The large variation in occupancy conditions typical for library and museum facilities requires designers to establish a means of providing real-time occupancy data to the control system.

Library and Museum HVAC: New Technologies/New Opportunities — PART 1

How new technologies can dramatically improve performance and economy of part-load operation in continuously operating systems

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Nowhere are new HVAC technologies more dramatically showcased for their practical application than in buildings such as museums and libraries. These buildings require continuous operation and precise control under widely varying loads for visitors and contents alike, and providing these improvements with economy is the ideal calling for recently introduced HVAC technologies. Today, the knowledgeable designer can develop facilities with performance features far better than ever before while working within limited first and operating cost budget constraints.

In Part 1 of this article, I will discuss how new technologies in such buildings can significantly improve part-load operation. The energy, maintenance, and control performance offered by these new technologies make them very attractive not only for new building construction but as retrofit opportunities as well.

Continuous HVAC operation

One of the most important but least recognized characteristics of HVAC design is the long hours most buildings operate at low-load conditions. Low-load operation is further increased in archival buildings where uninterrupted control of conditions, essential to the preservation of the materials they contain, requires some form of continuous HVAC system operation. Our industry's failure to capitalize fully on the benefits of new technologies has led operators of such facilities to believe that energy costs will be significantly higher because of the long hours of operation. It has been demonstrated in certain cases that the opposite is true. Integrated control and variable-speed technologies, properly applied, can actually reduce energy use when systems are kept running!

To see how this can be true, let's first be certain we understand the energy implications of part-load operation. According to fan and centrifugal pump laws:

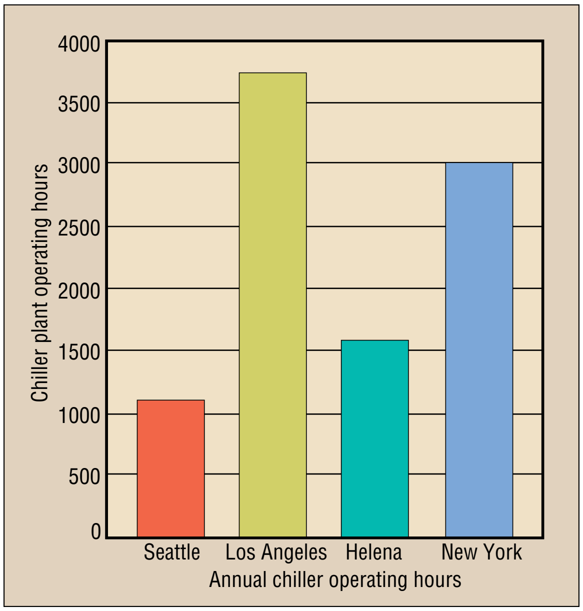
▼ Fluid flow quantity varies directly with speed of fan or pump.

▼ Static pressure delivered varies as the square of the speed.

▼ Power required varies with the cube of the speed.

These laws apply to axial and centrifugal fans as well as centrifugal pumps. They dictate that reducing fan or pump speed reduces flow in proportion to the speed but reduces power required by the cube of the speed reduction. This means that it is theoretically possible to provide 50 percent flow (or capacity) for 13 percent (0.5^3) of the full capacity power, an efficiency increase of almost 400 percent. Theoretically, power for 25 percent of the flow requires about 2 percent of full capacity power, an efficiency increase of over 1000 percent!

The importance of these high part-load operating efficiencies is illustrated in Figs. 1 and 2, which depict simulated chiller load profiles for a continuously operating building in four U.S. cities. Note that despite the wide variations in chiller plant operating hours as depicted in Fig. 1, the chiller plant load profiles for cities as shown in Fig. 2 are very similar and most certainly skewed toward low-load conditions. Note also that these profiles are based on a perfectly sized chiller plant. In practice, designers tend to oversize chiller plant elements, resulting in profiles even more skewed toward part loads.



1 24-hr building chiller operation.

A designer working with traditional technologies might develop an indirect evaporative cooling circuit to maximize chiller plant energy efficiency at all the various load conditions. This configuration uses tower water directly for cooling during low-load, low outside ambient conditions. The design might also employ multiple chillers of various sizes to permit combinations of chillers operating at maximum efficiencies (usually near peak load) to meet the various intermediate-load conditions. The result could be a complicated mechanical room and even more complicated operating sequence that is costly to install and difficult to support.

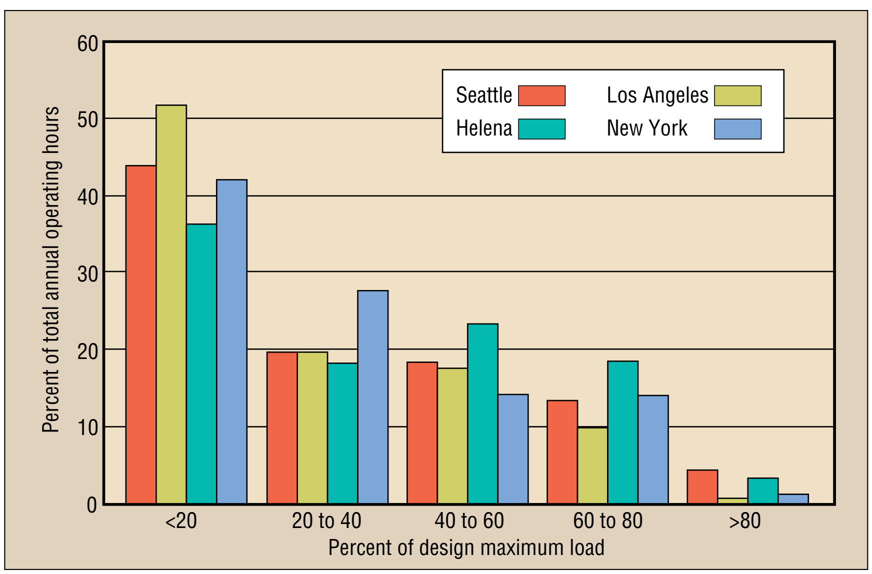
Part-load operation

If we consider all the energy consuming components employed to provide cooling in typical buildings, we find that all of them, the fans, pumps, and centrifugal chillers, are subject to the basic fan and pump laws. While we know that delivery efficiencies, the variance of system loads and outdoor conditions, and other factors make it unrealistic to achieve theoretical part-load operating efficiencies, we should expect to develop cooling systems that can operate much more efficiently at part-load conditions than at relatively infrequent peak conditions.

Designers often believe the solution to saving cooling plant energy at part-load conditions is simply to employ a variable-flow cooling distribution system with variable-speed drives operating distribution pumps. Unfortunately, present designs of these systems fail to optimize the energy reduction potential of such systems. For example, consider the chilled water distribution circuit in Fig. 3. In this widely employed design, the variable-speed distribution pump is controlled to maintain a fixed differential pressure set point. The location of the differential pressure sensor is usually at the end of the piping run. A controller operates each of the load control valves. Even though such systems are likely to be connected together in a DDC system network, the operation of each controller is almost always entirely independent of all others as shown in the figure.

In Fig. 3, each individual control valve is typically sized for a substantial portion of the total system pressure drop at full load (usually 30 to 40 percent). The differential pressure set point is the sum of the full-flow valve and load pressure drop, which is in the range of 75 percent of the total full-load pump head, the remainder being the full-flow distribution piping pressure drop.

The system operating curve for a system of this design is shown as the bold line in Fig. 4. Fig. 4 assumes the design full-flow head is 100 ft at 1000 gpm, and the differ-

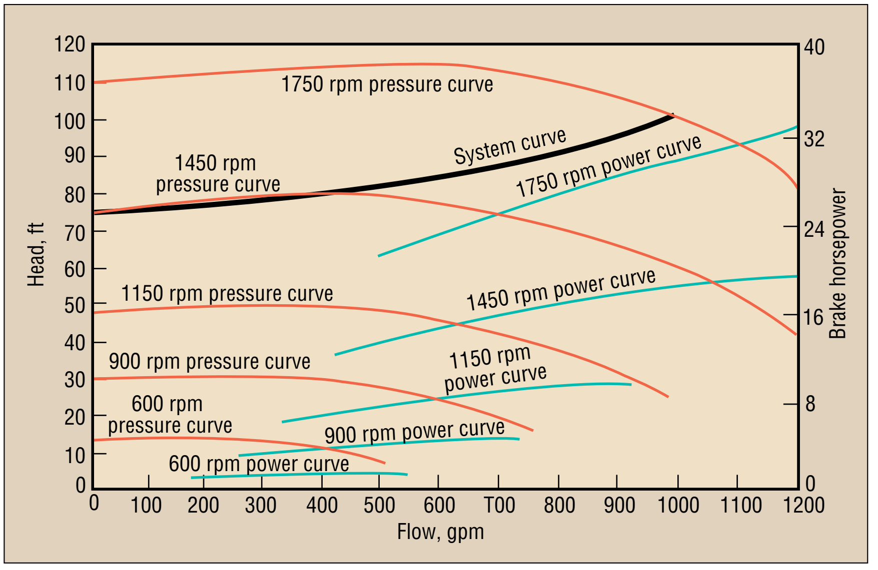


2 24-hr building chiller operation based on percentage of operating hours at various loads.

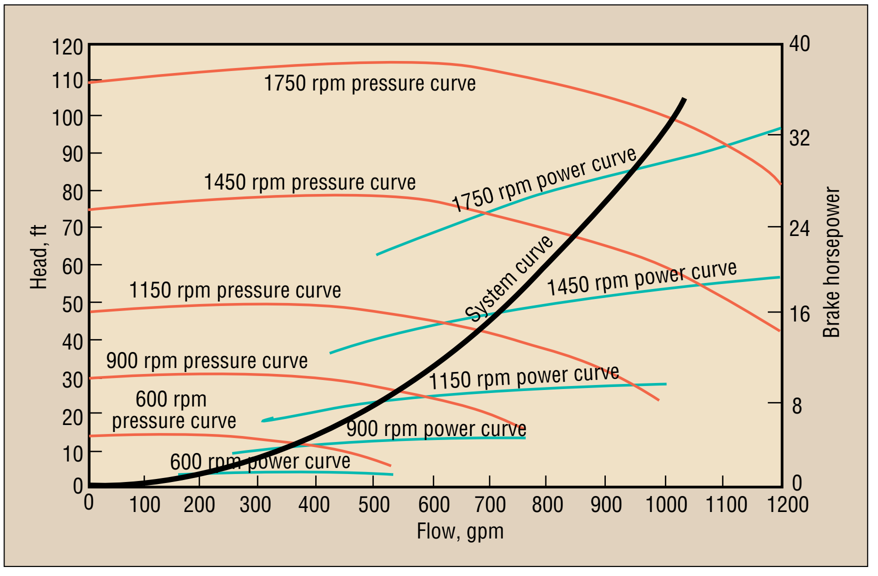
ential set point for the distribution pump controller is 75 ft. The Y axis intercept is the differential head set point because even at zero flow the pump must operate to maintain that pressure. Let's see how this design performs at various load conditions.

At full-load the power curve shows that the pump will draw about 33 hp. As flow is reduced to 50 percent, the pump speed is reduced to slightly more than 1450 rpm, and the pump draws about 14 hp. As flow drops further to about one-third, the pump speed remains approximately constant, and the power drops to approximately 11 hp. Further reductions see little further reduction in power.

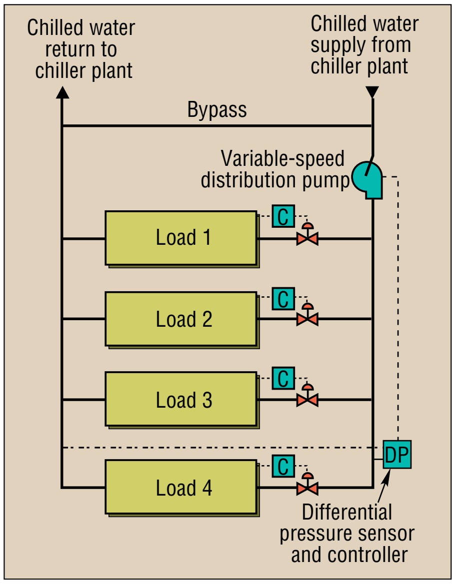
Although a reduction from 33 to 11 hp may seem to be substantial,



4 Operating curve for system shown in Fig. 3 assumes design full-flow head of 100 ft at 1000 gpm with the differential set point for the distribution pump at 75 ft.



5 Operating curve for a system design that permits the pressure differential across the valves and loads to fall as flow requirements are reduced, producing dramatic increases in pumping efficiency.



3 Schematic of typical variable-flow chilled water distribution system.

it is actually a stark display of the failure of this design. The operating efficiency (flow per hp) of the system remains almost constant despite the part-load conditions; one-third of the design flow requires exactly one-third of the design power. At lower flow requirements, the efficiency begins to decrease further.

Better part-load efficiency

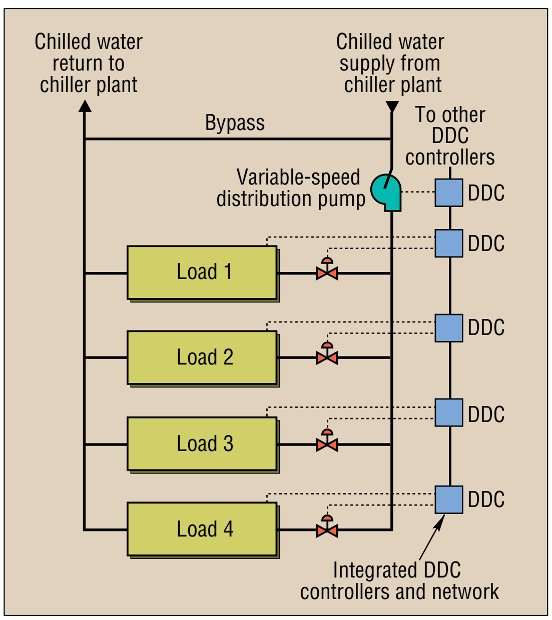
The challenge for designers today is to design systems that can better exploit the benefits of new variable-speed and control technologies. Because HVAC systems, especially for continuously operating public buildings such as museums and libraries, spend long hours at part-load conditions and because new technologies enable such enormous improvements in part-load efficiency, the industry's current focus on full-load performance criteria is missing the mark entirely. Instead, designers must come to view full-load operation as primarily a sizing issue. It is essential that each design adequately address full-load conditions. But let's be clear that at present, operating costs under these infrequent conditions are only a very minor portion of annual operating costs.

The failure of the widely employed variable-flow distribution schematic of Fig. 3 is that it does not attempt to mitigate problems associated with the second power relationship between pump head and speed. Because of pressure set point constraints, the pump in this example cannot operate at less than 1450 rpm. This severely limits power reduction as flow requirements are reduced. Now imagine a

The wide open areas typical in libraries and museums require special attention to ensure that suitable conditions can be maintained throughout the wide variations of indoor and outdoor loads and conditions they will experience.

design that permits the pressure differential across the valves and loads to fall as flow requirements are reduced. Such a system curve may look more like the one in Fig. 5. Note in Fig. 5 that as the flow requirement falls to one-third, the pump power drops to less than 2 hp, a nearly 600 percent increase in the pumping efficiency compared to full-flow conditions.

The question posed by Fig. 5 is how to accomplish such part-load efficiencies. Some answers are shown in Fig. 6. In Fig. 6, the control of the variable-speed distribution pump is accomplished by transmitting the conditions at each of the loads served to the pump controller rather than employing a differential pressure sensor as in the Fig. 3 schematic. Also, the load control valves would typically be line sized without a substantial pressure drop.



6 Schematic of variable-flow chilled water distribution system designed to maximize part-load energy savings.

As the cooling load requirements at each of the zones fall, the corresponding valve begins to close. If none of the valves are fully open and the loads are satisfied, the distribution pump slowly reduces its speed. If one or more valves is fully open and its load is not satisfied, the distribution pump gradually speeds up. Such a simple, network-based control scheme is very effective in substantially improving part-load efficiencies of a chilled water distribution system if the load profiles for the loads served (Loads 1 to 4 in this example) are similar.

Note that the control configuration in Fig. 6 is actually simpler than that of Fig. 3 since it employs no differential pressure sensor. Note also that the basic design philosophy employed in Fig. 6 can be extended to other components of a building cooling system, particularly the supply air fans and air distribution system. Operating an HVAC system suitably configured with these components continuously at low loads with corresponding high delivery efficiencies may use less energy than shutting them off and forcing them to start each day at high loads (to bring the building back under control) and correspondingly low operating efficiency.

Part-load design emphasis

Because HVAC design emphasis has not traditionally been placed on part-load operating characteristics, the fan, hydronic, and cooling systems in a great many buildings operate at lower efficiencies at part-load conditions than at full load. For buildings that must operate continuously, this is an especially enticing design opportunity because the opportunities for energy reduction are enormous. It is not too difficult to see how implementing or upgrading HVAC systems that operate at high part-load efficiencies can offer vastly improved performance and reduced energy costs.

A final note on part-load design emphasis regards assessing the level of occupancy to provide adequate ventilation air. For buildings that may experience substantial variations in occupants or visitors, and museums and libraries fit this category, it is an absolute requirement that building occupancy levels be determined continuously from real-time information. Virtually all museums have some mechanism for tracking visitors; often it is a turnstile count. Nowadays such data can be directed with relative ease to the HVAC control system.

Because the occupant density in libraries is usually low, occupancy sensors can be located throughout and connected to the HVAC control system to operate the lights as well as HVAC terminal units. Information from the occupancy sensors may then be suitable to assess occupancy of the building for a determination of the outside air requirement at all times. Whatever mechanism is employed, it is essential both for providing good environmental control and economy that the HVAC system design incorporate a means to assess real-time occupancy conditions accurately. This information is used by the control system to establish and maintain ventilation air flow set points as required throughout the facility.

Next month I will continue my discussion on library and museum facilities focusing on humidity, dehumidification, and building pressure control. HPAC