energy design resources

design brief

ENERGY MANAGEMENT SYSTEMS

HOW TO SAVE ENERGY WITH AN EMS

Summary

Energy management systems (EMSs) control energy-consuming building equipment to make it operate more efficiently and effectively. On average, EMSs save about 10 percent of overall annual building energy consumption,[1] and more than half of all buildings in the U.S. larger than 100,000 square feet have one, totaling one-third of commercial building floor space. However, many of these systems save less energy than they are capable of saving. In one detailed study of 11 EMSs, 5 were found to be underachievers.

Building owners and designers can do three things to improve the likelihood that the EMSs they purchase and recommend achieve the expected benefits: (1) use advanced control strategies that take full advantage of the computer processing power EMSs have; (2) specify EMSs in a clear and accurate manner, providing complete information about intended performance, control strategies, and project team responsibilities; and (3) adopt a comprehensive approach to quality control known as commissioning and recommissioning. In commissioning, rigorous performance tests are conducted before the building is occupied. In recommissioning, trending and energy consumption data are used to periodically verify, document, and improve a building's operation over the building's lifetime. The application of these techniques will not only improve the energy efficiency of buildings, but will likely make those buildings more comfortable.

CONTENTS

The control system carries the responsibility for making sure that equipment and systems are properly integrated and functioning as a whole.

Introduction

An energy management system (EMS) controls how energy is consumed in a building and how building equipment operates. EMSs may vary widely in sophistication, ranging from simple digital thermostats to systems comprised of multiple, networked controllers that can be programmed to provide any imaginable energy-saving sequence.

EMSs are most prevalent in large buildings, and more than half of all buildings in the U.S. over 100,000 square feet have one—that's nearly one-third of existing commercial building floor space.[2] More buildings might benefit from having an EMS, and many existing EMSs are often far less effective than they might be. For example, in 1995, 11 buildings in New England with computerized EMSs were thoroughly analyzed. At 5 of those buildings the EMSs were found to be underachieving, producing less than 55 percent of expected savings. One site produced no savings at all. The two main reasons behind their poor performance were that the EMSs were often being used only to perform tasks that far simpler controls could carry out and that intended EMS control strategies were never implemented.[3]

Careful management of EMS projects, starting with system design, is important to ensure that the money invested to buy advanced components or features is not wasted. Moreover, the need for proper system design, specification, and implementation at the EMS level is profound; the control system carries the responsibility for making sure that equipment and systems are properly integrated and functioning as a whole.

How Do Energy Management Systems Work?

To maintain comfortable conditions in buildings, energy management systems control both HVAC equipment operation (that is, when the equipment starts and stops) and its running capacity (regulating such functions as fan speed and supply air temperature). Many EMSs also control lighting, security, and fire control systems. The primary components of EMS systems are sensors, controllers, actuators, and software. **Figure 1** shows how sensors, controllers, and actuators can be incorporated in the structure of an EMS.[4]

Sensors

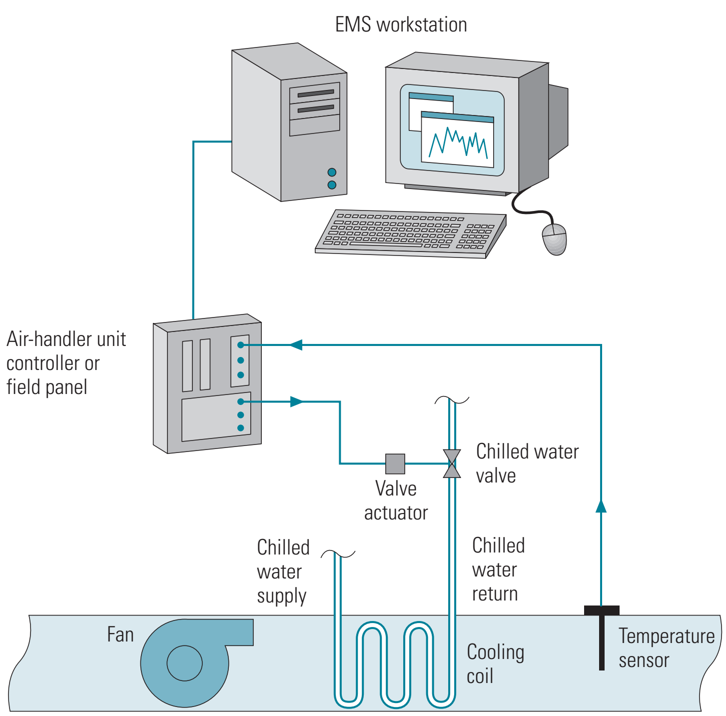
Sensors are devices that sense environmental conditions or equipment status and send that information to microprocessor controllers. They measure temperatures, pressures, on/off status, electrical current, and other variables.

Controllers

Controllers process sensor inputs and generate outputs that are delivered to actuators or other controllers. Inside a controller, sensor inputs are compared with other sensor inputs, outputs from controller calculations, or setpoints. The outputs often cause equipment operation to be modified—for example, by causing fans to speed up, dampers to close, or equipment to turn on.

Figure 1: How EMS components fit together

An energy management system (EMS) consists of sensors, controllers, actuators, and software. An operator interfaces with the system via a central workstation.



Courtesy: Platts; adapted from Portland Energy Conservation Inc. [4]

EMSs are capable of saving, on average, about 10 percent of overall annual building energy consumption.

Actuators

Actuators are mechanical devices consisting of assemblies of metal arms or shafts attached to valves or dampers. Either electric motors or pneumatic air pressure powers the actuators to turn, rotate, or push dampers or valves open and closed.

Software

Software programs reside in the controllers and in the user's personal computer (PC) workstation. The software contains the procedures that process incoming data and issue commands to equipment. Modern EMSs store all of the control software in the controllers to prevent loss of control in the event that the EMS front-end PC fails or is turned off. The PC is used to change setpoints and monitor equipment operational data.

Designing EMSs to Save and Manage Energy

EMSs are capable of saving, on average, about 10 percent of overall annual building energy consumption.[5] In general, EMSs save and manage energy by controlling equipment so that:

- Equipment is running only when necessary,
- Equipment is operating at the minimum capacity required, and
- Peak electric demand is minimized.

EMSs also may be used to save energy by monitoring equipment operational data, which may then be used for diagnostics and troubleshooting.

Running Equipment Only as Necessary

There is no simpler way to save energy than turning off equipment when it is not needed. EMSs accomplish this objective by scheduling equipment operation and "locking out" equipment operation when conditions warrant.

Scheduling. Scheduling is the practice of turning equipment on or off depending on time of day, day of the week, day type, or other variables such as outside air conditions. Improving equipment schedules is one of the most common and most effective opportunities for energy savings in commercial buildings. In the absence of an optimized schedule, it is not unusual for building equipment to run 24 hours when only 12-hour operation is required.

Improving equipment schedules is one of the most common and most effective opportunities for energy savings in commercial buildings.

- *Start/stop*. Needless operation after hours and on weekends is one of the largest energy wasters in commercial buildings.[6]
- *General scheduling*. EMS software can typically accommodate weekly and holiday schedules as well as one-time events.
- *Zone-by-zone scheduling*. HVAC and lighting systems can be scheduled at the zone level, so that systems in unoccupied areas can be shut down.
- *Override control and tenant billing*. When tenants need to work in the building outside of normal schedules, manual switches, telephone call-in, or override via card-reader access may be used to activate lighting and HVAC systems.
- *Night setup/setback*. This strategy, which is required by Title 24, California's energy-efficiency standard, changes setpoints during unoccupied hours to save energy by reducing the differential between inside and outside temperatures.
- *Optimum start*. Optimum start produces energy savings by starting equipment only as early as required to bring the building to setpoint at the time it will be occupied.
- *Optimum stop*. The optimum stop strategy determines the earliest possible time equipment can be turned off before unoccupied periods begin while still maintaining occupant comfort.
- *Morning warm-up/cool-down*. Morning warm-up strategies are used in conjunction with optimum start to bring the building to the desired temperature before occupancy after a night setup or setback with the least amount of energy, by closing outside air dampers.

- *Night ventilation purge.* In climates with a large nighttime temperature drop (dry climates), purging or flushing the building with cool outside air in the early morning hours can delay the need for cooling until later in the morning.

Lockouts ensure that equipment does not come on when it is not needed.

Lockouts. Lockouts ensure that equipment does not come on when it is not needed. They protect against nuances in the programming of the control system that may inadvertently cause the equipment to turn on.

- *Boiler system.* The boiler and associated pumps can be locked out above a set outside air temperature, by calendar date, or when building heating requirements fall below a minimum.

- *Chiller system.* The chiller and associated pumps can be locked out below a set outside air temperature, by calendar date, or when building cooling requirements fall below a minimum.

- *Direct expansion compressor cooling.* Direct expansion (DX) cooling can be locked out when outside air conditions allow economizer operation to meet the cooling loads. This should be subject to any relative humidity control that may require dehumidification with the DX, even during economy cycles.

- *Outside air damper.* The modulation of the outside air damper can be locked out when the outside air conditions are not conducive to "free cooling."

Operating Equipment at the Minimum Capacity Required

When equipment operates at greater capacity than necessary to meet building loads, it wastes energy. Examples of wasteful overcapacity include excessively cold chilled water, excessively hot heating water, or an excessively high supply air pressure. EMSs operate equipment at the minimum capacity required by resetting operating parameters.

Traditional design practice is to use a "proportional reset schedule." **Figure 2** illustrates a common reset schedule for chilled water. In this example, as the outside temperature decreases, the chilled water temperature is reset to a higher value to improve chiller efficiency.

Although resets are frequently based on outdoor temperature, that parameter is only an indirect indicator of building loads. It is more effective to base resets on direct information about loads. For example, as shown in **Figure 3**, the chilled water supply temperature might be varied based on the number of chilled water valves that are open.

Examples of other setpoints that may be reset to improve energy efficiency include the following:

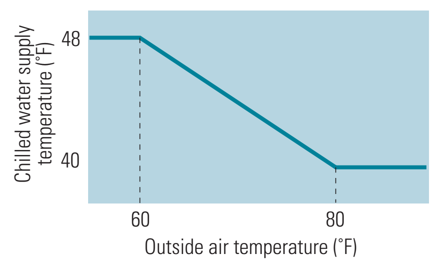
- *Supply air/discharge air temperature.* For fan systems that use terminal reheat, Title 24 requires that the supply air temperature setpoint be reset higher as the cooling load decreases. This reduces reheat energy and increases the efficiency of DX compressors. Typically, supply or discharge air is reset from outside air. However, greater energy savings may be achieved by basing resets on indicators of load that are more direct, such as "most open" cooling coil valve, reheat coil valve, or terminal unit damper.

- *Hot-deck and cold-deck temperature.* Multizone HVAC systems control temperature by simultaneously maintaining sources, or "decks," of both hot air and cold air. These types of systems are inherently inefficient, because they are designed for simultaneous heating and cooling. Resetting the deck temperatures based on heating and cooling load in the various zones decreases the differential between the decks and thereby reduces simultaneous heating and cooling.

- *Variable-air-volume duct pressure and flow.* Traditional variable-air-volume (VAV) fan control strategies use a fixed-duct,

Figure 2: Proportional reset schedule

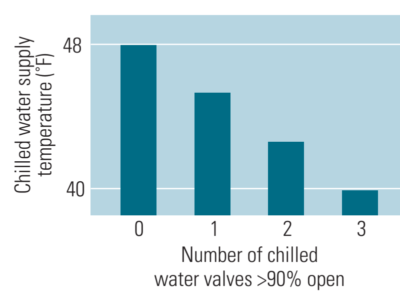
As the outside temperature decreases, the chilled water temperature is reset to a higher value.



Note: F = Fahrenheit. Courtesy: Platts; data from Portland Energy Conservation Inc. [4]

Figure 3: Direct load information reset

In this reset schedule, the cooling load is based on the number of chilled water valves that are greater than 90 percent open.



Note: F = Fahrenheit. Courtesy: Platts; data from Portland Energy Conservation Inc. [4]

Resetting the condenser water to the lowest value that is practical for the tower to make saves chiller energy with the smallest possible increase in tower fan energy.

static-pressure setpoint control that is independent of actual airflow requirements at the terminal units. However, by sensing damper position, the supply fan can be incrementally slowed to keep one terminal box fully open. The fan can then run as slowly as possible while still keeping all boxes satisfied. Another approach is to add the airflow requirements for all VAV boxes and then modulate the fan to supply this volume based on an airflow sensor mounted on the fan.

- *Heating water temperature.* Heating water supply temperature can be reduced as the heating requirements for the building are reduced. The most common reset is based on outside air (an indirect indicator), but it may be improved upon by resetting based on keeping one or two heating coil valves fully open.

- *Temperature of condenser water entering the chiller.* Often, the setpoint for condenser water entering the chiller from the cooling tower is set at a fixed value around 80° Fahrenheit (F). Less frequently, it is set to a low value such as 70°F. Both fixed settings may be inefficient. The 80°F setting does not take advantage of conditions during which the cooling tower can easily make cooler water, which increases chiller efficiency. The 70°F setting sometimes wastes energy trying to make 70°F water when outside conditions will not allow it. Resetting the condenser water to the lowest value that is practical for the tower to make (given the outside wetbulb and drybulb conditions) saves chiller energy with the smallest possible increase in tower fan energy. This can be done by having the entering condenser water setpoint equal to the outdoor wetbulb plus 10° to 15°F.

- *Secondary chilled water loop pressure.* Instead of controlling the secondary chilled water loop to a fixed differential pressure setpoint under all conditions (the typical method), this strategy resets the pressure down as the load decreases (as the chilled water valves close), so that one cooling coil valve will always be 100 percent open.

- *Chiller and boiler staging.* For multiple chiller and boiler systems, the ideal strategy is to determine the total cooling or heating load on the system, compare the part-load efficiencies and capacities of all available chillers or boilers, and determine the most efficient mix of chillers or boilers to have on-line.

- *Position of outside air dampers in accordance with carbon dioxide levels.* This approach, known as demand-controlled ventilation, controls the amount of fresh air that is brought in by the HVAC system based on indoor carbon dioxide level, which is a measure of building occupancy at any given time.

Some of the reset strategies listed above may interfere with the others, such that savings achieved by one component may be offset by losses in another. For example, in a chilled water system, when the cooling load decreases, the cooling capacity can be managed by resetting the chilled water to a higher temperature. For a given load condition, when the chilled water supply temperature is reset up, the chiller efficiency is improved. But the warmer water being sent to the cooling coils will cause the cooling coil valves to open up and call for more water, thus increasing pumping speed and energy use. In this case, chiller energy is saved at the expense of increased pump energy. The extent to which the chilled water should be reset in response to cooling load varies from building to building, depending on factors that include the efficiency of pumps and chillers. When this sort of interference arises, the situation is best evaluated on a case-by-case basis.

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The EMS can eliminate demand spikes by programming time delays between the startups of major electrical load–generating equipment.

Minimizing Peak Electric Demand

Because electrical demand charges can make up 40 percent or more of a utility bill,[7] many EMSs have demand-limiting functions.

- *Demand limiting or load shedding.* When the demand (based on kilowatts or current amps) on a building meter or piece of equipment approaches a predetermined set-point (it may be different each month), the EMS will not allow a predetermined piece of equipment—a chiller, for example—to load up any further.

- *Sequential startup of equipment.* The EMS can eliminate demand spikes by programming time delays between the startups of major electrical load–generating equipment so that the startup peak loads stay below the peak demand later in the day.

- *Maximizing the amount of load curtailment.* By integrating the operation of building systems, EMSs offer building managers the ability to quickly and reliably cut back on the maximum amount of electric demand at any time. This is useful in responding to time-of-day demand rates, real-time pricing, and utility-initiated demand shedding.

Using the EMS for Equipment Diagnostics

Building operators who use an EMS to monitor information such as temperatures, flows, pressures, and actuator positions gain the data they need to determine whether equipment is operating incorrectly or inefficiently as a part of day-to-day operations or as a part of a whole-building recommissioning, and to troubleshoot problems. However, few building operators use EMSs well for theses purposes.[8] One reason is that more monitored points than the number needed to minimally control the building to the specified sequences are often necessary. For example, the mixed air temperature is often not included as a point monitored by packaged rooftop units—

because it is not used for control—but it can be used to ensure that an air-side economizer is working properly.

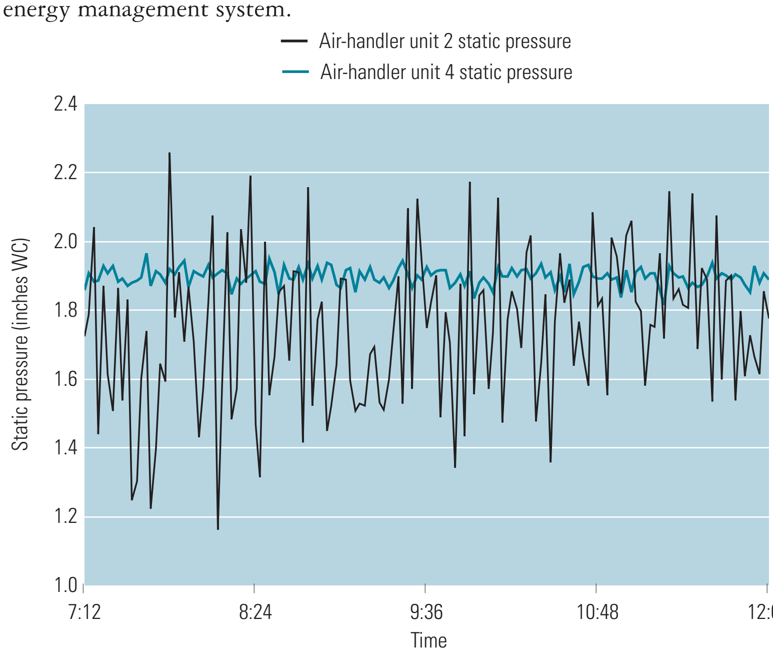
Figure 4 shows how one building operator monitored the discharge static pressure of two air-handler fans and then graphed the data to identify a problem. One air handler was properly controlled so that its static pressure remained within ±0.1 inch of setpoint, but the other air handler was fluctuating five times that much (±0.5 inches). This effect, known as hunting, can cause excessive wear on fan controls and waste energy by operating the fan at unnecessarily high static pressures. The operator found that the problem was caused by improper control parameters set in the EMS. Reprogramming those parameters solved the problem.

Using Direct Digital Control

Direct digital control (DDC) systems are a standard part of any EMS. DDC systems use electronic signals sent via computer to process data for direct system control (see **Figure 5**, page 12).

Figure 4: Discharge duct static pressure control

Air-handler unit 2 is fluctuating from setpoint five times as much as air handler unit 4. This problem was caused by improper control parameter settings in the energy management system.

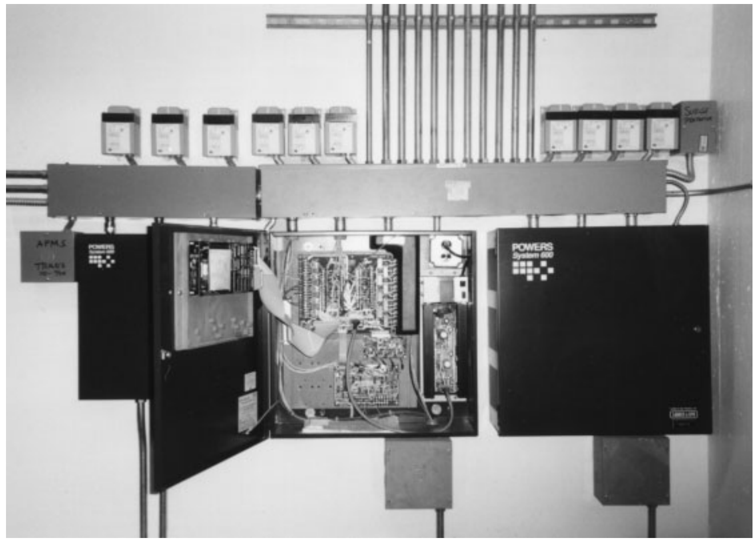


Note: WC = water column.

Courtesy: Platts; data from Portland Energy Conservation Inc. [4]

Figure 5: DDC controls field panel

This direct digital control (DDC) panel has been designed for a large air-handling unit.



Courtesy: Portland Energy Conservation Inc. [4]

They also typically provide feedback information from the building. One application of this information would be to base reset schedules on direct load indicators. For example, a DDC can provide feedback to the EMS about damper and valve position, airflow volume, temperature, and run time, simply through wiring. As a result, a DDC system can be used to implement a load-based supply air temperature reset strategy that could not be carried out with the outdated pneumatic systems used in some older EMSs.

The cost of DDC systems varies considerably depending on building size, space use, controlled equipment, and overall energy management needs. The metric most used to discuss DDC system cost is price per controlled point. To some, this value represents a price that includes all hardware, software, installation, and programming. The cost of the workstation, DDC field panels, actuators, wiring, and any other system component could be included in this number, resulting in a high value. Others may choose to cost out an EMS component-by-component, for example, separating the cost of the field panels and workstations from the cost of the point itself, resulting in a lower price per point. Considering these two extremes, it is common to encounter values that range from $100 to $2,000 per point. For terminal equipment, which may include several points, it is common to look at the cost on a per-unit basis, typically ranging from $600 to $1,200 per unit.

To estimate the cost of an entire EMS with full DDC capability for a new building, consider a typical office building of 100,000 square feet with no special space use or unusual energy management requirements. It is not uncommon for an EMS in this type of application to cost around $250 to $750 per point—a "rolled-up" value that includes all materials and labor for installing the system. However, there is no rule of thumb for how many points may be included in a building. It all depends on what type of equipment is present and how it is to be controlled. If we assume that 400 points are included for this hypothetical building, the majority of which are connected to VAV boxes, the total cost of the EMS could range from $100,000 to $300,000, or from $1.00 to $3.00 per square foot.

Integrated DDC has the potential to save energy by controlling systems better than stand-alone controllers can.

Advantages of Integrated Systems over Stand-Alone Controllers

Integrated DDC has the potential to save energy by controlling systems better than stand-alone controllers can. Chillers, air-handling units, packaged units, boilers, and other types of large equipment come with built-in control panels. These controls are usually very sophisticated and can function under many advanced control strategies. However, an integrated DDC system is better, because it receives more information about the condition of the building and the operation of other equipment systems.

As an example, consider the strategy of resetting static pressure for ducts. An air-handling unit with its own control panel does not permit this strategy unless it is integrated into an EMS. When an air-handling unit is used as a stand-alone system, common practice is to control duct static pressure to an

Most EMSs can be accessed via modem or the Internet for remote monitoring and control.

appropriate fixed value. This is less efficient than using static pressure reset, in which the pressure is lowered as much as possible to consume the minimum amount of fan power. An EMS can implement the reset strategy by obtaining damper position information from the VAV boxes, calculating whether less airflow could be delivered, and sending a new static pressure setpoint to the air-handling unit as appropriate. The controller for the air-handling unit cannot perform this operation because it has no way of sensing the position of the VAV box. In this example, the labor and programming costs required to allow the EMS to send the static pressure setpoint would range from $500 to $1,000. This strategy generally saves, on average, about one-quarter of the fan energy.[9] Thus, for a 40-horsepower fan motor that runs five days per week, 12 hours per day, the annual energy savings could be as much as 23,000 kilowatt-hours. At eight cents per kilowatt-hour, that would translate to $1,840 in energy cost savings, yielding at worst a 6.5-month payback.

In addition, integrating the stand-alone controls with the EMS gives the following advantages:

- *Centralized control.* Instead of having to keep track of a variety of different control locations throughout the building, the operator can view and control all systems from one location.
- *Remote access.* Most EMSs can be accessed via modem or the Internet for remote monitoring and control.
- *Monitoring.* Historical data may used for diagnostics and troubleshooting.

Communication Protocols for DDC Systems

To facilitate the exchange of information between systems and equipment, the industry uses two major communications protocols for DDC systems: proprietary and open (or standard) communications.

Proprietary communications. Proprietary communications are used for intercommunication among different components of a particular manufacturer's equipment. These systems may allow backward or forward compatibility with other generations of equipment from the same manufacturer, but they don't allow ready intercommunication with other brands of equipment. Systems that rely on proprietary communications are rapidly disappearing from the marketplace. Because such systems are unable to communicate with other systems, the user's choices for expanding this type of EMS are limited. The communication issue also reduces choices when a user is trying to purchase new equipment, which in turn limits the user's bargaining power. However, proprietary systems do offer the advantage of a single source of responsibility when there are problems.

Open communications systems are based on published protocols that are available to all manufacturers.

Open communications. Open communications systems are based on published protocols that are available to all manufacturers. There are two main choices for open standards in the area of building automation. The first, known as BACnet, was created by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) in 1995. The second is the LonWorks system created by Echelon. Most manufacturers of building controls have allied themselves with one or both of these standards.

There are several advantages to using an open communications protocol for an EMS. First, there is the assurance that the system will be able to interact with equipment from multiple manufacturers. And using equipment that is based on open protocols creates a competitive bidding environment for system additions and renovations, which helps to limit costs. It also helps ensure that the user will receive a good level of service and get more-effective responses to equipment/EMS problems.

Using an EMS and equipment with open communications also helps contain costs associated with interfacing the EMS to any

If the EMS and all additions to the system are specified as open/standard protocol, interfacing becomes easier and less expensive.

mechanical equipment. For example, it is normally difficult to extend the features of an EMS that uses proprietary communications to include monitoring temperatures, pressures, and flows for a new chiller. If the EMS and all additions to the system are specified as open/standard protocol, interfacing becomes easier and less expensive.

The "head-end" of an EMS is the central controller—usually a PC that is set up to monitor all of the distributed processors in the system. If you always specify open protocol for system components, the head-end equipment from the manufacturer of your choice should be able to interface with all equipment in your facility via standard communications, without separate gateways or a multitude of wires. Standard protocols also reduce the need for multiple head-ends and specialized interface equipment. The result is lower system costs and lower training expenses, fewer maintenance agreements and spare parts, and a single mode of system access.

When selecting a communications protocol, it is important to:

Clearly define goals for the EMS. The choice of standards and communications modes for an EMS should be considered in light of the overall system goals. Owners want an easy-to-use, single-seat interface (such as a PC) to access and share data among DDC systems in one or more buildings. Owners also often want to mix and match various components from different manufacturers in the same system—a feature called plug and play. The issue of how to integrate such complex systems raises questions about what is known as interoperability; that is, the ability of controllers to work together in an integrated fashion. It is not enough to simply specify standard communications; to have an effective EMS, it is necessary for all of the controllers to operate as a unified system. Focus on specifying performance, rather than protocol.

By carefully considering the goals and objectives you have for an EMS, it will be possible to decide just how important open communications are and whether gateways or other networking technology will be needed to combine existing equipment with a new EMS. Take time to fully understand what your system components can do and then take steps to ensure that all the networking and control equipment will be compatible, will interact in the manner desired, and will provide the data you need to properly manage the facility.

The ability to manage a facility using a web browser leverages the power of the Internet to network the EMSs for multiple buildings.

Clearly define lines of maintenance responsibility up front. Open communication protocols introduce additional considerations into the specifying and contracting process. For instance, for a system that includes head-ends from several manufacturers as well as a host of third-party controllers, the user needs to establish which vendor to call when any part of the network stops functioning. Care should be taken in the maintenance contracting process to clearly delineate the areas of responsibility for maintenance activities.

Whenever new components are installed in the field, the existing head-end will require additional programming. The program updates could be provided by the manufacturer, by a certified contractor who is proficient with the existing head-end, or by in-house personnel. The same is true for system changes that only affect a particular distributed processor. Some programming adjustments will be needed for the distributed processor whenever such changes are made, so staff or maintenance contractors need to be familiar with all of the distributed processors for on-site equipment made by different manufacturers.

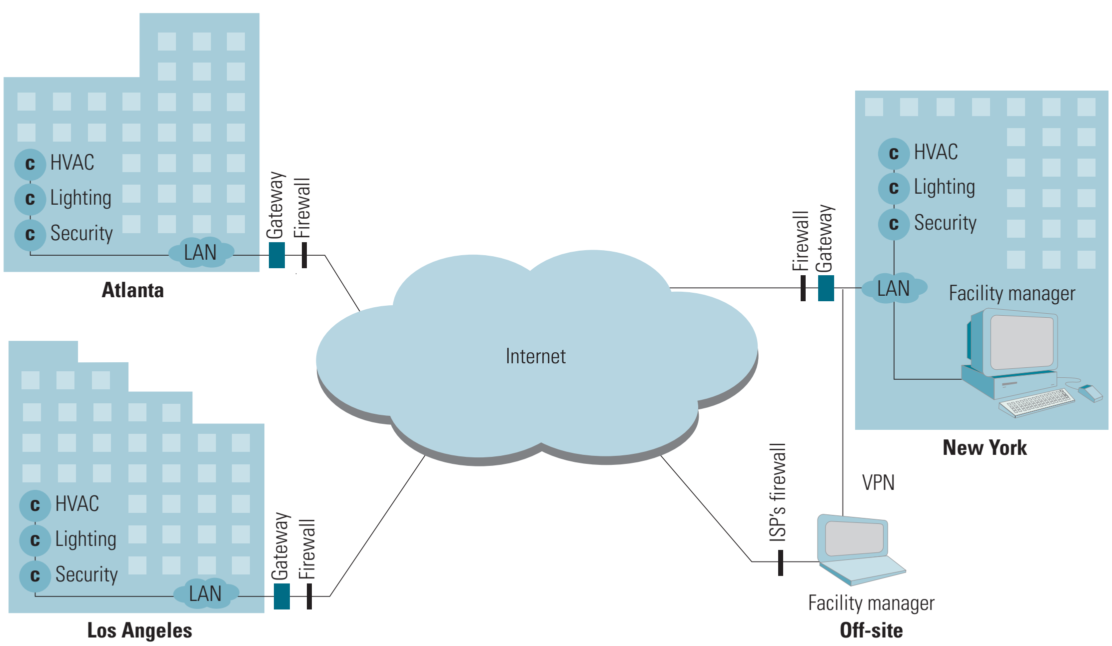
Web Browser Interface for Networked Building Control

The introduction of web browser interfaces may be the most exciting development in automation since DDC. A web browser is a piece of software that allows a user to access and view resources across the Internet. The ability to manage a facility using a web browser leverages the power of the Internet to network the EMSs for multiple buildings so that they can be controlled from one location (see **Figure 6**). It may also allow the EMS to communicate with other computer applications, such as online weather forecasting services. The concept of enterprisewide management for facilities throughout the world is exciting, including such possibilities as managing HVAC control for building comfort, maintaining fire safety, ensuring physical safety or security, or boosting an enterprise's buying power. For example, with the help of an EMS, procurement of electricity in a deregulated world can become a real-time, dynamic activity. The development of a computer language called XML may also help to boost the use of the Internet for building control (see sidebar).

Web browsers also offer some simple and pragmatic benefits for building automation. The proprietary hardware and software that was once necessary for a conventional system interface is no longer needed. The same off-the-shelf technology used to surf the Internet can now serve as the controller interface, opening up the

Figure 6: How a web browser interface works

Controllers embedded in lighting, HVAC, and security equipment communicate with each other via a local area network. Each building is then connected to the Internet through a gateway that is protected by a security firewall. Because these networked building systems offer remote-control capabilities, facility managers can monitor and control their buildings from any location with a web connection. They can also manage multiple sites simultaneously or aggregate them for load control.



Notes: ISP = Internet service provider; LAN = local area network; VPN = virtual private network.

Courtesy: Platts

system to any user with a computer and a web browser. However, it *is* necessary to build firewalls and ensure that security is maintained. Through the web, building owners or operators can combine the power of automated controls with data from the world at large to create an effective building management tool.

Case Study: Networked Building Control Cuts Costs

In 2001 the Lafarge Building Materials cement plant in Ravena, New York, installed a new networked building control system in which the EMS is connected to a local area network and to the Internet.

XML: An Emerging Standard

Many of the technology companies involved in data exchange over the Internet have developed a language called XML (Extensible Markup Language). XML is emerging as the standard language for data exchange in many business sectors and is starting to gain attention in the field of building automation.

XML is similar to HTML (Hypertext Markup Language), the language used to create the web pages that you see in your web browser. XML uses tags, much like HTML data tags, to record the relationships among the data elements in a file. The data in an XML file can associate a device, such as a controller, with numerous objects such as points, messages, and alarms. A computer reading the file would be able to "understand" the physical capabilities of the objects and configure the system accordingly. By contrast, the same data written with HTML would associate a list with the controller, but it would not enable the computer to interpret the relationship between the controller and the items in the list.

By supporting XML for building automation, manufacturers give their customers the flexibility to configure the system on their own, use a configuration package from another manufacturer, or use a third-party software package that supports XML as a file format. Examples of the latter include Microsoft Excel and Microsoft Access. Because Microsoft is freely distributing its XML software engine, it's much easier for manufacturers, software developers, or users to create custom applications that read and write XML data, possibly even reading proprietary configuration data files and exporting them in standard XML format. In the future, the use of XML may allow energy management systems to seamlessly communicate with other nonphysical systems such as accounting and scheduling packages.

XML is emerging as the standard language for data exchange in many business sectors and is starting to gain attention in the field of building automation.

During peak demand periods for the New York independent system operator (ISO), the system allows facility managers to implement load reduction while maintaining some production. Lafarge temporarily shuts down its crushing mills (which use very large amounts of electricity) and instead makes use of stockpiled, previously crushed materials in its kiln operations. Lafarge can shed up to 22 megawatts of demand on just one hour's notice. The reductions typically last for four to five hours.

Lafarge has found networking its controls to be a cost-effective method for demand response—the cost has worked out to about $12 per kilowatt.

Don Britt, an electrical engineer at Lafarge, says that in the early days, it took several hours to shut down mills and to document the power reduction.[10] His team had to read meters at regular intervals during the shutdown and calculate the kilowatt-hours shed based on the number of pulses. A five-hour shutdown took about five man-hours to manage. Now it takes about five minutes, and Lafarge gets accurate data on the power saved.

Because the EMS is tied into the Internet, Lafarge is also able to see accurate power cost data. Britt says, "We know what the cost of electricity during each hour of the day and each day of the week will be. For example, if on Wednesday power prices average 100 percent more than on Sunday, we'll schedule maintenance on machines for Wednesday."

The cost of electricity amounts to about 20 percent of Lafarge's cement selling price. So in March 2003, when the price of power rose to more than 20 cents per kilowatt-hour (normal is about 6 cents) during parts of the day, Lafarge simply shut down machines, because it was too costly to run them. That knowledge wasn't available with the old system.

Lafarge has found networking its controls to be a cost-effective method for demand response—the cost has worked out to about $12 per kilowatt. The new system has also enabled Lafarge to receive incentive payments every time the New York ISO asks the company to shed load. In 2001 and 2002, those payments totaled more than $1.5 million.

Specifying EMS Features for Energy Efficiency

Under tight, competitive conditions, contractors include features only if contract documents specifically require them to do so. Any vagueness or omissions by the designer may result in costly change orders. Changes to control features made during the design phase may have little or no effect on cost, but if left until construction, those same changes can be disproportionately or prohibitively expensive.

Effective EMS specifications share three key characteristics:

- *Clarity.* The specifications must be clear and understandable.
- *Accuracy.* The specifications must be correct and describe a system that will actually perform its intended functions.
- *Provision of performance criteria.* The specifications must describe a methodology for determining whether the system has been installed and is operating as intended.

Specifications are most effective when they provide clear and complete information about the design intent, the control strategies, the form and capabilities of the EMS itself, as well as the responsibilities of the project team. Specifications are also easier to follow when they describe how a strategy will be implemented rather than simply stating that the system is to be "capable of" a given strategy.

In one project, the designer was vague in specifying whether the packaged rooftop unit provided by the mechanical contractor or the central EMS provided by the controls contractor would be directly responsible for providing the supply air reset and optimum start functions. Later, the designer, contractors, project manager, commissioning provider, and owner spent hundreds of dollars and significant time before they were able to determine who the responsible party was. Ultimately, the controls contractor was required to provide those features.

Specifications are also easier to follow when they describe how a strategy will be implemented rather than simply stating that the system is to be "capable of" a given strategy.

Narrative about design intent is needed from the architect so the design engineers can design systems and write specifications.

Include Documentation About Design Intent

Design intent consists of the ideas, concepts, and criteria that the building owner wants for the facility. This information is often underdocumented by controls designers. A typical practice is to create building contract documents that simply state what to install and what the initial settings should be. In many situations, this does not provide the information required for performance verification before turnover, nor does it provide for good operations and maintenance after occupancy. **Figure 7** shows how important system information generated during design and construction is often lost at each stage of the building process, making it unavailable to others during subsequent stages of building delivery and occupancy.[11]

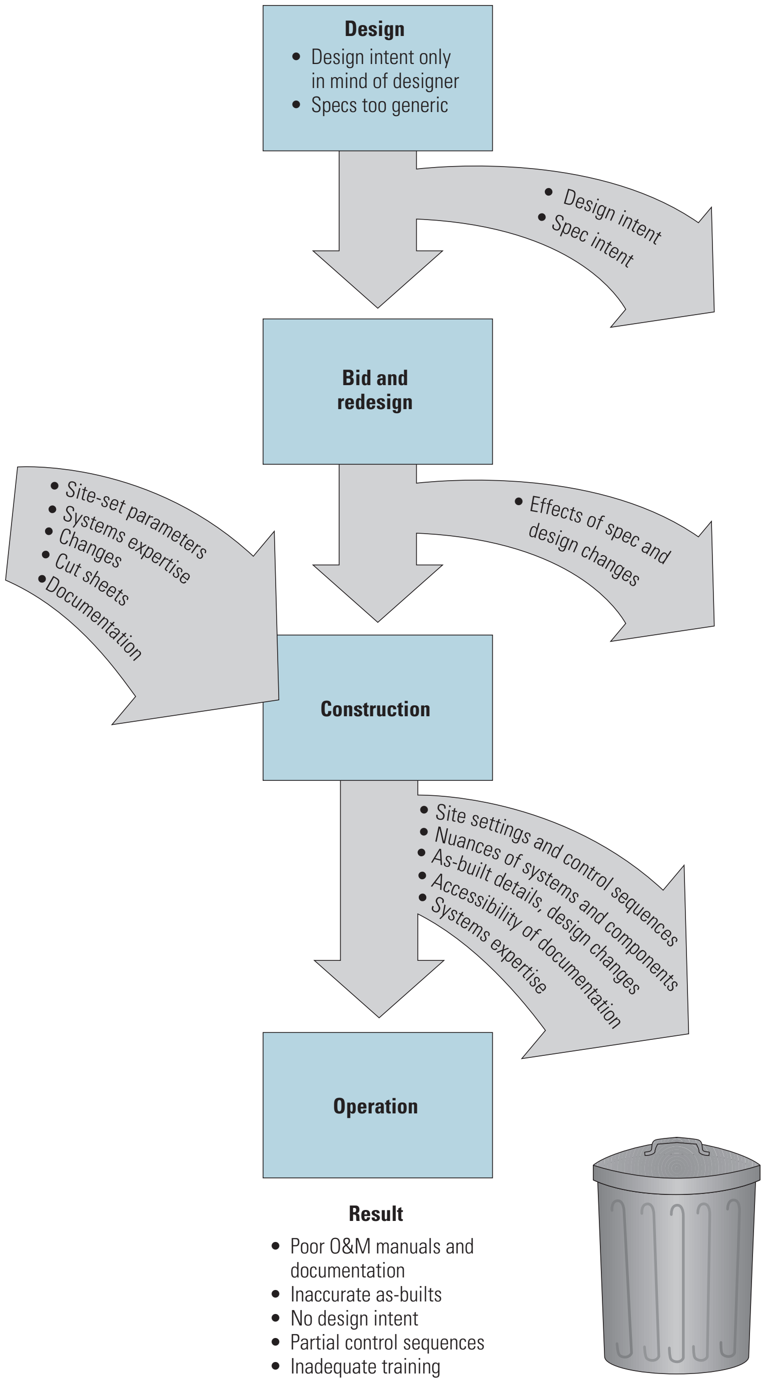
Narrative about design intent is needed from the architect so the design engineers can design systems and write specifications. It is needed from the design engineers and the architect so that building contractors and technicians can properly interpret other construction documents to build the system. Final design intent is needed from the building contractors and designers so that the building operator and maintenance contractors can properly maintain the systems over time.

Part of the solution to the problem of lost information is for the designer to fully document the design intent, even the aspects that seem basic or unnecessary. Basic items that should not be overlooked include a narrative description of a building system, what the objectives of that system are, how that system will meet those objectives, how that system interrelates with other systems, and why that system or control strategy was chosen, if it is nontraditional. Documenting design intent is especially important for energy-efficiency strategies, because many strategies—especially the more innovative ones—can be easily misunderstood.

Preparing a good design intent document for a given system is the job of the designer responsible for that system. The task

Figure 7: Information losses during the building process

Without full documentation of design intent, key information is lost.



Courtesy: Platts; adapted from Karl Stum [11]

It is economically sensible to use conventional thermostats on equipment that consumes a small amount of energy, such as a unit heater in a mechanical room.

requires some effort, because the document is dynamic, changing over time as adjustments are made and the design becomes more concrete and more detailed. The designer may consider the following important issues and questions when developing narratives about EMS design intent. Although many of these questions will eventually be answered in the specification, the specification does not yet exist when these questions should initially be documented.

- Briefly describe the system; why was it was chosen over other types?
- Review other sections of the specifications (mechanical and electrical) to verify that redundant controls are not being specified and that interfaces from this equipment to the EMS are properly specified.
- Clarify whether the actuators are pneumatic or electronic and determine where conventional electronic thermostats should be used. It is economically sensible to use conventional thermostats on equipment that consumes a small amount of energy, such as a unit heater in a mechanical room.
- What are the user-interface features (color, permanent CPU and terminal, laptop, keypad only, and so on)?
- What are the limitations of included modules as compared with their high-end counterparts?
- List all equipment that interfaces with the EMS; does the EMS control it fully or only partly? Enable or disable only? Monitor only?
- Provide a complete list of energy-conserving features and strategies.

Provide Full Sequences of Operation

Just as design intent documentation is often incomplete, sequences of operation may also be overlooked. The sequence of operation consists of the actual commands and actions that an EMS carries out—performing calculations, opening valves, moving actuators, and so on. Providing a full written set of sequences of operation for equipment is a key factor in realizing optimal energy efficiency. Sequences of operation are required by the controls vendor to program and set up the system, by the commissioning provider to test equipment performance, and by facility staff to efficiently operate and troubleshoot the system.

Providing a full written set of sequences of operation for equipment is a key factor in realizing optimal energy efficiency.

In extreme cases, sequences of operation are simply not included. More commonly, they are vague and incomplete. A designer can address this problem by including clear and detailed sequences in the specifications. It may take more of the designer's time initially, but that effort will likely prove worthwhile down the road when the controls programmer requires fewer clarifications from the designer. The designer's time reviewing controls submittals will also be reduced, as he or she will not have to tediously evaluate new detailed sequences for proper interpretation of the specifications. And, if the designer provides detailed sequences up front, when the startup and operation phases begin, there is less chance that systems will malfunction and require even more time from the designer for troubleshooting. Good sequences can ensure that designers' expertise and effort in energy-efficient strategies are correctly implemented.

For example, this is a poor sequence of operation:

> ***Supply Air Temperature Control.*** When appropriate for free cooling, the outside air dampers will open. The supply air temperature will be maintained at a setpoint, reset based on outside conditions.

This sequence is vague and ambiguous. When is it appropriate to use free cooling? Will dampers open fully? Will the dampers be allowed to be fully open when the compressor or chilled water valves are open, or will they go back to minimum? What is the reset schedule? A better sequence is as follows:

> ***Supply Air Temperature Control.*** The air-handler supply air temperature will be maintained at a setpoint, proportionally reset based on outside air temperature, according to the following user-modified schedule: If outside air is 45°F or less, supply air temperature is 62°F. If outside air is 85°F or more, supply air temperature is 55°F.
>
> The first stage of cooling will be the outside air economizer. When the outside air temperature is less than two degrees lower than the inside air temperature (sensed in the return air duct), the economizer will be enabled, and outside air and return air dampers will modulate together to maintain the supply air setpoint. When the outside air is equal to the return air temperature, the economizer is disabled and the outside air dampers return to minimum. When the economizer is unable to maintain the supply air temperature setpoint, the cooling coil chilled water valve modulates open, using a proportional-integral control loop to maintain the supply air setpoint. The economizer remains enabled if outside conditions permit.

Fifteen percent of the buildings studied were actually missing specified equipment.

Commissioning Energy Management Systems

Because commercial buildings and their control systems have become so complicated, building industry professionals need to take a new and comprehensive approach to quality control. For example, a 1997 study of 60 commercial buildings found that more than half suffered from control problems. In addition, 40 percent had problems with HVAC equipment, and one-third had improperly operating sensors. Fifteen percent of the buildings studied were actually missing specified equipment. And approximately one-quarter of them had EMSs, economizers, or variable-speed drives that did not run properly.[12]

In response to these types of problems, the commissioning process has evolved as a means to ensure that systems are delivered and operated as intended. Commissioning can be defined as a systematic process to ensure that all building systems perform interactively according to the documented design intent and the owner's operational needs.[13] Commissioning is now required for some buildings, such as some public institutions and LEED-certified buildings.

The commissioning process ideally begins in the design phase of a project. At that stage, a commissioning plan is written. Later, commissioning requirements are incorporated into the project specifications. During construction and installation, the EMS may be inspected. Before the building is occupied, the EMS is rigorously tested to demonstrate that it operates as intended. The commissioning process concludes when the building operators are thoroughly trained to maintain the EMS. Building systems are then recommissioned periodically to ensure that they will continue to perform at optimum efficiency throughout the life of the building.

The commissioning process ideally begins in the design phase of a project.

Building owners and designers can do three things to support a successful EMS commissioning process: select an able commissioning provider, incorporate commissioning requirements into the specifications, and ensure that the EMS is fully tested.

Select a Commissioning Provider

The commissioning of an EMS should be managed by an objective engineer who has experience with the commissioning process. Ideally, this commissioning provider will be hired as early as possible in the design phase so that the overall project can benefit from the provider's expertise. Over the course of the project, the commissioning provider reviews design documents, helps with specification writing, designs commissioning tests, observes the commissioning tests as they are carried out, and assists with operator training.

The EMS designer may act as the commissioning provider, overseeing the commissioning process. More often, though, Commissioning specifications will be more effective if they are very specific.

the owner selects an independent party to ensure objectivity. Either way, it is a good practice for the owner to hire an experienced commissioning provider who offers verifiable references and who has successfully completed projects involving EMS installations of similar scope and purpose.

Incorporate Commissioning into the Specifications

Commissioning is a fairly new practice, and specification writers may not have experience with commissioning requirements for EMS project specifications. Any vague specification is problematic. If the contractor interprets vague requirements differently than the owner and designer intended, disputes may arise during the project, or the project may not be adequately commissioned. Commissioning specifications will be more effective if they are very specific.

For example, a vague commissioning specification as commonly written by a controls designer might require that the contractor "conduct a point-to-point demonstration" as part of the commissioning and "provide the documentation to the commissioning provider." This specification does not say whether all points should be demonstrated; if a random sample is allowable and, if so, how big it should be; who should witness the tests; what acceptance criteria will be used; and who is responsible for retesting should failures occur. In addition, it does not mention the commissioning process. If these specifications were used for a project, the contractor might disagree with the owner on what constitutes a point-to-point demonstration and may not budget correctly for the intended work.

For commissioning to be most effectively included in an EMS project, the various commissioning activities must be fully integrated into the specifications. Important topics to include are the general roles and responsibilities of the project team, installation and initial checkout procedures, functional test requirements, training procedures, and documentation requirements.

Sample commissioning specifications are available from Energy Design Resources' Commissioning Assistant, a web-based tool designed to provide project-specific building commissioning information to design teams (see "For More Information" on page 32).

Carry Out the Commissioning Tests

The process of commissioning introduces a higher level of rigor in the testing of the EMS, both at installation and afterward. Traditionally, EMSs are checked out at the time of installation following vendor-provided checklists and procedures. Although installation checks ensure that all the equipment is wired up properly, they often do not reveal the entire picture of whether the system is fully operational. Functional commissioning tests do. For example, the initial checkout of the EMS control of the chiller may indicate that all valves are opening and closing on command, but it will not give a definitive answer on whether the chilled water reset strategy is functioning properly. In contrast, functional tests step the EMS through its sequences of operation, a process that usually reveals any problems that may be occurring in the software and programming or in the hardware and sensors. In particular, the performance of all open communications system components should be compared with the published and submitted manufacturer's performance data. For systems using the BACnet standard, protocol implementation conformance statements (PICS) should be submitted before construction to ensure compatibility at all appropriate levels.

Although installation checks ensure that all the equipment is wired up properly, they often do not reveal the entire picture of whether the system is fully operational. Functional commissioning tests do.

It is possible to find many standard functional tests that describe requirements and procedures for various equipment, including energy management systems, and that are available for public consumption. (See "For More Information" on page 32.) This is a good starting place for developing rigorous testing procedures, but in many cases it is necessary for a commissioning provider or other expert to customize these tests to more exactly match the technical requirements of the project.

The recommissioning provider checked, recalibrated, and in some cases relocated key sensors.

Case Study: Recommissioning

From 2002 to 2004, the building operations team at Alamo Community College District in San Antonio, Texas, recommissioned the buildings at three of its major campuses. The recommissioning included the following adjustments to the EMS:

- *Air-handling unit temperature resets.* The commissioning provider reset the supply air and the cold/hot deck temperature setpoints to reduce simultaneous heating and cooling.
- *Sensor calibration and repair.* The recommissioning provider checked, recalibrated, and in some cases relocated key sensors. These included the outside air temperature sensor, the air-handling unit cold and hot deck temperature sensors, and duct static pressure sensors.
- *Improved start/stop schedules.* To minimize runtime, the commissioning provider optimized the start/stop schedules of air-handling units using occupancy data collected from a room-to-room survey.
- *VAV box calibration.* The provider evaluated minimum and maximum VAV box airflow settings and properly adjusted them according to current occupant density and occupancy schedules. The provider also repaired and replaced broken DDC and pneumatic box controllers.

The budget for the overall recommissioning project was $834,170. It succeeded in reducing the college's total annual energy costs at the three campuses by at least 13 percent, or $315,000.[14]

EMSs and LEED

EMSs play a role in the Leadership in Energy and Environmental Design® (LEED) rating system created by the U.S. Green Building Council (USGBC) to accelerate the development and implementation of green building practices. The USGBC is a nonprofit organization founded to promote the construction of environmentally responsible buildings. It established LEED to serve as a brand for high-performance buildings and to provide a common standard for measuring the sustainability, or "greenness," of a building.

A building earns a LEED rating (Certified, Silver, Gold, or Platinum) based on how many points it earns in the following categories: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Material & Resources, Indoor Environmental Quality, and Innovation & Design Process. EMSs play a role in LEED in a number of these categories.

EMSs are capable of measuring and maintaining the minimum ventilation rates required for acceptable indoor air quality.

Energy & Atmosphere

- *Prerequisite 1: Fundamental building systems commissioning.* EMSs must be commissioned to function properly.
- *Prerequisite 2: Minimum energy performance.* All LEED buildings must meet either the local energy code requirements or the provisions of ASHRAE/IESNA Standard 90.1-1999, whichever is tighter. (Note: The next version of LEED will be based on the 2004 version of Standard 90.1.) In addition, the more efficient a building is, the more points it will be awarded, up to an additional 10 points. Although EMSs are not called out specifically, they are crucial to the energy performance of a whole building.
- *Credit 5: Measurement & verification.* This credit requires that a building incorporate submetering to confirm energy savings. This can be done with permanently installed metering equipment that is integrated with an EMS.

Indoor Environmental Quality

- *Prerequisite 1: Minimum IAQ performance.* EMSs are capable of measuring and maintaining the minimum ventilation rates required for acceptable indoor air quality.
- *Credit 1: Carbon dioxide monitoring.* EMSs are necessary to achieve this credit, which requires permanent monitoring of carbon dioxide levels for control of ventilation airflows.

- *Credit 7.2: Thermal comfort.* This credit requires that a building have a permanent system for temperature and humidity monitoring that allows building operators to control HVAC systems for comfortable thermal and humidity conditions. An EMS is the traditional choice for achieving this goal.

Innovation & Design Process

- This is a general category in which innovative EMS approaches that advance the state of the art or provide a benefit that is not already rewarded under existing LEED points may receive credit.

It is important to note that LEED is a rating system, not a "how-to" manual for sustainable design. Therefore, when planning to achieve LEED certification, it is important to design a sound building first, and then see where LEED points may be available.

For More Information

To learn more about EMSs, BACnet, and LEED, consult these resources:

- News about the large building automation industry, www.automatedbuildings.com.
- ANSI/ASHRAE Standard 135-2004, "BACnet—A Data Communication Protocol for Building Automation and Control Networks," www.bacnet.org.
- USGBC, "LEED Green Building Rating System for New Construction and Major Renovations," known as LEED-NC, version 2.1 (first released in November 2002, revised on March 14, 2003).

Several good sources for sample EMS specifications are available. The following are some examples:

- Automated Logic Corp., CtrlSpecBuilder, www.ctrlspecbuilder.com.
- American Institute of Architects & ARCOM, Masterspec, "Master Specification System for Design Professionals and the

Building/Construction Industry,"
www.arcomnet.com/visitor/masterspec/ms.html.

- ASHRAE, "Guideline 13-2000, Specifying Direct Digital Control System," Atlanta, GA, 404-636-8400, www.ashrae.org.
- Construction Sciences Research Foundation, Spectext, "Master Guide Specifications," www.spectext.com.

In addition, the following guidebooks contain information about control strategies, and some include sample EMS and commissioning specifications:

- Building Services Research and Information Association, "Library of System Control Strategies," www.bsria.co.uk/bookshop/system/index.html.
- National Building Controls Information Program, DDC-Online, www.ddc-online.org.
- "Energy Management Systems: A Practical Guide," prepared for the U.S. Environmental Protection Agency by Portland Energy Conservation Inc. (PECI), Portland, OR (October 1997), available from www.peci.org.

For information on commissioning, see the following sources:

- ASHRAE, "Guideline 1-1996, The HVAC Commissioning Process" (1996), Atlanta, GA, 404-636-8400, www.ashrae.org.
- PECI and U.S. Department of Energy, "Model Commissioning Plan and Guide Specifications" (1997), available from www.peci.org.

Energy Design Resources' Commissioning Assistant can be found at:

- Energy Design Resources, "Cx Assistant Commissioning Tool," www.ctg-net.com/edr2002/cx/default.aspx.

Notes

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2 DOE, Energy Information Administration, "Commercial Buildings Energy Consumption Survey" (April 1994), p. 11.

3 David N. Wortman, Evan A. Evans, Fred Porter, and Ann M. Hatcher, "An Innovative Approach to Impact Evaluation of Energy Management System Incentive Programs," *Proceedings, American Council for an Energy-Efficient Economy Summer Study* (August 1996), pp. 6.163–171.

4 Portland Energy Conservation Inc. (PECI), Portland, OR, 503-248-4636, contact@peci.org.

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6 "Energy Management Systems: A Practical Guide," prepared for U.S. Environmental Protection Agency by PECI, Portland, OR (October 1997).

7 "Energy Management Systems: A Practical Guide" [6].

8 Karl Stum, "Using Energy Management Control Systems for HVAC Operational Diagnostics," *Proceedings, Eleventh Symposium on Improving Building Systems in Hot and Humid Climates* (June 1998), pp. 209–210.

9 "VAV System Optimization, Critical Zone Reset," *Trane Engineering Newsletter,* v. 2, no. 2 (1991).

10 Donald Britt (April 13 and June 14, 2003), Electrical Engineer, Lafarge North America, Ravena, NY, 518-756-5075, donald.britt@lafarge-na.com.

11 Karl Stum, "Commissioning During the Design Phase," *Proceedings, Fourth Energy-Efficient New Construction Conference* (September 1996), p. 211.

12 "Commissioning for Better Buildings in Oregon," prepared for Oregon Office of Energy by PECI, Portland, OR (March 1997).

13 “Commissioning for Better Buildings,” prepared for Florida Power & Light by PECI, Portland, OR (October 1996).

14 M. Verdict et al., “The Business and Technical Case for Continuous Commissioning® for Enhanced Building Operations,” presentation at the Fourth International Conference for Enhanced Building Operation, Paris, France (2004).

Energy Design Resources provides information and design tools to architects, engineers, lighting designers, and building owners and developers. Energy Design Resources is funded by California utility customers and administered by Pacific Gas and Electric Co., San Diego Gas and Electric, Southern California Edison, and Southern California Gas, under the auspices of the California Public Utilities Commission. To learn more about Energy Design Resources, please visit our web site at www.energydesignresources.com.

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