Saving Commercial HVAC Energy By The Ton

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Techniques exist to reduce drastically the energy requirements of commercial HVAC systems. Typical commercial buildings have space cooling and ventilation energy intensities on the order of 2-4 kW-h/ft^2-y, cooling loads of 100-400 ft^2/ton, and total system efficiencies of 1.2 kW/ton or greater (COP$\leq$3), resulting in capital costs of 6-12 \$/ft^2 for mechanical equipment.

Through a combination of load reduction, passive and alternative cooling, improved controls, and efficient mechanical equipment, the energy intensity of space cooling in new construction can be cost-effectively lowered to less than 1 kW-h/ft^2-y, cooling intensity improved to 800 ft^2/ton, and system efficiency improved to 0.7 kW/ton. By downsizing mechanical equipment, capital costs can be reduced to less than \$4/ft^2 as well. Opportunities for retrofits to existing buildings also exist.

To achieve these savings, off-the-shelf components and proven technologies are combined in a synergistic manner. Load reduction techniques include advanced glazings and efficient lighting and office equipment; passive techniques include evaporative and desiccant cooling; and efficient mechanical equipment includes larger heat exchangers, lower condenser head pressures, parasitic loss reductions, cold air distribution, displacement ventilation, and high-efficiency axial fans.

This paper is an overview of a forthcoming Competitek report (The State of the Art: Space Cooling and Air Handling) which describes these technologies in detail and how they can interact to yield significantly lower operating and capital costs for space cooling systems.

Introduction

Space cooling and air handling uses nearly half of the electricity in the U.S. commercial sector and contributes disproportionately to summer peak load. Utility response to this important component of load growth has been focused on encouraging peak shifting through thermal energy storage. However, large opportunities for both kW (peak power) and kW-h (energy) savings exist in the systematic examination of mechanical systems for efficiency improvements.

With capital cost reductions from HVAC downsizing (due to reduced loads), increased rentable space (from smaller and quieter equipment), and additional benefits such as the potential for circulating chilled water in fire-protection sprinkler piping and reducing duct sizing by using low-temperature air, the cost-effectiveness of these measures becomes very attractive.

While the technical potential is large, many obstacles block the road to HVAC efficiency. The typical design process minimizes first cost, tries to avoid tenant complaints by providing overwhelming cooling capacity, shuns technical innovation in favor of familiar methods, and minimizes system design time through a "cookbook" approach that lends itself more to baking a cake than dealing with the complexities of conditioning a modern building for human habitation. "Optimized" or "efficient" HVAC systems are frequently claimed but seldom delivered.

It is important to consider the interconnections in building systems when seeking an efficient HVAC design. Structural layout, surface treatments, lighting loads, and occupancy patterns all affect HVAC systems typically designed by a mechanical subcontractor with little or no influence on these factors. To take full advantage of the HVAC efficiency potential, an integrated approach is necessary that creates both the incentive and capability for building-wide improvements and innovative design. For example, money saved by installing fewer light fixtures could be used to help pay for a more efficient central chiller plant in lieu of cheap rooftop package units. Performance contracting based on measured energy consumption is one way to encourage efficient systems. Creating such a design environment is a significant task in itself; in this paper we turn our attention to the most important technical areas for HVAC system efficiency improvements.

Load Reduction

Whether a new building is being designed or a retrofit is being contemplated, an efficient HVAC system begins with reduction of the loads imposed upon it. It is critically important that the mechanical equipment be selected to deal with the reduced load, in new systems by downsizing the chillers and air handlers and in retrofits by installing appropriate controls, then downsizing on later replacement. If this step is neglected, the result of load reduction will be overcooling of the space and little or no HVAC energy savings. In particular, chillers and fans should unload through adjustable-speed-drive (ASD) -equipped motors, with reliable sensors and controls.

A combination of load reduction measures described below can reduce the total cooling load on a typical commercial building by at least 50%, in both total cooling energy and peak equipment sizing.

Lighting

Reduced lighting power density is the most convenient and cheap opportunity for energy savings in the commercial sector, and is already widely exploited through utility DSM programs. In most situations, 95% or more of lighting energy turns into interior heat which must be removed by chillers. Typical designs call for 2-3 W/ft^2; the use of T-8 and other triphosphor lamps, electronic ballasts, efficient reflectors and diffusers, and occupancy and daylight controls can easily drop this to far less than 1 W/ft^2. Research by an independent organization describes how to cost-effectively save 92% of the lighting energy used in the fluorescent systems that dominate commercial office space while delivering the same illuminance with greatly improved quality (Lovins et al. 1988).

Appliances

The fastest-growing portion of commercial building electricity demand is information equipment--computers, fax machines, printers, scanners, and copiers. In 1980, commercial buildings were wired for plug load densities of 5W/ft^2; the current figure has doubled to 10W/ft^2, and some computer-intensive spaces range as high as 20 W/ft^2. The use of low-power office equipment such as cold-fusing or fuser-controlled copiers, notebook computers, and inkjet printers can dramatically lower plug load--from 62% to as much as 91% reductions (Shepard et al. 1990).

Shell

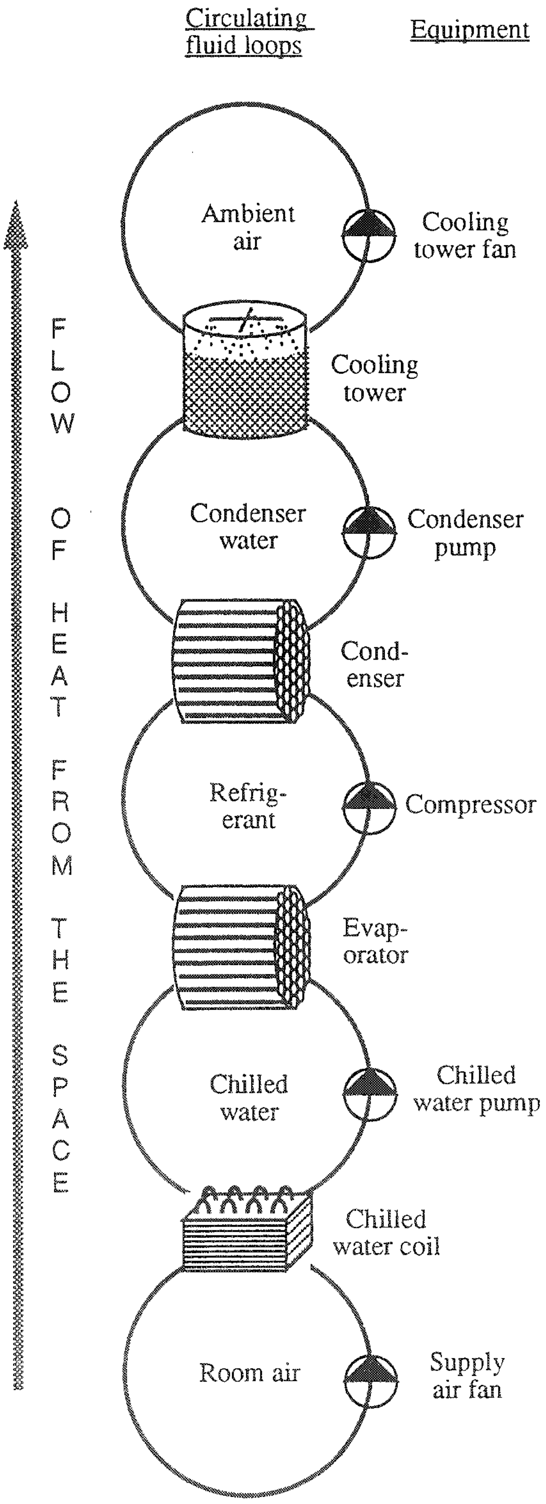
The most attractive means of external gain reduction is through the use of glazings that provide a high shading coefficient (solar gain reduction) and high visible transmission by separately controlling visible and infrared transmittance with high flexibility. Tinted glass and clear glass provide each of these properties individually, but spectrally-selective glazings with low-emissivity coatings or Heat Mirror™ suspended films (or both) can do both, with lower cost and greater reliability than mechanical shading systems. Useful--though less effective--gain control films are also available to retrofit existing windows. Since external heat moves cooling loads across a building's perimeter throughout the day, avoiding these gains has the additional benefit of simplifying zoning requirements, and can also greatly improve perimeter radiant comfort--even enough to eliminate perimeter heating.

Other external gain reduction strategies include: optimizing building shape and orientation, planting local vegetation, using light-colored surface treatments for the building and non-reflective surfaces for the surrounding areas, roof wetting, reducing infiltration, and increasing insulation.

Efficient Mechanical Equipment

Conventional mechanical cooling can be visualized as a series of five loops as shown in Figure 1. Fans circulate supply air through coils of chilled water, which is in turn cooled by evaporating refrigerant. The refrigerant is compressed in the main chiller loop, giving off its heat to circulating condenser water. The warm condenser water is pumped to a cooling tower where it rejects its heat to fan-forced ambient air. The most efficient system minimizes the parasitic power requirements for each loop.

Cheaper systems avoid some of these loops. For example, direct expansion evaporators skip the chilled water loop, and cool circulating air directly from the evaporating refrigerant. However, if air-cooled condensers are substituted for water-cooled, reduced capital and maintenance costs are traded off for significantly higher energy consumption, because air absorbs heat less well than water.



Strategies

Improve tower fan efficiency, control with ASD

Enlarge tower air passages for reduced air flow resistance

Increase tower fill surface area for more effective heat and mass transfer (and closer approach temperature)

Improve pump sizing, efficiency, control

Enlarge pipes for lower friction

Ozonate condenser water to avoid scaling and biological contamination

Increase condenser surface area for more effective heat transfer (and closer approach temperature)

Improve compressor sizing, efficiency, control

Enlarge internal refrigerant ducts for lower friction

Increase evaporator surface area for more effective heat transfer (and closer approach temperature)

Improve pump sizing, efficiency, control

Enlarge pipes for lower friction

Increase cooling coil surface area for more effective heat transfer (and closer approach temperature)

Widen coil for lower air face velocity

Improve fan efficiency, control

Enlarge ducts for lower friction

Improve temperature and humidity control in space, supply sufficient air motion, fresh air, and filtration

Figure 1. Strategies for Reducing Energy Consumption of Mechanical Cooling Equipment

Air handling systems represent the largest target for parasitic power reduction, as shown in Figure 2 (taken from measured performance of a large building retrofit). Typical field efficiencies of air handling units range from 20% to 50%, and the duct systems they push air through impose a stifling 3-4 "wg (750-1000 Pa) of static pressure, sometimes resulting in fans that consume more energy than their neighboring chiller compressors. Leaky ducts, dirty filters, stuck dampers, and poor or absent controls add to the losses. However, careful fan selection and installation allows 75-85% fan efficiency, and duct static pressure can be reduced to under 1.5 "wg (375 Pa) through improved aerodynamics, reduced dampering, and lower airspeeds. Especially important is a design approach based on low face velocity of air over the cooling coils and high coolant velocity through the coils. Similar savings come from applying these techniques to reducing cooling tower fan and chilled and condenser water pumping energy costs.

As can be seen from Figure 2, the energy required to deliver a given amount of cooling can be halved with more efficient mechanical system design.

Controls

Like most other HVAC technologies, control systems can have both positive and negative effects on system efficiency. Strategies such as optimal chiller start/stop, scheduling, chilled water temperature reset, and chiller lockout can save large amounts of energy. Unfortunately, reliance on a computer to drive a building's systems can

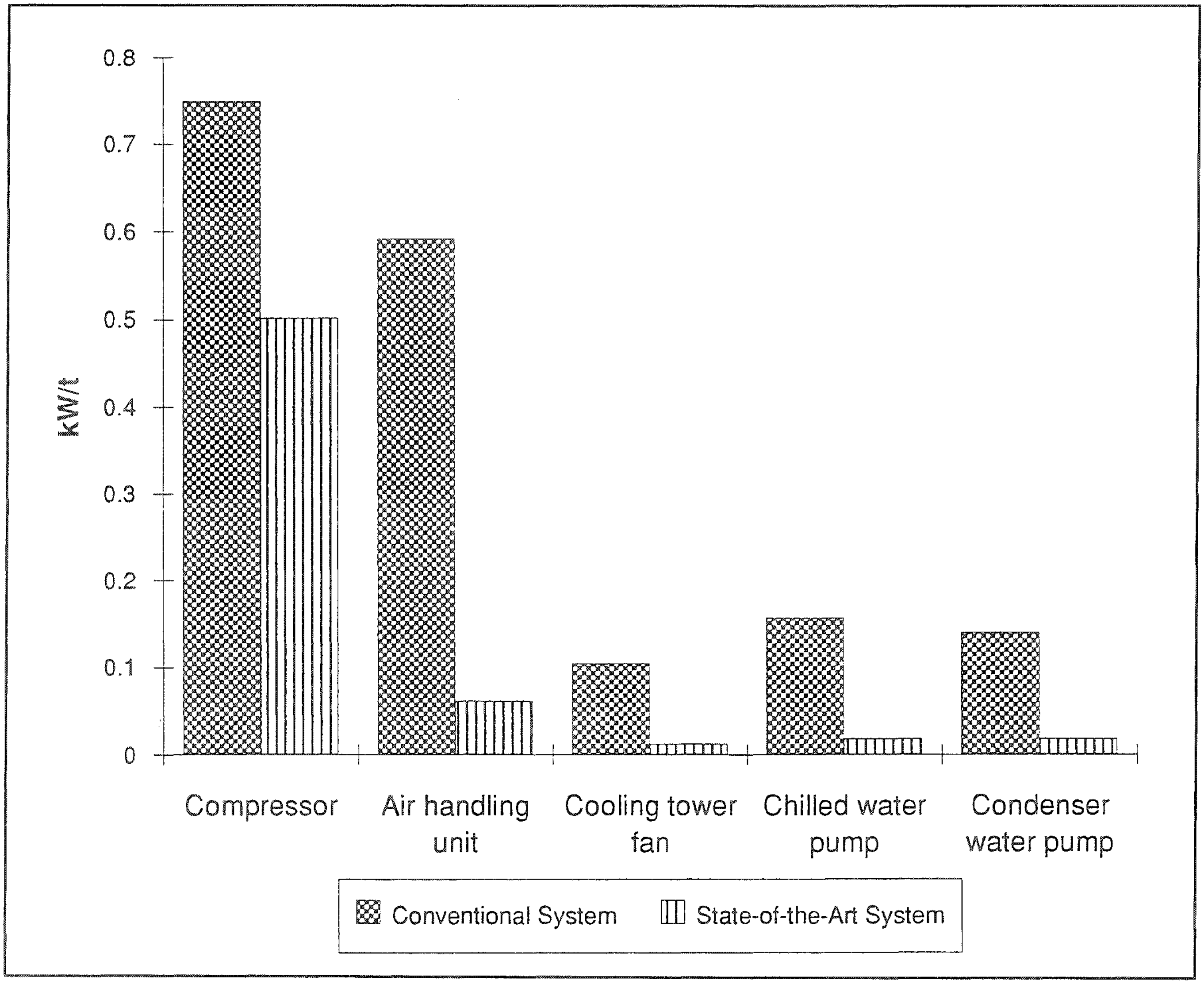


Figure 2. Distribution of Energy Use, by Component, Per Ton of Cooling

also result in energy waste, as when a malfunctioning sensor or thermostat calls for simultaneous heating and cooling, maintenance staff overrides the control system for night comfort, or myriad other problems go unnoticed, unrecognized or misaddressed. Still, intelligently applied HVAC system controls can deliver at least 20-30% energy savings compared to standard building practice.

Passive and Alternative Cooling Methods

There are a number of methods of cost-effectively reducing the load on mechanical cooling systems. Some are only applicable during certain times of year (when ambient temperatures are low enough, for example), though others are effective year-round.

Economizer

An "air-side economizer" directs a flow of outside (cool) air into the building when it can provide useful cooling, commonly done where outside air is often cool or dry enough. In San Francisco, for example, an air-side economizer can provide up to 77% of total cooling energy (Usibelli et al. 1985).

When for some reason air side economizers cannot be used, "water-side economizers" are an appropriate alternative. These use the evaporative cooling generated by the cooling tower (part of a normal mechanical cooling system) to cool the building directly, either by circulating evaporatively cooled tower water directly through the building's chilled water circuit, or via a heat exchanger.

Absorption

Absorption cooling is a well established technology which uses heat to regenerate an absorbent that produces a cooling effect. Absorption provides mechanical cooling without chlorofluorocarbons, and effectively substitutes a natural gas (or other heat source) -driven regenerator for an electrically driven compressor. The cost-effectiveness of this technique depends on the relative costs of electricity and heat. Combining absorption and vapor compression cooling (in two paralleled, half-sized units) can often offer the lowest-cost method of providing mechanical cooling (Duffy, 1990).

Evaporative

Evaporative cooling is a technique which uses water sprays or wetted media to cool supply air either directly or indirectly, allowing temperatures to approach the wetbulb temperature of the ambient air. This well-established technology can totally supplant conventional mechanical chilling in climates where the air is consistently dry, or supplement conventional chilling during periods of occasional dryness. The temperature reduction available from evaporative cooling is much greater with drier incoming air.

Direct evaporative cooling humidifies the airstream as it is reduced in temperature. Indirect evaporative cooling via an intermediate air-to-air heat exchanger adds no humidity, but is less effective and costs more. Both methods consume water for evaporation and electric power for fans, but the electrical consumption for either type of evaporative cooling is about 75% lower than for conventional mechanical cooling (Watt, 1986).

Desiccant

Desiccant drying is widely used in industrial applications, though less so in commercial. It is effectively evaporative cooling in reverse, where the airstreams are reduced in humidity but increased in temperature. (A source of heat energy is needed to regenerate the desiccant after it has absorbed water from the air.) The dried airstreams then can be easily cooled by heat exchange with ambient air, then evaporatively cooled to much lower temperatures than they began at.

The addition of desiccant drying as a first stage makes evaporative cooling much more widely applicable and effective. This technology, among others, may allow the total phase-out of CFC-driven cooling worldwide (Meckler, 1991).

Passive

A number of cooling techniques that work in concert with the natural environment--passive ventilation, ice ponds, nighttime water sprays, earth berming, and the use of shading and thermal mass--have been known for centuries. Although these techniques are most commonly applied to smaller, residential structures, they can also be used with larger buildings. Passive cooling is more an architectural art than an engineering science, but should be considered wherever low-energy cooling is the goal.

Conclusion

A combination of load reduction (both internal and external), more efficient mechanical cooling (with parasitic power reduction), appropriate supplemental alternative cooling, and improved controls can provide up to 90% energy savings, as shown in Table 1.

Table 1. Sources of 90% HVAC Energy Savings

	Cooling Load Reduction	Precooling & Economizers	Improved Controls	Improved Equipment
Individual savings:	50%	50%	20%	50%
Cumulative savings:	50%	75%	80%	90%

An example of these techniques in practice is a commercial building retrofit demonstration project sponsored by a large electric utility, which shows a cost-effective 93% reduction in design HVAC energy use.

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