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Building Comfort with Less HVAC

ARCHITECTS AND ENGINEERS MUST WORK TOGETHER TO REDUCE A BUILDING'S THERMAL LOAD AND DOWNSIZE THE HEATING AND COOLING PLANT.

by David Houghton, PE

Continuing Education

Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD / AIA Continuing Education article.

Learning Objective:
After reading this article, you should be able to:

1. Work with mechanical engineers to design energy-efficient commercial buildings.

2. Recognize areas where mechanical systems are commonly oversized by engineers.

3. Compare a building's cooling load to its heating load in terms of equipment, cost, and space.

4. Describe sources of thermal load..

5. Describe energy modeling.

Once upon a time, buildings were designed to stay comfortable passively. Thick masonry slowed the transfer of heat, walls were bermed to minimize temperature swings, openings were positioned to take advantage of prevailing winds, and roofs were shaded by overhanging trees. Now that there are chillers, ducts, boilers, and pipes, it's easy to rely on artificial means to keep inhabitants comfortable rather than designing the building itself for comfort. But reducing the thermal load instead of going all out on the HVAC system can reduce construction costs and minimize operating expenses by making more efficient, effective buildings.

Although the heating and cooling of buildings is the province of the mechanical engineer, the architect determines many of a building's thermal properties by selecting its shape, color, layout, and composition. Engineers, who are not often consulted on these decisions, may find themselves literally boxed into designing the size and capacity of the heating and cooling system based on the architect's selections.

"Architects don't think in terms of tons of air-conditioning," says Gary Gardner of Gardner & Pope Architects in Pittsburgh. "It's not in their vocabulary." But developing a mutually challenging partnership with the mechanical engineer means the team works together from the beginning to optimize the building's design. Such an approach, he says, results in greater comfort for occupants and energy savings—something that's increasingly important as more clients ask for energy-efficient buildings.

That said, it's important to recognize that most

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mechanical engineers are mortally afraid of not providing enough cooling in their designs. Thus, they introduce a safety factor—the amount of installed cooling capacity above the anticipated cooling load. Safety factors are expressed as a percentage of the anticipated load. If calculations show 300 tons are required, 380 tons might be specified instead. The safety factor is 80/300, or 27 percent. However, the load itself, 300 tons in this case, usually includes its own safety factor. This can compound to produce cooling systems that are overdesigned by 100 percent or more, significantly increasing energy usage and equipment costs.

Still, engineers know that if there is insufficient cooling, it will be blamed on them. The engineer is therefore liable for corrective action, which may be very expensive. “After a restaurant owner specifically instructed us to cut the cooling equipment down to the bone, he ended up having problems with kitchen ventilation and outside air infiltration,” says Jerry Novotny, a mechanical engineer in Boulder, Colorado. “The cost to fix the problem was nearly as much as the entire HVAC system. And there was a lot of scrambling and finger-pointing. It got pretty ugly.” While this is a reasonable thing to fear, there is no similar incentive to not oversize, so the safety factor can get quite large. To minimize this wastefulness, architects and engineers need to understand how improving the building’s thermal performance introduces a different type of safety factor, one based on the performance of the building itself.

Keeping cool

A building’s cooling load is the rate of heat rejection required to keep it cool inside. Conversely, the heating load is the amount of added heat needed to keep it warm inside. Of these two, cooling loads are the troublemakers because cooling capacity is more expensive to buy and install; chillers cost more than boilers. Cooling also eats up more building space than heating equipment and costs more to run—pumping 100,000 Btus of heat out of a building with electricity can cost twice as much as adding 100,000 Btus of heat with natural gas, especially during peak load times.

The cooling load, from outside and inside the building, depends on a number of variables, including solar radiation through glazing or thin wall sections, heat gain through the building skin, hot outside air brought in through the ventilation system, lights, people, and plug loads. Commercial buildings need more cooling than heating because they are blocky—internal areas without outside exposure have no windows through which they lose heat in the wintertime .

A useful benchmark for cooling load is cooling density, measured in square feet per ton. If you were to visit 100 commercial buildings and compare their size and the size of the cooling plant, you would find a remarkable cluster at about 350 to 400 square feet of floor space per ton. It turns out that this is the general rule that engineers use; more than 400 square feet per ton and most engineers start getting nervous that there won't be enough air-conditioning.

There are two factors in establishing a commercial building's cooling load. The first is the design load—the worst-case scenario for keeping the building cool. Most engineers use one of several software programs based on the calculation methods of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) to quantify thermal loading based on window area, interior lighting, plug loads, occupancy, and other factors. The program builds a thermo-dynamic model of the building using an internal library of weather data, then spits out a load report describing the peak heating and cooling loads for the hottest day of the year, assuming all the building's lights and internal devices are running and the building is occupied at peak capacity. A safety factor of 20 to 100 percent is added for good measure. This total, reflecting a situation that will probably never occur, is the design load.

The second, more practical aspect of cooling load is the actual operating load the building experiences throughout the year. The operating load is what actually reaches the chillers much of the time—usually much less than the design load. It's not unusual for a cooling system to operate at 20 to 50 percent of full capacity. This oversizing is expensive. If the cost of a cooling system plant is $1,500 per ton, downsizing one in a 100,000-square-foot building from 250 tons (a density of 400 square feet per ton) to 150 tons (a density of 667 square feet per ton) saves about $150,000.

Energy modeling

Simply downsizing an HVAC system's peak load capacity saves money. But for an accurate picture of where the heating and cooling energy will go before the equipment is specified, architects and engineers are using energy modeling software systems. The best known of these is DOE-2, developed by Lawrence Berkeley National Laboratory in the late 1970s. A new modeling package, EnergyPlus, based on DOE-2, will be available in prototype next year.

Energy modeling software requires time and money to run. Many architects hire consultants who specialize in energy modeling and may charge $10,000 or more to run these calculations. If carefully done, energy modeling provides an accurate and revealing look at the building.

Sandy Mendler, AIA, sustainable design advocate for Hellmuth, Obata + Kassabaum (HOK) in Washington, D.C., used modeling software to analyze the Environmental Protection Agency Campus, a one million-square-foot complex under construction in Research Triangle Park in North Carolina. She was surprised to learn that in the laboratory area of the building, the envelope accounted for a small percentage of thermal load. Because of the high air-change rate required, most of the cooling energy was going out with the exhaust air. In the office portion, however, the building envelope was more significant. That information allowed HOK to allocate its resources appropriately.

Energy modeling is especially useful and accurate for building renovations. System Design Consultants, who served as mechanical and electrical engineers for the renovation of the 103-year-old Portland (Oregon) City Hall, were able to mimic the actual building's performance, making it easy to see where heat was being lost. "We plugged in real numbers based on the building's history, instead of predicting these loads," says Gary Barnes, PE. The resulting design responds to these needs.

Reducing thermal load
There are many sources of thermal load, but the following are the most significant:

Solar load. A building's solar load is determined mostly by its glazing. Often the architectural program dictates the size and placement of glass, and cooling-load considerations take a backseat. By now most architects recognize that glass on the south and west facades of the building introduces heat, while glass on the east side generally provides beneficial morning light and warm-up

Specifying glass with a low solar heat gain coefficient (SHGC), the fraction of solar radiation admitted through a window or skylight, reduces heat gain. The SHGC replaces the shading coefficient as the indicator of a window's shading ability. Glass with an SHGC of 0.20 lets in 20 percent of the solar radiation that strikes its outer face. Most commercial glazing SHGC values are in the range of 0.10 to 0.60; using glass near the bottom of that range keeps cooling loads in check. At the same time, the visible transmittance of the window should remain above 20 percent to avoid a dark and gloomy effect.

Spectrally selective and low-emissivity, or low-e, coatings, which reflect heat, control solar gain while allowing visible light to enter. Tinted glass, which absorbs infrared waves, lessens the amount of and light entering a space. Tints, low-e, and spectrally selective glazing allow architects to use more glass without sacrificing thermal control.

Broad eaves, awnings, and other shading devices also reduce solar gain. HOK’s Mendler took advantage of the existing tree canopy to shade the western facade of the EPA Campus. “This was one solution that was absolutely free,” she says. Deeply recessed windows, light-colored precast concrete, and, most important, light-colored roofing material also

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help. Hashem Akbari, a researcher at Lawrence Berkeley National Labora-tory, says, “Buildings can typically save 15 to 20 percent of total cooling energy if they have a light-colored roof.”

Lighting. A decade or two ago, it was not uncommon to see lighting power densities of two to four watts per square foot. Connected lighting loads in new construction have now dropped to 0.5 to 1.5 watts per square foot, thanks to electronically ballasted T8 and T5 fluorescent systems, an ever-expanding array of compact fluorescent lamps and fixtures, and the decline in overall illumination levels that has accompanied the arrival of computer-based work.

Nearly all the heat generated by lights and other internal loads must be removed by the building’s cooling system. Introducing daylighting reduces operating loads, but not the connected load (the building must be operable at night). Few engineers are willing to discount the connected load in their cooling calculations.

Defining a low target for lighting power density—and making sure the engineer uses that value for cooling-load calculations—will make a significant dent in cooling tonnage. “When we tell the mechanical engineer that our lighting load will be one watt per square foot, they often don’t believe us,” says Nancy Clanton of Clanton Engineering, a lighting design firm in Boulder, Colorado. “There’s a fear and trust issue at work here. If there’s not enough cooling, the mechanical engineer is the first to take the blame. Why should they take a chance on what we tell them? So they go back to their computer and enter two or three watts. We see it all the time."

Many states now specify maximum lighting power density via the ASHRAE/IES Standard 90.1, Energy-Efficient Design of New Non-Residential Buildings. Some states, including Oregon and California, have their own more stringent requirements. Lighting consultants can also work with the engineer to reduce the lighting load.

Plug load. A certain mystery surrounds the power density estimates engineers use for plug-in devices, such as computers and copiers. Conventional wisdom holds that as the workplace becomes more computerized, plug loads increase dramatically. But many plug-in devices now use less power than ever—inkjet printers use a 20th of the power of laser printers, for example. Most engineers settle on an estimate between two and five watts per square foot, just to be safe.

Unfortunately, a "safe" estimate means oversizing the cooling plant. In an eye-opening analysis, building scientist Paul Komor, writing in the ASHRAE Journal, researched actual plug-load measurements. He found that they rarely exceed one watt per square foot. That's because all the electronic equipment in a building is seldom in full use. Shrinking computer storage media and an increasing reliance on laptop computers also reduce plug load density.

People. Population density inside a building affects the design cooling load; each person puts out about as much heat as a 150-watt light bulb. Typical design densities range from 100 to 250 square feet per person, though this depends on the use of the space. In real life, the diversity of work ensures that there are fewer occupants than expected.

Since engineers size for the highest expected density, it's worth checking the estimate to make sure it's reasonable. It should include the number people who will actually be in the space, as opposed to the maximum allowed by the fire code or the capacity of the parking lot.

Thermal mass. Concrete slabs, stone walls or floors, and other massive building elements, when they exchange heat with the ventilation system or the building's exterior, can buffer peak loads and take advantage of cool night temperatures or warm afternoons. Coupling greater floor mass with night ventilation (which allows cool air into the building when external temperatures drop to a certain level) allowed Ove Arup & Partners in San Francisco to reduce the size of the chiller in an office building by 25 percent. “We always try to use a passive design approach when the owner is interested in environmental issues,” says mechanical engineer Sarah Nicholson.

Insulation. Although the insulating value of a building’s walls might seem to be a big factor in determining heat gain, it doesn’t matter much for most commercial buildings. That’s because cooling load is dominated by internal loads and solar gain. Also, there isn’t much temperature difference between a 75-degree space and the 95-degree out-doors. Insulation does, however, have an impact on winter heating load. Then temperature differentials between indoor and outdoor air can easily reach 60 or 70 degrees. A typical wall section providing R-19 per- formance is good enough for most applications. Roof insulation is crucial, since the sun beats on the roof all day. For large single-story buildings in southern climates, heat transfer through the roof can amount to as much as 30 percent of total cooling load, and higher insulation values are warranted.

Engineers as friends
Aside from making better design decisions, architects can work with engineers to avoid oversized HVAC systems by expressing interest in the central plant design. If the engineer knows that the architect and the owner want a realistic system, instead of one that guarantees the absolute comfort of occupants, everyone can work together more responsibly. “Let the engineer know that oversizing is not acceptable,” Clanton says.

Architects can help by providing accurate occupancy and plug load estimates. Postoccupancy measurements of previous buildings provide some real-life examples. Willingness to work with the engineer, to approach the liaison as a way to solve problems and save money, will mean a better, more comfortable building and a happier owner. ■

Questions:

CLICK HERE FOR ANSWERS

1. *What are the two factors that are used to establish a building’s cooling load?*

2. *Why is the cooling load a larger problem than the heating load in designing energy-efficient mechanical systems?*

3. *What is energy modeling?*

4. *How could you reduce the thermal load on a building?*

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