Using Integrated Design Strategies And Energy Efficient Technologies To Enhance Green Buildings*

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ABSTRACT

Sustainable design principles promote the use of integrated design strategies that balance economic, environmental, and human considerations into a building design. By definition, energy efficient technologies should be a cornerstone of "green" buildings as they reduce operating costs, minimize the environmental impact of the building, and operate efficiently to offer optimal occupancy comfort. However, first cost and ease of design and construction have a tendency to control design decisions, in some cases edging out the energy efficient technologies. Examples will demonstrate how integrated design techniques can help reduce these roadblocks and support incorporation of innovative energy efficient technology applications in green buildings.

INTRODUCTION

The sustainable building design and construction industry is rapidly growing worldwide. Thousands of U.S. architecture and engineering professionals participate in professional societies[1,2] and non-profit associations[3] that are focused on incorporating sustainable design principles into design and construction projects. Sustainable design principles typically promote **integrated design** strategies that address siting and transportation considerations, water use, energy

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*West Coast Energy Management Conference, June 7-8, 2006; Track 3: Emerging Buildings & Sustainable Efficiency; Session 3B: Energy Efficient Technologies for Green Buildings use, materials use, indoor environmental quality, and operations and maintenance practices. The visible and measured outcomes from some sustainably designed projects include increased occupant satisfaction, reduced construction and operation-related waste costs, reduced water use, and improved energy performance.

In the U.S., buildings account for 65 percent of electricity consumption and almost 40 percent of total energy use.[4] It is critical that sustainable design efforts emphasize energy efficient technologies. Many of the U.S. sustainable design protocols emphasize energy consumption, but industry statistics[5], supported by anecdotal stories, indicate that extensive energy efficiency measures are not being incorporated into building designs at the same level as other sustainable design considerations. Although all of the technologies discussed in this article have the potential of being life cycle cost effective when applied to an appropriate building design, defending the life cycle cost and the first cost on an energy efficient technology alone does not tend to be enough when first cost becomes the primary design driver. The two reasons commonly given for not using innovative technologies are to decrease first costs and reduce the risk of design by selecting technologies and design strategies that have been successfully implemented by design team members in the past.

Recent case studies document how sustainable design and energy efficient strategies can be incorporated without a significant first cost increase.[6,7] This is due, in part, to using integrated design strategies where an increased first cost of one design component is offset by a decreased first cost of another component. Documenting the connection between the energy and non-energy benefits and how they work together to offset first costs provides potentially useful basis of design information for both the energy and sustainable design professionals. Armed with this information, the intent is that integrated design teams will be able to keep more energy efficient technologies in their sustainable building designs.

The purpose of this article is to offer a high-level summary of energy and non-energy benefits for a sampling of technologies that are typically designated as “energy efficient” and to use that summary as a starting point for a discussion on how to increase the use of energy efficient technologies in sustainably designed buildings. The first step will be to eliminate the evaluation of these technologies as single elements and have them evaluated as part of a system. For example, when the selection of a heating and cooling system results in the ability to reduce the overall building footprint, the cost savings associated with that materials reduction benefit needs to be tied to the purchase of the specific energy efficient equipment.

The benefits described in this article have been generalized to demonstrate the opportunity a systems approach can offer. Further research by the authors of this article is underway; it is expected to offer more detail on the energy and non-energy benefits for a set of energy efficient technologies. More detail on the first cost impact of these benefits will be explored. This research will also investigate how this information can be used to increase the probability of energy efficient technologies being included in more sustainably designed buildings.

Example Technologies

There are many technologies and design strategies that offer both energy and other sustainable design benefits. The four technology areas addressed in this article are:

- Heating and cooling;
- Duct and ventilation;
- Lighting, and
- Water heating technologies.

This section is not intended to be an all-inclusive list, but rather a section that highlights case studies, design guidance, pay and technology reports from governmental agencies, technical societies, manufacturers, utilities and building research centers. Each grouping contains a table with the energy and non-energy benefits of each sample technology summarized. “Benefits” include first cost and life cycle cost savings. The summary sections that follow the tables explain each of these benefits along with potential deterring factors.

The two heating and cooling technologies summarized here are:

- Geothermal Heat Pumps
- Underfloor Air Distribution Systems

A geothermal heat pump (GHP) is a renewable energy technology that is highly efficient when used for space heating, space cooling, and water heating. It has an initial cost that is competitive to conventional heating, ventilation, and air conditioning (HVAC) equipment. The GHP uses a series of liquid filled pipes looped either vertically or horizon-

Heating & Cooling

Energy Benefit	*Non-energy benefit*
Geothermal Heat Pumps	
44-72% less energy	• Reduction in operation and maintenance costs • Greater usable building space • Smaller floor-to-floor heights
Underfloor Air Distribution Systems (UFAD)	
10-20% less energy	• Improved daylighting • Reduced churn costs[8] • May offer lower first costs per square foot • Reduced ductwork • Reduction in operation and maintenance costs

tally buried in the soil that uses the fairly constant soil temperature as either a heat source in the winter or a heat sink in the summer. According to U.S. Department of Energy (DOE) studies[9], GHPs can use 44 percent less energy than air-source heat pumps and up to 72 percent less energy than electric resistance heating and standard air conditioning equipment. The operations and maintenance associated with a GHP is generally less than traditional equipment because there are fewer mechanical components prone to breaking. GHPs are smaller than traditional equipment and the duct space required is smaller, yielding smaller mechanical rooms and smaller floor-to-floor heights. The elimination of standard rooftop equipment results in a longer-lasting roof and smaller structural steel beams required. The simple payback of a GHP versus conventional equipment when considering installation costs, reduced energy, and maintenance costs is typically five years or less.[10] Note that GHPs are not viable at every building site due to soil, site layout, and building energy load.

An underfloor air distribution (UFAD) system provides direct heated or cooled air to individual workspaces, eliminating "dead zones" in the air flow. The air supply plenum is between the floor slab and floor panels and the return air plenum is above the suspended ceiling, taking advantage of the natural airflow pattern. The hours that the building can be primarily cooled or heated by outside air is increased because the UFAD supply air can be effectively delivered above 62ºF compared to conventional 55ºF HVAC air.[11] In some cases, this can allow for chillers to be downsized because it is no longer needed to supply cooling between 55ºF and 62ºF outside conditions. Supply air fans can also be downsized due to the lower static air pressure requirement for the underflow lower velocity air compared to the standard system. The increased supply air temperature and decreased air pressure requirements can account for 10 to 20 percent reduction in energy consumption when compared to traditional forced air HVAC designs. The Alcoa headquarters in Pittsburg took advantage of the smaller duct space to allow for 11′6″ ceilings, improving daylighting.[12] First construction costs have been higher or lower depending on the building design. Office reorganization (i.e., churn) costs can offset this first cost in a relatively short amount of time because electrical, power, and data boxes, and the air diffusers, are modular and more easily moved. The distribution system can be easier to maintain and operate than conventional systems, but commissioning costs can be greater due to the location and operation of the diffusers.[13]

The three duct and ventilation technologies summarized here are:

- Ducts in Conditioned Spaces
- Whole House Ventilation Fans
- Cold Air Distribution

The ducts in conditioned spaces and the whole house ventilation fan technologies are primarily residential concepts, whereas cold air distribution is a commercial technology, but the benefits seen in these three examples can cross over into both building sectors.

Ducts in conditioned spaces are primarily a design option in residential structures versus the standard practices of running ducts through attics, garages, crawlspaces, and basements. To move the ducts into conditioned spaces, they are usually run through bulkheads, dropped soffits, tray ceilings, open-web floor joists, and in closets. According to recent studies,[14] 25 percent of household energy loss in heating and cooling can occur in the ductwork. Case studies have determined that this 25 percent can be saved by running ductwork in the conditioned

Duct & Ventilation

Energy Benefit	***Non-energy benefit***
	Ducts in Conditioned Spaces
Up to 25% less energy	• Reducing size of mechanical equipment • Elimination of duct insulation • Minimizing duct length and diameter
	Whole House Ventilation Fans
Up to 75% less cooling energy	• Reduce moisture • Less noise • Reduction or elimination of air conditioning unit
	Cold Air Distribution
Up to 10% less energy	• Smaller mechanical equipment • Smaller ductwork • Shorter floor-to-floor heights • Increased indoor environmental quality (IEQ)

spaces. Efficiency can also be improved by the increased accessibility to filters for routine maintenance. In well-designed systems, running ductwork in conditioned spaces shortens the duct length, decreases the duct diameter, and removes the requirement to insulate the ducts. Running the ducts inside the drywall may affect interior volume, leading to increased costs in framing and drywall, but the material savings in the ductwork design can help offset these increased costs.

Whole house ventilation fans draw cool outside air through open windows and exhausts the hot indoor air to the outside through the attic. The fan is operated whenever the inside temperature is higher than the outside temperature. In certain climates, whole building ventilation fans can successfully function as the only source for air cooling. An Atlanta, Georgia, example shows that using a whole house fan versus a 2-ton air conditioner could cost the owner up to 75 percent less in electricity costs.[15] Ventilation fans typically reduce moisture more effectively and are quieter than conventional air conditioning units.

Installing a whole building fan does leave an uninsulated area in the ceiling, so it is imperative that a fan cover is installed during the winter months, which in turn increases the operation costs.

Cold air distribution is an adaptation of conventional all-air systems that supply air below 48ºF versus the standard of 55ºF. Reducing the supply air temperature by ten degrees can reduce the supply-air volume by up to 40 percent.[16] This reduction in air volume can lead to reduction in air-handling equipment, smaller VAV terminals, and smaller ductwork. The smaller ductwork leads to shorter floor-to-floor heights that can significantly reduce construction materials. A fan with less horsepower is required to move the smaller volume of air, which lowers the operating costs and may reduce fan-generated sound. The increased cost for required chiller electricity is usually offset and can yield a 10 percent energy savings by the installation of smaller HVAC equipment, less building materials, and lower fan operating costs. Using a cold air system can reduce the relative humidity which results in better indoor air quality and improved occupant comfort.

The two lighting technologies summarized here are:

- Energy Efficient Lighting
- High Performance Windows and Glazing Systems

Lighting

Energy Benefit	***Non-energy benefit***
Energy Efficient Lighting	
20-50% less energy	• Producing up to 90% less heat • Lamps last up to 10 times longer
High Performance Windows and Glazing Systems	
10-50% less energy, HVAC and lighting costs	• Daylighting • Ventilation • Increase the life of room furnishings • Reduced operations and maintenance costs

Energy efficient lighting technologies, including compact fluorescent lamps (CFLs), high performance (super) T8 lamps, and light emitting diodes (LEDs), can be installed to reduce electricity consumption, improve light quality, and increase occupant comfort and productivity. The U.S. Environmental Protection Agency (EPA) Green Lights Program estimates potential energy savings from lighting upgrades to be between 20 and 50 percent.[17] Using energy efficient lighting in a building reduces the waste heat output, which in turn reduces the amount of energy needed to cool the building. The impact of increased energy consumption to heat the building depends on its geographic location, but the cooling savings generally offset the heating costs. The cooling system may be able to be downsized to reflect the lower cooling loads. Another benefit to energy efficient lighting is the lifespan. For instance, CFLs last up to 10 times longer than traditional incandescent models.[18] The lifespan offsets first costs when examining the replacement costs savings of materials and labor, especially in hard-to-reach places. High performance T8 systems can show improvements of up to 31 percent in efficacy (lumens per Watt) over standard T8s, and up to 81 percent in efficacy when compared to T12s.[19] The quality of light over a period of time also has increased with these technologies. The non-energy results of these benefits is the ability to design a building with fewer light fixtures, while keeping the same amount of light in the space which can reduce first costs.

High performance energy efficient window systems are constructed from a variety of glass panes, structural frames, spacers, and sealants. The glazing systems refer to the sealant around the window as well as the coating, tinting, and lamination used to increase the moisture protection, thermal performance, safety, sound transmission loss, and visual appearance.[20] The performance of a window is directly related to its glass thickness, visible transmittance, U-factor (rate of heat flow), and solar heat gain coefficient (SHGC). Optimum window and glazing designs in residential structures can reduce energy consumption from 10 to 50 percent below standard values. In commercial, industrial, and institutional buildings, lighting and HVAC costs have the potential to be reduced 10 to 40 percent.[21] The use of high performance windows can reduce the heating and cooling loads, which in turn can eliminate the need for perimeter heating. Increased passive heating and daylighting will reduce loads as well, save on operations and maintenance costs, and offer higher occupant satisfaction. Certain glazings filter out ultraviolet wavelengths, which can increase the life of room furnishings and reduce glare.

The two water-heating technologies summarized here are:

- Tankless Water Heaters
- Gravity-Film Heat Exchangers

Water Heating

Energy Benefit	*Non-energy benefit*
Tankless Water Heaters	
Up to 50% less energy	• Reduced water heater footprint • Reduced replacement costs
Gravity-Film Heat Exchanger (GFX)	
30-50% less energy	• Shortens the time needed for the water heater to recover • Smaller water heater needed

Tankless water heaters, also called demand or instantaneous water systems, only heat water as it is used by a heating device that is activated by the flow of water when the hot water valve is opened. Tankless water heaters are available in electric, natural gas, and propane (LP), and come in a variety of sizes. They can be used for a single output location (a bathroom) or as a whole building water heater. Small boosters can be installed in a closet or underneath the sink. This can eliminate traditional storage water heaters or minimize the size of the traditional storage water heaters, which in turn reduces the space needed to house the tank. Tankless water heaters have a longer lifespan of 15 to 20 years versus storage tank water heaters that traditionally last 5 to 15 years.[22] The rate of water flow is limited by the output of the heater and sometimes there is a need to install multiple tankless heaters to meet the demand.[23] An integrated design process should address water conservation to minimize the need for larger capacity equipment.

A gravity-film heat exchanger (GFX) is a system that extracts heat out of drainwater and uses it to preheat the cold water entering the building. The GFX consists of copper coils around the copper wastewater drain. Warm wastewater can be utilized with a GFX from showers, clothes washers, dishwashers, baths, and sinks. The GFX has no moving parts, therefore operations and maintenance costs are low. In a single drain application, the compact construction replaces five feet of vertical drain line and can be installed in stud walls. A GFX is most beneficial when the supply of wastewater coincides with the demand of hot water. Based on a field evaluation conducted by Pennsylvania Power and Light, using a GFX system under a shower drain can yield 30 to 50 percent energy savings.[24] In residential settings, the simple payback can be between two and five years. GFXs shorten the time needed for the water heater to recover and in some applications the traditional storage water heater size can be downsized.

DISCUSSION

Think Systems, Not Technologies

Energy engineers and sustainable design professionals may ask why these technologies have not been incorporated into every applicable, new building design. Reasons given have ranged from unwillingness to take a risk on a new technology to increased first cost. Undocumented reports have included examples of energy efficient technologies that are included in the original design and then removed at later design stages to reduce overall project cost.[25]

Review of case studies, reports, design guidance, and other literature from governmental agencies, technical societies, manufacturers, utilities, and building research centers uncovered a sampling of technologies that offer both energy and non-energy benefits (i.e., cost savings). The literature also boasts that integrated design using these types of technologies can be incorporated into buildings at no added first cost to a project and also offer an improved life cycle cost. When these technologies are removed from the design, the undocumented reports continue that other design elements that were included based on the non-energy benefits of the removed technologies are typically not re-designed to match the change to replacement energy-related technologies, resulting in a sub-optimal design.

By documenting the non-energy benefits of these technologies in a basis of design document alongside the energy savings calculations, these energy efficient systems will have a better chance of being implemented as the integrated design team intended. This is accomplished by considering these energy efficient technologies as part of a system that includes the reduced materials use and decreased heating and cooling system requirements that can accompany the use of these technologies.

When the basis of design does not clearly document the connections between mechanical equipment sizing, materials choices, and the energy efficient technologies, there is the potential of their individual first cost being the target of first cost savings actions.

By connecting, through the basis of design and/or other key design documentation, the energy efficient technology and the supporting design adjustments (e.g., materials, equipment sizing, etc.), the first cost of the "system" has a better chance of being considered cost effective from both a first and life cycle cost perspective. The ongoing research on this topic will identify in more detail how the synergistic effects can impact the ability to more easily defend energy efficient technologies in sustainably designed buildings.

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