Reinventing HVAC Design for Green Buildings

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Sustainable HVAC systems can and should be as varied in their composition as the range of climates and regions where structures are built.

This multi-tennant building at 767 Third Ave. in New York uses over 1200 Therma-Fuser modules to provide occupants with better comfort and more control over temperature and air conditions, resulting in improved health and productivity. The building, which was designed by Fox & Fowle Architects and built in 1981, is owned by the William Kaufman Organization and managed by Sage Realty. Photo courtesy of Acutherm.

Noted green architect William McDonough, former Dean of the UVA School of Architecture, once said: “Our culture designs the same building for Reykjavik and Rangoon; we heat one and cool the other; why do we do it that way? I call this the Black Sun.”

The energy intensity of architectural design is chiefly in the heating, ventilating and air conditioning (HVAC) systems that create interior comfort by compensating for climatic conditions. Sustainability principles and green building performance characteristics have pushed architects and engineers to reinvent the definition of a climate-responsive design. New strategies for providing comfort in buildings are progressing rapidly but still have much room for improvement. The palette of HVAC options is more expansive than the typical suite of measures now used most green buildings. As this palette evolves, so too will climate-responsive design. Sustainable HVAC systems can and should be as varied in their composition as the range of climates and regions where structures are built.

Principles For Sustainable HVAC Systems Design

Sustainable building design should make optimal use of available energy flows in the local environment. Structural features and operations should be responsive to climatic conditions. In principle, it is best to use passive measures (such as heating by solar gain) rather than active ones (such as heating by burning fuel). Such techniques as natural ventilation, ground-coupled heat pumps and the like can economically contribute to space conditioning, even if they do not serve all of the required load, by reducing the size and energy intensity of HVAC system’s capacity.

But climate control strategies need not be based entirely upon passive approaches to be sustainable. As long as there remains a role for active methods, they should be as environmentally friendly as possible. Mechanical system design is a key feature of sustainable buildings. The equipment associated with climate control — fans, pumps, motors, ducts, pipes, etc. — significantly affect capital and operating costs, energy use, indoor air quality, and environmental impact.

Beyond Natural Ventilation and Raised Floor Distribution Systems

Relatively simple strategies for reducing HVAC energy consumption have come into common use in an effort to streamline project engineering. For example, most new green buildings incorporate either or both natural ventilation and raised floor air distribution. Both of these techniques can work well, yet questions remain about their suitability to all climates and applications. Is natural ventilation alone sufficient in climates with hot, humid summers? What is the range of optimal building sizes for raised floor systems? These questions cannot be answered generically and definitively because design criteria and conditions vary. Natural and underfloor ventilation approaches are sufficient in some cases but not in others. But where they are not appropriate, what are the alternatives?

The Palette: Sustainable HVAC Systems

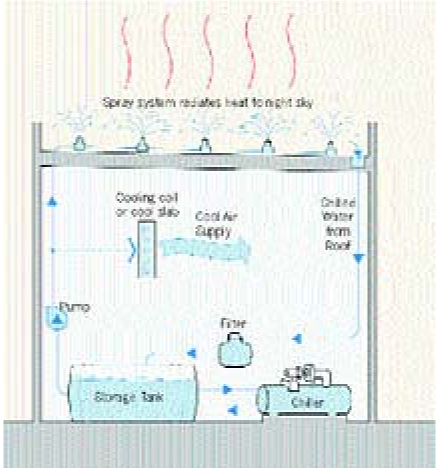

Figure 1. The NightSky Roof Spray System for Efficient Cooling

A recent exhibition of green buildings in Europe, Australia and the US, Ten Shades of Green, showcased numerous low-energy climate control strategies. Each of the ten buildings has a unique approach, yet remain many more economical and energy-efficient designs exist, each applicable to a range of particular projects and local conditions. As with other aspects of sustainable architecture, “one size does not fit all.” Below is a partial list of sustainable HVAC system features.

NightSky Radiant/Evaporative Cooling System

One of the more innovative cooling techniques available is the NightSky system, recently developed and pioneered by the Davis Energy Group in California (see Figure 1). It takes advantage of a simple natural phenomenon: The sky is colder at night than it is during the day, particularly in clear conditions, and heat moves from warmer buildings to the cooler sky. A thin layer of water is sprayed on the roof at night, cooled naturally by radiative heat transfer, and then collected for cooling during the day, typically in air handlers or slab cooling systems. While this system does not apply in all climates, it can provide more than 50% of the cooling in areas where night skies tend to be clear with temperatures well below daytime peaks.

The NightSky system has been used on a variety of projects, including a US Customs Border patrol station in Nogales, AZ. In that building, the radiant/evaporative roof spray was credited with consistently producing water temperatures at or below 50?F and increasing the measured average efficiency of the cooling system by a factor of 15.

Figure 2. Heat Exchanger Used in Free-Cooling Application

Free Cooling

While economizer cooling using outside air is widely used, another type of “free cooling” applies to buildings that have constant chilled water requirements, such as structures with fan coil systems, and high-load buildings, such as data centers. Free cooling is the process of creating chilled water directly from the cooling towers without the use of chillers, serving part (if not all) of the cooling load (see Figure 2). Free cooling systems typically reduce cooling system energy use by a factor of 10 (e.g., from 0.5 kW/refrigerative ton to 0.05 kW/ton). The cooling water is kept isolated from the chilled water by a plateand-frame heat exchanger with a close approach (e.g., 2 degrees Fahrenheit). When the temperature and humidity are low enough, the cooling towers can operate alone, and in many cases without fans. This system requires sufficiently low temperature and humidity levels, but many regions of the US experience large periods of the year where free cooling is possible.

One large San Francisco, CA, hotel has four-pipe fan coil units in each guestroom. For over half the year, the free cooling system serves the load, with energy savings exceeding $29,060 annually, which is equal to 34% of the cooling costs.

Graphic courtesy of Acutherm

Figure 3. Acutherm's Therma-Fuser (VAV Air Diffuser)

Therma-Fusers

In principle, more sustainable buildings provide occupants better comfort and more control over temperature and air conditions, resulting in improved health and productivity. One of the often-touted benefits of underfloor air distribution systems is the ability of each occupant in the space to control the temperature in his or her direct area. Another approach affords the same control with a conventional overhead ducting system. Acutherm's Therma-Fuser, an often-overlooked product, has been around for over 23 years, and enables individual temperature control of the area served by that device (see Figure 3). This technology allows for the elimination of variable air volume (VAV) boxes that are common in HVAC systems today. In addition to providing local control, these units allow much lower pressure drop (i.e., resistance to the airflow) in the ducting system. Typically 1 inch w.g. of pressure drop can be shaved off of the total fan system pressure drop. In most buildings this can save up to 25% in fan energy.

VAV air diffusers are most widely used in U.S. East Coast office buildings. The Ziff Davis headquarters building in New York has over 1,200 Therma-Fusers.

Radiant Heating and Cooling

Radiant heating and cooling systems are widely used in Europe, as well as in parts of North America, but a large potential for stateside application remains. Radiant slab heating technologies have been used in the U.S. since the 1960s, but many performed insufficiently due to poor equipment and installation. Today, radiant system technologies have vastly improved. Slab radiant systems can be used to both heat and cool a building (although radiant cooling is not as applicable in very humid climates).

The key to this system is to avoid putting very cold water in the slab while cooling. In most cases, the slab only needs to be kept in the 65–68?F temperature range to provide adequate cooling. In Europe, several sustainable buildings use new radiant chilled ceiling panels. Radiant systems lower a building's energy use by eliminating the need for fans. Although often overlooked, fans typically use as much as half of an HVAC system's annual energy consumption. Users of radiant systems are the biggest supporters of this technology, often noting the superior comfort it provides directly to occupants.

Low Cost/Low Energy Pumping Systems

Current pumping systems design is far from optimal. Many systems use three-way valves on air handlers, resulting in full water flow at all times, regardless of heating or cooling requirements. Another common system replaces the three-way valves with two-way valves, but then uses a primary/secondary pumping scheme. This adds cost to the project and often does not result in energy savings due to difficult control issues.

The most economical and energy-efficient design combines two-way valves and a primary-only pumping system with variable flow through the chillers or boilers. This system eliminates the use of all secondary pumping and saves considerable energy by varying the flow delivered to the cooling coils depending on cooling load.

In addition to lower energy costs and fewer pumps, two-way valve systems do not require costly balance valves or manual balancing. While a full description of the technical details is beyond the scope of this article, there has been extensive discussion of this system option in engineering magazines and journals, and many examples proven in practice in numerous facilities large and small.

At the Oakland Museum in Oakland, CA, an award-winning retrofit replaced three-way valves with two-way valves in combination with variable speed, primary-only pumping, saving over $4,100 per year in pumping system operating costs.A similar conversion in Building 858 at Sandia National Laboratories reduced flow by an average of 60%, saving over 470,000 kWh in pumping energy and $247,000 in operating costs.

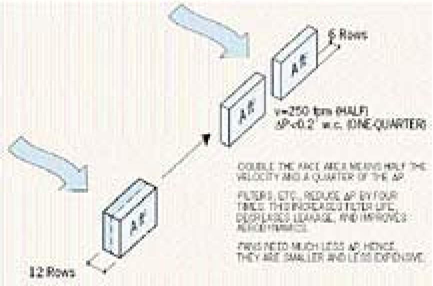

Figure 4. Low-Face Velocity Achieves High Ventilation System Efficiency

Low-Face-Velocity Air Handlers

Underfloor ventilation systems are attractive from an energy perspective because they decrease the pressure drop that fans have to overcome to provide heating or cooling to a space. However, the ducting that underfloor systems replace typically represents only one-quarter of the total pressure drop in air delivery systems. The majority of the total system pressure drop is in the duct shafts and in the air handlers. Air handlers filter and condition the air before it is sent out to the building (see Figure 4). Air handler design has not changed in many years and tends to be very similar around the globe. Optimized air handlers should be responsive to local conditions—including energy costs.

Most engineers size air handlers using a “rule of thumb” of 500 fpm face velocity. Face velocity is the speed at which air passes over the filters or heating/cooling coils in an air handler. While this sizing method saves time, it does not provide the lowest-cost-of-ownership air handler. Optimal face velocities are typically much lower. Lower velocities result in larger air handler boxes, but several benefits result:

- The pressure drop is reduced in proportion to the decrease in velocity squared. Therefore a 20% reduction in face velocity results in a 36% reduction in pressure drop and a significant decrease in required fan power.
- The motor, fan, variable speed drive (VSD), and electric wiring will be smaller.
- The coils will work more effectively, thus chilled water temperatures can be higher.
- Filters work more effectively at lower face velocities, thus improving indoor air quality.

The target for air handlers should be a minimum 25% reduction in energy costs, fan sizes and VSD sizes. Depending on the application and energy costs, optimal face velocities should be in the 250-450 fpm range.

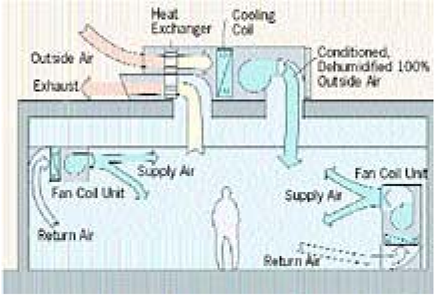

Figure 5. Dedicated Outside Air Systems in Combination with Low-Face Velocity Design Save Significant Space Conditioning and Ventilation Energy

Dedicated Outside Air Handlers

Variable air volume (VAV) air handling systems are the standard in most commercial buildings today. While these systems have significantly reduced fan energy use in buildings, they do present a unique challenge to ensuring good indoor air quality. VAV systems vary the amount of air supplied to the various zones in the building as the heating or cooling load changes. While this is good from a fan energy perspective, the amount of outside air (OA) delivered to a space is also lowered. Most VAV systems are set up to deliver a fixed percentage of outside air in the air delivery system. A better approach is to increase the relative OA percentage when the volume of air delivered to a space is reduced, in order to maintain the desired total amount of OA in the space.

A dedicated OA air handler solves the problem of decreased OA quantities delivered to occupied zones by maintaining a fixed flow of OA into those zones. A variation that further lowers energy use is to use a carbon dioxide sensor to reduce the amount of OA delivered to an occupancy zone as the number of people in that zone decreases. Also, the dedicated AHU can be used to improve indoor air quality by pretreating incoming OA with (de)humidification, filtration, and heating and cooling (see Figure 5). This allows the indoor air handling system design to focus primarily on return air management, reducing the conditioning requirements and therefore also decreasing the amount of filters, coils, pressure drop and lifecycle cost.

This approach was used in combination with a low-face-velocity air handling system and highly efficient equipment in the design for the new Missouri Department of Natural Resources headquarters building in Jefferson City, MO, designed by BNIM Architects. The design’s overall energy use was calculated to be well below 60% of a typical building in the area. Modeling indicates that the low-face-velocity ventilation, efficient equipment and dedicated OA units alone saved nearly 70% of the cooling system energy use when compared to a standard system in the same building. Most of the energy savings were realized due to the efficient ventilation.

An Integrated Approach

Green buildings with mechanical HVAC equipment can provide superior comfort and do not have to cost more than conventional buildings — and indeed, can cost less by simplifying or eliminating mechanical systems and other unnecessary capacity. But sustainable design requires an integrated, whole-systems approach to succeed.

Each building should be considered in the unique context of its local environment and ultimate purpose. Collaboration between owners, architects, engineers, contractors and tenants needs to begin at the earliest stage of the project. A broad range of climate control approaches should be evaluated collectively, since HVAC system selection both influences and depends upon many other aspects of the design.

Life-cycle cost analysis is vital, as all too often energy-savings measures (e.g., larger air handlers or VSDs) are rejected to reduce capital cost — thereby increasing energy use and total cost of ownership. Pressures to complete projects on time and under budget regularly produce decisions that are penny-wise but pound-foolish. Unfamiliar approaches, new and more efficient technologies, and innovative designs are frequently rejected lest they slow a project down or increase the risk to one of the participants.

Follow sustainable design principles, apply engineering fundamentals in innovative ways, and build confidence based on proven examples. The result will be buildings that are more economical, comfortable, life affirming, and pleasant to be in.

SIDEBAR: Key Resource Efficiency Design Principles

1. Big Pipes Principle
Bigger, smoother pipes save energy while maintaining desired flow. Increased pipe and duct diameters decrease friction, resistance, pressure drop, and velocities in air and water handling. This in turn allows reductions in the size and capital cost of the pumps, fans, and other equipment that serve the load, thereby reducing the total cost of the system. This is often referred to as the “big pipes, small pumps” principle.

2. The Square Law
Pressure drop is proportional to velocity squared. Doubling the surface area of a filter or coil (e.g., by increasing duct diameter, or pleating the filter) allows a 50% reduction in velocity while maintaining equivalent flow, and thereby reduces pressure drop to 1/4th.

3. The Cube Law
Fan or pump power is proportional to flow cubed. Cutting velocity in half reduces fan or impeller speed by about 50%, which reduces fan or impeller energy use to 1/8th.

4. Thermal Integration
Make use of all economically available differences in temperature from environmental conditions and facility processes before discarding them to the environment. Many buildings consume energy to create heat or coolth, and then spend even more energy removing “waste” heat or coolth from their inputs, processes and facilities, without matching up energy flows and applications. Even partial heating or cooling reduces the amount of fuel needed to complete the job. For example, “waste” heat from an oven or boiler can be used to preheat wash water or intake air. Municipal water or groundwater can act as a source of free cooling. Heat exchangers can allow energy transfer between media or flows that should not mix or make direct contact. In a sense even insulation can contribute to thermal integration, by reducing wasted energy through trapping heat or coolth that would otherwise be lost.

Above information courtesy of Rumsey Engineers.

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