ALTERNATIVE USES FOR FOSSIL FUELS

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INTRODUCTION

Is it possible to design sustainably using off-the-shelf equipment and fossil fuels? Yes, when designers consider a multi-tiered approach that considers everything from energy-conscious design to alternative uses of the old standards. Three case studies illustrate how, when alternative systems or fuels may not be readily available or cost-effective, designers can use current/standard technology and fossil fuels that are accessible in order to create sustainable systems. The Ohio Statehouse and Ohio Judicial Center, the Columbus Museum of Art, and Frank Lloyd Wright's Westcott house all presented particular challenges in heating and cooling, yet for these prominent public buildings, efficient and unobtrusive systems were a must.

ALTERNATIVE FUELS AND ALTERNATIVE BUILDING SYSTEMS

Research scientists are the people who really know what's new in alternative fuels and alternative HVAC and electrical systems, so I won't delve into those topics very much; rather, this paper is about my practical experience as an engineer/architect designing building systems for the past 30 years. Most of these systems were designed with off-the-shelf equipment from the best manufacturers in the business. The firm for which I work has done prominent buildings all over the world, from American embassies to a number of state capitols and a significant residence by the master of environmentally friendly architecture, Frank Lloyd Wright.

As an offshoot to my A/E practice, I instruct architecture students at the Ohio State University on the subject of building systems. When it comes to sustainable design, I tell them that it's their responsibility to lead the way for the next generation—that my generation dabbled in it, but they hold the responsibility for truly blazing the trail.

Alternative energy has been a hot topic since I started in the A/E business in 1977, yet it still accounts for just a fraction of the energy we use in the U.S. today. My contention is that, thus far, the U.S. has not needed to reach far into the world of alternative energies. Economics have allowed us to take the easy way out—energy has remained relatively cheap and clients have typically felt more comfortable using known technology. Now, however, building owners are becoming more aware of truly sustainable design, thanks to the recent focus on global warming and the growing acceptance of the U.S. Green Building Council's LEED® Certification Program. They want to know what it takes to be "sustainable;" however, some still back off when faced with the higher initial costs associated with sound sustainable systems. This is why a slightly different approach to sustainability sometimes helps. Building owners can be made aware that green design doesn't always include a wind turbine or solar panels or a hydrogen fuel cell. The biggest impact they are going to have on today's environment is to work with today's technology—but using a multitiered approach:

- Energy conservation
- Energy-conscious design
- Alternative fuels
- Alternative heating and cooling methods
- Alternative uses of fossil fuels

The first two bullets promote sustainability via methods such as using automatic sensors to turn systems off when not needed, or siting a building in an energy-conscious way. This article does not cover them in-depth because they should be standard practices when possible.

The third bullet, alternative fuels, represents a challenge to green design because alternative fuels are not necessarily readily available in all areas. If the opportunity arises to incorporate innovative solar technologies, and the project is right for it, and the owner

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is willing to fund it, by all means, it should be incorporated. But sustainability need not be an all-or-nothing proposition. By thinking a little differently about sustainability, existing technologies can be highly sustainable.

The following case studies illustrate the potential for sustainability in technologies that have been around for more than 50 years: natural-gas-fired cooling equipment, making and storing ice for future air conditioning, and using the earth for a heat source and heat sink. For the past 15 years, our firm has explored energy conservation and dollar savings with these three technologies. All of these examples use traditional fossil fuels. The difference between traditional fossil fuel usage and the usage demonstrated in these studies comes from taking advantage of off-peak usage, thereby reducing the strain on overtaxed infrastructure, or by using solar energy that was put here four billion years ago.

FIGURE 1. The Ohio Statehouse required a complete overhaul of the entire HVAC system, yet had limited space, and as the building is a National Historic Landmark, the new systems and associated equipment had to be incorporated invisibly. (Photo courtesy of Schooley Caldwell Associates.)

CHILLER-HEATERS

Columbus, Ohio, provides the backdrop for two very prominent landmarks: the historic Ohio Statehouse (1838–1860), and a newly renovated 1930s Art Deco masterpiece that became the new home of the Ohio Supreme Court (Fig. 1 & 2). Both buildings required a complete overhaul of the entire HVAC system with very limited space for modern systems.

Early in the design period during the system selection process, both buildings were analyzed with traditional chillers and boilers versus chiller-heaters through a 25-year life cycle calculation. What stood out on both was the cost of the natural gas in the summer when traditional natural gas usage was down. The utility company was willing to sell the owner natural gas at a substantial savings because of low demand. In addition, the manufacturers of the chiller/heater

FIGURE 2. The Ohio Judicial Center is home to the Supreme Court of Ohio as well as the state's law library. Limited floor-to-floor heights proved challenging when updating systems. (Photo by Feinknopf Photography.)

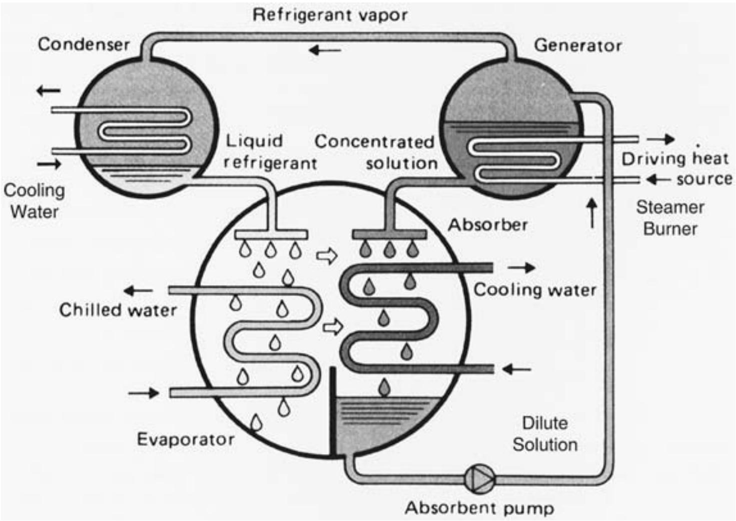

FIGURE 3. A chiller-heater operates via direct-fired, two-stage absorption units that use water as the refrigerant and lithium bromide as the absorbent. (Diagram courtesy of York Air Conditioning Systems.)

wanted to add these high-profile projects to their continuing marketing efforts, so they set a price that was lower than market conditions to get the project. Using a device that does not use electricity for cooling and that instead uses the natural gas infrastructure when demand is low eliminates the issue of these massive public buildings adding to the electrical grid's peak demand during traditionally high-peak times.

How the System Works

Gas-fired chiller-heaters (Fig. 3) operate via direct-fired, two-stage absorption chiller-heaters that use water as the refrigerant and lithium bromide as the absorbent. It is the strong affinity these two substances have for each other that makes this cycle work. The entire process occurs in five basic heat exchangers: evaporator, absorber, first- and second-stage generators, and condenser. The lower shell (absorber and evaporator) has an internal pressure of about one-hundredth that of the outside atmosphere, a relatively high vacuum. The vacuum allows water (the refrigerant) to boil at a temperature below that of the liquid being chilled. This two-stage, or "dual effect," absorption machine offers energy efficiency advantages over other single-stage absorption chillers and some electric chillers.

Because of extremely high electricity demand charges, for the past 30 years Japan has redefined gas-fired chiller-heater processes and developed a market for gas-fired absorption machines. Through the 1980s and 1990s, the market opened up in the United States, especially in areas with high electricity rates. Now, virtually every HVAC equipment manufacturer carries a line of chiller-heater equipment.

Besides the energy-efficient operations and favorable life cycle cost analysis, chiller-heaters afford an added bonus of space savings. Because the system does not require separate boilers, chiller-heaters take up to 40% less floor space than more conventional boiler and chiller systems. In the case of the Ohio Statehouse, even with extremely low head space—just over 100 in. (254 cm)—it was possible to get the chiller-heaters into the sub-basement central mechanical room (Fig. 4).

FIGURE 4. In the Ohio Statehouse, chiller-heaters offer space savings because they use less floor space; in addition, they had the advantage of being able to fit into a very tight head space of just over 100 inches. (Photo courtesy of Schooley Caldwell Associates.)

An additional advantage captured by using a gas-fired chiller-heater involved the ability to use waste heat from the absorption process to preheat domestic hot water year-round before the waste heat was sent up to the cooling tower for rejection. In the winter, the waste heat is diverted to the snow melting system at the entrance and exit ramps of the statehouse underground parking garage.

ICE STORAGE

Building owners have made use of ice as air conditioning since the early 20th century, when movie theaters hauled in large blocks of ice—used to cool the nighttime hot, humid air in order to attract more patrons to the five-cent flicks. Now, melting ice is once again serving modern A/C needs.

Located in downtown Columbus, Ohio, the Columbus Museum of Art (Fig. 5) faced a total renovation of its HVAC system. A review of the building's occupancy load profile showed a definite spike in air conditioning in the middle part of the day. Since asking patrons to visit the museum only during off hours was not an option, the HVAC designers investigated shifting the peak load away from the middle of the day by producing peak A/C in off hours.

Initial investigations looked at a system that would produce 100% of the building cooling load through stored ice. A life cycle cost analysis determined that only a partial shift—about 35% to 40%—of the peak electrical load was economically feasible. Once again, meeting with the utility company confirmed that buying electricity in the middle of the night (at a much lower rate) justified investing in a system that could store the ice until needed.

FIGURE 5. The ice storage A/C system at the Columbus Museum of Art allowed approximately a 34–40% shift of peak electrical loads. (Photo courtesy of Schooley Caldwell Associates.)

Most major manufacturers offer ice storage equipment and technology to integrate stored ice into conventional chilled water systems. At the museum, on most spring and fall days, the ice produced at night is all that is necessary to cool the building. During peak occupancy late in the day in July and August, we "shaved" the large peak off the electrical demand charge curve that allowed us to avoid larger demand charges during the heaviest load during the day ($10.50/kwh demand charge vs. $0.08/kwh to make it at night). In addition to the obvious dollar savings, we reduced our electrical peak demand on an already stressed electrical grid of the northeast and midwest portion of the country.

How the System Works

Traditional air conditioning systems work by using fans to blow air past coils that contain chilled glycol, which serves as the heat transfer fluid. The glycol is chilled using high-energy consuming electric chillers, which must operate whenever the air conditioning system is in operation. As the peak A/C load of the day occurs, the chillers are working hardest—consuming large amounts of power the whole time. The principle of off-peak cooling takes ice, which is made at night, and uses it to cool a building during the following day. While still relying on chilled heat-transfer-fluid to flow past blowers, the off-peak-cooling concept calls for the glycol to be chilled as it flows through plastic tubes that are encased in ice within large tanks. The ice is not a solid block; rather, it has the same consistency of a child's "slushy" drink.

Chillers produce this slushy ice during nighttime, which is the most cost-saving period as well as being the period where there is lowest demand. By the time higher daytime rates come into effect, ice will have formed in the tanks, and the chillers are turned off or used in tandem but at a lower energy consuming rate.

Chillers can be sized smaller than in traditional building systems because they work at night and build their capacity through the stored ice. In the case of the museum, we installed two 125-ton machines, and each 125-ton chiller performs like a 200-ton traditional machine. Ice storage cooling also reduces the

FIGURE 6. One of the two 125-ton chillers at the Columbus Museum of Art. Each has the capacity of a 200-ton chiller when used in tandem with the stored ice. (Photo courtesy of Schooley Caldwell Associates.)

FIGURE 7. Outdoor ice storage at the Columbus Museum of Art.

size of the building's other required air-conditioning equipment, including cooling tower and pumps and the electrical switchgear, which can be substantially smaller because of the much smaller A/C system.

GEOTHERMAL HEAT PUMPS

Around the turn of the twentieth century, a young upstart architect was asked to design a house for a young upstart automobile manufacturer named Burton Westcott in Springfield, Ohio. Along the row of large, Victorian mansions adorning East High Street, architect Frank Lloyd Wright designed his first and only Prairie Style house in Ohio. Designed and built between 1900 and 1905, of 11 homes designed by Wright in Ohio, it's the only one within what has been referred to as Wright's "First Golden Age." According to noted author/historian and Harvard professor Neil Levine, "The Westcott House is one of the top 20 buildings in Wright's career."

There were a number of owners after the Westcotts sold the house, and the house eventually fell into severe disrepair. In 2002, the Chicago-based Frank Lloyd Wright Building Conservancy purchased the property; restoration began soon after and was completed in 2005. The house has become a museum and learning center.

In creating an HVAC system for a Wright residence-turned-museum, designers had to contend with several unique circumstances. The system needed to be physically unobtrusive and quiet, yet carry the load required for the new public use of Westcott House. In addition, The Westcott House Foundation required that the system be the most environmentally friendly possible. Ground water heat pumps were selected based on a 20-year life cycle cost that showed a 2/3 annual energy savings compared to standard air-to-air heat pumps, and as an added benefit, no outdoor condensing units were necessary.

FIGURE 8. Adapting Frank Lloyd Wright's Westcott House into a museum required an HVAC system that would provide a 22-ton cooling load while remaining invisible to visitors. (Photo by Feinknopf Photography.)

How the System Works

Ground water heat pump systems simply obtain and reflect heat into the earth to provide heating and cooling for a building. The ground water piping can be laid horizontally beneath the soil (approximately 3 to 5 feet deep); however, these systems require a large amount of property to reject and gain heat from the earth. Another method—the method used at Westcott House—is to drill vertically and to have an array of deep wells.

The rule of thumb is one ton of cooling per 150-foot-deep well; however, soil formations can easily require 200 feet or more for a ton of cooling. For the Westcott House, it was determined that thermally enhanced grout in each well was a cost-effective way to provide the required amount of heat transfer versus drilling additional wells.

The final design incorporates 14 wells in the front yard to serve the house. There are two separate loops in the front yard, separated by 25 feet, while the seven vertical wells in each loop are spaced on a triangular pattern of 15 feet. There are eight vertical wells in the back yard, spaced 10 feet apart in a straight line, to serve the carriage house. Each well is 200 feet deep and has a loop of 3/4-inch diameter high density polyethylene pipe (HPDE). There are 2-inch HPDE horizontal headers located five feet below grade connecting the wells and routing the pipe headers into the house and garage. The fused HPDE well pipe has a 50-year warranty.

Geothermal heating and cooling operates on the fact that the earth maintains a fairly constant temperature of roughly 57°F, depending upon location. During the summer months, heat from the geothermal units is transferred into the earth, and the 200-foot-deep well fields will gradually rise from 56°F to as high as 90°F or 95°F. The process will then be reversed during the winter months, and the well field can drop into the 30s as heat is pulled from the earth. The earth surrounding the well field will constantly try to restore the entire field back to 57°F. Since the calculated heating and cooling loads appear to be fairly equivalent throughout the calendar year, the well field should not retain heat or be super-cooled

FIGURE 9. At Westcott House, the design used 22 vertical deep wells—14 in the front yard serve the main residence, and 8 in the back yard serve the carriage house. (Photo courtesy of Schooley Caldwell Associates.)

FIGURE 10. The indoor heat pump unit at the Westcott House with three zone pumps.

after several years of operation. An environmentally friendly 20% methanol brine solution (with a freeze point of 15°F) is added to the water flowing through the well field to prevent freezing.

CONCLUSION

Research for more environmentally friendly, energy efficient systems must and will continue. But until there is a significant change in price for energy, the shift from standard fossil burning fuels will be slowed by pure economics (initial investment vs. payback). The system at Westcott House had close to a 20-year payback, but the foundation decided to go ahead anyway based on what they thought the master architect Wright would have wanted.

The building industry is changing its acceptance of longer payback periods for innovative design strategies. During the '70s and '80s, if an investment couldn't pay back in less than three years, most clients with whom we worked would not go for it. Now, simple paybacks ranging from eight to twelve years are being taken seriously.

The chiller/heaters at the Ohio Statehouse, installed in 1993, were the first of their kind used in a large state office building in Ohio. The state was very nervous about using such a different type of system, and as a result our firm presented information to many groups of skeptics who did not want to be the first ones on the block with a new type of system.

As a practicing architect and engineer and not a research scientist, it is interesting to me how slow the HVAC equipment manufacturers are to bring really new systems to market. Certainly this has to be based on supply and demand and the prices of fuel, or they would be available by now. I read articles about forward-thinking design strategies for heating and cooling building systems on both coasts of the U.S.; my belief is that higher fuel prices or more stringent code requirements in these areas, particularly on the west coast, are major factors driving innovation.

There are methods of sustainability that we can offer by using current technology in a slightly different way than that to which we are accustomed. A multitiered approach to HVAC designs can stretch our overtaxed infrastructure and nonrenewable fuel supplies until alternative fuels and ways of conditioning buildings become more mainstream and acceptable to the clients we serve.