for the HVAC system, cold deck reset, variable speed for pumps, high-efficiency boiler, skylights, and the application of solar thermal and PV systems. The final simulation results show that the estimated Energy Use Index (EUI) of the school by applying all the measures but the solar thermal and PV systems would be 29.9 kBtu/sqft (i.e., 38.6 % energy savings against the baseline school). In addition, solar thermal and PV systems were designed to provide half of the electricity demand and all the SWH demand of the school building, respectively. The final EUI for the school with the solar thermal and PV systems was estimated to be 15 kBtu/sqft.

INTRODUCTION

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.

Numerous 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 (i.e., low SHGC and low U-value) for southern climates, 2) High albedo roofs, or roofs with high solar reflectance for southern climates, 3) High R-values for walls and roofs, 4) T5 or T8 fluorescent lamps with electronic ballasts, 5) Occupancy sensors to control interior lighting, 6) Solar photovoltaic (PV) and solar thermal systems, 7) Ground source heat pumps, 8) High AFUE (e.g., over 90%) boilers, and 9) High efficient SWH 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 the energy savings potentials for an existing K-5 school building by applying several high performance measures and renewable energy systems. The description of the baseline school, the calibrated simulation, and the AEDG for K-12 compliant school simulation results were presented in the previous paper (Im and Haberl 2008b). In order to achieve this purpose, five 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, which was used as the baseline school for the analysis.

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.

4) More energy savings potential is estimated by applying additional high performance measures including a daylighting strategy to the AEDG for K-12 compliant school.

5) Application of solar thermal and PV systems is simulated to estimate the final energy use for the high performance school building.

This study focuses on the objectives 4 and 5 as the previous study (Im and Haberl 2008b) presented the methodologies and results of the first three objectives. Therefore, this study demonstrates how much energy could be reduced by applying the selected high performance measures and the renewable energy systems to an existing school building, and analyzes the effectiveness of the each measure.

CALIBRATED SIMULATION OF A CASE STUDY BUILDING

As mentioned earlier, the details of the case study school was presented in the previous study. The selected case study school is an elementary school, which has about 74,000 square feet of the conditioned total floor area. 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. The detailed building characteristics are shown in Table 1. The school was modeled with DOE-2.1e simulation program (see Figure 1 for building geometry), and the initial model was calibrate with one year of hourly energy data, a classroom & AHU temperature and humidity measurement using portable loggers, interview with maintenance personnel, and actual weather data including hourly solar radiation.

The calibrated simulation results shows that the Normalized Mean Biased Error (NMBE) and the Coefficiency of Variation of the Root Mean Square

Table 1 Case Study Building Characteristics

| 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
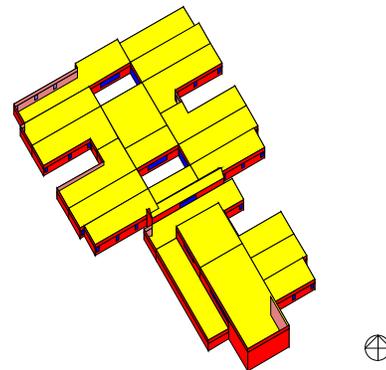
Figure 1 3D Simulation Rendering of the Building Geometry of the Case Study School
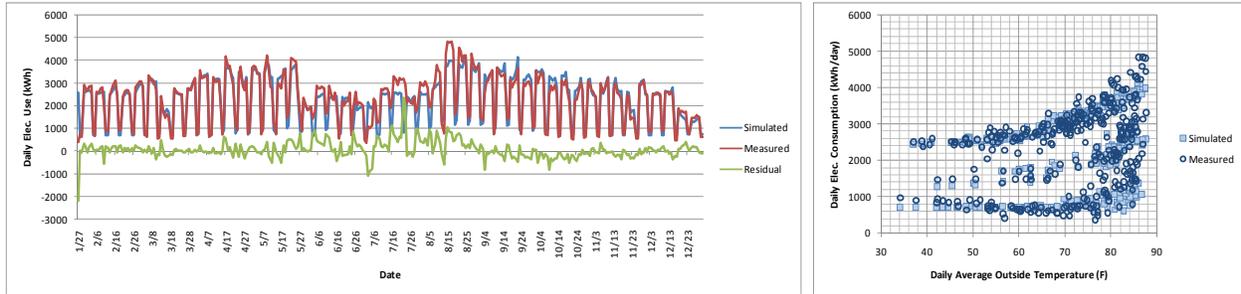
Figure 2 Daily Calibrated Simulation vs. Measured Energy Uses

Error (CV(RMSE)) [2] for whole building electricity were calculated as 1.4% and 16.6%, respectively, which means that the simulation model can be declared to be calibrated based on

ASHRAE Guideline 14-2002 (2002). Figure 2 provides the comparison with the measured hourly electricity data compared with the calibrated simulation. 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

The calibrated simulation was, then modified to be compliant with ASHRAE Standard 90.1-1999. The energy consumption of this code-compliant building was used for the baseline school building energy use through the whole paper to estimate the energy savings from the selected energy efficient measures. The calibrated simulation model was modified to be compliant with the code based on the Energy Cost Budget (ECB) option as described in ASHRAE 90.1-1999. In addition, the OA ventilation rate was increased from 5 cfm/person to 15cfm/person to be compliant with the code.

From the comparion of the code compliant simulation with the calibrated simulation of the building, the most noticeable change in the end uses is the lighting energy use. The 834.7 MMBtu of lighting energy use from the calibrated simulation increased to 1,043.3 MMBtu 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. The final EUI for the code-compliant school building was estimated to 48.7 kBtu/ ft^2-yr.

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

SIMULATION FOR THE AEDG FOR K-12 SCHOOL BUILDINGS

In this step, 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. Table 2 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.

Table 2 Eight Measures Recommended from the AEDG for K-12

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)	U-1.27	U-0.45
	& SHGC	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 for Lighting	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

Figure 3 presents 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.

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 (22.8% decrease). Although the AEDG for K-12 claimed the 30% energy savings against ASHRAE 90.1-1999 compliant school buildings, the results in this study show only 22.8% energy savings. The possible explanation for this discrepancy is that: 1) the case study school has relatively lower windows-to-wall ratio compared to the study school in AEDG for K-12. Therefore, the higher energy savings cannot be achieved by replacing the code compliant glazing by more energy efficient glazing recommended in the AEDG for K-12. and 2) the EUI for the case study code-compliant school was already low compared to the baseline EUI shown in the AEDG for K-12.
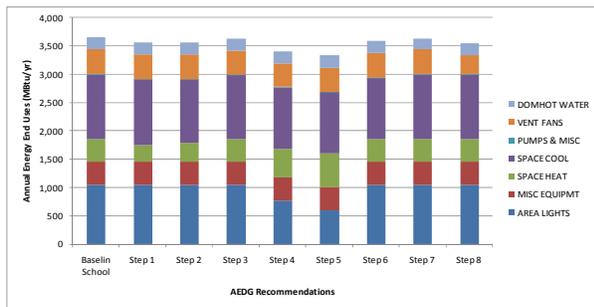

Figure 3 Individual Energy Savings from Energy Efficient Measures (AEDG Recommended)

APPLICATION OF HIGH PERFORMANCE MEASURES

In this section, several additional high performance measures were applied to the AEDG recommended school. The selected high performance measures are: 1) lower glazing U-value, 2) use of a VFD instead of inlet vane for fan control, 3) cold deck reset, 4) variable speed for the pump, and 5) higher boiler efficiency. These measures are summarized in Table 3.

The energy savings by applying the individual high performance measures were shown in Figure 4. As shown in this figure, of the five measures, the most energy savings were achieved by applying VFD fan control instead of inlet vane (i.e., 8.6% of total energy savings against the AEDG for K-12). Not surprisingly, most of this savings are from the decreased fan energy. The second most energy savings were achieved from the application of the cold deck reset. The constant cold deck temperature was modified to have reset schedule based on the outside air temperature. By

applying this measure, both of the space cooling and heating energy uses were decreased (i.e., 7.6 % of total energy savings against the AEDG for K-12).

The cumulative energy savings are shown in Figure 5. Instead of showing the results from step 9 to 13, in this comparison, the final cumulative savings are compared against the baseline code compliant simulation results in order to estimate the final total energy savings based on the code compliant school. By applying the all 13

Table 3 Energy Efficient Measures for the Above AEDG Recommended School

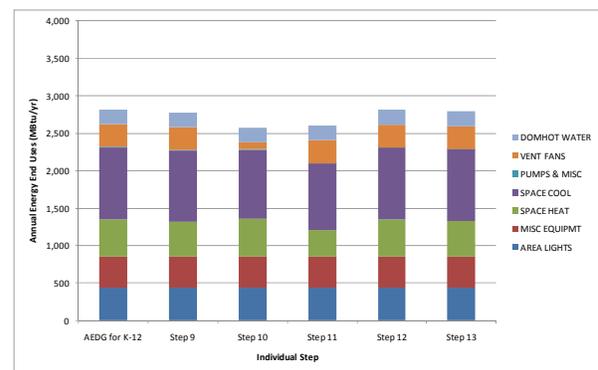| Step	Measures	AEDG Recommended School	High Performance Measures
9	Glazing U-value	U-0.45	U-0.20
10	Fan Control	Inlet Vane	VFD
11	Cold Deck reset	Constant	Reset Schedule
12	Variable Speed for Pump	Constant	Variable
13	Boiler Efficiency	80%	85%

Figure 4 Individual Energy Savings from High Performance Measures (above AEDG)

measures, the final energy efficient school would achieve a 36.8% reduction in the total annual energy savings compared to the baseline school. When converting this energy savings to the cost savings using the average energy rate in Texas, the final high performance school will save $37,784 annually, which is 66% less than the baseline school The EUI for the school was reduced from 48.7 kBtu/sqft-yr to 30.8 kBtu/sqft-yr by applying the all 13 measures.

The next step is an application of a daylighting strategy to the ASHRAE 90.1-1999 compliant school building. The daylighting strategy selected for this application was simple toplights. This type of daylighting strategy was selected given the fact that 1) the DOE-2 simulation program can calculate the daylighting impact reasonably close to the more detailed daylighting simulation when using simple toplights
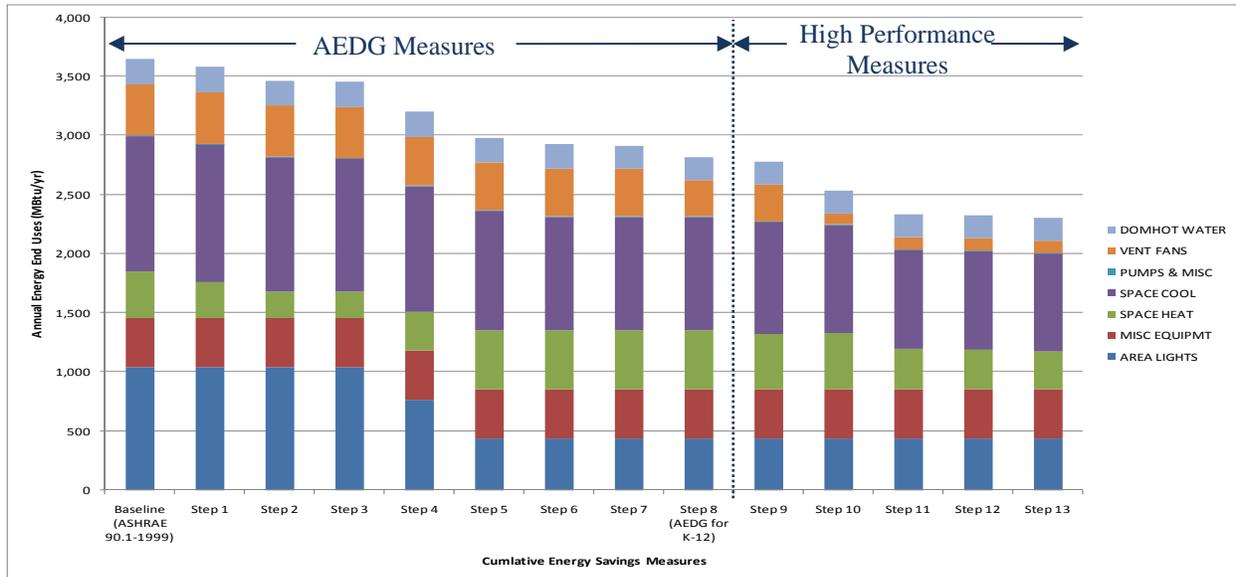
Figure 5 Cumulative Energy Savings from the 13 Energy Efficient Measures

and 2) this type of daylighting can provide good application for uniform light distribution according to 2006 CHPS Practice Manual (CHPS 2006). In addition, patterned toplighting is known as one of the most simple yet cost effect daylighting strategies.

In this study, the gymnasium, the library, and the cafeteria of the school building were modified to be installed with patterned toplights (See Figure 6). The design of toplights (i.e., size of toplights, distance between toplights and from the wall) followed the recommendations from the 2006 CHPS Pracitice Manual, and the effectiveness of the final design was evaluated with the Desktop Radiance model. For the DOE-2 simulation model, a lighting reference point for each space was defined with two steps of dimming lights (i.e., 50 fc for no supplement light needed, between 25 to 50 fc for half of supplemental lightings turned on, and below 25 fc for all supplemental lightings turned on). After the simulation, the energy saving over the ASHRAE 90.1-199 compliant school building was calculated individually and cumulatively.

As applying the toplights in the code compliant school, the total annual energy use was reduced from 3,649.9 MMBtu to 3,546.9 MMBtu (i.e., a 2.8% decrease). As expected, the lighting energy use decreased about 11.2% (i.e., from 1,043.3 MMBtu to 926.5 MMBtu). The space heating energy increased (i.e., a 5.0% increase) due to the decreased internal heat gain, and the space cooling energy decreased (i.e., a 0.5% decrease) due to the same reason.

When the final cumulative simulation input that was associated with the all 13 energy efficient measures was modified for the daylighting strategy, the cumulative energy savings over the ASHRAE 90.1-1999 compliant school building was increased to 38.6% (i.e., 3,649.9 MMBtu/yr to 2,241.3 MMBtu/yr), and the final cost saving is $38,533, which is a 40.8% annual cost savings.
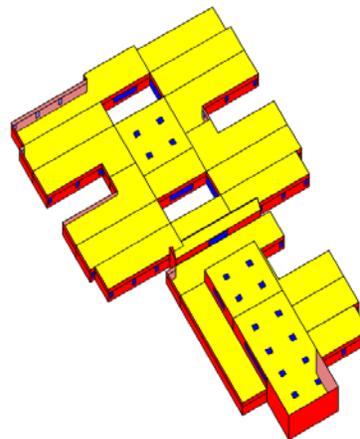

Figure 6 Toplights for the Case Study School Building

SOLAR THERMAL AND PV SYSTEMS

As a final step of this study, a solar thermal and PV system was applied to the baseline building to provide the entire SWH demand and part of electricity demand

of the building. Since the DOE-2 simulation program is not capable of simulating solar thermal and PV systems, the F-Chart and PV F-Chart program were used to calculate the hot water and the electricity generation from a solar thermal and PV system, respectively. Then, the DOE-2 simulation results and the F-Chart and PV F-Chart simulation results were integrated.

For the service water heating input parameters, the monthly energy use was obtained from DOE-2's SS-P report, using the Energy and Part Load DHW Tank Operation report. The monthly use was then used to match the DHW energy use calculated by F-Chart. The F-Chart calculation shows that ,with a total collector area of 1,630 sqft, the entire SWH demand for the school can be met. Therefore, the final annual natural gas consumption would be decreased from the 476.8 MMBtu to 283.45 MMBtu, which excludes the SWH energy use.

For PV selection, a grid-tied solar PV system was selected due to the cost effectiveness and the space available for the PV installations. In order to integrate the PV systems with the target school, first, the building's reduced monthly electricity use was simulated using the DOE-2 program. Based on the monthly electricity required for the building, the solar PV system was sized to provide whole or some percentage of the electricity demand. Then, the PV generated electricity was estimated using the PV F-Chart with the corresponding simulation input and the same weather data for the DOE-2 simulation, and the solar-generated electricity use was subtracted from the total electricity use.

In this study, the selected PV panel for the school is the Suntech STP 180 panel. The efficiency of this panel is about 13.3%. Since the cost effectiveness was not considered in this study, the PV system was designed to provide about half of the electricity consumed in the school building. From several runs with various PV array areas, a 17,864 ft^2 area was chosen for the PV system (i.e., about 1,300 Suntech 180 panels, which cost about $800,000 as of December, 2008). These panels will cover about 20.9% of the total roof area, and provide about one half of the building electricity needs. Figure 7 presents the monthly electricity demand of the high performance school building which was simulated with 14 measures and the monthly electricity generated by the installed PV systems. The remainder of the electricity would be provided by the local utility. Since there is still more than 80% of the roof area available for PV panel installation, if one does not consider the cost effectiveness, the entire school building could easily be

powered by a PV system, which would also have extra electricity to send back to the utility during the summer days.
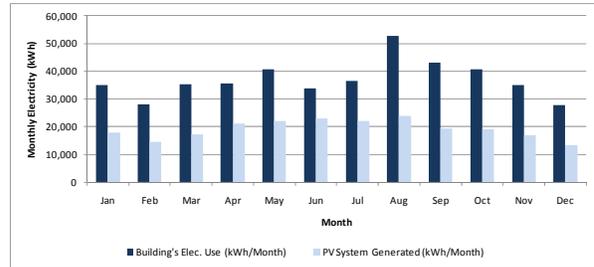

Figure 7 Monthly PV F-Chart Results with DOE-2 Results

Finally, the annual total electricity use for the high performance school building with solar PV system designed in this section would be decreased from 517,017 kWh to 257,361 kWh. Therefore, with the solar thermal and PV systems designed in this section, the net energy consumption of the final high performance school would be 1,162.1MMBtu, which is corresponding to the 14.9 kBtu/sqft-yr of EUI, which is 68.2% energy savings over the code compliant school building. When this energy savings converted to the energy cost savings, the final school with solar PV and thermal systems would save $65,976 (i.e., 69.9% savings over the code compliant school) annually. Figure 8 shows the step-by-step cumulative energy savings from the baseline school to the final high performance school building with the renewable systems.

SUMMARY

The energy savings potential from the application of the selected high performance measures including a daylighting strategy and a solar thermal and PV system was discussed in this paper. The EUI from the calibrated simulation was calculated as 49.3 KBtu/ ft^2-yr. The calibrated simulation was modified to be compliant with the ASHRAE Standard 90.1-1999, and this model was set as a baseline building for the analysis of this study. The EUI for the code-compliant simulation was 48.7 kBtu/ ft^2-yr. As a next step of the study, the AEDG for K-12 recommended 8 energy efficient measures were applied to the code compliant school simulation. The EUI by applying the 8 measures all together was 37.6 kBtu/ ft^2-yr, which corresponds to 22.8% of energy savings.
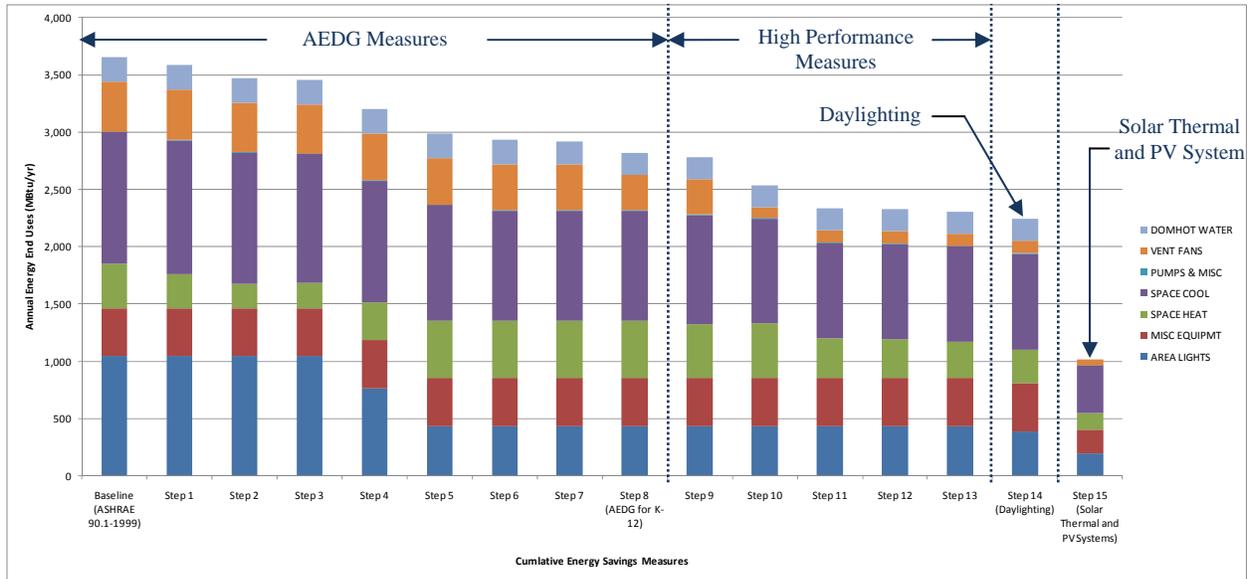
Figure 8 Final Cumulative Energy Savings by Step

In order to achieve above the AEDG for K-12 schools, 5 more energy efficient measures were applied to the school. The final high performance school building consumes 36.8% less energy than the ASHRAE 90.1-1999 compliant school building. As a result, the EUI for the school was reduced from 48.7 kBtu/sqft-yr to 30.8 kBtu/sqft-yr by applying the all 13 measures (i.e., eight from the AEDG for K-12 schools, and five from above AEDG).

A daylighting strategy was also applied to the school building to evaluate the energy impact. The gymnasium, cafeteria, and library were modified to be installed with skylights on the roof. Based on the available daylights, the artificial lights in the spaces were dimmed. The simulation result shows that the application of the skylights for the selected spaces could reduce a 2.8% of the total annual energy use compared to the ASHRAE 90.1-1999 compliant school. The final cumulative energy savings from applying the 13 measures and the daylighting strategy were simulated as 38.6% energy savings over the ASHRAE 90.1-1999 compliant school.

As the high performance measures, a solar thermal and PV system was designed and applied to the high performance school developed in the previous step to verify the additional energy savings potential. The solar thermal and solar PV system were designed to provide all needs for the service water heating loads and one-half of the school's electricity use, respectively. The results show that the net energy consumption of the final high performance school with the solar thermal and PV systems would be 1,162.1 MMBtu, which corresponds to 14.9 kBtu/sqft-yr of EUI, which is 68.2% energy savings over the code-compliant school building.

APPENDIX

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

$$NMBE\ (\%) = \frac{\dfrac{\sum_{i=1}^{n} Residual_i}{n - p}}{M} \times 100$$

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

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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