Building Automation Systems

The building automation system (BAS) has become the accepted technology used in controlling HVAC and other systems in most new commercial and institutional buildings (Figure 1). Existing buildings can be retrofitted with BASs, a change that has been shown to provide economically beneficial improvements in energy efficiency and occupant comfort. Although most BASs are designed primarily for HVAC control, many incorporate additional functions, such as lighting control, computerized maintenance scheduling, life-safety functions (such as smoke control), and access (security) control.

Figure 1: How building automation systems fit together

A building automation system (BAS) consists of sensors, controllers, actuators, and software. An operator interfaces with the system via a central workstation or web browser.
Building automation systems, which are present in more than half of all buildings in the U.S. larger than 100,000 square feet, save between 5 and 15 percent of overall building energy consumption. Generally, BASs are most cost-effective in buildings that consume lots of energy, such as data centers and hospitals. Older or poorly maintained buildings can also benefit greatly from a BAS retrofit, sometimes yielding savings of over 30 percent.

In addition to saving energy, BASs can reduce overall building maintenance costs by identifying operational problems early and often. For example, BASs can collect data from multiple zones around a building and display it on the system’s front-end computer. This enables the building operator to monitor and access the data to diagnose an operational problem rather than deploying a maintenance crew to search for it.

Unfortunately, many building automation systems save less energy than they could if set up optimally. In one detailed study of 11 buildings in New England with BASs, five of the buildings were found to be underachievers, producing less than 55 percent of expected savings. One site produced no savings at all.

To improve the likelihood that your BAS will achieve the expected benefits, you should take advantage of advanced control strategies that use the computer-processing power of a BAS.
and adopt a comprehensive approach to quality control known as commissioning. This process is now required for some buildings, such as public institutions and buildings certified by the U.S. Green Building Council’s LEED (Leadership in Energy and Environmental Design) program. Commissioning includes reviews and inspections throughout the design and construction process as well as rigorous performance tests that move the system through its sequences of operation before the building is occupied. Commissioning concludes when the building’s systems are working as planned and the operations team is thoroughly trained in using all of the system’s features.

It’s also important to ensure that a BAS continues to work properly over time. Recommissioning—in which building operators use trending and energy consumption data to periodically verify, document, and improve a building’s operation—can be conducted throughout the life of the building.

WHAT ARE THE OPTIONS?

There are many decisions that designers face when specifying a BAS, including:

- What control strategies to implement;
- Extent of the control to be provided by the BAS;
- Type of communications protocols to utilize; and
- Use of a web browser interface and Internet communications.

Energy-saving control strategies

Here is a list of the most common strategies that building automation systems employ in order to use energy more efficiently.

**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 effective measures for saving energy in commercial buildings. A feature called "Optimum Start," offered by all BAS manufacturers, can increase energy savings by automatically starting a system no
earlier than necessary based on daily variations in the weather.

**Lockouts.** Lockouts ensure that equipment does not come on unless necessary. They protect against nuances in the programming of the control system that may inadvertently cause equipment to turn on. For example, a chiller and its associated pumps can be locked out according to a calendar date, when the outside air falls below a certain temperature, or when building cooling requirements are below a minimum.

**Resets.** HVAC systems typically use less energy when their operating parameters are adjusted to meet the building load. Because this load varies with the weather, a BAS can help equipment to operate at greater efficiency levels by automatically varying these operating parameters. The simplest approach is to use a proportional reset schedule based on outdoor temperature (**Figure 2**). Although that method works reasonably well, a more effective method is to base resets directly on building loads (**Figure 3**). Examples of building control parameters that can be reset include supply-air and discharge-air temperature for fan systems that use terminal reheat, hot-deck and cold-deck temperatures for multizone HVAC systems, and heating-water supply temperature.

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**Figure 2: Proportional reset schedule**

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

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**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.
Direct digital control (DDC). All modern BASs use DDC technology—solid-state sensors and controllers that control valves, dampers, and other system components. Until the 1980s, pneumatic controls, which operate using compressed air, dominated the market. But pneumatic systems are more prone to failure and require more calibration and maintenance to ensure a clean and dry source of compressed air for controlling components such as actuators.

DDC systems also use a more advanced control algorithm called PID (or proportional-integral-derivative) that can be implemented in the BAS’s computer code. Due to the complexity of this algorithm, older pneumatic or electronic controls used only the proportional form of this control technique, which is known for its inability to reliably maintain the temperature setpoint. If applied properly, PID can both save energy and provide improved comfort. However, note that proper implementation of a PID control algorithm is a complex process that is best left to experienced professionals.

Demand limiting. Because electrical demand charges can comprise 40 percent or more of a utility bill, many building automation systems can benefit from demand-limiting or load-shedding functions. For example, when the demand on a building meter or piece of equipment, such as a chiller, approaches a predetermined setpoint, the BAS does not allow the equipment to load up any further. In buildings with electric heat, electrical demand charges can be reduced if the heat is staged on in the morning over a several-hour period starting with the coldest spaces first. Other demand-limiting strategies are expected to be developed as utilities implement time-of-day or real-time electrical pricing in their rate structures.

Diagnostics. Building operators who use a BAS to monitor information such as

![Chart showing chilled water supply temperature and open valves](image-url)
temperatures, air and water flows and pressures, and actuator positions may use that data to determine whether equipment is operating incorrectly or inefficiently and to troubleshoot problems. A thorough job of building diagnostics typically requires the building operator to monitor more points than the minimal number needed to simply control a building, but a modern BAS gives users a good head start on a recommissioning or ongoing commissioning program. A modern BAS helped personnel from Texas A&M's Energy Systems Laboratory to cut energy bills at a state office building by 27 percent. The BAS helped to implement nighttime shutdowns and chart actual building temperatures to identify opportunities for temperature setback during unoccupied hours.

Extent of control provided by the BAS

A major BAS design issue for both new and existing buildings is the extent of control provided by the BAS. This issue is handled differently for new buildings than for BAS retrofits in existing buildings:

**New buildings.** HVAC equipment is often packaged with temperature controls provided by the equipment manufacturer. In many cases, these controls are a necessary part of the equipment and cannot be removed (for example, boiler and chiller operating controls and safety limits). In this case, the BAS can still provide a certain amount of control that will improve the efficiency and comfort of the building. For example, a BAS usually provides chiller, pump, and cooling tower staging for plants with multiple chillers. The BAS can also reset the chiller's operating parameters and monitor other chiller operating conditions. Note that boiler and chiller manufacturers sometimes provide their own "central plant" control systems. These are usually not recommended because they diminish the BAS's capability to perform energy-efficient control and provide diagnostics.

Manufacturer-provided controls for other equipment (for example, air handling units [AHUs], rooftop units, and variable air volume (VAV) boxes) are usually optional. The advantage of using manufacturer-provided controls is that it reduces project costs and can often provide better control (because the controls are designed around the equipment). The disadvantage is that a communications protocol connection to this equipment will be needed to fully allow the BAS to perform energy-efficient supervisory control and provide diagnostics. Even with this communications connection, the manufacturer controls sometimes do not allow the BAS to adequately perform the necessary supervisory control. Because of this, many designs involve the field-installation of BAS controls on HVAC
system components.

**Existing buildings.** Existing buildings with older conventional controls (for example, pneumatic and/or electronic controls) present a different design challenge. The existing hardware may limit the extent to which the BAS can provide system control. This challenge is due to the payback associated with the cost of replacing conventional controls versus the energy-savings benefit provided by the BAS. As a general rule, the use of a BAS to replace existing conventional controls for central equipment (for example, boilers, chillers, and AHUs) usually results in a short energy-savings payback (under five years). On the other hand, replacing conventional controls (typically a pneumatic thermostat) on terminal HVAC equipment (typically VAV boxes or reheat coils) usually involves energy-savings paybacks that can be in the 10-to-20-year range. Note that the improved comfort of building occupants and enhanced ability to monitor, understand, and diagnose malfunctions in the HVAC system often provide value above and beyond the energy savings that a BAS offers.

In general, BASs that provide full DDC (Figure 4) offer many more benefits over systems that use manufacturer-provided controls or depend on older, conventional controls.

**Figure 4: Direct digital controls field panel**

This panel controls a large air-handling unit.

![Direct digital controls field panel](image)

Courtesy: Portland Energy Conservation Inc.

Communications protocol

Two major communications choices are available: proprietary and open (or standard).

**Proprietary communications protocols.** Some BAS manufacturers use proprietary protocols that will communicate only with their own control equipment. These protocols may also be
used on HVAC equipment manufacturer’s controls that, with the explicit permission from a BAS manufacturer, were designed to communicate with the BAS. Proprietary systems may allow backward or forward compatibility with equipment generations of the same manufacturer, but they don’t allow ready intercommunication with other brands of BASs. Many manufacturers sell gateway devices, which convert one communications protocol to another to increase the compatibility of their components with other manufacturer’s components, but these gateways are expensive.

Systems that rely on proprietary communications are rapidly disappearing from the marketplace. Because a proprietary system does not communicate with other systems, the user’s options for expansion of the BAS are limited. Choices are also reduced for the purchase of new equipment, which 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 protocols.** Open communications systems are based on published protocols that are available to all manufacturers. For building automation, BACnet and LonWorks are the two primary choices for open communications. Although these protocols differ in the approach that they use to achieve interoperability—the ability of controllers to work together in an integrated fashion—both have been successful at creating interoperable systems. BACnet was created by ASHRAE (the American Society of Heating, Refrigerating, and Air-Conditioning Engineers) to provide a standard protocol that all manufacturers could use. LonWorks was developed by Echelon Corp., a control networks manufacturer, for similar reasons, but LonWorks requires that a proprietary chip be embedded in all control devices used in a LonWorks network. Currently, BACnet appears to be the dominating open protocol in the building automation market. To compare the advantages of each open protocol standard for a given system design, seek assistance from a building controls designer.
There are several advantages to using an open communications protocol for a BAS. First, there is the assurance that equipment from multiple manufacturers will be able to interact. Using BACnet products that have been listed by BACnet Testing Laboratory ("BTL listed") ensures that they have been tested to confirm compliance with BACnet standards. Using equipment with open protocols also creates a competitive bidding environment for system additions and renovations, which helps to limit costs. This situation also helps keep manufacturers that have on-site equipment from becoming too comfortable and ensures a good level of service and response to problems.

Another advantage is the containment of expenses associated with interfacing the BAS to mechanical equipment. For example, it is normally difficult to extend the features of a BAS with proprietary communications to monitor temperatures, pressures, and flows of a new chiller. If all additions to a system are specified as open protocol, however, interfacing becomes easier and less expensive.

The use of open protocols also reduces the need to run multiple software packages on the BAS workstation or to utilize specialized interface equipment to communicate with devices using different protocols. The result is lower system costs and training expenses, fewer maintenance agreements and spare parts, and a single mode of system access.

**Web browser interface and Internet communications**

The introduction of web browser interfaces is the most important BAS development since the introduction of open communications protocols. Web browser capability is available via a software package (which usually runs on a dedicated web server) or may even be built into the highest-level controllers provided with a BAS. It allows a user to access and view the BAS through the Internet using a computer that is running web browser software. Users can take advantage of this capability to monitor and control the BASs in multiple facilities from a single computer (see Figure 5).

**Figure 5: 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
Connecting a BAS to the Internet allows it to communicate with other computer applications such as online weather-forecasting services. The concept of enterprisewide management for facilities throughout the world is exciting, whether it concerns the management of HVAC control for building comfort, fire and physical safety, security, or buying power. Procurement of electricity in a deregulated world, for example, can become a real-time, dynamic activity facilitated by the BAS. Use of an Internet communications protocol called XML may also help to boost the use of the Internet for building control (see sidebar, "XML: An Emerging Standard").

**XML: AN EMERGING STANDARD**

Many of the technology companies involved in data exchange over the Internet have developed custom Internet applications using the Internet protocol called XML (Extensible Markup Language). XML has emerged as the standard protocol for data exchange in many business sectors and has gained 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 can view using your web browser. The XML technology 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 will 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, such as 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.

Due to the popularity of the Internet and XML applications, new standards are emerging that simplify the use of XML communications in BASs. ASHRAE recently published an extension to the BACnet standard that defines how BACnet protocol information can be communicated using XML (the associated tools called "Web Services"). Concurrently, an organization known as CABA (the Continental Automated Building Association) has developed a building automation-oriented protocol called oBIX that also utilizes XML. As these new standards see wider use, more and more aspects of building automation communications will undoubtedly migrate to use of the Internet. Further, the use of XML may allow building automation systems to seamlessly communicate with business enterprise software, such as accounting and business scheduling (for example, Outlook) packages.

HOW TO MAKE THE BEST CHOICE
Clearly define goals for the BAS. Begin by talking to a variety of consultants and controls vendors. This process will provide the education you need to properly define your goals and needs and then match them with a good performance specification.

Today the choice of standards and communications protocols dominates discussions about system selection and should be considered in light of system goals. Owners want an easy-to-use, single-seat interface (such as a personal computer) for the access and sharing of 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 "interoperability," which means that controllers can work together in an integrated fashion. It requires that they operate as a unified system—a result that is not ensured simply by specifying standard communications. In other words, focus on specifying performance, not protocol.

By carefully considering the goals and objectives for the BAS, it will be possible to determine to what degree open communications protocols are important and whether gateways or other networking technology will be required in order to combine existing equipment with the new system. Take time to understand and ensure that all the networking and control equipment is compatible, will interact in the manner desired, and will provide the data necessary to manage the facility.

Collaborate with the IT department. If choosing a web-based system, be sure to collaborate with your IT department to get their buy-in—their support can ensure the success of the project. IT staff can be responsible for handling software upgrades, network connections, and any computers that manage the BAS. Also, determine whether the IT staff can employ security; IT staff are often willing to host BAS software on the corporate servers so that they can ensure security for the enterprise network with appropriate firewalls and encrypted data transfer.

Include commissioning considerations in the selection process. Commissioning is a systematic process improving the likelihood that all building systems will perform interactively as they were intended to. It includes specifications in the design phase, inspections during the installation process, tests conducted after installation is complete, and operator training.
Building owners and designers can do three things to ensure a successful BAS commissioning process:

- **Select an able commissioning provider.** Hire an objective engineer with commissioning experience to review design documents, help write specifications, design tests, observe the testing phase, and assist with operator training.
- **Incorporate commissioning and recommissioning requirements into the specifications.** These specifications should be detailed and should include the project team’s roles and responsibilities, installation and initial checkout procedures, functional test requirements, training procedures, and documentation requirements.
- **Ensure that the BAS is fully tested.** Although many standard functional tests describe requirements and procedures for testing building automation systems, in many cases it is necessary for a commissioning provider to customize these tests to more exactly match the technical requirements of the specific project.

In particular, open communications systems should be thoroughly commissioned, and the performance of all system components should be compared with the published and submitted manufacturer’s performance data. With BACnet standard systems, protocol implementation conformance statements should be submitted before construction to ensure compatibility at all appropriate levels.

**WHAT’S ON THE HORIZON?**

BAS technology is advancing to offer the following new functionality in the future:

**Increased use of the Internet.** The BAS industry is currently transitioning its systems to exclusively use web browser interfaces (which may even include building this capability into the individual controllers). More and more BAS components are being redesigned to use Internet communications for sharing information with the rest of the system. BAS designers are increasingly specifying Internet-based communications to improve building operators’ access to the system and to improve system communications. ASHRAE has added XML and web services to BACnet in order to standardize how BACnet systems run...
web services to exchange data with other computing applications over a network. One initial use of web services is to enable sophisticated functionality such as creating “virtual thermostats” that give users control over the temperatures in their own areas.

**Price-responsive buildings.** As demand-response and smart-grid technologies continue to grow in popularity, offering consumers real-time information about their electricity consumption, we will likely see more systems that can integrate building controls with real-time pricing tools. This trend could ultimately lead to automated energy procurement based on price—allowing businesses to reduce operating costs, which adds value to their bottom line. Two current projects are pointing the way.

The first involves automated demand response—integrated with a BAS—that uses web-based electricity pricing and event notifications to automatically initiate preprogrammed control strategies. These strategies provide fully automated management of building energy use. When electricity prices are high or when the power grid is nearing full capacity, these control strategies reduce electric loads. Lawrence Berkeley National Laboratory has begun to examine which demand-response strategies can be automated in facilities. Additionally, work is underway on a tool that can help determine what strategies and peak savings are feasible for an existing facility.

Another real-time pricing project is the NewEnergy Alliance, an organization founded by energy service provider Constellation NewEnergy that includes equipment manufacturers, building automation companies, system integrators, and software businesses. This group is working to develop BAS technologies that are integrated with real-time energy market information and pricing signals. In December 2008, the NewEnergy Alliance released its first product, called VirtuaWatt, an online application that enables commercial end users to optimize their demand response participation by scheduling load reductions ahead of time.

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**BUILDING AUTOMATION RESOURCES**

The following are excellent sources for further information about building automation:

WHO ARE THE MANUFACTURERS?

- Automated Logic
- Delta Controls
- Honeywell
- Johnson Controls
- Novar
- Siemens Building Technologies, Landis Division
- Schneider Electric
- Trane HVAC and Building Controls

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