A SURVEY OF HIGH PERFORMANCE SCHOOLS

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ABSTRACT

This paper presents a survey of existing high performance schools in terms of energy efficiency. In general, high performance buildings are the buildings designed to maximize operational energy savings, improve comfort, health, and safety of occupants and visitors, and to limit detrimental effects on the environment. The survey provides the general literature review of the energy efficiency measures for school buildings and the case studies of several existing high performance schools.

BACKGROUND

Today, with the growing concerns for increasing energy costs and demand for healthy places to live and work, a high performance building (or green building) attracts attention because of its energy savings and environmentally friendly spaces. High performance buildings are buildings designed to maximize operational energy savings, improve comfort, health, and safety of occupants and visitors, and to limit detrimental effects on the environment (DDC 1999).

In general, high performance building features can be categorized by several features: energy and water efficiency, indoor environmental quality (i.e., air quality, thermal comfort, and lighting), material, environmental effects (i.e., waste management and emissions), etc. When these features are successfully incorporated into the building design phase, the building can be called a high performance building. The major benefits of a high performance building can be listed below (EERE 2006a)

- Energy use reduction of 50% or more.
- Reduced maintenance and capital costs.
- Reduced environmental impact.
- Increased occupant comfort and health.
- Increased employee productivity.

High Performance Schools

Not surprisingly, schools are one of the popular target buildings for high performance applications. Particularly, in a school, the energy efficiency and the IAQ (Indoor Air Quality) are considered as the most important aspects. 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, and the application of high performance strategies to new and existing schools can be an effective solution for this need. Furthermore, the average age of America's public school is 42 years (Rowand 1999), therefore the vast majority of existing schools could greatly benefit from energy savings improvements.

Along with the energy efficiency, the IAQ issue has always been a big concern in school buildings. According to the U.S. government's General Accounting Office (GAO), one in five schools in the United States has problems with indoor air quality (GAO 1995, 1996). Several studies have reported how IAQ affects the health and performance of students in schools. Many of them concluded that it is critical to provide the adequate amount of outdoor air and to keep proper relative humidity levels to provide a healthy and productive learning environment for students (Bayer et al. 2000).

This study is a part of ongoing research to develop high performance schools in hot and humid climates. Although the IAQ issue is a significant aspect in schools, this paper only explores the high performance features in terms of energy efficiency. The ongoing research will investigate the IAQ features of the high performance schools as well.

Objectives

In this study, we present a survey of existing high performance schools in terms of energy efficiency. The results are divided into two sections: 1) a survey of the energy efficient building components in schools, and 2) a survey of the existing high performance schools. Although energy efficient building components are often not considered individually in high performance building studies, the potential for energy savings is significant. Therefore, for this survey, various sources were used to find the technical reports and previous literature that covered these technologies. These include ASHRAE abstract archives, the proceedings of ACEEE, the Energy and Building Journal, the high performance buildings database of USDOE's Energy Efficiency and Renewable Energy (EERE) program. Specifically, it is worthy to note that the buildings database of EERE (EERE 2006b) provided most of the case studies for existing high performance schools.

ENERGY EFFICIENCY STUDIES IN SCHOOLS

In this section, the previous general energy efficiency studies about school buildings were reviewed. As mentioned earlier, even though the schools analyzed are not defined as high performance schools, this review yielded general references about what types of energy efficiency measures have been applied in school buildings. Many papers on energy efficiency in school buildings have been written over the years. For this research, over fifty papers were reviewed[1]. Of these, sixteen studies were selected for a closer review. Table 1 shows a summary of the selected papers. This table presents the author of paper, the classification of energy efficiency measures, the application of energy efficiency measures, the climate zones[2] where the schools are located, the number of schools analyzed in each study, the total floor area of the school, the method of energy use analysis if any, and finally, the energy savings compared to other conventional schools.

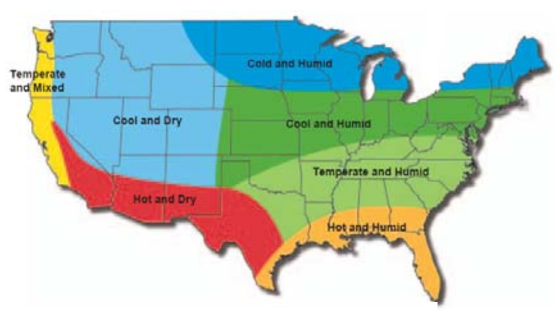

Figure 1: Climate Zones for Energy Design Guidelines

In general, the energy efficiency measures analyzed in the previous studies can be classified into two types: building envelope and building systems. Of the sixteen papers, three papers showed the energy savings from the use of an energy efficient building envelope such as tight windows, high insulation levels, shading devices, etc. Eleven papers presented energy efficient HVAC systems for schools such as ground source heat pumps, ice thermal storage system, dual path air distribution system, etc. The annual energy savings from these studies varies from 1% to 49%. However, most of the annual energy savings are in the range of 20 through 40%. The energy savings were most often calculated by measured energy use. In general, the baseline energy use was measured from the typical existing school buildings nearby. Some of the papers used building energy simulation programs such as DOE-2.1 to calculate the savings. In the following section, a detailed review is provided for studies that covered energy efficient envelope and HVAC systems.

Energy Efficient Envelope

Akbari et al. (1997) reported on the energy savings effects of high-albedo roofs. They monitored peak power and cooling energy savings from high-albedo coatings from one house and two school buildings in Sacramento, California. The measured and simulated cooling energy saving in the two schools was 3.1 kWh/day (35% of base-case use), and the peak demand reduction was 0.6 kW(41% of base case-use).

Hunn et al. (1993) presents the results of a study of the effect of shading devices on annual heating, cooling, and total energy use, peak electric demand, and energy cost savings in a school as well as residences, a small office, and a high-rise office in Minneapolis, Minnesota. To estimate energy savings, the DOE-2 building energy simulation program was used. The results show that the annual energy savings for schools were less than 1%. This value is much less than the annual savings for residence (4%), small office (5%), and high-rise office (5%). Even though the annual energy savings for the school was marginal, the savings can be significantly increased in cooling-dominated climates. For example, another study (Pletzer et al. 1988) shows that the proper application of shading devices on residential buildings in Austin, Texas reduced annual energy use by 14%.

Energy Efficient HVAC System

In school buildings, ground source heat pumps have been one of the most popular choices for energy saving strategies particularly given the large land area that surrounds the schools. Five papers (Cane et al. 1995, Dinse 1998, Goss 1992, Rafferty 1996, and Shonder et al. 2000) present results of analysis of

[1] References in this paper show the list of the studies

[2] For this study, the climate zones defined in the Design Guideline for High Performance Schools (USDOE 2002). See Figure 1.

ground source heat pumps in schools. Dinse (1998) described the energy and cost effectiveness of the geothermal systems installed in an existing school. In the study, the original school system, located in Washington County, Tennessee, which was a two-pipe chilled water system for cooling and electric resistance heating, was replaced with the geothermal heat pump (i.e., a water loop heat pump with a closed loop geothermal heat exchanger). The measured energy consumption indicated that the annual energy consumption was reduced from 3,481 MWh to 2,298 MWh (i.e., 34% savings), which corresponds to a six year simple payback time. This study is particularly noteworthy because it provided results from measured data from a retrofit to an existing school.

Another detailed study about geothermal heat pumps (GHP) in schools was conducted by the Oak Ridge National Laboratory (Shonder et al. 2000). This study verified the energy efficiency and life-cycle cost savings of the GHP systems installed in four identical schools in Lincoln, Nebraska. According the measured data and utility bills, on average, the GHP schools used 26% less source energy per square foot per year than the non-GHP new schools nearby. Furthermore, the GHP schools had 100% of their floor area cooled and met the ASHRAE 62-89 ventilation requirements.

Another interesting study about school HVAC systems is the dual-path approach for school buildings developed by Khattar et al. (2003). “A dual-path system is one in which the ventilation air and recirculation airstreams are conditioned separately, each with its own set of heating, cooling and dehumidification coils.” (Khattar et al. 2002, p.39). One of the benefits of such systems is that they can achieve improved air quality by providing the needed ventilation to the space while maintaining desired temperature and good indoor humidity control at part-load conditions. In this study, the energy uses of two schools (i.e., one with dual-path systems integrated with thermal storage vs. a conventional system without thermal storage) in Florida were compared. The measured indoor air temperature and humidity level indicated that dual-path system maintained lower and more comfortable humidity levels (i.e., 40%-50% relative humidity, which is 10% less than comparable area schools with the conventional system) as well as improved indoor air quality. The results showed that the school with the dual-path HVAC system and the TES system used about the same amount of energy as the school with the conventional system. However, more energy would be required for the school with the conventional system to maintain the same range of comfortable humidity levels as the school with the dual path HVAC system. Therefore, the system would have saved more energy if the interior conditions had been adjusted. This study was one of the first to show the potential benefit of using dual-path systems for schools, specifically, in hot and humid climates.

In summary, various energy efficient strategies for schools are available in literature. Of the sixteen papers examined, three showed the energy savings from the application of energy efficient building envelope, and eleven presented energy efficient HVAC systems for schools. It was found that a proper selection of energy efficient HVAC system according to climate area and effective design of building envelope can reduce annual energy consumption in school building as well as peak demand in summer. Also, in the study of the dual path systems, it was shown that IAQ can be significantly improved by system type.

CASE STUDIES OF HIGH PERFORMANCE SCHOOLS

As mentioned earlier, the high performance buildings database on EERE (EERE 2006b) has been used to search existing high performance schools around the world. The High Performance Buildings Database resulted from research sponsored by the U.S. Department of Energy seeking to improve building performance by collecting data on various factors that affect a building's performance, such as energy, materials, and land use (EERE 2006a). As of March 2006, there are six K-12 schools and seven higher education buildings in the database. Table 2 presents a summary of these buildings. The table shows the Energy Use Index (EUI) for each school building. The EUI is a measure of the total energy use normalized by conditioned floor area, often used to compare the energy use of different buildings.

As shown in Table 2, the EUI for high performance schools (K-12 only) in this database is about 23 to 60 kBtu/sq.ft. (i.e., on average, 28.8 kBtu/sq.ft.) These values can be compared to the national average EUIs for K-12 school buildings, provided by several sources. These include 59.2 kBtu/sq.ft. from the CEUS database (PG&E 1999), 68 kBtu/sq.ft. from a Florida Solar Energy Center (FSEC) report (Callahan et al. 1997), and 75 kBtu/sq.ft. from a 1999 CBECS report (EIA 2001). If one assumes that 28.8 kBtu/sq.ft. is the average EUI for high performance schools, then the high performance schools use about 51% to 62% less energy annually compared to the national average schools in U.S. Unfortunately, since the national average EUI for schools were calculated not only from new schools but also from old schools that have inefficient systems and poor insulation, the energy savings benefit from high performance schools could be overstated. Therefore, it is better to compare the high performance schools to average new schools, which are schools that are compliant with ASHRAE Standard 90.1-1999 (ASHRAE 1999)[3]. Table 2 shows the energy savings based on the school buildings compliant with ASHRAE Standard 90.1-1999. From the comparison to ASHRAE Standard 90.1-1999, high performance schools use about 20 to 40% less energy than the baseline schools (i.e., average new schools). The EUI and the energy savings from the high performance schools can give an idea how much energy could be saved when a school is designed as high performance building.

In table 2, the various green strategies, specifically energy efficient aspects are mentioned in the right-hand column of table. Of the strategies listed, several common green strategies for school buildings can be found. These are:

- High performance glazing (i.e., low SHGC)
- High albedo roofs
- T5 or T8 fluorescent lamps
- High R-values for walls and roofs
- Occupancy sensors to control lighting
- Photovoltaic (PV) systems
- Ground source heat pumps
- High AFUE (e.g., over 90%) boilers

From the EERE database, however, it is difficult to differentiate the energy efficient strategies according to climate area. Different strategies for difference climate areas should be considered when a high performance school building is designed. Plympton et al. (2004) analyzed the affordable green design for K-12 schools from each of the nine climate zones in U.S. Table 3 shows the green strategies used for each K-12 school. According to the table, high efficient lighting (e.g., T5 and T8 fluorescent lighting) seems the common strategy regardless of climate zone. In addition, variable speed drives for HVAC systems have been used for several climate areas. In some schools, photovoltaic (PV) systems have been installed. For example, a 1-2 kW PV system was installed at Tucson Unified School District, Arizona (i.e., hot and dry climates).

More detailed design guides for high performance schools by climate were also found. For example, one well-documented design guide is "Energy Design Guidelines for High Performance Schools" by U.S. Department of Energy (USDOE 2002). In this document, there are nine design guidelines corresponding to the nine different climate zones in the U.S. (i.e., the same climate zone definition from Plymton et al. 2004). Each guideline presents a specific design strategy varied by climate zone. For example, according to the design guideline for hot and humid climates, the guideline recommends the use of desiccant dehumidification and cooling, enthalpy exchangers, which can reduce the need for mechanical cooling. Also, natural gas and/or solar-driven absorption cooling were recommended as a method of reducing peak electricity consumption. However, none of the case-study schools utilized these systems.

[3] Many of States in U.S. currently use ASHRAE Standard 90.1-1999 or 2001 as their building codes for new commercial buildings including school buildings

SUMMARY

Energy efficiency studies of schools including those that covered existing high performance schools were reviewed in this paper. The major findings from the review are as followings

- The annual energy savings from the application of energy efficient building components compared to less efficient components varies from 1% to 49%. However, most of the annual energy savings are in the range of 20 through 40%.
- Ground source heat pumps and ice storage systems have been frequently adopted by schools to save energy and reduce kW demand.
- The EUI for high performance schools (K-12 only) in the USDOE's EERE database is about 23 to 60 kBtu/sq.ft. (i.e., on average, 28.8 kBtu/sq.ft.).
- The average EUI for existing high performance schools from the EERE database is about 51% to 62% less than the national average for existing schools in the U.S.
- The average EUI for existing high performance schools from the EERE database is about 20% to 40% less than the schools compliant with ASHRAE 90.1-1999.
- The most popular choice of measures for high performance schools includes: high performance glazing (i.e., low SHGC), T5 or T8 fluorescent lamps, high R-values for walls and roofs, occupancy sensors to control lighting, photovoltaic (PV) systems, ground source heat pumps, and high AFUE (e.g., over 90%) boilers.

- Different strategies by different climate zones should be considered in the design phase of high performance schools.
- Dual-path systems for schools appear to be a promising system because it resolves indoor humidity problems in hot and humid climates

Surprisingly, what was not found in the existing literature on schools was information regarding

- Methods for reducing kitchen energy use
- Use of co-generation systems
- Use of solar thermal systems

Therefore, there is an opportunity to continue to explore alternatives for high performance schools in hot and humid climates.

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No.	Authors	Classification	Application	Climate Zone	# Bldgs Analyzed	Size (ft2)	Energy Use Analysis*	Energy Savings (%)							Remarks
								10	20	30	40	50	60	70	
S1	Akbari et al. 1997	Envelope	High-albedo Roof	Hot and Dry	2	958	**M,S**		**25 -**	**35**					Cooling Energy Savings
S2	Becker et al. 1990	HVAC System	Four Different Types of Heating and Cooling Systems	Temperate and Mixed Cool and Humid Temperature and Humid	16	62,200, 46,700, 31,293	**M,S**								
S3	Butala et al. 1995	Envelope	Tight window, more insulation	Slovenia (Heating dominant)	24	3,422 ~ 287,278	**C**		20						Heating Energy Savings
S4	Cane et al. 1995	HVAC System	Closed-loop ground source heat pump (GSHP)	Ontario, Canada	1	185,000	**M,S**								Simulation of the performance of a GSHP (compare w/ measured data)
S5	Desideri et al. 2002	N/A	Survey existing schools find most efficient school	Central Italy	13		**M**			38					Heating Energy Savings
S6	Dinse 1998	HVAC System	Geothermal systems	Temperature and Humid	1	160,000	**M**			34					
S7	Fuller et al. 2003	HVAC System	Small reverse cycle air conditioner	Australia	4	940	**M**		20 - 27						Heating Energy Savings
S8	Goss 1992	HVAC System	Direct and indirect use of groundwater	Cool and Dry	1		**M**			33					This school was an ASHRAE award winner in 1986
S9	Haughey 2003	HVAC System	Ice thermal storage	Cool and Dry	1		**M**								4.1 years of simple payback
S10	Hunn et al. 1993	Envelope	Shading device	Cold and Humid	1	54,746	**S**	1							
S11	Khattar et al. 2003	HVAC System	Dual-path, low temperature air -distribution system w/ thermal energy storage (TES)	Hot and Humid	2		**M**		22						
S12	Montgomery 1998	HVAC System	Ice thermal storage	Hot and Humid	1	103,114, 166,162									1.5 years of simple payback
S13	Rafferty 1996	HVAC System	Groundwater heat pump systems	Temperature and Mixed	2	55,000 56,000	**M**	1.7 (California)			49 (Oregon)				
S14	Santamouris et al. 1994	N/A	Audit and estimate of the potential for energy savings	Greece	23				20						
S15	Shoner et al. 2000	HVAC System	Geothermal Heat Pump	Cool and Humid	1	69,000	**M,S**		26						Compared to 50 schools around
S16	Stotz et al. 1992	HVAC System	Using heat recovery and aquifer wells	Hot and Humid	1	210,000	**M**								

** Energy Use Analysis*
M: Actual measurement
S: Simulation
U: Utility Bills

Table 1: Summary Table for Literature Review

No.	Authors	Building Name	Climate Zone	Location	Bldg Type	Const. Year	Floor(s)	Size (ft2)	Baseline	Energy Use Analysis*	EUI (kBtu/sq-ft)							Energy Savings (%)							High Performance Strategies
											20	40	60	80	100	120	140	10	20	30	40	50	60	70	
SC1	EERE, 2006	Baca/Dlo'ay azhi Community School	Cool and Dry	Prewitt, NM	K-12	2003	1	78,900	ASHRAE 90.1-1999	S (Using Trane Trace® 700 Software)	26.9								20						* Low SHGC (0.52) * T8 fluorescent lamps * Occupancy sensors * Whole-roof R-value of 25 or greater * VAV systems
SC2	EERE, 2006	Clackamas High School	Temperate and Mixed	Clackamas, OR	K-12	2002	2	265,000	ASHRAE 90.1-2000	S (Using Visual DOE)	28.1										39				* Natural ventilation w/ fan coil back up unit * Thermal mass * 90% AFUE boiler * T8& T-5 fluorescent lamps
SC3	EERE, 2006	Clearview Elementary School	Cool and Humid	Hanover, PA	K-12	2002	2	43,600	ASHRAE 90.1-1999	S (Using Power DOE v.1.17)	23.3										40				* Ground source heat pump * Wall R-value of 25 or greater * Windows U-factor less than 0.32 * Heat-recovery ventilation * UFAD systems
SC4	EERE, 2006	Durant Road Middle School	Temperate and Humid	Raleigh, NC	K-12	1995	1	149,000	N/A	N/A	25														* Low SHGC (0.52) * T8 fluorescent lamps * Occupancy sensors * Whole-roof R-value of 25 or greater * VAV systems
SC5	EERE, 2006	Hidden Villa Youth Hostel & Summer Camp	Temperate and Mixed	Los Altos Hills, CA	K-12	2001	2	3,370	N/A	S (Using Energy Scheming Software)	9.49														* Ground-source heat pumps * High internal thermal mass * Evaporative cooling * Photovoltaic (PV) system * Replace incandescent lamps with CFLs
SC6	EERE, 2006	Third Creek Elementary School	Temperate and Humid	Statesville, NC	K-12	2002	1	92,000	N/A	S (Using Trane Trace 600)			59.8												* R-45 roof, R-22 walls, and low-emissivity windows * AC systems with a high efficiency rating * Windows U-factor less than 0.32 * Heat-recovery ventilation * Occupancy sensors * 97% Boiler efficiency
SC7	EERE, 2006	C. K. Choi Building for the Institute of Asian Research	N/A	Vancouver, Canada	Higher Education	1996		34,400	N/A	U		41.6													* Natural ventilation (no air conditioning) * Use light colors for surfaces and finishes * High-efficiency luminaires * Occupancy sensors * Achieve a whole-wall R-value of 15 or greater
SC8	EERE, 2006	Environmental Technology Center at Sonoma State University	Temperate and Humid	Rohnert Park, CA	Higher Education	2001		2,200	California's Title 24	U				80				2.32							* Photovoltaic (PV) system * High-efficacy T-5 fluorescent lamps * Direct-gain passive solar heating * Mass-wall passive solar heating
SC9	EERE, 2006	Management Building at Technology Square, Georgia Institute of Technology	Temperate and Humid	Atlanta, GA	Higher Education	2003		248,000	N/A	S (Using DOE-2.1E Build 133)			59.5												* Use light-colored exterior walls and roofs * Use high-efficacy T8 fluorescent lamps * VAV systems
SC10	EERE, 2006	Adam Joseph Lewis Center for Environmental Studies--Oberlin College	Cool and Humid	Oberlin, OH	Higher Education	2000		13,600	N/A			30.1													* Photovoltaic (PV) system * High internal thermal mass building * Windows U-factor less than 0.25 * Occupancy sensors * Roof R-value of 25 or greater * Closed-loop geothermal wells
SC11	EERE, 2006	Rinker Hall at the University of Florida	Hot and Humid	Gainesville, FL	Higher Education	2003		47,300	ASHRAE 90.1-1999	S (Using DOE-2.1E)		30.1										57			* High performance glazing * Occupancy sensor * Enthalpic heat-recovery ventilation * Reflective shade
SC12	EERE, 2006	Smithsonian Tropical Research Institute Research Station	N/A	Bocas del Toro, Panama	Higher Education	2003		7,530	N/A	U		42.6													* Building-integrated photovoltaics (PV) * High-efficacy T8 fluorescent lamps * Use light colors for surfaces and finishes
SC13	EERE, 2006	Vermont Law School James L. and Evelena S. Oakes Hall	Cold and Humid	South Royalton, VT	Higher Education	1998		23,500	N/A	N/A	27.2														* T-8 fluorescent lighting * Triple-glazed, argon-filled units with a single low-e coating (less than 0.25 U) * Enthalpic heat-recovery ventilation

** Energy Use Analysis*
M: Actual measurement
S: Simulation
U: Utilty Bills

Table 2: Summary Table for Case Studies

Climate Zone	Schools	Green Strategies
Temperate and Mixed Climates	Corvallis School District 509J, Corvallis, Oregon	* T-8 lighting * Digitally controlled heating, ventilating, and air-conditioning (HVAC) equipment * Energy-efficient boilers.
Hot and Dry Climates	Tucson Unified School District, Tucson, Arizona	* 1-2 kW photovoltaic system installations * Lighting upgrades * Vending machine controls * Energy management control systems.
Hot and Humid Climates	Marion County Public Schools, Ocala, Florida	* Lighting * Variable-speed drives for HVAC systems, * High-efficiency water fixtures, * Energy management system controls
Temperate and Humid Climates	Roanoke County Public Schools, Roanoke, Virginia	* T-8 lighting * Energy management system (EMS) * Monitor/controller unit for boilers.
Cool and Humid Climates:	Montour School District, McKees Rocks, Pennsylvania	* EMS * Energy efficient motors * Lighting controls
Cold and Humid Climates:	Elk River School District No. 728, Elk River,Minnesota	* Passive heating and cooling * Daylighting techniques
Cool and Dry Climates:	Council School District #13, Council, Idaho	* Biomass energy system fueled by wood chips * New T-8 lamps, new ballasts * Light reduction in areas tested for light intensity * Digital controls.
Arctic and Subarctic Climates:	Buckland K-12 School, Buckland, Alaska	* Aerodynamic form of the new structure (to reduce heat loss) * Better insulation (reducing fuel costs) and daylighting
Tropical Island Climates	Chiefess Kamakahelei Middle School, Lihue, Kauai, Hawaii	* Natural ventilation * VAV systems * High performance shell, with tinted, low-e windows and R-19 roof insulation * T-8 lamps

Table 3: High performance school case studies from Plympton et al. 2004