Building Controls and Facilities Management in the 21st Century

Srinivas Katipamula, Enron Energy Services
Peter Armstrong, Pacific Northwest National Laboratory
Mike R. Brambley, Pacific Northwest National Laboratory
Rob G. Pratt, Pacific Northwest National Laboratory
David P. Chassin, Pacific Northwest National Laboratory

ABSTRACT

Managing buildings requires a wide array of skills and tools for building operations, maintenance, engineering, forecasting, budgeting, health, safety, and security. Recent developments in open communication standards for building automation systems (BASs), as well as the pervasive use of Internet and intranet technologies, have created a flood of new options for owners and operators of facilities.

The ability to manage facilities over the Internet enables remote monitoring, remote equipment diagnostics, improve operational efficiency and load aggregation – all of which require significant data and image transfers in real-time. In this paper, we present a conceptual design to extend the traditional role of the facilities management. The advantages of managing facilities that are distributed over the Internet are also described. Implementation and integration of various facility management functions (remote monitoring, remote diagnostics, load aggregation, and whole facility optimization) are described as well.

For the last decade, the building automation industry has developed standard communication protocols so that the products from different vendors can interoperate, although "true" interoperability is still more myth than reality. A fully distributed processing architecture (with intelligent devices [sensors and controllers] that have capability to self-configure and ability to communicate with other devices on the network[s]) is needed for simple, seamless and scaleable device interoperability.

In addition to presenting a conceptual design to extend traditional roles of facility management, we present a framework to extend the current building control functions using fully distributed architectures that can lead to "true" interoperable devices and benefits from such an implementation.

Introduction

Building owners and operators, facility mangers, and energy service providers are being increasingly challenged to find innovative ways to control and manage facilities. Deregulation in the utility industry presents additional opportunities and challenges. The impact of these new market developments is the increasing need for available building-generated information. These requirements, along with recent developments in open communication standards for building automation systems (BASs) as well as the pervasive use of Internet and intranet technologies, have created a flood of new options for owners and operators of distributed facilities (Katipamula et al. 1999b).

With the ability to monitor, control, and manage facilities over the Internet and intranets, the facility manager can track energy use (for budgeting) or energy savings from retrofits. In addition, the ability to perform remote diagnostics on equipment will not only extend the life of the equipment but also reduce energy waste. If the facility is on a time-of-day or real-time pricing rate, the facility manager can keep track of the electricity/gas consumption of individual sites and aggregate loads and make decisions in real-time regarding the operational changes needed to avoid excessive utility costs.

Although, over the last decade, the building automation industry has been successful in standardizing the protocols so that information can be shared between devices from different vendors, "true" interoperability is still elusive. Building owners and operators expect true interoperability to mean "plug and play," similar to the what is provided by the manufacturers of personal computers. Even the state-of-art in building control systems falls far short of plug and play expectations. Plug and play capabilities cannot be achieved by standardizing the hardware specification and the communication protocol alone. In addition, the control devices need more intelligence to be able to support self-configuration and standardization of the software protocols and the interaction between the devices.

Computing technology is becoming inexpensive to build and support intelligence into the design of building and heating ventilation and air conditioning (HVAC) sensors and control devices. Inexpensive and reliable networking coupled with the new intelligent devices can transform building controls product offerings to provide true interoperability and plug and play capability.

The two main objectives of this study are to: 1) present a conceptual design to extend the traditional role of facilities management using the pervasive Internet technologies and the advantages of managing distributed facilities over the Internet, and 2) present a framework within which a fully distributed processing architecture such as Jini™ and Universal Plug and Play can be used to develop truly interoperable (plug and play) building control device.

Facilities Management for the 21st Century

Having a BAS in every building is not sufficient to address the growing needs of facility management. The networks that tie the BAS with the rest of the enterprise and the intelligent software applications that manage the BAS are the keys for the next generation of distributed facilities management systems (Bayne 1999). Controls manufacturers, engineers, and researchers are developing software solutions that take advantage of integrated networks to provide easy access to operating and control data (Olken et al. 1996; O'Neill 1998; Brambley et al. 1998; Katipamula et al. 1999a; Chassin 1999). Use of state-of-the-art controls that facilitate distributed processing, coupled with gateways that provide interfaces between the control networks and the data networks (Internet and intranet, respectively), will provide better monitoring and control of the building systems and enable management of distributed facilities from central and remote locations.

Infrastructure Requirements

Networked software applications that can harness the vast potential of integrated control networks with the Internet require access to data from control panels or sensing devices that are distributed across buildings. Being able to exchange data and information between field devices and software applications is the key to successful implementation of networked software applications (Bayne 1999). Although software applications are independent (and should always be) from the process of gathering data, the ability to gather data is dependent on the functions provided by the BAS and the communications protocols it uses. The type of interface (gateway) that exists between the control network and the Internet is also important (Figure 1).

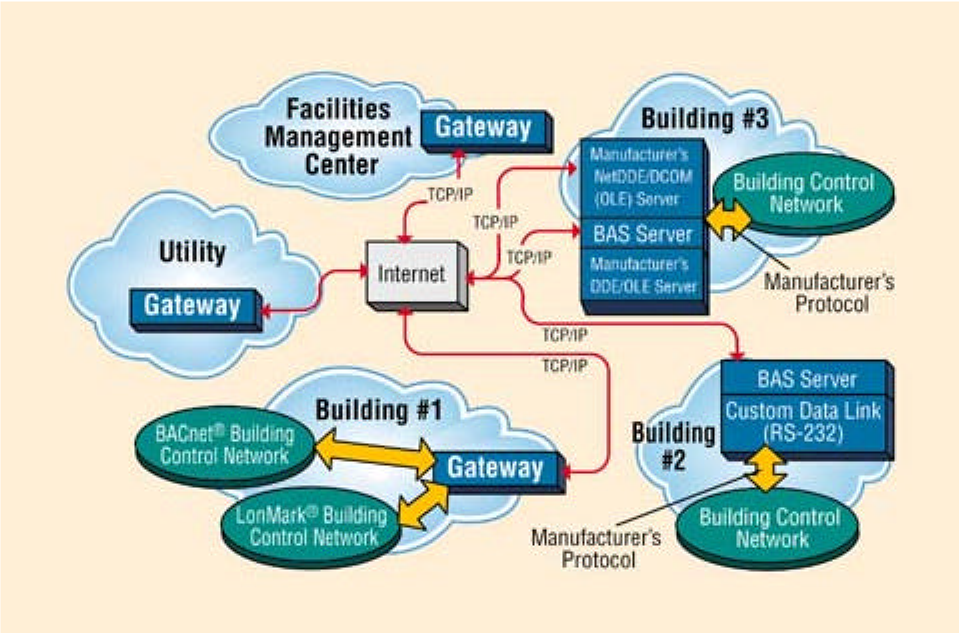

Figure 1. Example of Integration of Controls Networks to Internet from Different Buildings

An infrastructure supporting the next generation of software tools to manage distributed facilities requires:

- a control network with a BAS or intelligent devices (in each building),
- a mechanism or a transport layer that ties the field panels and the devices on the control networks to the Internet,
- and finally, the "killer software applications" that enhance facility management.

Networking Developments

Building automation systems have evolved over the past two decades from pneumatic and mechanical devices to direct digital controls (DDC). Today's BASs consist of electronic devices with microprocessors and communication capabilities. Widespread use of powerful, low-cost microprocessors; use of standard cabling; and adoption of standard protocols (such as BACnet, LonWorks) have led to today's improved BASs. Most modern BASs have powerful microprocessors in their field panels and controllers and microprocessors will soon be embedded in the sensors as well (Kovacs 1996). Therefore, in addition to providing better functionality at a lower cost, these BASs allow for distributing the processing and control functions within the field panels and controllers without having to rely on a central supervisory controller (Figure 2).

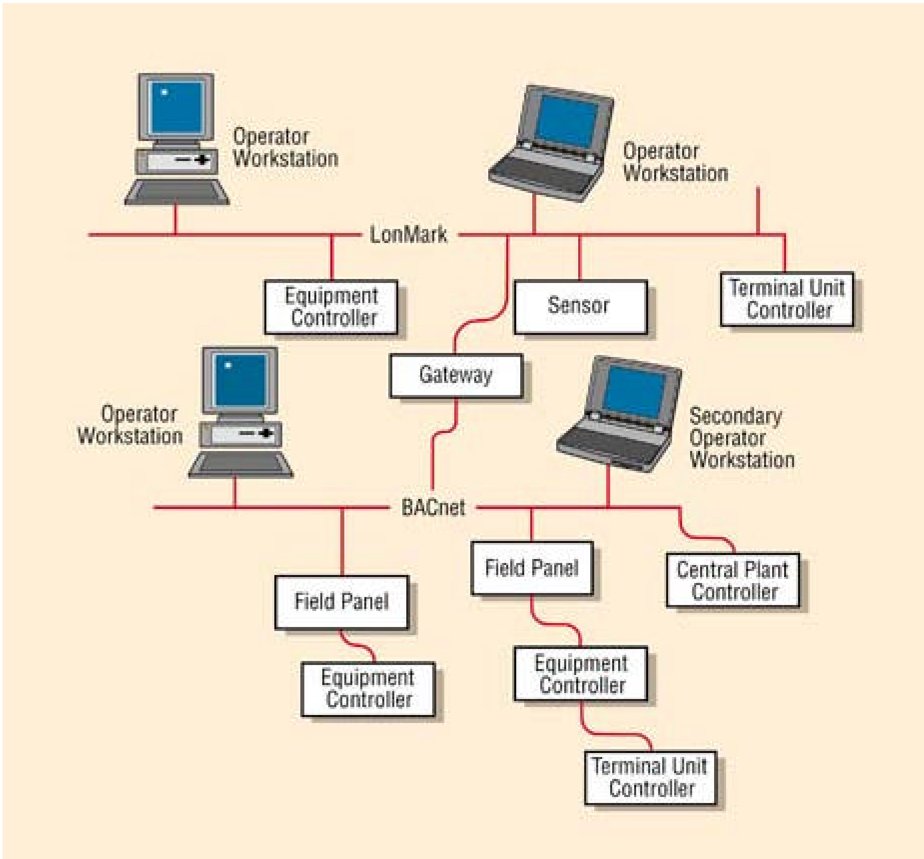

Figure 2. Modern BASs. The field panels and controllers have powerful microprocessors that allow for processing of information and control action with the devices rather than at a central supervisory controller.

Many BAS manufacturers support either BACnet or LonWorks protocols; some even support both (EUN 1999). The manufacturers of BASs are also developing gateways to connect modern proprietary control networks to the Internet, making it easy for distributed software applications to share information. However, there are many legacy BASs in the field for which gateways are needed but do not exist or will never be developed. In such situations, there are three ways to connect these systems to the Internet: 1) dynamic data exchange (DDE), 2) object link and embed (OLE), and 3) developing a custom interface between the BAS and the Internet for legacy systems that do not support either DDE or OLE. Many modern BAS manufacturers provide DDE/OLE servers to facilitate data exchange between controllers/devices and software application programs.

Benefits of Integration of Control Networks with Internet

In addition to monitoring and control, seamless integration of the control networks with the Internet will open new opportunities, such as:

- automated, remote fault detection and diagnostics of building systems and subsystems,
- tracking energy use and energy end-uses by building or group of buildings can lead to better monitoring and verification of guaranteed savings contracts, and better reporting, and benchmarking of building performance,
- ability to forecast energy budgets and prepare energy purchasing plans,
- optimization across multiple buildings and building systems,
- ability to control load and equipment in response to varying utility rates (e.g., real-time pricing, time-of-use rates).

The primary beneficiaries of control-network integration with the Internet include single facility managers, as well as facility management staff responsible for multiple building complexs, such as university campuses, school districts, retail stores, restaurant chains, U.S. General Services Administration buildings, and banks. Property management firms, energy service providers, and utilities also stand to benefit tremendously from these opportunities. Benefits from integrated facilities management include:

- lower energy expenses,
- fewer occupant complaints and faster resolution of problems,
- reduced liability and litigation expenses (relating to indoor air quality [IAQ] issues),
- reduced churn (i.e., turnover of tenants),
- higher tenant rents (commensurate with higher quality facilities),
- improved performance of occupants, such as students and teachers or manufacturing and office workers, because of a better indoor environment.

New Powerful Applications

Connectivity of control networks with the Internet allows third-party software developers, in-house developers, and BAS manufacturers to develop independent software applications that can be deployed from a central location. These applications put networking capabilities to work by gathering and processing data, sending out control commands, and generating reports. The cost of these software applications can be spread over a large number of buildings when used from a central location. Centralized monitoring also enables facilities and service providers to hire expert HVAC engineers and analysts to analyze several buildings rather than one or a few, and these experts can to do their analysis remotely.

Remote Automated Diagnostics

Effective use of diagnostic tools can help facility managers and operators cut the cost of operations and consumption of resources while improving the comfort and the safety of occupants. Continuous diagnostics for building systems and equipment will help remedy many problems associated with inefficient operation of buildings by automatically and continuously detecting system performance problems and bringing them to the attention of building operators (Brambley et al. 1999). Some of these problems might otherwise go undetected. Advanced diagnostic tools can even suggest causes of problems, make recommendations for solving problems, and estimate the cost of not solving a problem. Until recently, access to data in real-time was one of the major obstacles for widespread deployment of remote automated diagnostic tools.

Although fault detection and diagnostics have been an active research topic for several years, only a few software applications are available today (Katipamula et al. 2000). Lack of a well-defined infrastructure and difficulties in accessing sufficient quantity and quality of data are two of the reasons for the slow start.

Tracking Energy End-Uses

Because energy accounts for a significant portion of the operating cost in many facilities, facility managers, energy service providers, and owners alike will benefit from a software tool that tracks energy end-use. For example, the benefits for an owner of a retail chain or a facility manager of a large campus with distributed facilities include:

- ability to generate reports in several different formats (e.g., by region, sales volume, or building type),
- ability to benchmark historical, normalized (e.g., with respect to weather, size, sales) end-use consumption between similar buildings/facilities. Comparison with benchmarks can help identify operational inefficiencies.
- ability to forecast energy budgets and prepare energy purchasing plans.

An energy service provider who has signed a guaranteed savings (i.e., performance) contract with a facility can reduce his risk and increase his reliability by tracking end-use consumption and calculating savings continuously. From a central location, the energy service provider or facilities personnel can also identify problems associated with unscheduled operation of equipment (such as lights and HVAC equipment) because of control malfunctions or errant programming.

Methods to estimate savings from energy-efficient retrofits using measured end-use data have evolved over the past 10 years (Claridge 1998). The early developers of software tools for tracking savings often used special data logging equipment coupled with low bandwidth phone lines for communication – a cumbersome application. With integrated networks, the software applications can collect, analyze, format, and display data more easily for multiple buildings and synthesize the data into a variety of reports, depending on their end-use. Real savings from energy conservation measures can be compared easily with estimates from engineers, contractors, and operators.

Load Aggregation

To negotiate favorable utility rates and tariffs in a deregulated utility environment, as well as ensure that the contract limits are not exceeded, the aggregated load and demand profiles of individual buildings and the entire distributed facility are required. Aggregation is facilitated by connecting existing meters or control networks to the Internet and passing the meter or sensor readings as data in real-time for subsequent analysis by operators or other building staff or outside specialists. Aggregating real-time data across the facility can help identify where to curtail energy use if demand is close to exceeding a negotiated limit.

Whole-Facility Cost Management

In the deregulated utility environment, one of the greatest cost-savings opportunities for facility managers and operators lies in the ability to control and optimize whole-facility energy consumption. Due partly to deregulation, utilities are now offering rates that vary by hour-of-day and day-of-week, similar to the real-time pricing rates and time-of-use rates offered by some utilities. To take advantage of time-varying rates, facilities will need advanced control strategies (Kammerud et al. 1996). Strategies include: HVAC load shedding (for chillers, thermal storage, supply and zone temperatures, fans, and pumps); load shifting (using pre-cooling or thermal storage); and fuel shifting (gas, oil, and steam standby generators) (O'Neill 1998). These strategies not only require access to data from sensors and meters but also the capability to control equipment from a central location.

Intelligent Building Control Systems for the 21st Century

In the rest of the paper, we will present a vision for intelligent building control systems and highlight the benefits to the users and building operators from using these systems.

Interoperable building control systems and sensors, automated building systems diagnostics and self-commissioning of building sensor and control systems are some of the distinguishing features of an intelligent building. To be able to support these features, an intelligent building must be equipped with the electronic and physical infrastructure that supports the use of advanced communication, data processing, and control technologies by its occupants and operating personnel.

Although for the last decade the building automation industry has been trying to standardize the protocols so that information can be shared by the products from different vendors, "true" interoperability is still more myth than reality. Part of the confusion is the definition of what constitutes interoperability. There are various definitions and expectations of what interoperability means. In general, the industry believes that a realistic objective of interoperability is the ability of equipment or systems from different manufacturers to share information for the purpose of daily operations (Turpin 1999). Based on this objective, most new BASs, strictly speaking, do meet the criterion. In contrast, most users and building operators expect "true" interoperability to mean "plug and play," similar to installing a video card in a personal computer and having it work immediately.

Enabling Technologies for Plug and Play Devices for Building Systems

Even the state-of-art in building control systems falls short of what is meant by plug and play. Plug and play cannot be achieved by standardizing the hardware specification and the communication protocol alone. In addition, the control devices need more intelligence to be able to support self-configuration, standardization of the software protocols and peer-to-peer interaction among devices. Computing technology is becoming inexpensive to build and support intelligence into the design of building and HVAC control devices. Inexpensive and reliable networking coupled with the new intelligent control devices can transform building controls product offerings to provide true interoperability and plug and play capability.

A fully distributed processing architecture is required to make building control systems truly plug and play. A number of architectures have been recently proposed to fill this void. These architectures are essentially coordination frameworks that propose certain ways and means of device interaction with the ultimate aim of simple, seamless and scaleable device interoperability. Two of the well know contenders are Universal Plug and Play spearheaded by Microsoft Corporation and Jini™, championed by Sun Microsystems (http://www.jini.org). Although the basic objectives of the two architectures are the same, they take different approaches to achieving them. According to California Software Laboratories (http://www.cswl.com/whiteppr/tech/upnp.html), device coordination essentially means providing a subset of the following capabilities to a device:

- Ability to announce its presence to the network.
- Automatic discovery of devices in the neighborhood and even those located remotely.
- Ability to describe its capabilities as well as query/understand the capabilities of other devices.
- Self-configuration without administrative intervention.
- Seamless interoperability with other devices (wherever meaningful).

All of the above attributes are essential for true plug and play controls.

Traditional versus Plug and Play Controls

In this section the steps needed to install and configure an air-handling system today using the current state-of-art BAS versus a truly interoperable plug and play enabled controls network of the future are discussed.

Traditional Controls

In a traditional system today, the controls technician or engineer must:

- First, install the controllers and wire them to an existing control network.
- Install actuators for the valves and dampers and install the necessary wiring to the controllers and the control network.
- Install the sensors and wiring and configure the controllers to recognize them.
- Install the front-end software and configure it to allow access to program the controllers.
- Program the controllers and verify that the controls actually work.

The biggest challenges in traditional installation are configuring, tuning, and commissioning the controllers, sensors, and actuators. This process is not only error-prone and time consuming, but also requires a skilled technician or an engineer. Use of standard devices from different manufacturers further complicates the installation process. The standard protocols define the functional requirements and methods to share information between devices. However, proprietary programming languages and tools are generally required to configure and program the standards compliant devices. Therefore, devices from different manufacturers are seldom used. Furthermore, if a device needs replacement, even when using the state-of-art BASs that support standard communication protocols, more often than not one is forced, by practical considerations, to replace it with a device from the original manufacturer. Although a device from a different manufacturer could have been used at a lower cost, the building operators and owners prefer to use a replacement component from the same manufacturer because they are familiar with the configuration and programming requirements of the device. In this sense, most traditional state-of-art systems are not truly open. To be truly open, a device should not only be functionally equivalent and be able to share information with other devices, it should also provide an open configuration interface so that tools made by other manufacturers and software companies can install and configure it (Arnold 1999).

Another drawback of the traditional controls paradigm is that its structure revolves around a vertical subsystem architecture, wherein each subsystem has its own cabling, management system and service contract (Arnold 1999). These vertical islands of automation are often tied together using expensive gateways. In addition, the traditional control devices lack intelligence, which makes self-calibration or tuning nearly impossible. Unless these devices are calibrated manually, over time, they lead to control errors and waste of resources.

Plug and Play Controls for the 21st Century

Controls based on an open distributed computing architecture with plug and play devices can overcome many of the shortcoming of the traditional building controls. With truly open and distributed architectures such as Jini™ and Universal Plug and Play, the installation, configuration, and commissioning process will be simplified and completely automated as described below:

- First, the controllers, actuators, valves, dampers, and sensors are plugged into the building control network, which incidentally is also the Internet network (TCP/IP).
- Actuators are installed for the valves and dampers and are connected to the control network.
- After all devices are plugged in, nearly everything else will happen automatically as follows:
- The devices will announce their presence to the network and describe their capabilities and application domain. For example, the supply air temperature sensor may limit its availability to just one air-handler (the application domains are not pre-programmed; they have to be established at time of initial device power-up or after connection to the network).
- The sensors, actuators, and controllers will self-calibrate.
- The devices will self-configure. For example, the controllers will automatically request the services of sensors and actuators that are relevant for it to make control decisions and actions.

To simplify and automate the installation, configuration and commissioning process requires 1) standard network wiring, 2) standard network management services, 3) standard network applications (tools), 4) standard functional profiles for all commonly used building systems, 5) standard device messaging, and 6) standard device configuration.

The foundation for the intelligent plug and play controls is the network infrastructure. The network should be readily available, easy to install, and support scalability. The best choice, therefore, is the widely used standard data network (Internet) wiring supporting

TCP/IP protocols. Use of standard data networks for all building-wide controls eliminates islands of automation and gateways.

Along with the standard networks, there is a need for standard network management services. Both Jini™ and Universal Plug and Play architectures use existing data networks and TCP/IP protocols for communication to support network management and services. The goal of both approaches is to provide true plug and play architecture; the methods by which they achieve the goal differ. By using the network services developed by these open distributed architectures, multiple tools from multiple manufacturers can coexist. By adopting a standard architecture, which many manufacturers adopt and develop devices for, the real benefits of open control networks for building-wide automation will be leveraged.

For any coordination framework to work, it must introduce some standards into the operations of devices. Otherwise, the devices simply cannot coordinate. However, there must be a balance between standardization and autonomy (use of proprietary protocols and techniques). Standardization is required for specifying a set of functional requirement for devices, as well as messaging between different devices.

Standard device messaging is also crucial for seamless integration of devices and communication between devices. Use of open and standard architectures will force manufacturers to adopt standard messaging.

The ability of the devices to self-configure is an essential ingredient for reducing labor cost and to support interoperability between different vendors. Because the devices in the plug and play controls paradigm are intelligent, the configuration information can be encapsulated into the device itself. However, some level of standardization may be required.

Security Issues

Although integrating control networks with the Internet or using Internet networks as control networks can expose them to attacks from elsewhere on the Internet, there are technologies available in the market today that provide tight security (e.g., authentication and authorization) to overcome security problems. In addition, the privacy of the data being transmitted over the Internet can also be protected by encryption.

Conclusions

As BAS manufacturers continue to adopt open standards and provide interfaces to connect control networks to the Internet—and as networked software tools are developed – building managers, facility operators, and energy service providers will gain access to more sophisticated and automated software tools that will enable them to manage distributed facilities more efficiently. These advances will provide better controls capability and help enhance automated remote diagnostics; support predictive and preventive maintenance; help verify performance contracts; increase productivity; allow better integration and use of sensors, actuators and controllers; improve overall energy management; and lower facility management cost. However, to achieve the true interoperability and plug and play capabilities that building owners and operators dream of, manufacturers should adopt the new distributed computing architectures and leverage the existing data networks (Internet) for building controls.

We recommend that building owners and operators stop using proprietary systems and insist on systems that are based on open standards to take full advantage of recent technology advances.

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