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Relational

Network-enabled approaches to improving the efficiency and effectiveness of HVAC operation

Despite numerous technological advances, digital building controls are woefully underutilized. Why? Because the fundamental control methodologies they most often are configured to apply are little changed from the early 1900s, the time automatic building controls were introduced. As a result, the control applied in many building comfort systems consists primarily of a large number of independent, stand-alone control loops. As building systems become more integrated and complex, the continued use of this control threatens to severely undermine performance, precision, stability, efficiency, and reliability.

Rising energy costs and a widening gap between electricity-generation capacity and electricity demand are driving interest in the networking capabilities of modern control systems. Taking advantage of these capabilities and creating tremendous synergies between equipment and operational requirements is a series of new control methodologies termed "relational"[1] because they optimize the operation of HVAC-system components in "relation" to one another.

This article will examine the broad concept of relational control, focusing on its potential benefits and long-range prospects.

CURRENT CONTROL METHODOLOGIES

For about as long as building controls have been around, the control model shown in Figure 1 has been employed in one form or another in HVAC-system applications to adjust capacity or flow by modulating valves, dampers, vanes, motor speed, and other devices and variables. Once a very simple analog device, the "controller" module has grown in sophistication over the last several decades. Today, this PID (proportional, integral, derivative) controller is extremely flexible, incorporating variable-gain and even self-tuning

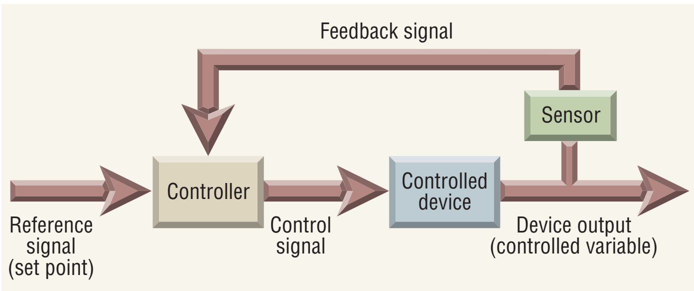
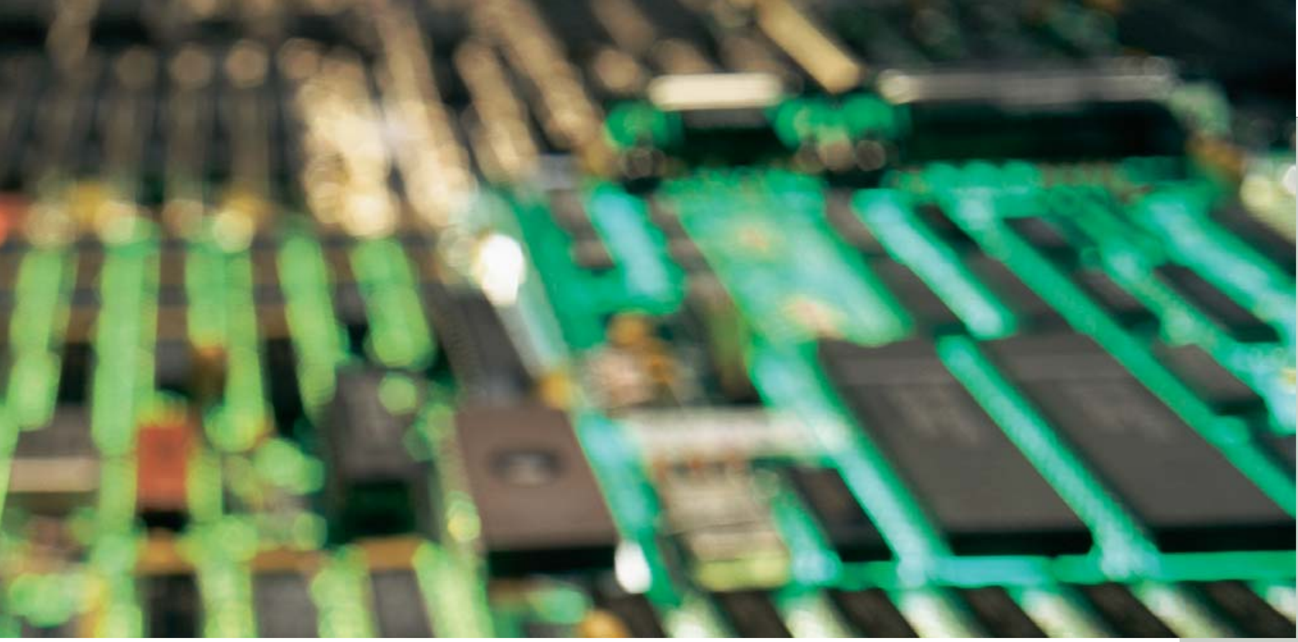


FIGURE 1. "Closed-loop" control.



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capabilities, which ensure device output remains at or near the reference signal (set point) under widely varying conditions. Unfortunately, for modern HVAC applications, the control architecture is fundamentally flawed, most significantly in terms of:

• *Applications-level control.* Figure 1 depicts "closed-loop" control. "Closed loop" means the feedback signal links the controller and controlled variable so that the output signal to the controlled device is adjusted automatically to maintain the desired reference signal (set point) as conditions change. In the very simple comfort-conditioning systems employed a century ago, closed-loop control could be provided at the applications level easily. For example, by modulating a steam valve to a simple heating device, with a space-temperature sensor providing feedback to the controller, a space-temperature set point could be maintained under a wide range of load conditions.

In today's typical HVAC system, closed-loop control at the applications level is not so easily achieved. For example, in a variable-air-volume (VAV) system, if spaces are not being satisfied, there normally is no feedback to drive down supply-air temperature. This open-loop characteristic significantly limits the performance of today's more complex HVAC systems.

• *Control coordination.* Today's VAV-system controls employ two major control loops: one for supply-air temperature and another for duct static pressure. For optimum efficiency and comfort, changes in airflow and temperature in response to changes in a VAV system's cooling requirements need to be coordinated. Most VAV systems, however, lack the control mechanism necessary to coordinate the temperature and flow of supply air in response to changes in load. Likewise, VAV-box data seldom are employed effectively enough for the air system to be adjusted optimally as cooling load changes.

RELATIONAL CONTROL FOR SYSTEMS SERVING MULTIPLE PROCESSES

Consider a chilled-water distribution pumping system. If the system were to be controlled traditionally, a pressure sensor would be incorporated across the supply and return headers at the end of the distribution loop, the idea being that as long as differential pressure between the headers is adequate, every load in the circuit will have sufficient pressure to deliver design flow and, therefore, meet design load conditions. For simple distribution configurations, this strategy works. In many configurations, however, branches from mains have adjacent loads that can experience high concurrent loading, meaning local areas may experience low differential pressure and flow starvation under certain conditions—even when the design pressure is maintained at the sensor location. At least as problematic is the fact this method of control results in poor pumping efficiency at part-load conditions, which constitute nearly all of a typical pumping system's operating time.

Relational-control techniques replace this pressure-based control with more-direct flow-based control. The network collects data on the condition of each load served, which can be condensed easily for much-more-efficient pumping-system operation at all load conditions. Because each load is checked continuously, proper servicing can be ensured. Such a method of control is shown in Figure 2. Here, pump speed is calculated at timed intervals based on valve-position (and load) data retrieved from the local load controllers (ASC [application-specific controller] 1 through ASC 5). This multi-input method of control can be much more stable than conventional PID control because it does not involve continual readjustment based on a set point and error signals. Methods of self-correcting control, which make adjustments at loads, rather than at plants, have been developed.[2,3,4] These result in smoother, more stable control.

At the applications level, the type of relational control depicted in Figure 2 is closed loop because of the direct link between multiple processes (cooling loads) and a single controlled resource (a chilled-water distribution pump). To a limited extent, this link can be made with conventional PID controllers by using valve-position feedback from all of the loads to "reset" the distribution-pressure set point. Because the controlled variable (pressure) is non-linear with respect to the controlled output, however, such an approach often becomes unstable under certain circumstances. Not only must gains change as set point and load conditions change, the accuracy of pressure readings at low-flow conditions often is a problem.

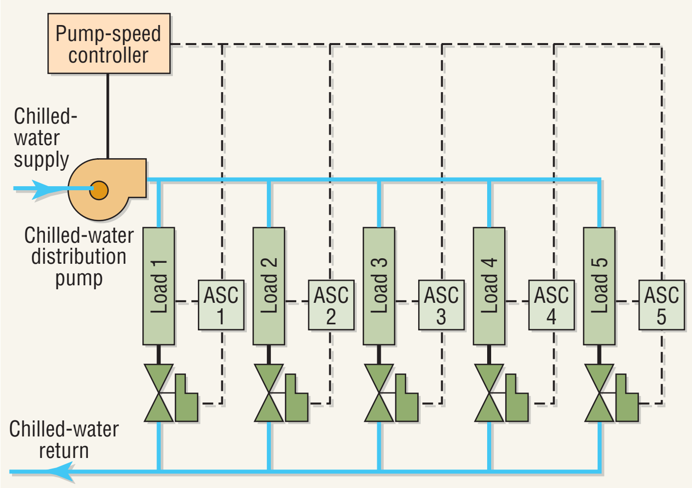

FIGURE 2. Closed-loop relational control.

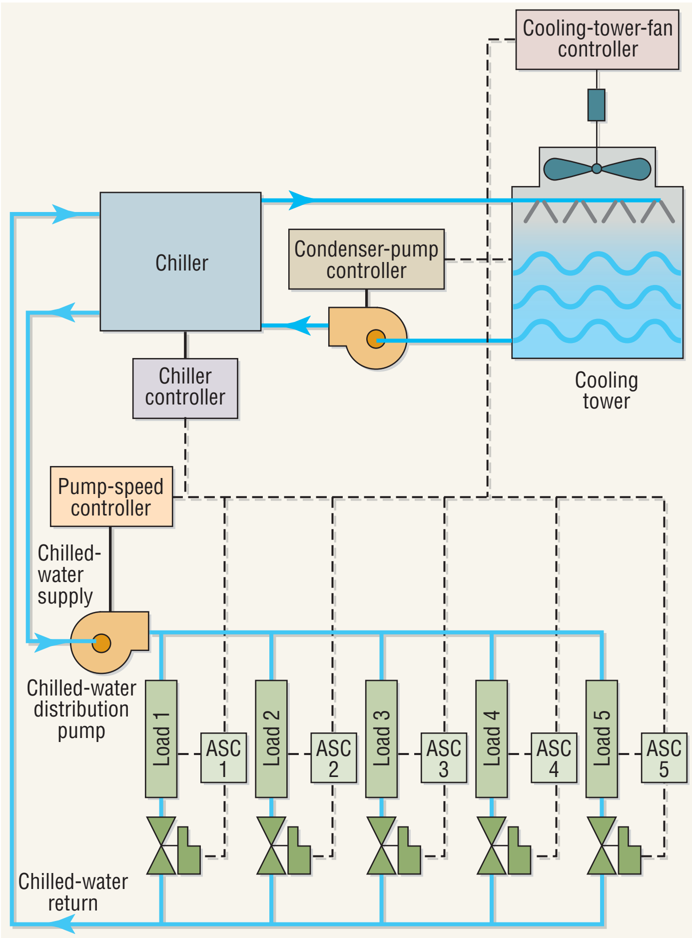

FIGURE 3. Closed-loop relational control.

RELATIONAL CONTROL FOR SYSTEMS WITH MULTIPLE COMPONENTS

Many HVAC systems today employ multiple components to provide desired output. Consider the system in Figure 2. While the chilled-water distribution pump appears to be the only element required to provide chilled water, we know that is not the case. Figure 3 is a more realistic diagram of the system.

According to the Equal Marginal Performance Principle,[5] to optimize operating efficiency, every component in a cooling system must be adjusted simultaneously as load conditions change. Although such integrated, multicomponent control is beyond the capacity of conventional control with independent PID controllers, it can be achieved with a flexible, network-based control system.

To get an idea of how much more effective a cooling system will be with relational control based on the Equal Marginal Performance Principle, consider that chilled-water systems generally incorporate some degree of decoupling to accommodate stand-alone control of their various components and that low delta-T almost always is an issue. When relational control is applied, however, such decoupling is unnecessary, and chiller-capacity-loss problems from low delta-T vanish.

In addition to solving problems that have plagued HVAC systems for decades, relational-control strategies greatly enhance the operational efficiency of systems with multiple components and, when coupled with relational-control approaches for systems serving multiple processes or loads, ensure that each load in a system is met effectively.

CONCLUSION

The use of simple stand-alone, single-process feedback control limits both the effectiveness and efficiency of modern HVAC systems. The networking capacity of digital control systems, on the other hand, opens our industry to new methods of relational control that offer complete closed-loop and fully coordinated control. These new approaches will significantly improve both the efficiency and effectiveness of HVAC operation while allowing simpler and more stable systems. In this era of rising costs and limited electric-energy resources, relational-control methods have an important role to play in the development of energy-efficient HVAC systems.

Relational control will significantly improve both the efficiency and effectiveness of HVAC operation while allowing simpler and more stable systems.

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