Network Based Control: An Imperative for Green Office Buildings

by
Thomas Hartman, P.E., Principal
The Hartman Company
Marysville, Washington USA

INTRODUCTION

Today's office buildings require effective network based communication technologies for their inhabitants to work efficiently. Green office buildings must also apply effective network based communication technologies for the energy systems to work efficiently. Although the capacity to operate building systems with network based control has been available for some time, applying network control to improve building energy efficiency is seldom employed. Now, new network control technologies coupled with the demand by forward looking developers of sustainable construction are making the use of network based control strategies an imperative. Network based building energy system control is ideal for green building design because network control technologies can make simpler, smaller and lower cost building energy systems operate as much as 30% to 50% more efficiently than conventional system configurations with the same component efficiencies. Network based control also enhances the comfort of buildings and provides a platform for individual control and other valuable occupant amenities.

Network based control is based on the understanding that a building HVAC system is a single system whose energy efficiency and comfort performance is optimized when the operation of all components is coordinated to meet the actual needs in the spaces served. This is not a radical idea, but how such a concept can be implemented is new. Technical information from equipment manufacturers generally encourages the isolation of each system from others, and little information exists about the value or methods of effectively integrating network based control into building energy system design. The result is that truly integrated controls are almost never accomplished in practice. Therefore, even energy efficient buildings built today cost more, consume more energy, and are less comfortable than they would be if effective network control were implemented.

The purpose of this paper is to explain in a straightforward fashion how network based control ***always*** improves building energy system performance by reducing energy use. The focus for this paper is on air systems and chiller plants, the two major energy consuming building comfort systems in Asian and Pacific Rim buildings.

CHARACTERISTICS OF BUILDING LOADS

To start a discussion of energy optimization with network based controls, it is important to consider the nature of building loads that must be satisfied for comfort conditioning. Figure 1 illustrates comfort cooling load profiles for typical commercial buildings located in several climates. This figure shows the percentage of total time comfort systems spend operating at various loads within each of several climates. Efficient structures generally employ smaller comfort systems that use less total energy than less efficient buildings, but the load profile for all buildings is usually very much the same for a given climate. Note that for all climates shown in Figure 1, building systems spend only a very small percentage of their time operating at high (80% to 100%) loads. Thus, the overwhelming majority of building comfort system operating hours are at loads well below the design maximum load for comfort conditioning systems, and the key to improving the overall energy efficiency of building comfort systems is to focus on improving their efficiency at part load conditions.

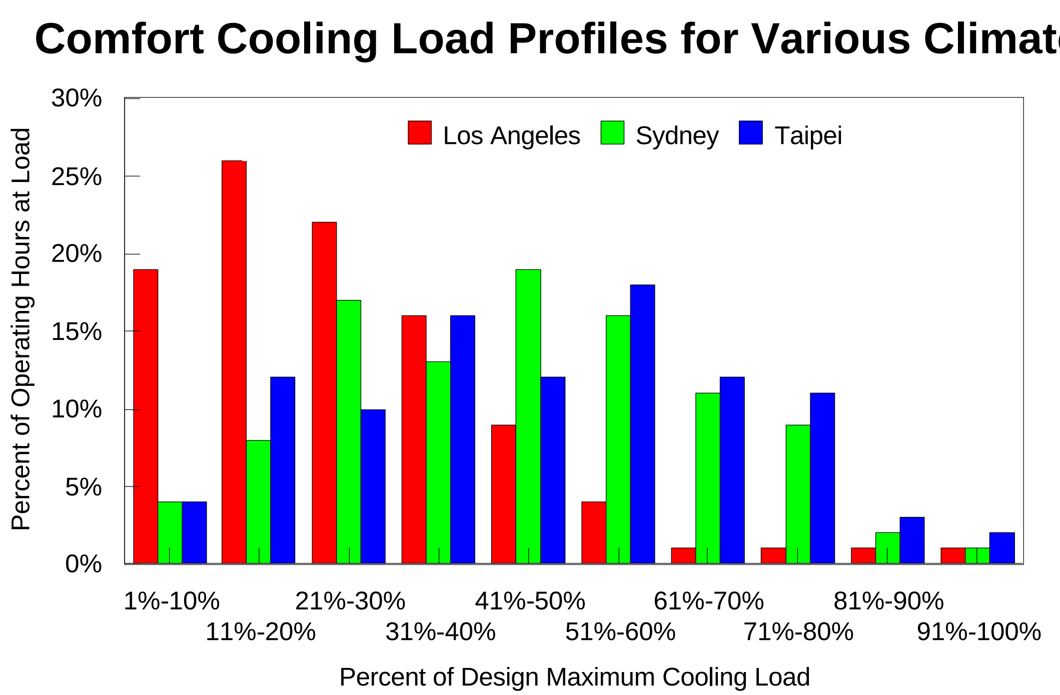

Figure 1

BENEFITS OF VARIABLE SPEED TECHNOLOGIES

Until about a decade ago, the primary method of modulating flow or capacity for equipment employed in comfort conditioning systems at part load conditions was with mechanical limiting devices: vanes or flow regulating valves. These flow control techniques reduced capacity of mechanical equipment by simply restricting flow and "riding the curve" of the fan, pump or compressor, or with pre-rotational inlet vanes that improved part load efficiency somewhat by changing inlet conditions such that the pressure differential across the fan, pump or compressor fell slightly at lower flow rates. At reduced capacity requirements, these methods of flow control provided some energy reduction, but they failed to drop the head across the fan, pump or compressor to the full extent possible, and they also operated the equipment outside the range of highest efficiency at partial loads. The performance curves for capacity control of typical constant speed fans, pumps and compressors are shown in Figure 2 below.

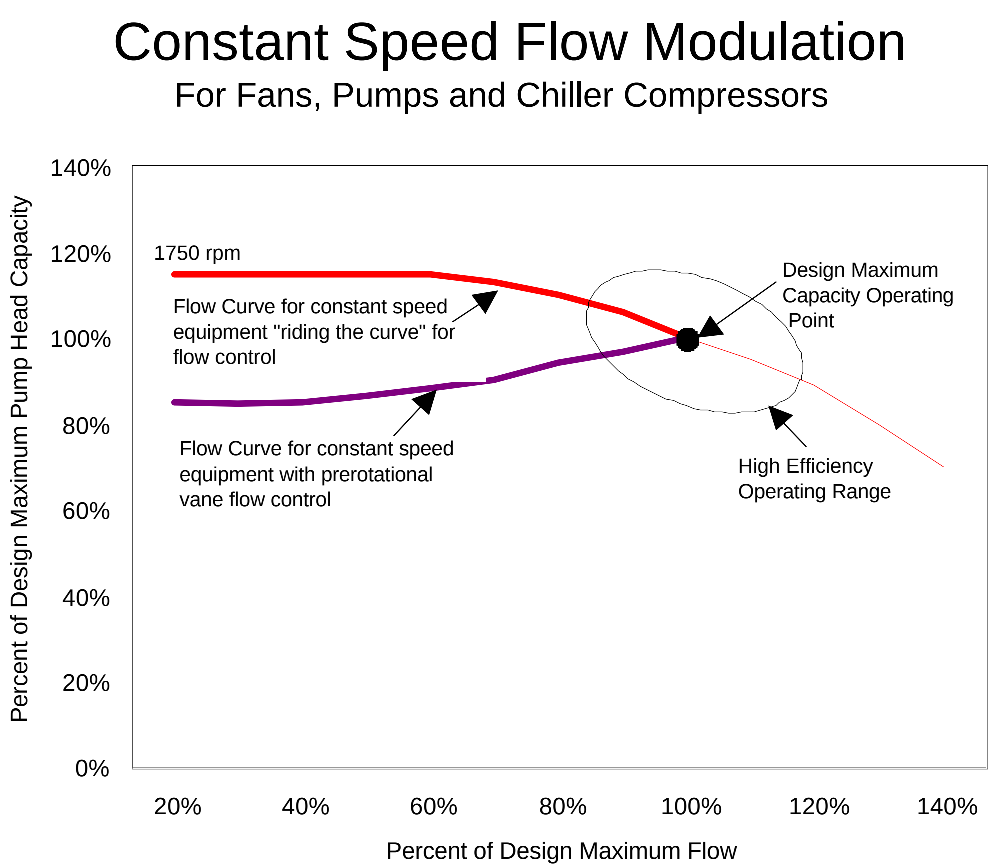

Figure 2

When variable mechanical flow control is replaced with variable speed control to modulate capacity in partial load conditions, a great potential for improving operating efficiency at part loads is created due to the fan and pump laws which dictate that a centrifugal fan, pump or compressor can supply 50% of design flow (or capacity) at 50% speed and require only 12.5% (0.5^3) of the full flow power. This means that as the capacity requirements of variable speed devices decrease to one-half, the operating efficiencies can increase by 400% (50% divided by 12.5%), so long as the pressure at which the fluid is supplied is permitted to fall to 25% (0.5^2) of the full flow pressure. If the relationship between flow and pressure contained in the fan and pump law is maintained then the device operates at highest efficiency at all loads and the overall efficiency actually increases at part load conditions. These relationships are shown in Figure 3.

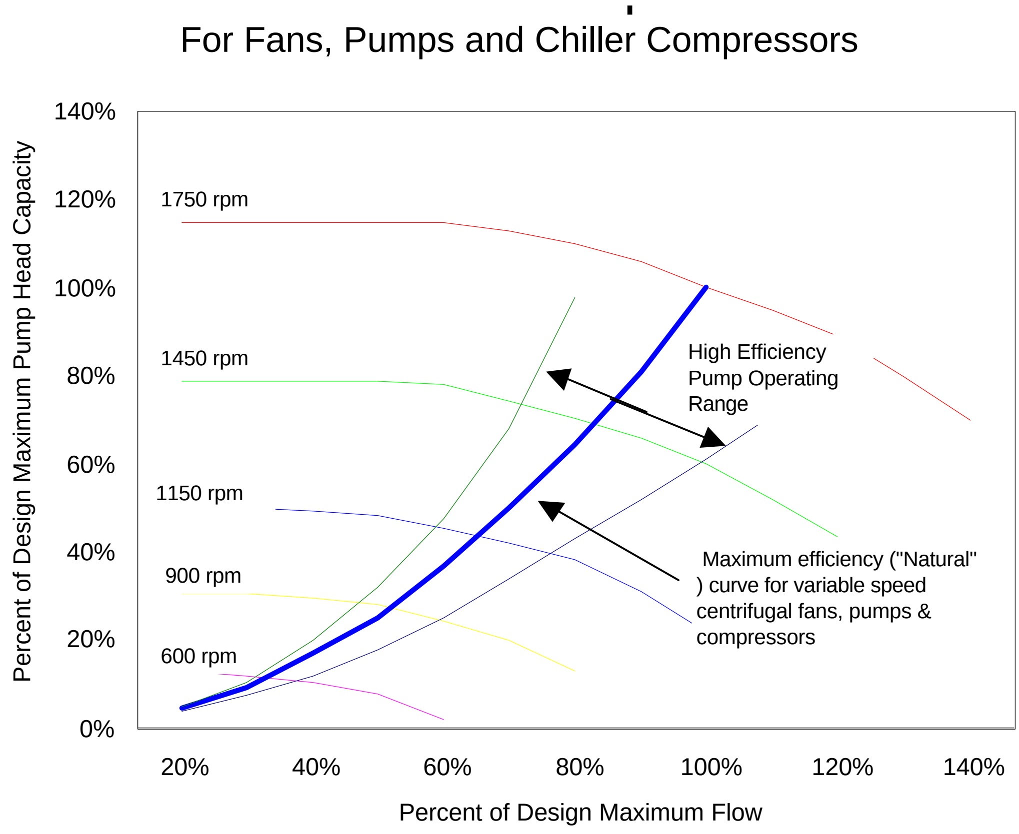

Figure 3

Since energy employed by the fan, pump, or compressor is proportion to the flow multiplied by the working head and divided by the impeller efficiency, Figure 3 shows clearly why the power falls significantly at part loads when a variable speed device is allowed to operate according to its "natural" curve.

A NEED FOR IMPROVED CONTROL

As described above, the fan and pump laws dictate that a centrifugal fan, pump or compressor can supply 50% of design flow (or capacity) at 50% speed and require only 12.5% of the full flow power, but only if the pressure at which the fluid is supplied is permitted to fall to 25% (0.5^2) of the full flow pressure. If the supply pressure does not fall with the square of the flow requirements, then the pump speed cannot be reduced as the law allows and substantial energy is lost due to a reduction in both flow and fan or pump efficiency. Unfortunately, the method of control most widely employed for fans, pumps and chiller compressors in today's building comfort systems ensures that the full energy savings capacity of variable speed cannot be achieved. Consider the method of control shown in Figure 4 below:

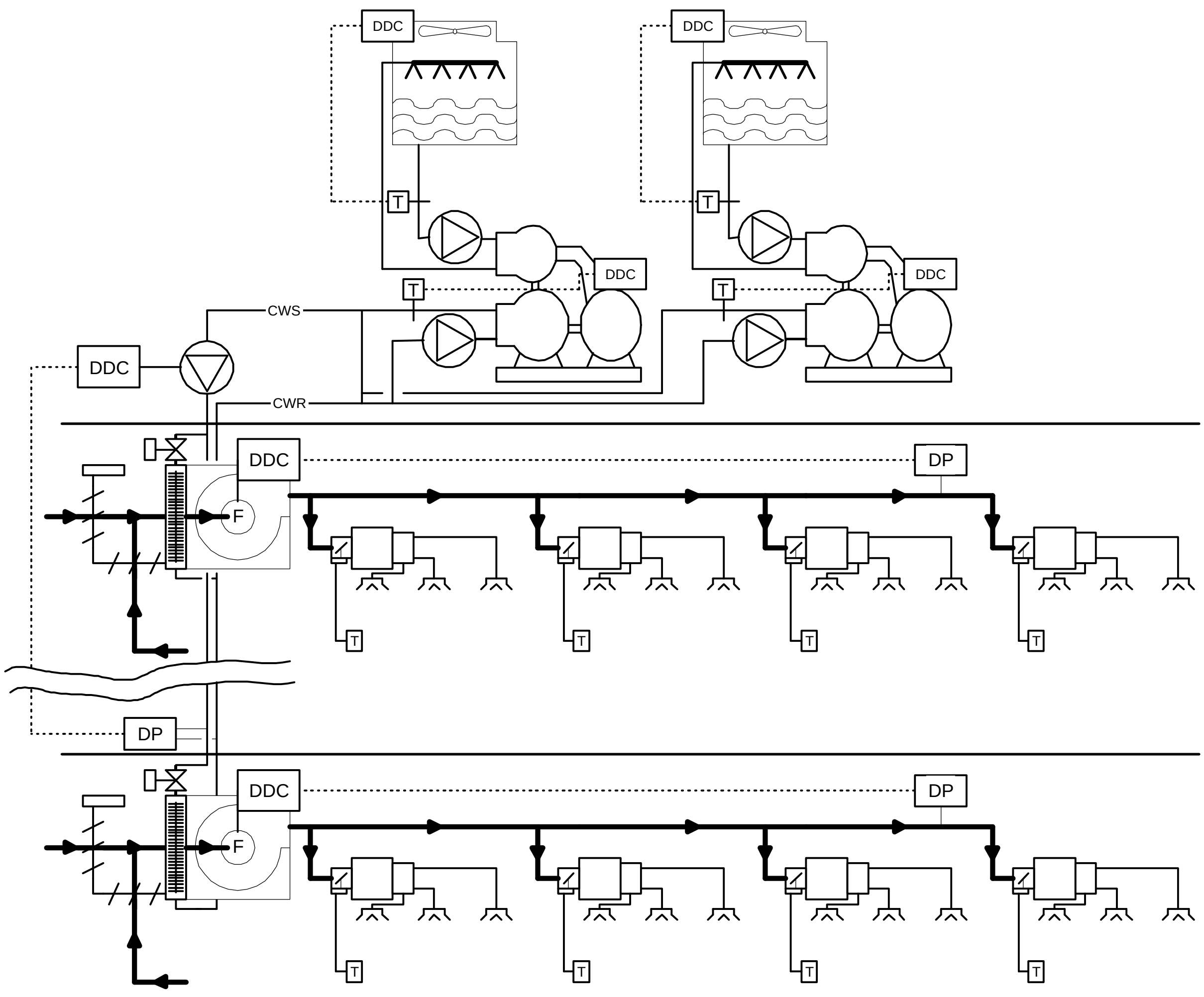

Figure 4

Figure 4 shows the means of control most often applied in today's building comfort systems. Building fans are operated to maintain a constant duct static pressure, chilled water pumps are operated to maintain a distribution header differential pressure, and chillers are operated to maintain a fixed chilled water temperature. Even in applications in which these pressure and temperature setpoints are adjusted under certain conditions, the adjustment is nearly always limited to small ranges. When this type of control is applied to variable speed centrifugal fans, pumps and chillers, the performance curve follows the system curve "A" in Figure 5 below:

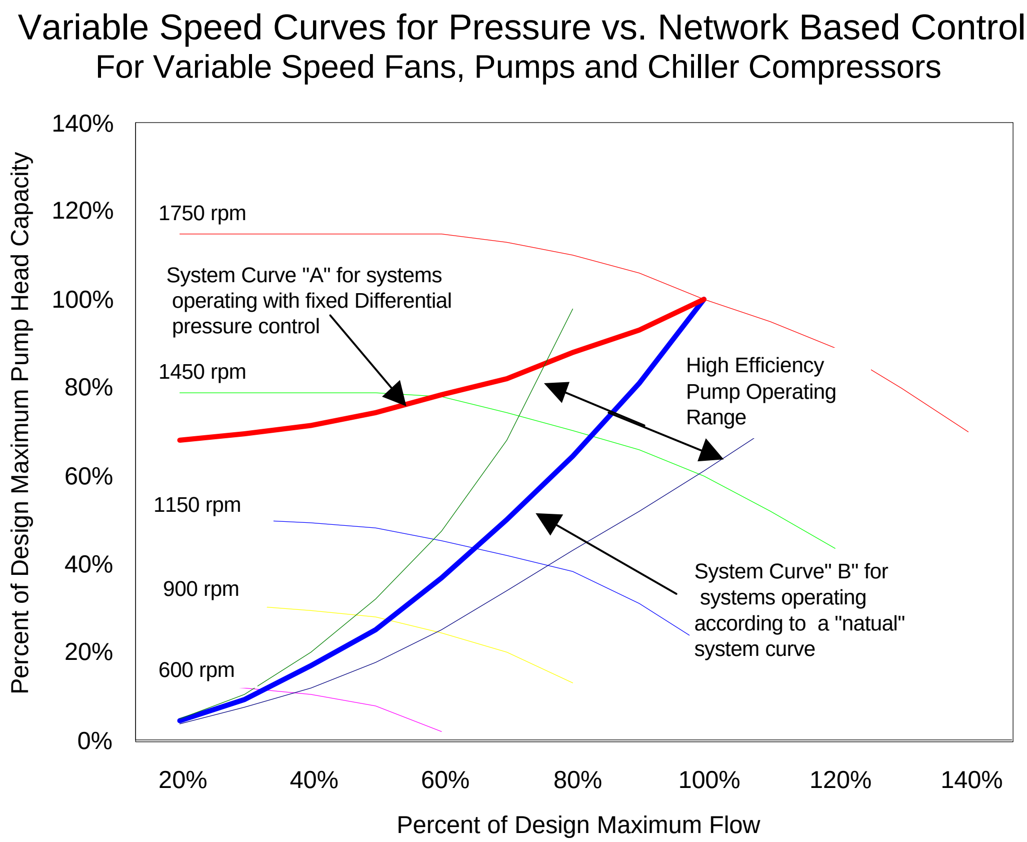

Figure 5

Figure 5 shows that the type of control employed most widely today offers only marginal savings below the types of mechanical control that are employed on constant speed equipment. Note that the curve "A" in Figure 5 is nearly the same as the curve for pre rotational vane control for constant speed equipment shown in Figure 2. Curve “A” operation, reduces part load energy savings for pumps, fans or compressors for two reasons:

1. Reduced operating efficiency because the device is not operating on its optimum efficiency (natural) curve.

2. Increased energy consumption due to the higher than necessary operating (head) pressure.

The combination of these two energy penalties limits power reduction opportunities at part loads for most variable speed centrifugal chillers, pumps and fans in operation today. This lack of energy reduction is the reason some have claimed that variable speed equipment is not cost effective for comfort conditioning applications.

However, Figure 5 also shows how much greater the energy reduction at part load conditions will be if the variable speed equipment is controlled to operate in accordance with its "natural" curve (curve "B"). If the variable speed equipment can be made to operate within this curve as capacity requirements change, it will operate at highest efficiency. To do so, the head pressure requirements must fall with the square of the flow as shown in system curve “B.” Such a system curve ensures the device operates at optimum efficiency through all flows, and that power required falls with the cube of the flow requirements.

Because centrifugal fans, pumps and compressors are simple devices that are very efficient at their “sweet spots” (the high efficiency zone in Figure 5), it is reasonable to try to find ways to accommodate their limitations and develop control concepts that permit the pressure to fall as flow decreases in order to operate them at the highest possible efficiencies throughout all flow conditions.

IMPROVING ENERGY PERFORMANCE AND COMFORT WITH NETWORK CONTROL

To achieve the full potential performance capabilities of variable speed equipment, designers must consider more closely the actual objectives of an HVAC system. Building occupants seldom call their building operator to complain about the chilled water temperature, or air or water supply pressure. Rather, most complain when their comfort or environmental quality expectations are not being met. Controls employed for most variable speed equipment today not only fail to achieve optimum efficiencies of variable speed equipment, but also only indirectly affect the ability of an HVAC system to meet occupants’ environmental requirements. HVAC systems are designed to maintain certain space conditions at one or more calculated peak load conditions. Equipment is then selected to perform with sufficient capacity to meet these conditions while operating at certain established setpoints. So, those setpoints are implemented into the controls, and the system is turned on when the building schedule declares it to be occupied. No information concerning the actual space conditions is employed to adjust the operation of the plant and distribution systems. If a number of spaces in the building begin to overheat, the central systems do not self-adjust to try to provide more cooling to those spaces. Nor when all spaces are satisfied, does the systems self-adjust to meet the reduced load with greater efficiency. To do these things requires a “network” based control scheme that employs the control network to communicate with the loads being served. Network based control is very cost effective because in most circumstances it requires no additional equipment or controls. In fact, when properly applied, network control requires less equipment and often employs simpler configurations than the conventional systems and controls it replaces.

WHAT IS "NETWORK" CONTROL?

While the purpose of network control is to tie the operation of all HVAC equipment to actual space conditions, this does not mean that chillers and towers operate directly from space temperature sensors. Rather, network control optimizes HVAC operation by coordinating the operation of all components to meet the actual needs in the spaces served. This approach is not generally considered because HVAC designers are so bombarded with out of date technical information that entreats them to isolate systems from one another. For example, while low delta T is a serious problem in chiller plants, designers still regularly employ "decoupling lines" that permit direct mixing of supply and return chilled water (and a reduced delta T) under the outdated notion that system isolation and independent control of plant equipment is the correct approach.

Actually, the opposite is true. It is intuitive that coordinating the operation of a chiller plant and the chilled water distribution system is a requirement for achieving the highest overall system efficiency, but the industry's approach continues to be to isolate the two as separate systems and operate each by nonintegrated stand alone controls. The chiller plant is operated to maintain a specific chilled water setpoint and the distribution system to maintain a specific pressure setpoint. Does this make sense? Obviously not. What does make sense is to integrate these control functions together and operate all equipment as a single system to most efficiently meet all cooling loads at all times. That is what network based HVAC controls have been developed to do.

HOW A "NETWORK" CONTROL HVAC SYSTEM WORKS

The question is, "How does one accomplish network based control effectively?" To help answer this question, consider the building air conditioning system diagram in Figure 6 which shows the same HVAC system as Figure 4 operating under a network control strategy. In Figure 6, the zone temperature sensor still operates the box damper, but the air handlers coordinate supply air flow, outside air dampers and cooling valve to ensure that the desired cooling level in each zone is maintained most efficiently while also ensuring adequate ventilation and air flow. Under network control, air handlers are not operated to maintain static supply temperature and pressure setpoints, but to satisfy the thermal loads and comfort requirements of the zones they serve. For typical VAV systems this means that both total fan air flow and outside air are maintained within certain ranges at all times. The fan speed, mixed air dampers and cooling valve are adjusted within the ranges established by basic system requirements as the need for cooling in the zones served changes.

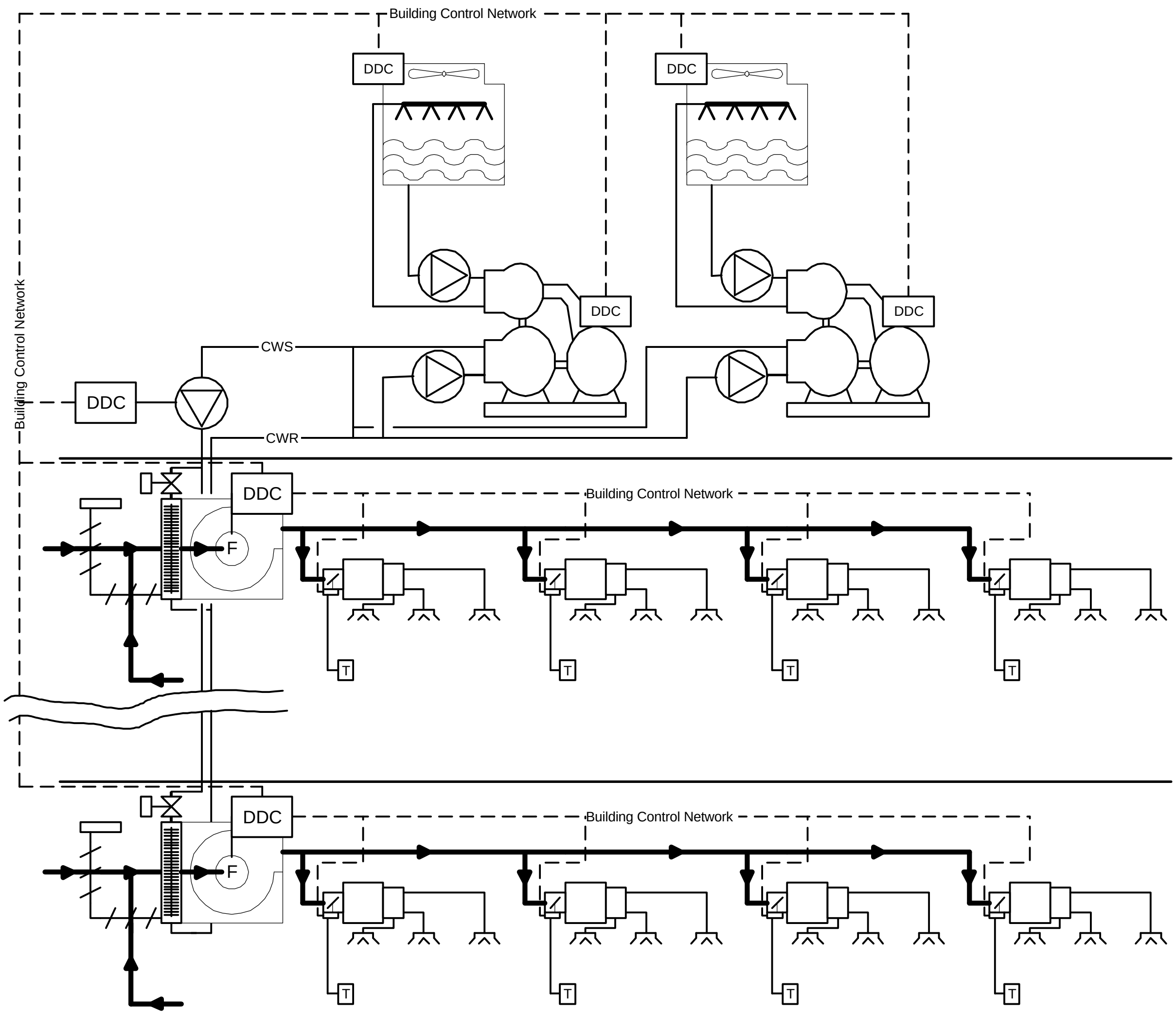

Figure 6

Under the network air system control (called TRAV for terminal regulated air volume), the fan digital controller employs the network to determine two separate real time characteristics of the loads served: 1) the average load, and 2) the deviation (or extreme loads). The value of the average load served indicates generally how much cooling energy needs to be expended. The deviation is employed to determine the relationship between the air flow and cooling effect of the air delivered to meet these loads. When the deviation is small, the supply air flow and cooling effect are coordinated to provide optimal overall energy efficiency through simple flow relationships. However, when the deviation increases, the cooling ratio of the supply air is

increased away from optimal as the most effective means of meeting exceptional localized space conditions.
Under this network control regimen, the chillers and chilled water distribution equipment are operated in a fashion similar to the air side equipment, except the loads served are the cooling coils, not VAV boxes. This network control regimen for chiller plants is called "LOOP" control. Like TRAV for networked air side control, chillers, towers and pumps operating under LOOP control continuously collect real time data concerning average load and deviation. This data is employed to operate the plant such that each load it serves is met effectively, but also with the highest possible efficiency.

By communicating and acting on actual zone conditions in the operation of plant and distribution equipment, these network control strategies improve building comfort and environmental quality as well as improve the energy performance in buildings. While enhancement to comfort and environmental quality is often best determined subjectively, the energy savings attributable to network based control can be accurately determined by hourly simulation. The simulation results for the electric portion of the HVAC system in a Taipei high rise office building is shown in Figure 7. This building was designed as a low energy building, using less than 70,000 BTU/SF (about 750 MJ/SM) total energy annually. Note that despite the initial low energy design, the network based control further reduces the electric energy use of the chiller plant and HVAC distribution system by 50%. At the same time this networked control results in a more comfortable building and a higher level of indoor environmental quality.

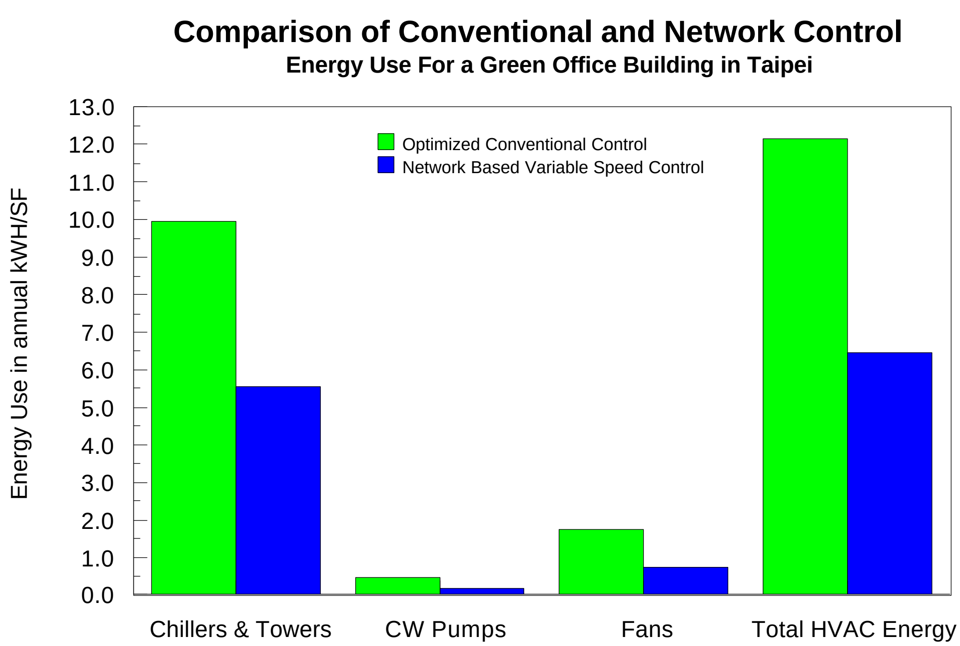

Figure 7

A TECHNOLOGY WORTH PURSUING

By employing network based control, equipment can operate at improved efficiency and also operate to meet the loads served more effectively. Network control is possible because most DDC systems now have the ability to "network" (or share the value and status of points) among controllers. If you are a designer who wants to improve the comfort and environmental quality of your projects and at the same time improve their energy efficiency, it's time to consider network based control. Imagine a building in which control is provided by actual load requirements sent over the system's communications network. Fans, pumps and chillers operate at all times to meet flow and capacity requirements as efficiently as possible. Properly designed, such a building requires no time schedule, since the entire system reacts to current occupancy conditions in the building. The most exciting feature of network control strategies is that they can provide savings in both first costs and annual energy/operating costs, and still result in more comfortable buildings.

SUMMARY AND CONCLUSION

While the industry employs modern HVAC equipment, the energy efficiency and comfort enhancing capabilities of this equipment can be substantially improved by applying "network" based control strategies. However, the full performance capabilities of network controls technology is rarely achieved. Current design and implementation practices act to limit the potential effectiveness of these advanced technologies. A promising prospect that could change this situation is the development of network based control technology "products." To undertake this challenge, the industry needs to hear all interested voices to determine if, and then how, such packaged products can be developed and implemented in HVAC systems to achieve higher performance.

Additional information on technologies discussed in this article is available at www.hartmanco.com. Comments and questions about the article may be addressed to Mr. Hartman at tomh@hartmanco.com.