Green Building Design for Schools— The Next Time Around

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ABSTRACT

Special care must be applied to the proper planning and design of public school facilities. Student populations for this age group are prone to high levels of inner ear deficiencies, and they struggle in difficult acoustical environments. Additionally, students with asthma conditions must contend daily in building environments with marginal ventilation systems. What can be done? Schools must be free from unnecessary ambient noise and indoor air pollutants. The design professional must provide extraordinary design leadership through the use of natural daylighting and daylight modeling. Qualified acousticians should be engaged to evaluate designs for better learning environments. Operations and maintenance staff can be trained in the benefits of good indoor air quality. Pesticide and herbicide use can be reduced or eliminated. Town constituency, school board members, parents, staff, and students should be educated on the benefits of the LEED initiatives and the certification process. Since children spend vast amounts of time in these facilities during critical physical growth periods, they need to be afforded the protection of such building design and construction.

Accordingly, in Radnor, Pennsylvania, such an initiative is underway—the construction of a LEED-driven middle school with a different twist. For this project, the school district, the engineer, and the architect have all completed "green" projects in the last few years. Armed with the experience of lessons learned, the project team is endeavoring to provide a high performance school for the township. A school that is not only energy efficient, but also healthy, comfortable, well lit, and providing all the amenities needed for a quality education.

The project team for the Radnor project will discuss "green" features evaluated and utilized in previous projects. Construction costs and associated paybacks that make economical sense will be evaluated without compromising the overall quality of the environment. The project team

discusses the rationale for inclusion or exclusion of these features into the new Middle School Project. And finally, the completed design for the school will be presented and discussed.

INTRODUCTION

Design consultants for public schools are normally driven to design buildings with the lowest first costs because public funding drives these projects. While the desire to provide inexpensive buildings is obvious, one must be cognizant of the trade-offs.

The "first-cost" design mentality incorporates lower priced materials and equipment. This mindset burdens facility owners with equipment that generally costs more to operate and maintain. The diligent school consultant must design school facilities as if the client was building a high-level corporate facility by providing ambient environments free from unnecessary noise and indoor air quality pollutants. Use of research for health and productivity benefits of natural daylighting and daylight modeling to forecast environmental consequences are mandatory. Qualified acousticians need to be involved to evaluate designs for ideal learning environments. System life-cycle costs for all pertinent building features should be analyzed (Figure 1). Final design need not

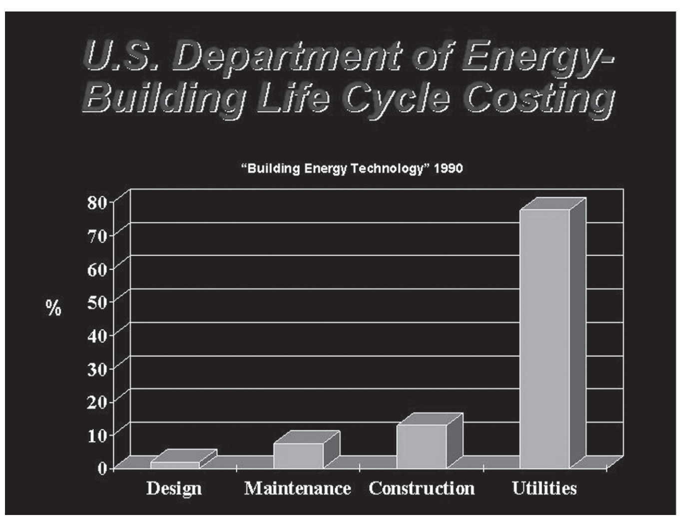

Figure 1. US Dept. of Energy Building Life Cycle Costing

be based on first costs alone. When operating, maintenance, and replacement costs are properly evaluated, the final system selections are generally the most cost effective over the entire life of the facility.

Educate your constituency, school board members, staff, parents, and students on the benefits of LEED certification or at least considering the particular aspects of LEED. When you're done with the building, clean it using non-toxic compounds and use finishes with no heavy metals and low to no volatile organic compounds. Eliminate the use of pesticides and herbicides on school properties and train operations and maintenance staff in the benefits of good indoor air quality. Be your children's advocate. They spend the most critical time period of their lives in these facilities.

DESIGNING A LEED CERTIFIED MIDDLE SCHOOL

Applying LEED principles (Figure 2) to the design of a new school is relatively easy at project kick-off. With a site selected and the architect's conceptual space plan in front of the audience, conducting the LEED charette is smooth and productive. Many ideas come forth in this brainstorming session. The energy and enthusiasm are dampened when the first construction cost estimate indicates the project is over budget. This is the defining moment for any project and the first indication that LEED principles are in jeopardy. The project team can "make or break" a LEED project at this point. It depends on how the priorities

What is LEED?

LEED which stands for **L**eadership in **E**nergy and **E**nvironmental **D**esign, is a voluntary national standard for developing high-performance sustainable buildings.

The system was developed by the U.S Green Building Council, a building industry coalition, to define common metrics for "green building".

LEED Rating System is a point based rating system that awards points in the following categories:

- Sustainable Sites
- Water Efficiency
- Energy & Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation & Design Process

U.S. GREEN BUILDING COUNCIL MEMBER

Figure 2. What Is LEED?

are set. Let's look at the popular LEED mission statements and dissect how they can be met without exceeding the budget.

"Better buildings improve productivity"

No argument there—and little cost impact. Is a LEED certified building a "better" building? If done correctly, yes, because the occupant benefits from an interior environment that shows some thought has been put into it. Conventional building interiors are usually made with modular items like 2x4 lay-in ceilings; recessed fluorescent light fixtures, carpeted floors, and stud framed or block walls. Heating, ventilating and air conditioning (HVAC) is distributed from the ceiling, and windows account for 20 percent of the exterior skin. Indoor climate control includes a thermostat for every 2000 to 4000 square feet of floor space manipulating the room temperature +/- 6°F.

A typical LEED building will have operable windows, an exposed ceiling coated with reflective paint, with suspended fluorescent light fixtures, high efficiency HVAC with a means of controlling the room temperature for every 500 to 1000 square feet of floor area, and the ability to minimize energy consumption during non-peak and unoccupied periods. Emphasis will be placed on designing an air distribution system that is quiet and unobtrusive, yet effective. The window area may still be 20 percent; however, careful planning will orient the windows to gain brighter daylighting levels, yet shade them during peak solar orientation. Ventilation air will be tempered with the energy regained from the exhaust air stream. Higher productivity comes from the occupants having better views and daylight access, more precise temperature control, and the psychological benefit of a higher volume space.

BETTER BUILDINGS IMPROVE PRODUCTIVITY

Lighting/Daylighting/Views

Recessed fluorescent light fixtures have been the standard for years. They consist of a light source wrapped in a metal box on five or six sides allowing dispersion of light down towards the floor only (Figure 3). If you unwrap a light source and suspend it a few feet below a light colored ceiling, the amount of light is greatly increased (Figure 4). Much more effective lighting with the same wattage input to a given fixture is experienced. When applying this principle to a 1000 SF classroom, fewer fixtures are required to achieve the same amount of light while consuming less energy and contributing less waste heat into the room.

Windows will be oriented to take in maximum daylight, while provided with a low "e" coating to minimize solar heat gain (Figures 5 and 6). Lighting fixture control will be arranged to shut down fixtures closest to the windows to take advantage of natural daylight when available. Control of these fixtures can be performed via sensors that automatically dim the lights when adequate natural light is available. This feature is desirable; however, budget constraints may warrant manual switching. This meets the intent of the LEED principles and has a lower first cost. Occupancy sensors, which turn off the lights

Figure 3. 2 x 4 Parabolic Unit

Figure 4. Pendent Classroom

when the room is unoccupied, are now widely used. It is an accepted feature that building owners understand must be built into the basic cost of the building.

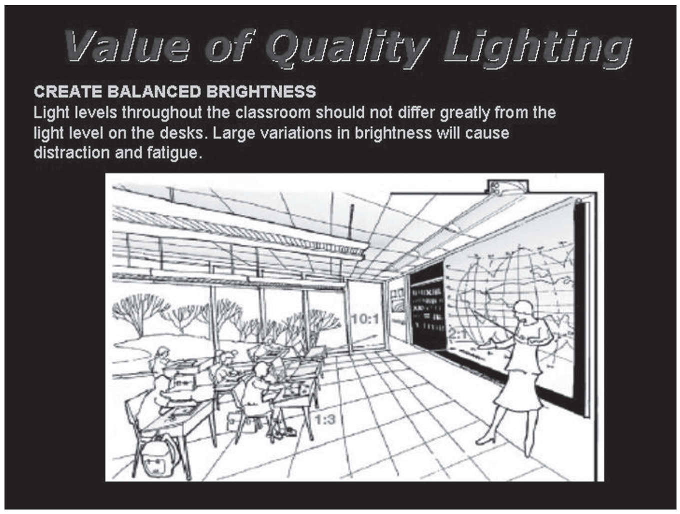

Figure 5. Value of Quality Lighting

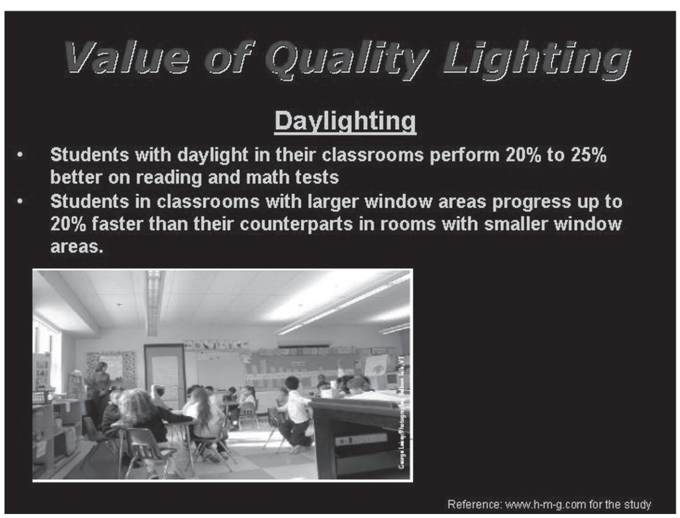

Figure 6. Daylighting

Acoustics

Recent standards have provided more stringent requirements for room acoustics. In classrooms, HVAC equipment has traditionally been the largest contributor to background noise. Unit ventilators located along the window wall moved all the air in the room, with outside air intakes behind the cabinet allowing a mixture of return and outside air (Figure 7). Exhaust for that outside air was ducted through the corridor ceilings with inlet grilles in each classroom ducted to rooftop exhaust fans. Students were exposed to the constant sound of air rushing from the top of the unit ventilator with little or no sound attenuation (there was typically no distribution ductwork to muffle sound.) Recent unit ventilators included air conditioning; some were fitted with self-contained compressors, which also added low frequency sound waves to background noise. Because of acoustics, current school HVAC design has moved away from unit ventilators.

Current systems tend to be ducted into the classrooms, significantly reducing noise. The location of terminal equipment greatly influences the acoustic performance to the HVAC system. Central rooftop air handlers tend to be some of the quietest systems, but they have not found great acceptance in school design due mainly to concerns of their ability to

Figure 7. Unit Ventilator

deliver the proper amounts of fresh air to each space (Figure 8).

Heat pump systems (Figure 9), both water source (WSHP) and geothermal (GSHP) integrated with outside air energy recovery, are gaining acceptance, as well as the more traditional fan/coil units fed with chilled and hot water (Figure 10).

Ideally, HVAC equipment shall be located outside the room served to minimize sound transmission. The difficulty is that there is not always enough "outside the room served" space available for this ar-

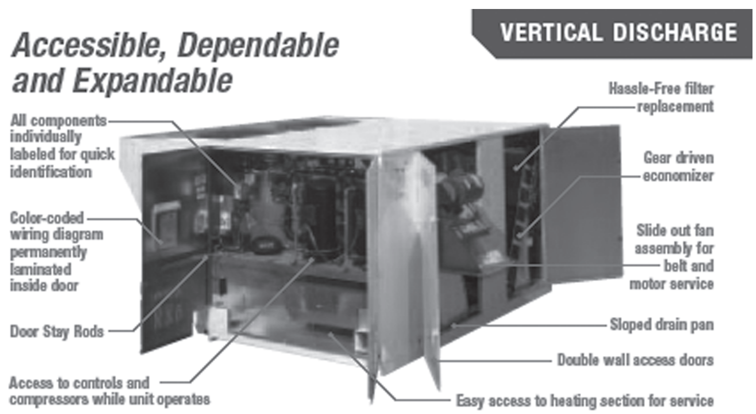

Figure 8. Rooftop Air Handler

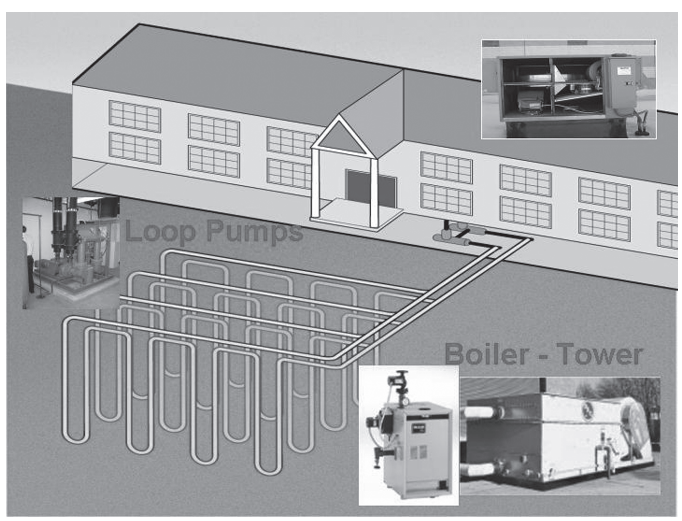

Figure 9. WSHP & GSHP

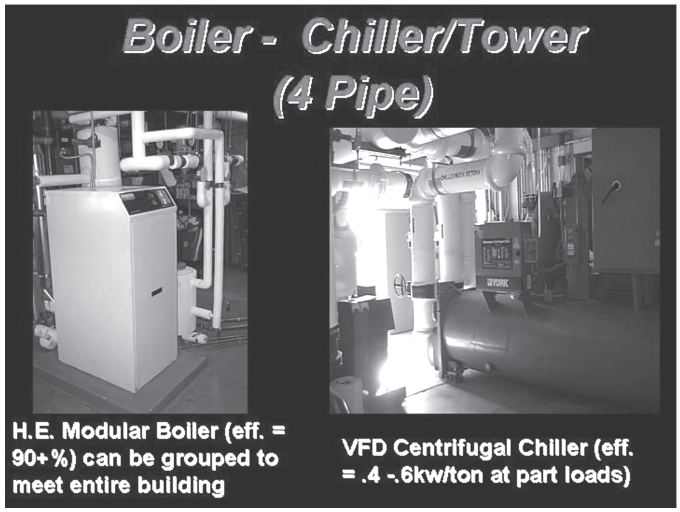

Figure 10. Boiler Chiller/Tower (4-Pipe)

rangement. Locating units above the ceiling in the corridors appears to be a simple solution. However, corridors are the main access ways for all building services. When equipment is added into the corridor-ceiling cavity, a congested space is created. This is a maintenance headache with limited access to filters, fans controls and power connections due to congestion of piping and ductwork occupying the same zone.

Another solution is to locate the HVAC equipment within "closets" that open to the corridor (Figure 11). This efficiently moves the equipment out of the occupied space while allowing access for maintenance. The units are ducted into the classrooms, keeping noise to a minimum. A closet design requires valuable floor space, something that requires the engineer to convince the architect of its merit. Radnor Middle School utilizes this closet design with counterflow heat pumps discharging to an underfloor plenum.

Ventilation

Ventilation is necessary to remove contaminants which can build up inside a building (e.g. CO_2, off gases from cleaning agents, building materials, etc.). Fresh air has been used to purge those contaminates out of the building. This creates a challenge for the HVAC engineer;

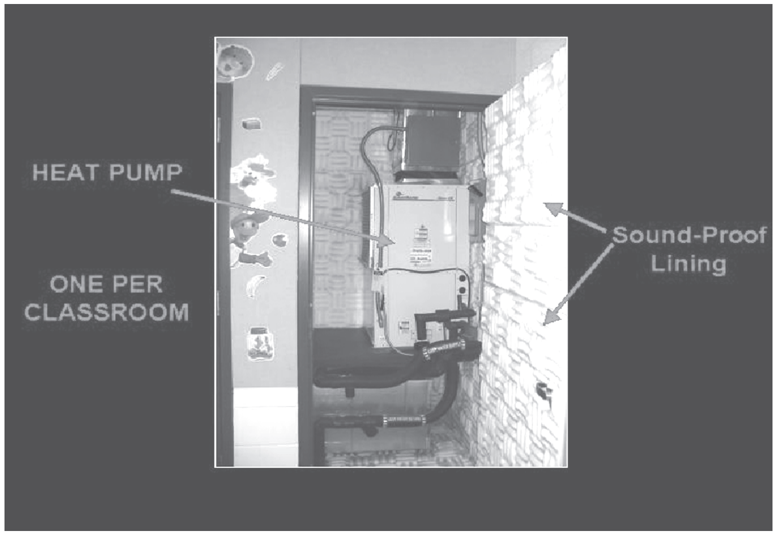

Figure 11. Heat Pump

fresh air tends to be too hot, too cold, or too humid to be comfortable. Previous designs utilized raw fresh air to mix with the return air stream and an exhaust system sending treated air to the atmosphere. The advent of energy recovery units improved this system. They typically use large heat wheels (analogous to Lundstrom Air Heaters) to transfer energy from the exhaust stream to the outside air stream. Thus, changed the conditions from 14°F outside air mixing with 70°F return air to 45°-50°F outside air mixing with return air. This reduced the load on all interior-recirculating systems, saving energy. This passive type of energy recovery allowed for some humidity control, but still relied on the terminal equipment to fine-tune humidity for each space.

Some recent energy recovery systems include a natural gas fired desiccant dehumidification feature (Figure 12). This allows for active humidity control of the fresh air prior to it reaching the space. These systems can be decoupled from the room recirculation systems and be discharged directly into the space. Aside from the obvious reduction in energy costs from heat recovery, these units are programmed to run only during occupied periods. Combining energy recovery with humidity control for ventilation air will incrementally reduce the room loads, which results in smaller terminal units. This offsets the increased cost of the energy recovery equipment.

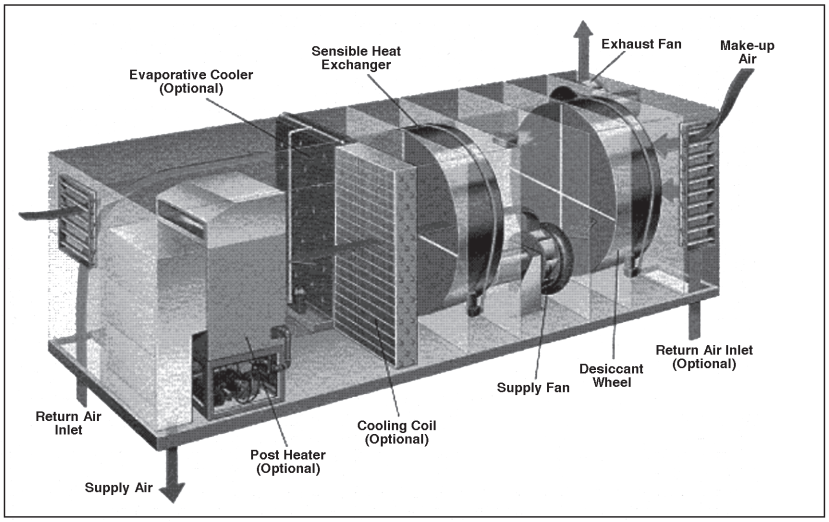

Figure 12. Desiccant Energy Recovery Unit

Thermal Comfort

Research has shown that the best temperature range for learning math and reading is between 68° and 74°F. Additionally, humidity should be maintained between 40 percent and 60 percent relative humidity. Elements impacting thermal comfort are building envelope, outside air treatment, temperature and humidity control, and air distribution. A preferred air distribution system for a classroom is under-floor supplies with high exhaust/return grilles. Unfortunately, preliminary studies, or the first value engineering session, typically try to rule this option out due to higher construction costs. Hence, distributing from the ceiling and returning low is sometimes utilized as a compromise. Having a thermostat/humidistat located in each room provides individual room control. This is typical in current school design.

Innovations

Several innovations were considered for Radnor Middle School:

Displacement Ventilation

Ventilation is provided by a displacement ventilation system. Displacement ventilation delivers fresh outdoor air to the space at a low level, at low velocity, and at a temperature only slightly lower than the

desired space temperature. This allows the fresh air to "spill" evenly across the entire space. The fresh air is driven upwards by buoyancy forces around the heat sources (e.g. people, computers, etc.) within the space. This air mixes rapidly with room air as it convects upward, drawing heat and contaminants up and out of the room. The exhaust air passes through an energy recovery unit, which enables a large portion of the energy from the exhaust air to be recovered to preheat the ventilation air being delivered to the building. Displacement ventilation continuously purges air pollutants from the occupied space by supplying 100 percent fresh air to the space, and exhausting 100 percent of the contaminated air out of the space. Because this one-pass air path does not mix contaminants back into the room air, indoor air quality is greatly increased. Furthermore, this induction effect allows a reduction of the air volumes required to remove heat gains from the space.

As an additional benefit, because the supply air is at a temperature only slightly lower (6-8ºF) than the room temperature, under-floor air systems eliminate cold ventilation drafts and increase thermal comfort within the conditioned space. Finally, the higher supply air temperature results in ventilation system energy savings by extending periods of free cooling, decreasing fan pressure, and allowing chillers to operate at higher efficiencies.

Radiant Slab Heating and Cooling

Heating and cooling is provided by a low intensity radiant temperature control system with its elements incorporated into the concrete slab deck of the building (Figure 13). The heavy concrete structure with a high-performance building envelope is used to create essentially a "constant temperature indoor environment." The exposed concrete ceiling surfaces absorb or radiate low-intensity heat from, or into, the occupied space to compensate for instantaneous cooling or heating gains inside the building. The concrete slabs are maintained at a virtually constant temperature (ranging from 72º to 80ºF depending on the season) by circulating heated or cooled water, generated by a boiler chiller combination via plastic piping cast into the concrete slab. With radiant systems, people are heated or cooled by radiant heat transfer from their bodies to adjacent surfaces (typically ceilings) whose temperatures are held within a few degrees (5-10º) of ambient. Space conditioning energy is usually moved from chiller or boilers to concrete slabs using water as a medium. This produces impressive savings, since water has considerably more energy transport capacity than air. Even accounting for the pressure drop involved in pumping water throughout a building, a hydronic system can transport a given amount of heating or cooling with substantially less energy than air with fans.

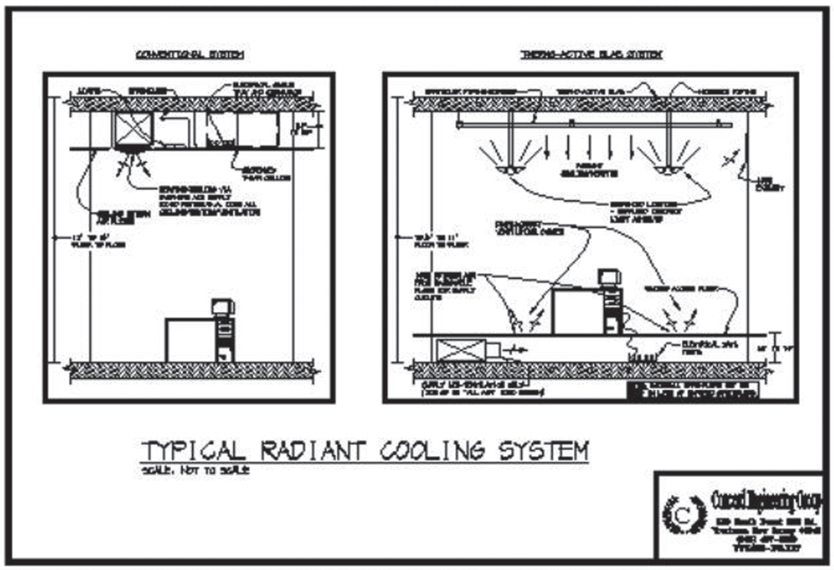

Figure 13. Typical Radiant Cooling System

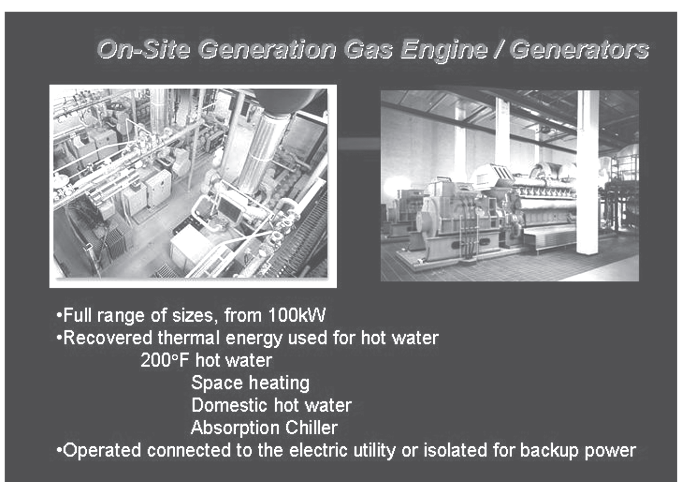

Figure 14. On-site Generation Gas Engine

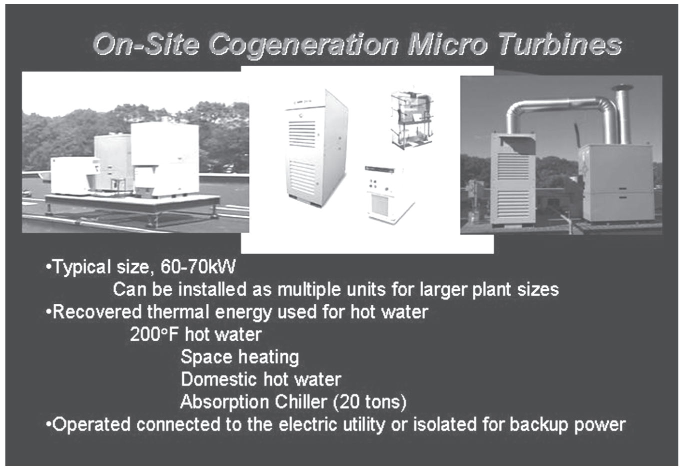

Figure 15. On-site Cogeneration Microturbines

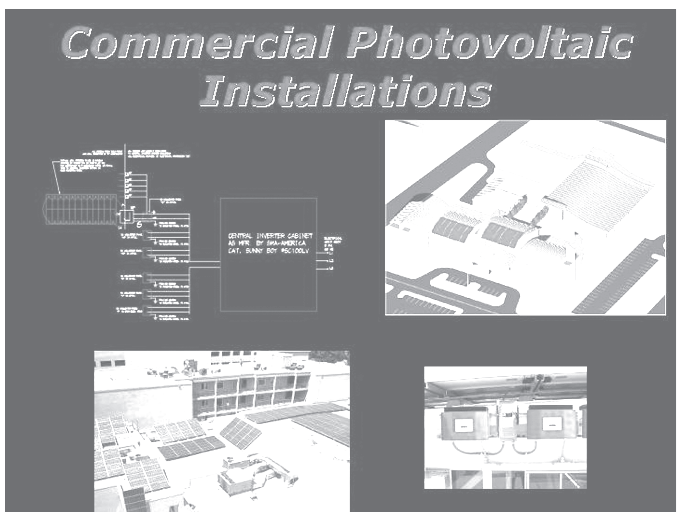

Figure 16. Commercial Photovoltaic Installations

HIGHER UP FRONT COSTS CAN BE RECOVERED

The owner must think long term and weigh the life cycle costs more heavily than first cost. A high performance green building is an efficient building. Savings in energy costs of 20-50 percent are common through integrated planning, site orientation, energy-saving technologies, on-site renewable energy-producing technologies, light-reflective materials, natural daylight and ventilation, and downsized HVAC and other equipment. Building owners realize significant savings during the life of a building through other measures, such as natural landscaping, water-saving equipment, low-maintenance materials, salvaged construction debris, and smart building controls. With the help of these kinds of efficiencies, green buildings can save money throughout their life cycles. Everyone must seek out means to fund the additional costs. There are alternate sources of funding available. Consider the operation and maintenance budget. Capital from future energy savings, money normally allocated for this budget could be utilized or borrowed against. Rebates are available. Some utilities are mandated by their governing state to allocate money to supplement high efficiency equipment costs.

Lower Energy Costs

Our goal in designing a LEED certified building is to realize considerable savings in energy consumption when compared to a base ASHRAE 90.1 building. Aside from high efficiency HVAC equipment, the building envelope needs careful attention. Increased roof and wall insulation, low-"e" and sometimes triple pane windows are major contributors. Something as simple as a shading overhang on south facing windows can contribute significantly. Ventilation air must be pre-treated to minimize both latent and sensible cooling loads. Some common conservation features found in LEED certified buildings:

- Geothermal heating and cooling system
- Variable frequency drive circulation pumps
- Individual room thermostats
- Energy recovery ventilation (with desiccant dehumidification)
- Demand ventilation for assembly spaces using CO2 sensors
- High SEER HVAC equipment
- Occupied/unoccupied modes for HVAC
- Premium efficiency motors
- High efficiency fluorescent lighting fixtures (direct/indirect)
- Daylighting
- Occupancy sensors for lighting
- Point-of-use domestic hot water heaters for small toilet rooms
- High efficiency condensing boiler for kitchen hot water
- Waterless urinals
- Low-flow faucets

The effect of the above-listed items is reduced energy consumption. Some of the features have a premium first cost associated with them and require up-front analysis to determine payback. An educated building owner will recognize this and accept higher building costs; however, every building is built to a budget, and conservation features, as well as every other component, stand the chance of being value engineered.

Lower Maintenance Costs

New equipment is usually less expensive to maintain than something that has been in service for several years. New equipment is also built to more rigorous tolerances and operating efficiency standards. Keeping equipment close to the floor generally reduces maintenance costs merely by making the equipment more accessible. One important building block for an efficient maintenance program is easy access. If equipment is difficult to access (e.g. equipment located above ceilings, in mezzanines, on difficult to access roof, etc.), maintenance suffers.

A design feature utilized to facilitate maintenance is a closet for heat pumps. The closet is positioned next to the entrance of the room with its door opening into the corridor. Within the closet is the vertical heat pump on a stand, ducted into the ceiling of the room. The return air grille is located in the back wall of the closet, communicating to the room. Outdoor air is then ducted into the return plenum and mixed. Branch piping, condensate drain, disconnect switch, control box, volume dampers, and filters can be accessed through the closet door without disturbing the occupants of the room. Although the closet occupies approximately 16 square feet of floor space, the maintenance benefits are immense.

Modern building automation control systems provide more detailed information in a timelier manner. This allows the maintenance staff to address equipment problems in a preemptive manner. It is also a basis for a more thorough preventative maintenance program. Scheduled maintenance can be programmed with reminders that pop up on the screen, alerting the user and keeping a record of what gets done when. Trending can help determine when peak energy is consumed, and measures can be taken to reduce unnecessary loads.

Integrated Design Savings

A key to reduce increased first costs on a green building is integrated design savings:

- By improving the building shell, the mechanical systems were downsized due to reduced peak loads.
- By increasing reflectance of interior surfaces, lighting was reduced.
- By increasing mechanical and lighting efficiency, electrical distribution requirements were reduced.

DESIGN TO OPERATION IS SEAMLESS

Design is Constructible/Reliable

Effective design is a team effort. A green building approach includes the architect, engineer, construction manager, commissioning agent, and owner. (After bidding, the contractors will also be an intrinsic part of the team.) Designing a green school begins with the architect. The architect works in collaboration with the owner to develop a design concept. It is at this early stage that the rest of the project team must get involved. The architect must get input from the remainder of the team.

The engineer will require a building design that will accommodate all building systems. This is a process that requires innovation and compromise. The process can be arduous, as there are many obstacles. Typically, corridor ceilings are the highways for ductwork, piping cable tray, and conduit. Building utility space (mechanical and electrical) is generally minimized to reduce initial costs. Floor-to-floor heights are also minimized (save a course of masonry and shorten steel lengths) to reduce construction costs. The engineer must also design in accordance with more stringent codes which require higher ventilation rates. This generally requires larger ductwork, which is in direct conflict with higher ceilings envisioned by the architect and owner. This issue should be resolved early in the design process.

Commissioning

The commissioning agent is invaluable for a school project. Commissioning agents oversee the project from the schematic design phase forward. They review the design and follow construction and startup. A design benefit is early detection of potential construction and operations issues. Caught early, these items can be addressed with minimal cost impact. Changes could cost considerably more during construction.

During startup, when equipment is being set up to run at operating conditions, commissioning agents will witness tests and review results to assure compliance. They also serve as contacts for the owner, and should be able to address operational questions for the owner prior to turnover. Proper equipment start-up and testing is key to a successful project. Proper system and equipment operation must be verified prior to turnover. With a myriad of components from different manufacturers installed by different contractors, this process can be challenging. Control systems must run through full sequences to assure all systems function as intended. Piping must be carefully flushed, then filled immediately to avoid internal corrosion. Many projects have difficulty starting up due to clogged strainers, directly attributed to wetting, then draining steel pipe, weeks before the system was once again filled and rust inhibitors applied. The commissioning agent will synchronize manufacturers' start-up and coordinate the interaction of systems. The commissioning agent on site during start-up shepherds this effort. He must also provide detailed and organized documentation.

Operation

Modern building operators need to understand how their buildings are set up to run and have the ability to make operational changes to fine-tune systems as needed. The building automation system must be user friendly to encourage its use. Personnel need to be trained on the installed systems to familiarize themselves with operation. Start-up procedures and operational training should be video taped so future operators can share the same baseline information.

The building maintenance staff must have input in the design phase and throughout the project. This will increase the probability of project success. First, the insights of the maintenance staff will be beneficial to the project team throughout the project. Secondly, the operations staff will develop a feeling of ownership because of its input. A committed operations staff is essential for long-term project success.

It must also be reemphasized that the commissioning agent must help facilitate the transition to operations. The commissioning agent is a conduit from design through operation. He is the person who reviewed the design, witnessed construction and startup, ensured operator training, and assembled system manuals, all of which are necessary steps for a successful project.

CONCLUSION

Economic Case

A life cycle cost analysis typically compares three or more systems to ascertain the lowest overall costs, including operational costs. When looking at alternative systems, it is important to include initial, energy, and maintenance costs. Initial costs should address peripheral costs (e.g. additional mechanical room floor space, roof dunnage, supplemental steel, etc.). Building costs must be evaluated holistically (e.g. pre-treated ventilation air, decoupled from the room terminal units allow incremental downsizing, something that is generally overlooked when doing a cost analysis. In large 100,000 SF + buildings, this savings can offset the increased cost for rooftop heat recovery/conditioning equipment). Operating costs need to address the efficiency, reliability, replacement part, and labor costs. These costs must have appropriate escalation factors. With these factors included, a more realistic conclusion can be drawn. It is essential that life cycle cost (not first cost) be the basis for decisions.

Environmental Quality Case

The end result is a healthier building. This leads to better daily attendance and improved student performance. Ultimately the building owner will reduce his liability exposure. More specifically, controlling the indoor environment of a building not only has immediate results observed by the occupants, but also minimizes potential for mold growth and the spread of contaminants, a condition many buildings suffer from today. Adequate outside air combined with humidity control and daylighting keeps occupants healthy and productive while keeping energy costs at a minimum.

When the building is complete, it must be cleaned using non-toxic compounds. Finishes must contain no heavy metals and low to no volatile organic compounds. Pesticides and herbicides must be eliminated on school properties and operations and maintenance staff must be trained on the benefits of good indoor air quality.

Community Perception

A school is a commitment by the community to its future. In its best case, a school serves as a beacon to the community demonstrating civic pride. Accordingly, designing a building using LEED principals creates a public relations opportunity, bringing attention to something special within the community. Attention must be paid to the environment during design. This will include careful choices in building materials and energy efficiency. If this process is communicated, people will want to learn more. Word will spread that this building is special and the community will embrace having something to be proud of.

It is important to educate your constituency, school board members, staff, parents, and students on the benefits of LEED certification or at least considering the particular aspects of LEED. The community will do the rest.

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