GUIDELINE

ASHRAE Guideline 13-2015
(Supersedes ASHRAE Guideline 13-2014)
Includes ASHRAE addenda listed in Annex G

Specifying Building Automation Systems

See Annex G for ASHRAE approval dates.

This guideline is under continuous maintenance by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the guideline. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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Includes Web-based access to Example Specification for Building Automation Systems (Requires Microsoft® Word®)

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NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.

(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

FOREWORD

This guideline is intended to provide a designer of building automation systems (BASs) with background information, recommendations for good practice, project considerations, and detailed discussion of options with respect to the design of a BAS.

The reader should be aware that the technologies available in BAS products change more rapidly than those in the rest of the HVAC industry. A careful review of suppliers' offerings should be made before proceeding with creation of any BAS design. The creation of a BAS specification is a process similar to that used to design the rest of a facility's systems. This guideline attempts to guide the reader through this process. Informative Annex E provides guidance for specifying various levels of performance monitoring.

This guideline includes online access to an example specification, presented as excerpted parts and embedded throughout the document and also available as a separate file in Microsoft Word® format. Its function is to illustrate the concepts described in the body of the text. The example should be used as it was intended—as an example only. The example is not a guide specification; it does not include exhaustive options for every conceivable project system architecture, requirement, or configuration. It does not fit all applications, nor is it the best way to proceed on every job.

The example is protocol neutral, and refers the BAS designer to the cognizant organization for the selected protocol. Many of these organizations have guide specification language based on their protocol.

The excerpted parts of the example are presented in a typeface different from the text of the guideline, with lines above and below. An outline of the example specification is included as an annex to this guideline to allow the reader to see how its sections fit together.

Download the Microsoft® Word® version of the example specification at www.ashrae.org/G13Spec. Refer to Informative Annex G for a summary of changes to the 2014 edition of the guideline.

1. PURPOSE

The purpose of this guideline is to provide recommendations for developing specifications for building automation systems (BASs) in heating, ventilating, and air-conditioning (HVAC) control applications.

2. SCOPE

This guideline covers building automation systems (BASs) for HVAC control, monitoring, and management functions. The guideline specifies hardware performance, installation, and training. It also addresses system architecture, input/output structure, communication, program configuration, system testing, and documentation. The guideline only includes examples of how to integrate to fire, life safety, lighting, and other systems. The design and specification of these non-HVAC systems is not part of this document. There is also no specification of facility management functions, as this is beyond the scope of this document.

3. PREAMBLE

3.1 Intent of this Document. This guideline provides building automation system (BAS) designers of BAS with a tool to help them create and edit specifications for projects of virtually any size, scope, or complexity. It is the result of industry consensus obtained from the controls and equipment manufacturers, users, consulting engineers, installation contractors, and testing contractors who composed ASHRAE Standing Guideline Project Committee (SGPC) 13.

This guideline discusses the options, considerations, perceived benefits, and concerns associated with each part of an installed system. The authors chose specific configurations, components, and methodology. One such selection decision was the architecture or topology of the system. These selections are not the only way to build a system, nor are they necessarily the best for each project. The information provided should assist the reader in understanding why these selections were made and how to make these decisions for his/her project.

This guideline represents a standardization of approach to the design, documentation, and specification of BAS for HVAC control and energy management applications. This standardization should improve both the quality and value of BAS for building owners and users. The guideline should *not* be used as a statutory standard for compliance. The examples are not an exhaustive representation of all types and features of BAS. This guideline and its annexes require substantial editing and customization for the particular requirements of any given project.

3.2 Use of this Guideline. This guideline is to be used when preparing written and drawn specifications of BAS control and energy management systems and can be a reference for the design of these BAS as well. The term *direct digital control* is only used when referring to the process of controlling equipment directly with digital controllers.

The terms *BAS designer*, *contractor*, *subcontractor*, and *owner* are used throughout this document. These terms are used for clarity—they are not intended to define contractual or legal requirements of any party.

BAS designer: the creator of the work or the author of the specification. The BAS designer may be a consulting engineer, a licensed professional engineer, a facility master system integrator, or other. It is possible that with the need to have Internet connectivity and sharing of control-point data, there could be more than one party involved in the specification of the work.

contractor: the performer of the work defined in the specification; the person or company who enters into contractual agreement to execute the work and the entity responsible for its completion in accordance with the contract documents.

subcontractor: the performer of the work defined in the specification; this person or company is contracted by the contractor—not the owner—to perform some or all of the work defined by the specification in accordance with the contract documents.

owner: the person or company that executes the contract for the work; this entity will assume ownership of the completed work in accordance with the contract documents.

3.3 Organization of the Guideline. This guideline is organized into 14 chapters, called *clauses*, each with a main heading. Also, appendices, called *annexes*, are attached. The document is divided into eight major parts:

a. Introduction: Purpose (Clause 1), Scope (Clause 2), Preamble (Clause 3).
b. A general introduction of the principles of design and documentation (Clauses 4 and 5).
c. An article-by-article discussion of the content of a written specification for a BAS (explanation of each specification article has been included to help the BAS designer). (Clauses 6 through 9)
d. Information about the BAS that will be important to other subcontractors (Clause 10).
e. Additional information regarding valves and dampers (Clause 11).
f. Annexes: Outline of example specification, BACnet® discussion, interoperability case studies, and performance monitoring.
g. IP networking requirements (Clause 12). This section contains information about graphics, submittals, training, etc., that is found in Clauses 6 through 9 that is specific to the IP networking and integration of the BAS device network into enterprise.
h. Legacy systems (Clause 13). This section discusses various options for managing legacy systems and the relationship to a modern control system.
i. References (Clause 14). This section provides additional references and resources for designers and specifiers.

The example specification follows the format determined by the Construction Specification Institute (CSI). Under the 1995 CSI MasterFormat™, a controls specification will typically be placed in Division 15 for mechanical systems, usually in Section 15900 or 15950, although the exact placement varies. The specification is divided into three parts ("General," "Products," and "Execution"), each consisting of articles, paragraphs, and subparagraphs. Under the 2004 CSI Master Format™, control specifications are in Division 23, "Heating, Ventilating, and Air Conditioning," Section 23 09 00, or in Division 25, "Integrated Automation." The electronic version of the sample specification is applicable to both the 1995 and 2004 formats.

4. BUILDING AUTOMATION SYSTEM (BAS) OVERVIEW

4.1 Benefits of a Building Automation System (BAS). A BAS provides the technology platform by which the owner's project requirements for energy efficiency, sustainability, and occupancy conditions can be monitored, controlled, and tracked over the life of the building. A BAS provides the following benefits:

a. A BAS comprises microprocessor controls that provide a flexible platform onto which one or all of the following can be applied: control algorithms, scheduling events, event notification, trend data collection, and network communications. Combinations of these applications are not possible with pneumatic or electric control systems.
b. A BAS can incorporate the algorithms for energy conservation and system optimization specified in ASHRAE/IES Standard 90.1 and ASHRAE/USGBC/IES Standard 189.1. Controls strategies such as night setback, optimum start/stop and demand limiting, and setpoint reset for variable-air-volume (VAV) systems require a BAS, as these strategies cannot realistically be accomplished using pneumatic or electric controls.
c. With the advent of networked lighting systems, the BAS can also read the state of the occupancy or vacancy sensors on the lighting system and can have the terminal equipment controllers reduce the airflow when the space is unoccupied for a specified period (e.g., 30 minute timeout per California Title 24 rules).
d. A BAS provides the ability to match control performance to control application requirements. Sensors, control devices, and DDC controllers must be selected to meet control performance goals in order to meet end-to-end accuracy requirements for control application performance monitoring requirements. The issue of accuracy to meet control performance goals is discussed in detail in Informative Annex E.
e. A BAS provides advanced scheduling features. A BAS allows building equipment and systems to be scheduled to operate under different time-of-day schedules for seven different day types (i.e., Sunday through Saturday), as well as scheduling for nonbusiness days (i.e., holidays) for years in advance. The BAS can also permit occupied and unoccupied setpoints to meet energy savings targets. Scheduling can be further modified using optimized start/stop algorithms.
f. A BAS provides event notification for alarms, system, and operator events. BAS activities such as event notification can provide a time/date stamp to allow the building operator to track and monitor events. System activities can be sorted by time/date, point name, system, device type, unit, or panel to allow the building operator to observe the order in which events occur. BAS software also comes with built-in audit trail functions that will log the operator's identity as well as the time/date of changes the operator made, such as changes to a setpoint or manually stopping a fan.
g. A BAS provides the ability to collect trend data from any controller that resides on the BAS network. Trend data may be collected by change-of-value (COV) or by synchronized time interval. The ability to collect trend data from the BAS is a valuable tool for commissioning and performance monitoring of building systems.
h. One of the barriers to BAS use was that older systems required their own separate network infrastructure. BASs can now co-exist on the enterprise Local Area Network (LAN) along with desktop computers, servers, and other devices. Maintenance of a separate network infrastructure can be performed by the Information Technology (IT) department, not necessarily by the facilities department. The IT department can secure BAS assets and the informa-

tion they contain and grant access rights in the same manner as other computing devices on the enterprise LAN.

i. A networked BAS can utilize both hardwired and wireless network protocols. The BAS designer must evaluate the suitability of wired versus wireless solutions or a hybrid of both. Some owners prohibit the use of wireless for security reasons. Wireless does have the advantage of not requiring more cabling infrastructure. A wireless solution is particularly advantageous in existing buildings or buildings with high ceilings, like hotel ballrooms or arenas.

j. Integration of other building systems (such as weather station, lighting, security, fire, submeters, emergency generators, etc.) into the BAS provides the opportunity for global optimization of building systems for energy conservation, occupant comfort, and safety. Integration of other building systems is accomplished by the use of different industry standard communication protocols. This guideline specification does not cover the specification of these other non-HVAC systems. This guideline does provide guidance on the integration of these systems into a BAS.

k. A BAS reduces labor and energy costs through remote monitoring and troubleshooting. The response time for correcting building system problems can be minimized through the use of remote monitoring and commissioning services. In many cases, on-site operations can be eliminated or reduced through the use of remote monitoring as a central monitoring service or an off-site technician with a cellular phone or tablet device that provides remote access to the BAS.

l. A BAS is often necessary to meet specifications of sustainability guidelines such as LEED™, Green Globes™, and Go Green™. The BAS allows the user to commission the systems to meet these sustainability guidelines. A BAS will also monitor the various systems to ensure compliance to these standards so that energy savings are maintained over the long term, and it can be used as a measurement and verification tool.

m. A BAS offers a viable platform for implementing performance monitoring, which can provide facility managers and operators with the means to easily assess the current and historical performance of the building/facility as a whole, as well as its significant energy consuming systems and components. Performance monitoring can be implemented as part of a new construction project or as part of a BAS installation or upgrade project in an existing building. With the advent of initiatives such as ASHRAE 189.1, LEED, Net-Zero, and ASHRAE 201P SmartGrid interoperability, a BAS must now respond in a dynamic fashion to changes in price signals from the local utility (called demand response), weather events, or power outages.

n. Many BAS device manufacturers offer product that conforms to worldwide interoperability standards at no extra cost over a proprietary communications protocol. Unless an owner is making an extension to a proprietary protocol installation or has a specific requirement that necessitates the use of a proprietary protocol system, it makes no sense to design and specify a proprietary protocol BAS. While the current project may be only an HVAC project, in the future the owner may install lighting, security, or fire-alarm systems and will expect interoperate with the original HVAC system.

o. When is a BAS not required or is not the primary means of control?

   1. In the past, it was common not to install a BAS for small buildings with one or more rooftop units. This is often not the case today as rooftop units, heat pumps, or other packaged equipment come with their own built-in automation controls that allow this equipment to be connected to a building network or directly to the Internet to permit remote monitoring and control. With energy and servicing costs rising and the cost of onboard networkable controls becoming commonplace, it makes good sense to utilize these onboard controls.
   2. There will be cases such as high-hazard buildings where electronic controls that could generate a spark are not allowed. In this case, pneumatic controls or intrinsically safe electric controls may be the only solution.
   3. UL, cUL, or other codes may necessitate the use of hardwired interlocks between the fire alarm and the corridor pressurization fans in the facility. The BAS designer should consider providing BAS controls to monitor these nonelectronic control interlocks. Some BAS suppliers offer UL or cUL 864 (UUKL7) listed DDC devices specified for smoke control. Such devices maintain the UL chain of continuity between the fire-alarm panel and BAS smoke-control algorithms. The use of such listed BAS devices may reduce or eliminate hardwired interlocks and will allow for more sophisticated monitoring during operation. The suitability of such devices needs to be evaluated during the project design stage.
   4. Hardwired interlocks may also be required by the equipment supplier. It is common practice to wire a flow switch through the chiller starter circuit rather than making a software interlock between these two devices with the BAS.
   5. Unit heaters in shops or mechanical rooms often use simple line voltage controls, which may not require a BAS. Even in this case, the BAS designer should not rule out the option for controlling this equipment via the BAS so as to permit remote monitoring and control. The BAS is a tool, a powerful one, but requires skilled system operators to provide a properly operating system.

In summary, BASs provide tangible savings in both energy conservation and maintenance. More importantly, the technology gives the owner better control over the building and can save labor and energy costs through remote diagnosis and troubleshooting. Pneumatic or electronic controls cannot provide the sophisticated alarm and trending features that are available as standard items on most commercially available BASs.

In making a decision on controls, property owners and managers need to understand that BAS technology is not a solution to all building problems. A BAS should not be installed before a proper needs assessment is made. A BAS cannot correct problems with mechanical systems that are under capacity, poorly designed, or do not meet current codes.

This is of concern primarily in retrofit projects. In this case, the BAS designer must make the owner aware of these issues, or the BAS, once installed, may be unfairly blamed for these pre-existing problems.

4.2 System Overview. The BAS comprises both hardware and software that combine to produce a seamless architecture that provides complete integration of a building's HVAC systems and may include control over, or monitoring of, lighting, security, and fire systems in the building. The BAS can continuously and automatically monitor and—through control of the HVAC mechanical and refrigeration systems—maintain desired ambient temperature, static pressure, relative humidity, indoor air quality, and energy management.

The control system normally consists of several microprocessor-based controllers that have electronic sensors connected to measure temperatures, pressures, electrical current, status, and other environmental variables. These inputs can be either binary (on/off), such as fan status, or analog (variable), such as static pressure. The signals from the analog inputs are digitized for further processing. The controllers run a program to compare the measured values to the desired results and, using proportional-integral-derivative (PID) algorithms, determine how the system outputs should be controlled. This is the essence of DDC. In addition to control, BAS devices also provide coordination, monitoring for out-of-normal or alarm situations, scheduling, graphics, and other functions. Each BAS manufacturer has a slightly different approach to providing the same solution, as well as a slightly different architecture.

Several types of local area networks (LANs) are used by BAS vendors to allow information sharing between controllers. These LAN types include Ethernet (ISO 8802-3) and ARCNET (ASTM 878.1), LON TP/FT-10 (ANSI 709.3/ISO 14908.2), and EIA-485. Communication over these LANs may involve a proprietary communication protocol or may involve an open protocol, such as ASHRAE's building automation and control network (BACnet) protocol or the ISO/ANSI Local Operating Network (LON) Standard protocol developed by LonMark International.

4.3 Impact of the Internet on the BAS Design and Specification Process. The Internet has changed how BASs are designed and specified. Before the advent of the Internet, BASs were isolated systems that were accessible only by dialup modems. The Facilities Department was normally the only user of BAS trendlog and alarming information. BASs can now be designed and specified to co-exist with computers, tablets, smartphones, and other IP-based devices now found in the enterprise. BASs have energy monitoring, alarms, runtime and data on equipment health that owners want to share with other departments in the enterprise.

Migrating the BAS device network to the internal enterprise network or Intranet, now falls to the BAS Designer. This section outlines how this work can be specified. For purposes of this discussion, all references to the internet in this guideline shall be to the owner's enterprise network.

4.3.1 Options for Setting up the BAS Device Network on the Enterprise Network. From the point of view of the BAS designer, BAS devices and the networks that they are connected to can be thought of as either IP or non-IP network devices, where an IP device contains an Ethernet MAC address. The reason for this distinction is that non-IP BAS devices and network wiring to these devices are normally specified by the BAS designer and are installed by the BAS contractor. In the case of IP devices such as routers and switches and IP networks, the work could be done by the owner's IT department, the facility master system integrator (FMSI), the cabling contractor hired for the contract, or the BAS contractor.

At one time it was common for each BAS supplier to provide his or her own network infrastructure. There can now be a cabling contractor who provides all IP network cabling. This change is similar to how firestopping work is now handled. Firestopping used to be provided by each individual trade. As firestopping work became more specialized and difficult, it is normally performed by one trade. The firestop contractor provides this service for mechanical, electrical, architectural, and other trades.

In the case of non-IP networks, it is normal practice that the division providing the devices is also responsible for the non-IP network connectivity. Examples of this include VAV boxes, lighting, security, and fire alarm. It is certainly possible in a contract that the IP network contractor could provide the network wiring for fire alarm devices but this would blur responsibilities and create problems. The more likely interrelationship is that all non-IP cable is identified using unique identifiers and cable colors that are set for the facility as a whole. Identification and tagging standards would also be set in this manner. The non-IP network could be run using plenum cable, run in conduit, or sharing a common cable tray.

The BAS can be set up as a physically separated IP network or can be on the enterprise network and then separated by creating a virtual local area network (VLAN). BAS devices are now designed to operate on the enterprise network. These devices must coexist on the Intranet, or the owner's IT department will not allow them to be added to their network. Someone must take responsibility for managing the unique IP addresses for all devices on the Ethernet backbone and ensure no duplicates and no communication issues. This is typically an IT department responsibility, or it can be managed by assigning a block of addresses to the BAS contractor and letting them perform installation. A good check-and-balance system is required in order to ensure reliability.

One concern for IT departments is that the BAS devices must not consume excessive bandwidth. This is usually not a problem as BAS devices are normally designed to run on a stand-alone basis, so bandwidth usage is minimal. If network communications fail, the BAS devices will run based on the last known values for occupancy or outdoor air temperature. In a campus of buildings, each building may have its own occupancy schedule and either its own outdoor air sensor or sensors shared by multiple buildings. Losing network connectivity means that alarms cannot be reported centrally or trend data may be lost, but the chiller, boiler, air-handling unit (AHU), pumps, lights, etc., operate on a stand-alone basis until network connectivity is restored. Prolonged network outages were common in the early days of the Internet. This is not the case now, as IP switches and routers are designed to be fault tolerant. These devices are backed up by uninterruptible power supply (UPS) and may have a generator to provide backup power to the BAS network until commercial power is restored. In mission-critical facilities there are redundant IP networks and redundant power sources. These provisions result in fewer power or communications outages in practice.

Security is a significant concern presents ever increasing issues regarding authorized/unauthorized access to BAS networks. Clause 12 identifies the key elements of a control network specification for network security. However, local project requirements must enforce owner and local code security requirements. Fundamentally, BAS control networks should follow standard IT best practices and enforce strong pass phrases, lockdown of devices that provide outside access, blocking of unauthorized access, and properly managed firewalls. Balancing security and reliability/access is of significant importance to the BAS designer, and one should coordinate with the relevant IT professional before mandating certain components, access, and tools. For example, providing the ability for a controls contractor to install their own cellular modem gateway for remote access should be strongly scrutinized for security issues before adopting.

The level of connectivity to the Internet began with large building controllers. Now, it is not unusual for a chiller, a boiler, a meter, or even a thermostat to be an IP device.

The following subclauses discuss the three basic design options for IP-based BAS networks.

4.3.1.1 BAS Design Option 1—All Devices in the Building are IP Devices. Under this option, all devices on the BAS network are IP devices. This design option might be used in warehouses or big-box stores whereby the rooftop units are all IP devices. These BAS devices would have their own onboard controllers. The IP connection to these devices could be hardwired or wireless. The thermostats may also be IP devices or they may be hardwired back to the remote terminal unit (RTU). Conversely, the thermostat/sensor in the space could be the IP device that controls the RTU.

This design option would not normally be used in an office, as the costs to run twisted-pair networks (such as BACnet MS/TP or LON ANSI 709.3 TP/FT-10) to VAV boxes are less than the costs to run Ethernet cable to each device. In many secure facilities wireless is not allowed, so connections to BAS devices must be hardwired.

4.3.1.2 BAS Design Option 2—One IP Network Connection per Building. For purposes of this discussion a *building* is a physical structure to which there is a connection to either the public Internet or the enterprise network. There is one IP network drop to an IP-based BAS device. All devices and network wiring from this device are non-IP devices that might use BACnet MS/TP, LON TP/FT-10, ARCNET, Modbus, or a proprietary network that is usually installed by the BAS contractor.

This design option was common in the early days of the Internet when IP connectivity was expensive.

Most BAS equipment suppliers and suppliers of chillers, boilers, meters, etc., now offer both IP and non-IP connectivity for their devices. As IP network connectivity costs fall, more larger devices such as chillers are IP-based. Devices such as VAV boxes are usually non-IP based. The issue for the BAS designer is to resolve the responsibility for who does what work.

4.3.1.3 BAS Design Option 3—Mixture of IP and non-IP Devices in a Building. This option (Figure 4.3.1.3) is now the most common design approach. Most BAS equipment suppliers and device suppliers (chillers, meters, etc.) offer both IP and non-IP connections. The BAS designer must weigh the benefits and costs of IP connectivity at the device level. A chiller supplier might want IP connectivity so that the technician can make a direct network connection to a service and configure the device. It is not unusual for the manufacturer to have proprietary software for this purpose. These proprietary data points may not be exposed on the BAS device network. If the device is part of a BAS contractor's device network, the BAS contractor will have to give access to the chiller manufacturer and effectively assume responsibility for the security of the device. IP connections are usually more expensive than non-IP connections. The IT department may have a limited number of addresses available for BAS use. Once the chiller is on the enterprise network, IT has to secure the device. While IP connections are now reasonably stable and robust, if the BAS contractor relies on the owner's network for controlling the device, then the principle of stand-alone control is not being followed.

One issue for the BAS designer is that in a public bidding situation, where the procurement rules require a minimum of three acceptable products, it may be difficult to find enough device suppliers able to offer a device with an IP connection. If these networking requirements are not specified correctly, one might end up with a meter with a Modbus connection, chiller with a BACnet/IP connection, and a boiler with a LON.

The first solution is to structure the contract so that there is a single FMSI. The FMSI is an umbrella position within standard construction divisions to help oversee the specification and implementation of BASs. The FMSI is usually accountable for assuring interoperability between subsystems and different buildings, for providing a common graphical user interface, and for assuring products from multiple bidders and vendors meet the intent of a specification as well as the letter of a specification, and for acting as a technical go-between for the various involved subtrades (controls, electrical, and mechanical, etc.). The FMSI would either report to the general contractor or the owner. This role could also be performed by a well-qualified BAS contractor.

The second solution is to have the network communications information built into the equipment specification (integral solution). Under this option, networking requirements are specified as for any other requirement, such as the correct voltage or phasing. If the device exceeds the allowed weight or height requirements, or if the device is too big to fit into the mechanical room, it is not acceptable. Similarly, if the device cannot support IP connectivity or a specific protocol, it is not allowed in the project.

Choosing which solution to follow is up to the BAS designer and the owner. The FMSI solution has a single source of responsibility for device communications. The FMSI solution also adds an additional reporting layer to the construction process that adds cost to the job. Building the network requirements into the equipment specification does

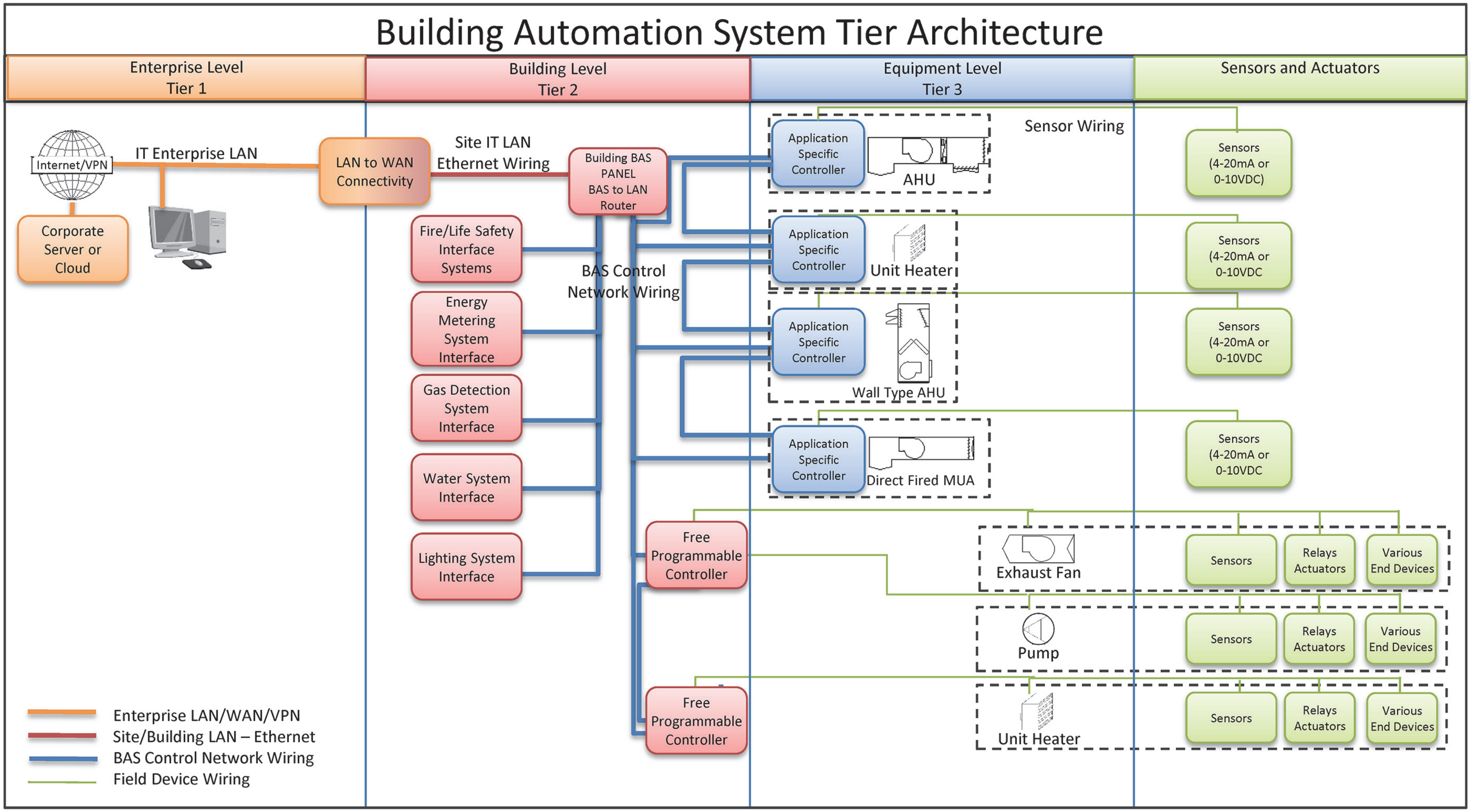

FIGURE 4.3.1.3 BAS design option 3—mixture of IP and non-IP devices in a building.

not add this additional reporting layer. The integral solution will mean that the BAS designer needs to review the submittals more carefully to ensure that they reflect the networking design intent correctly.

Specifying BASs typically falls into two categories of project types: performance based or prescriptive. Both have benefits and drawbacks. Performance based, such as where the FMSI has the general direction to make the system work, can be effective if the FMSI is experienced and knows their scope, the systems, technology, and equipment involved, and has in their scope very clear sets of responsibilities. The prescriptive model requires substantially more effort up front to define all requirements, roles, and responsibilities, including contractor-to-contractor hand-off. Performance-based projects are harder to enforce but easier to write. Prescriptive specs are easier to enforce but harder to write and ensure all of the details are correct. The system designer must choose the model that works best for their situation.

4.3.2 Dealing with Devices with Embedded Networkable Controls. In the past, devices such as boilers, chillers, etc., came without on-board controls. The device was placed on the housekeeping pad and it was the controls contractor's responsibility to fit the equipment with controls. Now, devices come with controls on board.

The same options that are provided for networking can be used to provide controls to devices.

In the first option, the device—for example, an air-handling unit—comes without controls, and the BAS contractor field mounts the controls. In the second option, a device—for example a packaged rooftop unit—comes with all controls on board, and only a network connection (IP or non IP) and a power connection are required.

As with the network discussion above, the more likely situation is that devices may come with certain controls on board but without other controls that need to be added as hardware devices in the field—for example, a gas detector located in a garage or an external damper actuator for relief air control. In this case, the BAS designer needs to decide who supplies, installs, and controls these external devices and which are shared with the BAS.

Another use case is where data from one system is used by another system on the BAS network. An example of this is sharing occupancy status from the lighting system with the VAV-box controller so that the VAV box can be put to a minimum position when the lighting vacancy/occupancy sensor shows that the room is unoccupied for a fixed period of time.

In each case, the BAS designer must outline the trade responsibilities on a device-by-device basis indicating the following:

a. Who supplies, installs, and networks the BAS devices
b. Who provides external controls devices
c. Who supplies power to these devices
d. How data from one BAS device network shares data with another BAS device network

4.3.3 Managing the Volume of Points Now Available from Devices with Embedded Networkable Controls. Now that devices such as boilers, chillers, etc., can come with onboard controls, points that were normally only available through the local controller display device can now be exposed for remote access using the BAS network. Most variable-frequency drives (VFDs) still come with hardwired terminal strips that allow for 0% to 100% speed control, enable/disable of the drive, and a common alarm. This wiring strategy allows control of the device. If the common alarm point is activated, the user still needs to go to the device display panel to determine the cause of the alarm. If the input and output points can be accessed via the network, then the costs to hardwire each point is substantially reduced. If all the alarm points are exposed on the BAS network, the user can look at the alarm or fault points remotely using the BAS front-end software to determine how critical the alarm is and whether the drive can be used or if a technician needs to come to the site to fix it. These network-accessible points are often referred to as *virtual points*, *network data points*, or *network variables*. A collection of points from a device is often referred to as a *network object*, *device profile*, or *equipment profile*. Standardization of equipment profiles is useful to the integrator as well as to the BAS front-end programmer, as a significant reduction in time and cost is typical due to commonality and interoperability. Use of common or standard device profiles also helps the design engineer ensure that the equipment supplier is providing all of the required points for the required sequence, monitoring, and control.

While remote monitoring reduces maintenance costs, the volume of points that can be exposed is very high. A single VFD may have 50 to 75 internal status, fault, control, and configuration points. If an installation has 100 VFDs, the BAS contractor would need to expose 5000 to 7500 points for this one set of devices. DALI lighting ballasts have 22 standard points. Any facility of any size will have hundreds of these ballasts, resulting in vast quantities of data that need to be brought into the BAS front end. If the user desires graphics, the costs of this work can be very high. Exposing too many points on a network can also hamper performance. The designer must be aware of the network bandwidth limitations, burst traffic issues, and other communications-related issues when defining the quantity and rate of point data updates.

Point list tables contain detailed information for each piece of equipment. If interoperability is an objective, standard point lists for types of equipment should be defined such that the supplier understands the mandatory and optional variable requirements. Most commonly, this is performed through a point list table such as those shown in Informative Appendix F. Point list tables typically not only include information about the point type but also provide guidance for the BAS integration requirements. Table 4.3.3 shows an example of a point list table for a simple temperature sensor object/variable.

Complex equipment can have dozens of analog, digital, and virtual (calculated) points. To help reduce change orders and improve the bidding process, provide a completed table that includes the total number of each point, and information for the FMSI that is required to integrate the equipment, including any monitored, trended, alarmed, and GUI display requirements. Table 4.3.3 is an example; however, additional information, such as frequency of variable updates, default values, protocol-specific information (default heartbeat timers, configuration properties), etc., may be valuable.

TABLE 4.3.3 Example Elements of a Point List Table

Point #	Mandatory or Optional				Point Type						FMSI Integration Requirements								Point Alarm Limits			
	Project Specific	Variable Name	Variable Type	Description	Bound or Polled	Digital Input	Digital Output	Analog Input	Analog Output	Virtual Point (Calculated)	Monitored	Controlled	Logged	Trended	Alarmed	Scheduled	Display (Local Panel)	Display (Operator GUI)	Low Limit	Low Low Limit	High Limit	High High Limit
	Profile Defaults			Object Scope	Instructions: Enter 1 for each point type. Totals on last row.																	
1	M	Space temp.	Temp. deg. Celsius floating point	Space temp. input				1			1		1	1	1		1	1	18.0	16.0	24.0	26.0
				Totals				1			1		1	1	1		1	1				

While these points are available in the device, there are costs to expose the points to the BAS. The BAS designer needs to determine what the user's real data requirements are so that the job can be specified properly and then priced with a minimum of surprise change orders during construction. The following subclauses describe the options that BAS designers can consider when determining the project points count requirements.

4.3.3.1 Option 1—BAS Designer Does not Provide a Point List. The only benefit of this option is that there is no work for the BAS designer. Unclear specification documents will likely mean variations in the bid prices as bidders attempt to make assumptions for providing points. For example, it likely means that there will be change orders, as the front-end supplier may not have allowed for mapping in any points even though the VFD supplier has provided a set of points that now comes embedded in VFDs the supplier sells. This option is not recommended.

4.3.3.2 Option 2—BAS Designer Provides a Detailed Point List. While thorough in practice, generating such point lists requires a lot of work of the BAS designer. While Informative Annex F provides some examples and cites sources for such point lists for typical devices, most device vendors will have their own proprietary extensions to such lists. If Vendor A supports VFD drive temperature and Vendor B does not, is Vendor B considered equal to Vendor A? Which points are mandatory and which are optional? Be aware of feature creep if too many supplier-specific optional variables are defined, as this can significantly reduce interoperability.

4.3.3.3 Option 3—BAS Designer Provides the Minimum Mandatory Point List. The BAS designer might require that only the mandatory points listed in Informative Annex F sources be required. Mandatory points normally include points required for basic, simple control. Implementing this option will certainly reduce the volume of points, but including only a subset of available points may not meet the user's needs. For example, most VFDs have kilowatt and kilowatt-hour monitoring, but these points are usually not mandatory, as they are not essential to the control of the device. This option also requires extensive consultation with the user to determine in advance what the needs are. Users who are new to having such data available may restrict what is specified to bring the project to the construction budget only to find in the middle of the project that having energy monitoring or detailed fault detection is desired. The BAS designer is then put in the position of having to write a change order to have these additional points provided as part of the job.

4.3.3.4 Option 4—BAS Designer Provides a Points-Count Budget for Each Networked Device Supplied for the Project. The BAS designer could specify that every VFD supplied and installed in the project will have a minimum of 25 points that need to be brought into the BAS front end. This option provides guidance to the VFD supplier as to how many points are required and the BAS contractor who must expose the points to the BAS. The real benefit of this option is that the BAS integrator or front-end supplier knows that the license and/or devices must allow, for example, for a total of 5000 points on the job. This budget then sets the hardware and software license requirements that are often tied to a points count. This option is a compromise between being too detailed and limiting the point scope of work prior to the project bid.

Clause 12 provides suggested point lists for the devices being integrated into the BAS device network.

4.3.4 Dealing with Front Ends and other Third-Party Software Tools Such as Energy Dashboards. Multiple options exist for how front end functionality is provided. Originally, all systems were represented as graphics on one front end provided by the BAS contractor. Now it is common to have multiple front ends or multiple applications ("apps") using a common workstation or interface (tablet, smartphone, PC), where each app is responsible for a subsystem or a specific function (analytics, reporting, scheduling, alarming, etc.). For example, there could be a separate front end for the lighting system. There could be a Web appliance in the chiller room that hosts the graphics only for the chiller plant. The BAS designer must decide who is responsible for what graphics and where these graphics should reside.

New software packages, such as energy dashboards, exist to take the data from one or more facility system and create graphics that show energy consumption for a 24 hour period or which compare energy consumption between this month and the same period last year. These systems normally do not provide direct control over the building systems. That functionality is handled by the front end(s).

Specialized pieces of software exist that perform fault detection and diagnose when valves or dampers, etc., are performing poorly. Alarms could be reported to a regional monitoring center for all facilities in the enterprise. BAS devices also support transmission of alarms as e-mails to a smart cell phone or tablet device. Printing alarms is no longer required.

Finally software exists that will archive all data into a common database to permit multiyear analysis of trend log data. This archiving system needs to be specified properly to avoid misunderstandings and change orders.

Numerous options exist for providing these additional software tools. The BAS designer and owner need to decide what is appropriate for the project. The BAS designer needs to lay out what software tools are needed, who will provide them, and where they are to be located within the enterprise.

4.3.5 Dealing with the Enterprise IT Department. IP-based network connectivity will require involvement by the IT department at the early design stage of the project. Requesting IP addresses and the authority to connect the BAS device network to the enterprise network at the end of the job will only frustrate everyone involved in the project. Even if all BAS devices are on their own dedicated network, the administration and maintenance of this separate network is normally performed by the enterprise IT department or by IT personnel working for the facilities department.

There is an understandable reluctance on the part of IT to have BAS devices that may be considered foreign on the enterprise network. The bandwidth issue has already been discussed, and for many BAS devices that use open protocols, such as BACnet or LON, bandwidth consumption is minimal compared to video or CCTV.

The other major issue for IT is security. Every BAS with an IP network drop that is accessible by non-IT personnel is considered a security hole through which unauthorized persons can gain access to sensitive or classified information. IT will likely insist on using IT-based security measures to prevent such unauthorized access. It usually falls to the BAS designer to ensure that the devices to be installed on the enterprise network are approved by IT for such network connections. This responsibility may be assigned to the FMSI or others responsible for the construction.

It is often difficult for IT to permit outside access to authorized maintenance service providers. From the facilities department perspective, outside access allows these service providers to diagnose problems without having to come to the facility. This remote access improves response times and reduces labor and transportation energy costs. From IT's perspective, this is another potential security hole. Software and hardware solutions exist to reduce the potential of unauthorized access but no solution is guaranteed to be safe. IT may disallow this access in principle. It is then up to the facility manager to make the case internally for remote access or to budget for additional service calls to site.

This work includes the following:

a. Who is responsible for the installation of the IP cabling? Does BAS cable installation need to be installed to the same standards as the rest of the IP cable requirements in the enterprise? Is the BAS cable identified per IT or other standards?
b. If a cable tray is available, can BAS IP network cable be installed in the common cable tray? Does this include non-IP based network cable (BACnet MS/TP, Modbus, LON TP/FT-10, proprietary protocol)?
c. Who assigns IP addresses so that there are no duplications of addresses? Does control over IP addresses extend to private networks such as the lighting device network?
d. Normally, there is a communications closet for each building floor or area. Can the BAS cable terminate in an IT-managed switch, or does BAS provide its own switched network and communications closets? If it is possible to use switches under IT controls, who is allowed to perform the terminations? Does the BAS carry a cash allowance to cover these costs, or are these costs borne by the project as a whole?

4.3.5.1 Coordinating the Construction Work with the IT Infrastructure Work. IT normally begins their work when the furniture is in place and the computers are on the desks. The HVAC, BAS, and electrical contractors will want their equipment started up and commissioned long before the furniture and computers are installed. IP connectivity at some level is therefore required long before the enterprise network is brought online.

The BAS designer needs to make provisions for temporary access during the latter stages of construction and the commissioning phase so that the various building devices and systems can be started up and commissioned. This is no different from providing temporary power, heating, lighting, and other services to allow the construction to continue in a smooth manner. The construction contract may require the installation of temporary switches or the BAS switches with either patches to the network cabling or broadband/wireless access to the devices so they can be started up and commissioned. IT may disallow wireless when the enterprise network is operational but may allow wireless on a temporary basis as long as the BAS cable plant is not connected to the enterprise network.

The important issue is that whatever temporary services are allowed, it is best if there is no requirement to change the IP address, as this usually cannot be performed remotely. Requiring the startup technician to return and put in the new IP address after the device is started up and commissioned increases costs and adds delays at a time in the life of the project when the general contractor is trying to close out the job.

The temporary arrangements can be removed once IT is on site and is commissioning their own equipment (desktop computers, printers, switches, etc.). Normally, IT has a certification and accreditation process that must be followed before any device can be connected to the enterprise network.

BAS devices must go through these procedures or remain on a physically separated LAN. Assuming that the BAS device network can be accessed from the enterprise network, it is good practice to create a separate VLAN that limits inbound and outbound traffic across the VLAN boundary. IT may add other measures to limit access to those individuals who are authorized to have access to the BAS network of devices.

4.3.5.2 Granting Other Users in the Enterprise Access to BAS Device Network Information. Historically, once the job was turned over to the owner, only the facilities department required access to the BAS device network so that the devices could be maintained properly. Chillers, boilers, lights, and other devices contain a wealth of information that can be made available to authorized users on the enterprise network. Secure remote access is also possible.

Examples of such uses include the following:

a. *Utility monitoring:* The BAS can monitor the electric, gas, and water utility meters so that consumption and costs can be precisely tracked. Submeters may exist on major electrical feeders so that the lighting, motor, and other loads can be tracked. Chillers, VFDs, and other devices now have built-in kilowatt and kilowatt-hour meters so that consumption and demand can be tracked at the equipment level. This data can be presented using energy dashboard software and forms part of the green facilities policy for the enterprise. External standards such as LEED or Green Globes also require ongoing monitoring. Normally, this monitoring is performed by the enterprise utilities or finance department, so they may need access to the BAS device network.
b. *Consumption and demand management:* The enterprise may be enrolled in a SmartGrid program with the local utility provider or independent service operator (ISO). Under this program, the enterprise may receive money to shed lighting or motor loads or run a diesel generator when requested to do so. An outside contractor may need access to the BAS device network to ensure that the demand management targets are met.
c. *Ongoing commissioning:* The facilities department may have a commissioning authority (CxA) on contract that is responsible for ensuring that the equipment is operating properly. The CxA will usually require outside access to these networks.
d. *Contractor service work during the warranty period:* There is normally a one year warranty on all equipment, including BAS network devices. The more sophisticated equipment may require factory support, and this will be difficult to perform if the factory is far from the facility. If IT will permit remote access to the BAS device network, warranty servicing is faster and less expensive than waiting for on-site service.
e. *Ongoing maintenance:* Granting remote access to ongoing maintenance providers will also improve response times and reduce costs.
f. *Feedback to the design team:* The original designers may appreciate access to the BAS device network so that they may improve operation of the current design or improve the design of subsequent projects for the enterprise.

4.3.6 Specifying the Network Requirements. Clause 12 of this guideline has been written as a stand-alone specification document. The BAS designer may decide to specify this work or may have this work performed by the FMSI or the IT consultant for the project.

4.3.7 Radio-Frequency-Based Networks. Radio frequency (RF) devices and systems are becoming viable in building automation projects. RF-based devices offer the advantage of no new wires being required and is suited well for retrofit applications. RF-based solutions have inherent design considerations relating to placement, obstructions, power, and more that must be addressed.

Several current RF-based protocols/radios are currently available with more on the horizon. The following subclauses give a summary of each.

4.3.7.1 Zigbee Using 802.15.4 Radio. The Zigbee Alliance has developed a mesh networking RF solution that has been used successfully in a variety of applications in the commercial, industrial, and residential space. Zigbee is based on the 802.15.4 radio transceiver with several added protocol layers to define mesh networking access. Zigbee-based devices are being used in remote metering, lighting, and some other building systems.

4.3.7.2 EnOcean Using Low-Power RF. The EnOcean Alliance has developed a low-power energy harvesting technology that has applications in room control. Low-power-consumption devices such as switches and sensors can harvest energy from a variety of sources, such as ambient light or kinetic energy, and transmit their information to a receiver that is then connected to a wired network. Useful in room control where there is a desire to add sensor and control devices without running new wires. The EnOcean technology is good for relatively short distances making it suitable for in-room control.

4.3.7.3 LowPan Using 802.15.4 Radios Internet Protocol Smart Object (IPSO) Protocol. This RF solution ties RF devices to an IPv6 Ethernet backbone. This approach adds significant address space and promotes the "Internet of things" approach. The additional capability of the 6LowPan/IPSO approach has applications in equipment-level and sensor/actuator-level devices. It runs on the same radio as Zigbee; however, different media access schemes are used.

4.3.7.4 WiFi Using 802.11.x Radios Running TCP/IP Over RF. This is becoming a common mechanism to access building controllers not easily accessible via a wired network. A simple example application is connecting to remote buildings where trenching new cable is not feasible. Installing a WiFi router between the two buildings and enabling the BAS on either side to connect or tunnel information between the two networks is a simple and very cost-effective solution. Also, WiFi networks can enable user interfaces such as tablets, notebooks, and cell phones to connect to a local BAS network without the need for an Internet connection, helping to improve security.

As RF solutions mature, issues regarding interoperability, interference, reliability, security, and others will be addressed. Any specification allowing for or requiring RF-based solutions should ensure these issues are specifically addressed such that the delivered solution meets expectations and performs reliably.

4.3.8 Specifying the BAS Controller and BAS Device Network Security Requirements. BAS controllers and the BAS device network will rely primarily on IT to provide security. Even though this work may not be a BAS specification item, the BAS designer needs to ensure that security is being covered in the project or IT may not permit the equipment to reside on the enterprise network. IT will expect the BAS controllers to meet the same security requirements as any other device on the enterprise network.

These IT-based security measures are normally a combination of network, personnel, and physical access security measures. These measures may include one or more of the following:

a. Implementing measures to protect BAS devices from public Internet security threats. The BAS device network is installed behind a firewall managed by IT, and there are no open ports to permit unauthorized access. Remote access, if allowed at all, is permitted only with a secure virtual private network (VPN) tunnel under the control of IT.
b. The BAS device network may be set up by IT on its own VLAN. One must have permission from IT to access the network. This type of security is provided by a VLAN-enabled switch under the control of IT. Only those devices that are members of the BAS device VLAN will have access to the devices on the VLAN.
c. Access to the BAS front end and Web-server computers may be physically restricted to IT personnel. Normally, the computers that host this software are located in secure server rooms, not on the user's desk. These computers are patched regularly with updates from the operating system vendor or from the virus software provider. Only IT has administrative rights to the machine. The BAS front-end software must run without requiring these administrative rights or IT will not allow it to be installed on the enterprise network. Passwords such as "PASSWORD" or "1234" are not allowed. Sharing passwords is not allowed. Normally, IT will track logins to the BAS device network only. The BAS front-end software will track changes made by the authenticated user in a tamper-proof audit log.
d. Physical security measures may include requiring keys or card access to the room where a BAS controller is located. The BAS controllers are located in a locked cabinet. The IP connection to the network is bound to the media access control (MAC) address of the panel. This measure prevents a user from unplugging the RJ-45 connection from the BAS controller and plugging the connection into an unauthorized laptop.
e. Any laptops, tablets, or other devices are controlled by IT in what is referred to as a *managed environment* device. This means that the device can only be used to connect to the enterprise network. Personal devices are not allowed to connect to the enterprise network.
f. Certain organizations such as the military may require that the BAS contractor have a security clearance before the contractor can install, commission, and maintain the BAS devices. Other nonmilitary organizations may require a background check.

Some communications protocols in common use today, such as BACnet, offer the option of purchasing devices with built-in network security. Similarly, the LON protocol has a built in security authentication algorithm that can be enabled for higher security applications on a message-by-message basis. When using either LON or BACnet, best practices dictate the use of strong passwords, proper use of firewalls, limiting open ports, limiting "back door" networks and access, and other security measures when attaching the control network to the data network. Refer to Clause 12 for additional details and responsibilities. Devices that support intrinsic network security will likely be more expensive than panels that do not support this capability. See Informative Annexes B, C, and F for references to obtaining specific open-protocol guideline specification language.

4.4 Characteristics of a BAS

4.4.1 Distributed Control Components. The BAS is a distributed system controlling individual HVAC systems, thereby performing the processing of information close to the source of the inputs and their controlled devices.

This guideline specification defines three broad types of controllers: building controllers, custom application controllers, and application-specific controllers (ASCs). Most manufacturers support these three types of controllers with comparable functionality.

4.4.1.1 Building Controller. A *building controller* is a general-purpose term used to describe a variety of controller types, depending on the environment, protocol, vendor, or integrator terms.

In general, a building controller is programmable. This controller may have a high concentration of input and output (I/O) points or may have no I/O at all. Typically, it may connect to a subnetwork of custom application programmable controllers, application-specific controllers, and/or network interfaces. One common purpose of the building controller is to coordinate and provide building management functions for all of the devices on the subnetwork. In some cases, this is a master/slave type of network. In other situation, the building controller acts as a peer on the network and can store and forward information to the GUI. These functions typically include communication, time-of-day scheduling, alarm processing, trending, sequencing, and other custom programmed functions. The building controller also provides DDC capability for any on-board I/O points.

Building controllers typically reside on the same network as the personal computers that serve as the operator interface, but they can also reside directly on the control network, depending on the technology platform and system requirements. Communication over this network is typically controller-to-controller, also referred to as *peer-to-peer communication*, and results in a more reliable system, as no single panel is responsible for communication management.

4.4.1.2 Custom Application Controller. A custom application controller is a device that normally controls specific pieces of complex, custom equipment, such as an air-handling unit or a cooling tower. This controller is programmable in the manufacturer's programming language. It has sufficient memory for controlling the piece of equipment to which it is connected. It normally resides on the subnetwork but also may exist on the system network. The controller may be a peer device on the sub-LAN (connected to the building controller above) or may be in a "master/slave" relationship to a building controller. *Master/slave* means that the controller can control the equipment in a stand-alone fashion but relies on the building controller to ask it for updated data or to pass to it variables such as outdoor air temperature.

4.4.1.3 Application-Specific Controller (ASC). An ASC is normally used to control VAV boxes, chillers, rooftop units, water-source heat pumps, and other equipment. The controller comes complete with preprogrammed ("canned") routines prepared by the manufacturer. The user selects the appropriate sequence from a menu (e.g., does the VAV box have reheat or does the unit ventilator have cooling?). ASCs are typically more economical, but they offer less flexibility than custom application controllers.

4.4.1.4 Programmable Controller. This is a flexible controller that can have a variety of uses: as specific for equipment or sets of equipment; as a specific subsystem interface, such as a fire system interface controller; or as a special-purpose building controller used, for example, to connect to a legacy proprietary system.

4.4.1.5 Supervisory Controller. This is typically a device that performs a higher level function or set of functions for a system, subsystem, or set of equipment. An example might be a scheduling or alarming supervisory controller.

4.4.1.6 Building or Equipment Network Interface. Some larger building equipment/subsystems, such as packaged chiller, have their own internal control network and require an external interface. The internal controls are interfaced to the building network through a building controller network interface.

4.4.1.7 Web-Server Appliance. Web-server appliances that provide data storage and user interface capabilities are becoming more common. These devices connect to a local Ethernet LAN and provide the user with a browser-based interface that can be accessed from a PC, smartphone, tablet, or imbedded device and simply display Web pages. They can also include some control logic, scheduling, data store-and-forward, protocol translation, media translation, and more functionality (see Clause 4.4.1.8).

4.4.1.8 Combination Device. Any device that combines multiple functions into one device. With the advent of advanced programming and microcontroller technology, this type of device is becoming more common. An example is a device with programmatic capability such as performing optimal start/stop lead/lag programming, acting as a network interface to an IP-based BAS network, and serving as a Web server, all in one piece of hardware.

4.4.1.9 Different vendors and integrators use these terms differently and one must be aware of the usage of the term.

4.4.2 Other Communication Devices. In addition to the functions described for the building controller, custom application controller, and ASC, some vendors offer devices whose only function is to provide communication. This fourth type of device is often referred to as a *communication gateway.* Gateways are typically used to convert between two communication protocols and may be used to convert between proprietary and standard protocols, between two proprietary protocols, or between two different standard protocols. Gateways may be used to interface equipment such as packaged chillers and boilers. They also may be used to connect existing (or legacy) systems to standard open protocols. Depending on the manufacturer, this translation may be performed by a building controller, a custom application controller, or by a separate hardware device. The communication function is covered in the specification regardless of whether a separate gateway device is used or the communication function is built into the panels. Other network infrastructure capabilities, such as routing (see Clause 4.5.3) or media translation (e.g., Ethernet to ARCNET) may also be accomplished in a system by a controller or by a separate device.

4.4.3 I/O Devices. BASs interact with the outside world through I/Os that are connected to sensors and actuators. Input sensors sense temperature, pressure, humidity, air and water flow, equipment status, utility metering data, and alarms. The input sensors transmit information to the controller by a change in voltage, current, or resistance. Outputs include the start/stop of equipment and modulation of dampers, valves, pumps, and fans. The functionality and selection of the various input and output devices is discussed in Clause 8. A complete BAS also includes controller power supplies, relays, conduit, and wire.

4.4.4 Operator Interface. The operator interface should be specified based on the building operator's needs. This operator interface is a software package that provides for setup and operation of the system and usually includes schematic representation of air-handling systems, boilers, and other systems. The operator can use these graphics to view temperatures and status, change setpoints, and override equipment. Graphical operator interfaces should be intuitive and user-friendly. Graphical workstations reside on the same LAN as the building's BAS controllers. Operator interfaces also may be used remotely with a dial-up connection or may operate on a laptop computer and be carried by a service technician. The operator interface also could be a local liquid-crystal display (LCD) that is mounted on the BAS panel. These displays usually have several lines of text and selection pushbuttons to permit the operator to perform basic functions, such as changing setpoints or schedules, without the need for a computer.

The PC-based operator interface will typically use a multitasking operating system. This allows it to be used for other functions in addition to monitoring, control, and display. This includes editing documents, processing work orders, or using other PC-based software programs. Even though the operator interface is not dedicated exclusively to BAS, this is the primary purpose of this machine and it should be specified and included as part of the BAS.

4.5 Interoperability Issues. This clause describes the issues and rationale that are involved in implementing an interoperable system specification. Case studies that help illustrate how this decision process may be applied are included in Informative Annex D.

4.5.1 Issues Driving a Choice for Interoperability. The demands of the BAS owners are requiring manufacturers to design and build products that have the ability to integrate information between systems of different manufacturers. Several factors that have driven this need.

4.5.1.1 Vendor Independence. This allows the customer the freedom to select from a variety of price and performance options and not be limited to the offerings of one manufacturer. This desire for freedom to choose may be based on purchasing-through-bidding requirements, the diversity of system expansion requirements, or unique requirements that cannot be cost-effectively met by a singular manufacturer.

4.5.1.2 Integration with Other Applications. Although building subsystems are often purchased in isolation, they do not operate that way. Integrating these systems selectively and intelligently should allow for device interactions and provide additional comfort or convenience.

An example of this is the possible interaction between access control, lighting, elevators, security cameras, and HVAC control systems. For example, a person entering a building using an access badge is an event that could affect a number of building subsystems. The closed-circuit security camera will pan toward the door to record the entry of that person; it will cause an elevator to go to the first floor to pick up that person; and the lights and the HVAC system will turn on before the person enters the office.

4.5.1.3 Single-Seat User Interface. This refers to the ability to operate, from a single seat or workstation, a variety of dissimilar subsystems through an interface that displays information in a common format. It allows data from different systems to be grouped into a single display and uses a common methodology to execute commands. This increases productivity and greatly reduces the learning burden for facility management personnel. The alternative is to have nonintegrated systems that have their own workstations and/or unique information displays and command methodology, thus complicating the building's monitoring and control process for the operator. The user can choose from a variety of front-end software options that are not necessarily provided by the hardware equipment vendor, improving fair, competitive bidding.

4.5.1.4 Media Sharing. Many sites have an existing LAN or WAN for business or other applications and have sufficient bandwidth to allow for more use. Allowing the BAS to use the existing network can decrease installation expense. Consideration must be given to the risk of network failure or downtime and its impact on building-wide monitoring and control.

4.5.1.5 Investment Protection. The useful life of an existing system can be extended through interoperable systems by adding new technology incrementally, rather than performing a complete system replacement or upgrade. Factors that determine the economic feasibility of the expansion or replacement decision are based on the size of the existing system, cost of maintenance, cost of failure, accessibility to assistance (and parts), and annual capital budgets.

The aforementioned benefits can yield a decrease of cost to a user, but these costs must be put in the proper perspective. The life-cycle costs or total cost of ownership must be evaluated for the system. While costs may have been decreased through interoperability or an open system, these factors may act to increase the total cost of ownership.

4.5.1.6 Maintaining Multiple Vendors' Equipment. For each new manufacturer added, the operating personnel must be trained in that system and stay current with it, and a certain amount of repair inventory must be added. Diagnostic tools are often sophisticated and plentiful *within* a particular system, but tools can be very limited or nonexistent between systems.

4.5.1.7 Complexity of System Integration Issues with Multiple Vendors. When an interoperable system falls short of performance expectations, someone must spend time troubleshooting and perhaps acting as a referee. Unless specifically designated before installation, the purchaser bears the burden of total system performance. Each vendor can prove that its piece is operating properly, but someone must orchestrate a system-wide troubleshooting plan in order to achieve the desired system-wide results. The following should be taken into account when considering interoperability:

a. How will this data be used and stored? For example, the majority of the trend logs are only retained for a month, whereas energy trend logs may be retained for years.
b. Who within the organization and team will need access?
c. What systems will be connected?
d. What equipment will be connected?
e. Which data points are shared?
f. How much control is required?

For example, there may be full control over the HVAC system, but the fire alarm system is only monitored because the front end is not a UL-hardened workstation. Other systems, such as lighting, may have a hybrid of control in that the lighting system is monitored for alarms and the user has the ability to shut lights on and off to satisfy energy requirements. Otherwise, the lighting system runs on its own programmed sequences.

4.5.2 What Needs to Happen to Achieve Interoperability. Once it has been determined that an interoperable system is an economic benefit to the user from a life-cycle standpoint, the next step is to define the degree of interoperability within the system.

4.5.2.1 Define what Information Needs to be Exchanged. While the sequence of operations describes the outcomes desired from the control system, it is essential to specify the object information desired to be available on the network. As described in Clause 5.3.5, the object list is an ideal mechanism for addressing this issue, where each interoperable object is identified in terms of "read" (see value) and/or "write" (command to new value) capability. The "write" objects include setpoints, operating and tuning parameters, as well as calculated variables such as airflow (L/s or cfm). These variables must not be inadvertently omitted from the object list.

4.5.2.2 Define How Far Down into the Network Openness Must Occur. The point in the network architecture at which an open protocol is employed affects system performance and cost (see Table 4.5.2.2).

TABLE 4.5.2.2 Level of Interoperability

Opens at this Level	Provides these Benefits	Adds these Costs	Best Use
Tier 1—Enterprise/ site management	Allows clusters of different brands of control systems to pass information to a host system that can view all systems in a common format. Fundamental overrides and commands can be performed at the host.	At least one gateway (depends on gateway's object) per each additional brand of control system; additional host hardware and software if none of the existing control systems can act as host; programming of each gateway.	Multiple building complexes where one or more buildings have a different brand of control system and there is a need for single-seat user interface.
Tier 2—Building automation system	Same as previous level, plus information is passed between clusters of control systems to allow for global control interoperability (outside air temperature sensing, demand limiting, etc.).	At least one gateway (depends on gateway's object) per cluster of control systems; programming of each gateway; programming of each cluster to incorporate global information and interaction.	Multiple building complexes or large, singular building complexes where there is a need for limited, distributed information access, single-seat user interface, and global interprocess interaction.
Tier 3—Equipment and devices	Allows different brands of dedicated controllers to be connected on the same bus and provides for global communications, global control, and inter-process interaction.	Unless the controller communicates using an open protocol, a gateway must be added per each controller or each group of similar controllers.	Systems that have few controllers and are spread out over a large area.
Tier 4—Sensors, actuators, and field devices	Allows for multiple addressable field devices (temperature sensors, actuators, etc.) to communicate on one pair of wires.	Each field device must have special digital addressing capability.	Systems in which field devices are spread out over a large area and/or are running multiple wires are very costly.

4.5.3 Performance and Architecture Gateways. Computers require very precise, rigidly defined rules or protocols for successful communication. Even slight variations can render communication impossible. In order for two computers using different protocols to communicate, some kind of translation must take place. The device that performs this translation is called a *gateway*.

Gateways are sometimes confused with routers because gateways also perform routing tasks in addition to translation. The distinction between a gateway and a router is important.

4.5.3.1 Routers. Like a gateway, a router is used to connect two or more communication networks. Routers and gateways filter message traffic because messages pass through only if the source of the message is on one side and the intended destination is on the other. The difference is that for a router, the connected networks all use the same application protocol messages. Translation is not needed. A router's job is to forward the message to the next network in the path to its destination. This makes routers much more simple than gateways.

For example, compare sending a message between two different networks to sending a letter from an intra-office mail system through a postal service to its destination. Using this analogy, a router removes the letter from the intra-office envelope, puts it in a postal service envelope, addresses the envelope, puts the correct postage on it, and sends it on its way. The letter itself remains unchanged. A gateway, on the other hand, opens the letter, translates it into another language (if possible), puts it into a new envelope, re-addresses it, and then sends it on.

4.5.3.2 Gateway Benefits and Limitations. No universal right answer exists to the question: Is it a good idea to use a gateway in a BAS? Careful consideration of the benefits and limitations of the costs of the gateway in comparison to other options is needed before making a decision. The following subclauses describe the two use cases where gateways are now used in open-protocol systems.

4.5.3.2.1 Use Case 1—Integration of Proprietary Protocol Devices into the Open-Protocol System. For example, a generator, fuel tank monitor, or an elevator may speak a proprietary protocol that is unique to the manufacturer. If the BAS designer wishes to monitor the device(s) in the open-protocol system, there will be a need for a gateway (likely provided by the equipment supplier) to expose the points to the open-protocol system. The gateway is sized to expose the required points needed to monitor or control the device. This will be a common occurrence until the manufacturers of the equipment offer both proprietary and open-protocol communication cards.

4.5.3.2.2 Use Case 2—Integration of Legacy System BASs into the Open-Protocol System. The BAS designer needs to consider the following if there is a need to pass data between the legacy BAS and the open-protocol BASs. There may be multiple devices on both sides of the gateway that are sharing data points. The gateway may also need translated trend alarms and schedules. The following subclauses describes the design considerations when the BAS designer is faced with the need to provide a gateway of this type.

4.5.3.2.2.1 The most important step in evaluating the use of gateways is to determine what information needs to be exchanged:

a. What information is critical?
b. What information is important but not essential?
c. What information is desirable but not worth significant additional expense?
d. What kind of future expansion is anticipated?

Benefits

a. In some situations a gateway can provide connectivity between devices that would not be possible any other way.
b. A gateway can create a competitive bidding situation. The financial savings resulting from competition may make the limitations and cost of the gateway worthwhile.
c. Gateways provide a way to retain installed proprietary equipment that is still functioning satisfactorily, while migrating toward open, interoperable systems in a step-by-step manner as the proprietary systems and components reach the end of their useful life.
d. A gateway can provide the opportunity to allow connectivity between different BASs, such as life safety and HVAC control, yet maintain the integrity of the critical life safety systems. The gateway can integrate and manage both systems, while at the same time retaining some isolation because the gateway limits the interaction.

Limitations

a. All gateways have finite information storage and processing resources. The gateway must somehow map the information and concepts from one protocol to another. Specifications for gateways must clearly state what information must be available through the gateway and how much future expansion is required. Often, using a gateway will require a compromise between getting all the desired information and keeping within the budget.
b. Gateways have a limited ability to translate dissimilar concepts. Simple concepts, such as temperatures and on/off status, are generally easily translated. However, problems arise for more complex concepts, such as schedules, alarms, prioritized commands, and trending data. In some cases, one or more of these functions simply will be impossible to do through the gateway.
c. Many control systems provide a way to program or configure controllers over the network. It is usually not possible to accomplish these tasks by passing messages through a gateway. Instead, a separate connection that bypasses the gateway is usually required.
d. Failure of the gateway results in a loss of communication between all devices on opposite sides of the gateway.
e. Gateways can introduce time delays when attempting to retrieve information. What happens, for instance, if the gateway passes previously stored data that are now obsolete? Will the recipient be able to tell the difference?
f. Gateways make troubleshooting network problems more difficult. Different tools are needed to see and interpret the protocols on both sides of the gateway. Even the limitation in the amount of information accessible through the gateway can make troubleshooting difficult because it may not be possible to access all of the information needed to diagnose the problem.
g. The throughput or speed of the gateway may make accessing data a slower process. This issue should be carefully considered and included in the performance criteria specification.
h. If the equipment or system that the gateway is used to integrate is replaced or upgraded, the gateway often needs to be replaced or reprogrammed in order to enable continued data exchange.

A gateway is a useful and effective tool to achieve limited connectivity between otherwise incompatible devices. As the amount and variety of information that needs to be exchanged increases, the viability of using a gateway to accomplish the task diminishes. The BAS designer may ultimately determine that it makes sense to replace the legacy BAS with an open-protocol BAS instead of trying to install and maintain a gateway between the two BASs.

4.5.4 Define the Open Protocol to Be Used. It is necessary to specify the protocol to be used in an open system in order to drive communication conformance toward that certain set of criteria or standards. In every case of writing an interoperable specification, the designer must specify which open protocol is to be used in each network segment. This is especially important if he or she is integrating equipment controllers (such as chiller and boiler controls or lighting controls) that are specified elsewhere and supplied by manufacturers other than the building controls' manufacturer. Otherwise, the goal of integrating with these other applications will be left to chance.

4.5.4.1 Categories of Protocols. The word *standard* is often used in discussions of protocols. There are degrees of propriety to the standards continuum, and they can be explained as follows:

a. *Industry recognized standard:* A protocol that is formally recognized and/or listed by an independent, industry standards organization as a set of operational criteria. Examples are BACnet (recognized by ASHRAE and ANSI) and LON (recognized by ISO/ANSI/CEA). See Informative Annexes B, C, and F for references to obtaining specific open-protocol guideline specification language.
b. *Defacto standards:* Very popular proprietary protocols in the marketplace that have been embraced by users and manufacturers and are offered as communications options on a variety of equipment. Examples include Modbus, Allen Bradley DH+, and Opto 22.
c. *Proprietary standards:* A manufacturer makes proprietary protocols available on a limited basis or shares the protocol with the public at large for use in integrating other products into that manufacturer's network. Often, proprietary protocols have a required license and usage agreement associated with them and may or may not have a fee associated with their usage.

These classifications may be helpful in understanding the type of endorsement and support a protocol may have but do not suggest how popular or how broad the base of users may be. Some protocols of major control system manufacturers are also implemented by a defined, but limited, number of other manufacturers to bring a broad-based, interoperable solution to the market. The size of that number may exceed the number of solutions possible through the use of an industry-recognized or defacto standard.

4.5.4.2 Customer Satisfaction. The protocols you specify will limit the number of companies to those that can offer a solution. The customer, or end user, of the system must ultimately feel comfortable with those manufacturers' products. Also, the total number of companies able to offer the solution (which could be limited to just one or two) must be acceptable. These issues should be considered in advance in order to avoid disappointment with the interoperable solution, even though the technology may be functional.

4.5.4.3 Case Studies in Annex. Each interoperable solution depends on the factors surrounding the client's needs. Two case studies have been assembled in Informative Annex D in order to illustrate how project and client needs drive the various interoperable decisions and dimensions.

5. DESIGN AND CONSTRUCTION OF A BAS

The following clause describes the steps involved in providing a building automation system (BAS) from design through the end of warranty. The BAS designer is the focal point for many of these steps and the contractor will be responsible for implementing the steps. If these steps are performed properly, the end result will be a satisfied client with a BAS that runs the facility in the most efficient manner.

5.1 Steps in Providing a BAS. The steps involved in providing a BAS are shown in Figure 5.1.

5.2 Defining Project Scope. The BAS designer must use caution to design a BAS that meets the users' needs. Some users will have very basic needs. Others may require an extensive degree of alarm management and reporting. The complexity of the system has a direct relation to the project cost.

The assessment of the desired features is a continual process that must be weighed against the proposed budget for the project at key stages. The features must be prioritized so that the low-priority items can be removed during the design stage if necessary to stay within budget.

The BAS designer begins by asking the following questions:

a. What is the size of the project? How many systems? What equipment? How many points/tags?
b. What is the building's proposed use?
c. Is the property owner-occupied or leased
d. Do special control needs exist, such as low cost, high accuracy, comfort, or lowest energy use?
e. Who will run the building and what are their capabilities?
f. Does the owner have other buildings that will be connected to this site?
g. What is the proposed HVAC system?
h. What is the HVAC and controls budget?
i. Is the project a retrofit? If so, what control system is presently installed and will it need to be expanded or replaced?
j. What are the IP connectivity requirements? How does this work? What data from the various BAS subsystems (HVAC, lighting, fire alarm, gas detection, security, etc.) need to be shared? What are the IT security requirements for each BAS subsystem?
k. What level of local support is available for the desired system and technology choices?

Based on this information, the BAS designer should be able to begin designing and establishing the project budget.

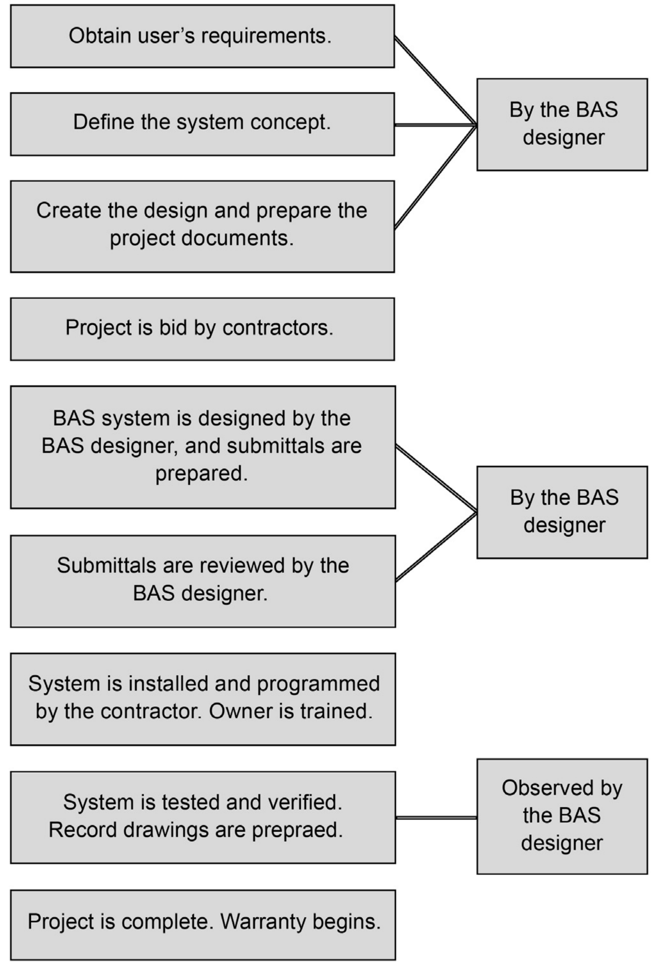

FIGURE 5.1 Steps in providing a BAS.

The BAS designer needs to confirm the preliminary design with the owner based on the above information.

Once the facility's needs have been defined in terms of the number of HVAC systems, user requirements, number of points, and criteria, the system designer can complete the design of the BAS.

If an owner desires to include performance monitoring as part of the project requirements, the specification will need to define the functional capability that is desired. This includes the required monitoring points and performance metrics, system accuracy, network throughput and enhanced data management, and graphical data displays. Detailed example specifications can be found in Informative Annex E.

5.3 Designing the BAS

5.3.1 Steps in Creating the Contract Documents. Once the project scope is well understood, the BAS designer can begin system design. There are several methods for achieving this, and the correct method is up to the individual designer. The method recommend by this guideline is as follows:

a. Isolate each unique type of system for the project. If multiple systems are used, a single typical system can be created, and minor modifications can be shown. A system

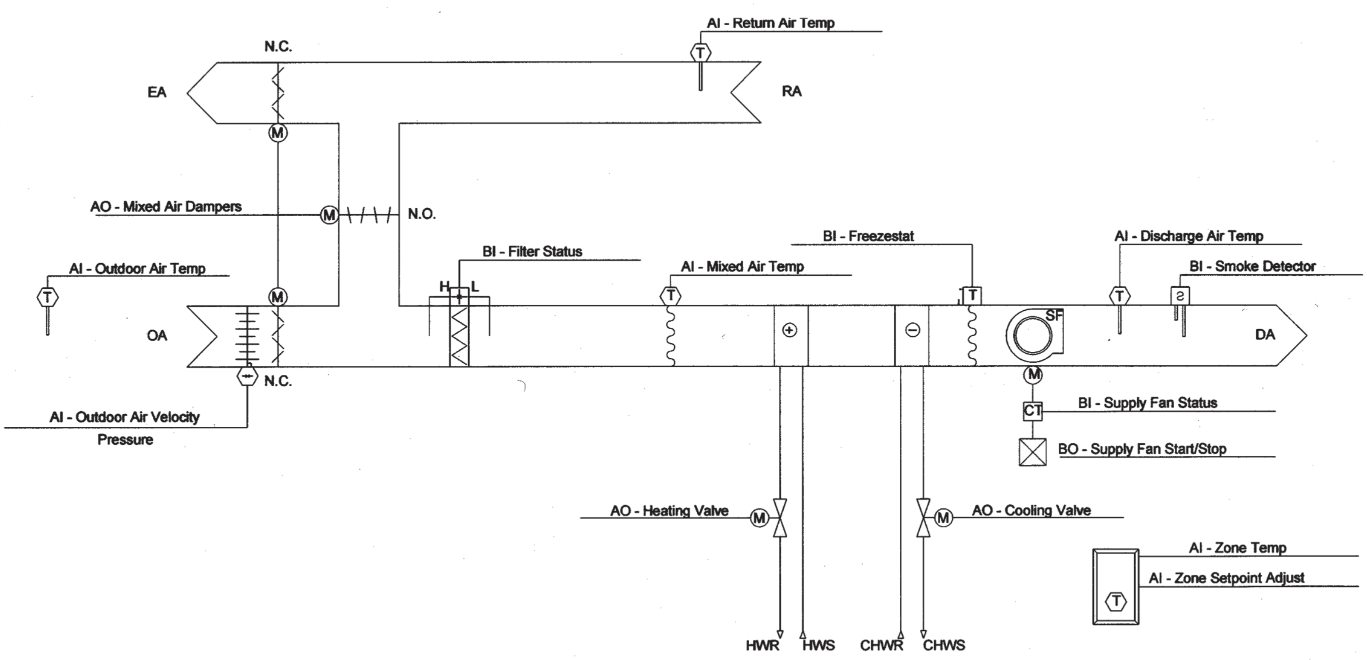

FIGURE 5.3.2 Sample control schematic.

may be an air handler with variable-air-volume (VAV) boxes, chiller plant, boiler, heat recovery, smoke control, or other.

b. For each system, the BAS designer should produce a system schematic drawing. This is a very basic illustration that is schematic in nature. The drawing will need to show the critical control components. See Clause 5.3.2, "Creating Project Drawings," for examples and details on creating project drawings.

c. Using the drawings, create the sequences of operation. When creating a sequence, you must determine what the system will need to do under a variety of circumstances. For example, what should the system do when the building is occupied or when it is unoccupied, during the summer, or during the winter? What happens during a fire emergency or during a power failure? The sequence will need to answer all of these questions. See Clause 5.3.4, "Sequences of Operation," for examples of and details on creating sequences.

d. With the sequence and the system drawing, the BAS designer can now prepare a system object (or points) list. This is an important system document that shows which hardware and software points the contractor will need to provide, along with the key functions of these points. See Clause 5.3.5, "Object List," for examples of and details on creating object lists.

e. Add control elements to mechanical and electrical drawings. The project drawings that have been prepared to meet the mechanical and electrical specifications. The drawings will need to show BAS elements. These will typically include equipment locations, space and outdoor sensor locations on the floor plans, damper locations and schedules on the mechanical plans, and locations of control panels requiring 120 VAC on the electrical plans.

f. Create the project specifications. In reality, the BAS designer will rarely sit down and create a BAS specification from scratch. Most firms have built up a series of "master specifications" that can be edited to meet the needs of a project. Many of these specifications were originally obtained from controls companies and have been refined over many years of use. The master specification will provide a good starting point for producing an unbiased document, but it must be edited to suit the considerations of each individual project.

g. Determine who is responsible for the IP and non-IP network connectivity.

h. Determine how the system will be secured.

i. Determine how the system will be designed and who will perform the design work. For example, the mechanical and electrical designers design the equipment and systems. The integration of these systems into a common BAS may be performed by others such as the facility master system integrator (FMSI).

The sequences of operation and the object list can appear either in the system drawings or in the written specification. These project documents should only appear in one place. Placement of the documents in the project drawings will tend to ensure that they are kept as part of the building record. Placing the documents in the specification will make them easier to be transmitted to potential bidders by e-mail.

5.3.2 Creating Project Drawings. Control drawings (see Figure 5.3.2) are a critical element in documenting the system design. A drawing shows the contractor the physical relationships of various components, such as fans and coils. The control devices can be accurately located relative to the system components (e.g., the freezestat should be shown upstream of the heating coil). Flow diagrams showing a schematic layout of piping and equipment should be provided for steam, hot-water, and chilled-water systems. Control devices (sensors and valves) should be shown in the appropriate locations in the piping.

The benefits of including control drawings as part of the contract documents include the following:

a. There is a graphical depiction of the design for the contractor.
b. There is a clearer definition of the control hardware requirements.
c. Control drawings allow the designer to see the overall design concepts and verify the implementation of these concepts.
d. The drawings facilitate system checkout during both the shop drawing and installation phases of the project.
e. Since the drawings depict the hardware types and locations, all of the bidders are on the same page.

Preparation of drawings takes time and money. The resources used in control drawing preparation are paid back in several ways:

a. They help define project scope and reduce prebid questions.
b. Shop drawing preparation and review are expedited.
c. Bid pricing is more uniform.
d. Fewer change orders may result from documentation misunderstandings.

5.3.3 Network Connectivity Requirements. The following connectivity requirements should be identified in the project specification:

a. Control network infrastructure, including wiring, routers, gateways, panels
b. Data network (LAN/Ethernet) network infrastructure, switches, routers, hubs, and BAS connectivity points
c. Coordination of responsibilities between IT, FMSI, controls contractor, and equipment supplier
d. Requirements for the BAS front-end software server, software, graphics, and integration with BAS devices
e. Security, access, firewalls, and related infrastructure issues, i.e. passwords, user levels, administration rights, etc.

5.3.4 Sequences of Operation. The sequences of operation describe how the system shall function and are the designer's primary method of communication to the control system programmer. A sequence should be written for each system to be controlled. In writing a sequence, care must be taken to describe all operational modes and to ensure that all I/O devices needed to implement the sequence are shown on the object list and drawings.

5.3.4.1 Writing Control Sequences. Writing clear, unambiguous, concise yet comprehensive sequences of controls is very difficult. It first requires a clear understanding of how controls work, the limitations of the specific controls hardware specified, the limitations of the HVAC system design, and a knack for clear thinking and writing. It also takes practice and experience. The following are suggestions to assist in developing successful control sequences:

a. Provide a description of the system at the beginning of each section to assist the reader in understanding the system. This should include unusual or custom system or control requirements to help explain the rationale behind sequences.
b. Organize sequences into the logical hierarchy of systems and the subsystems they serve. The most energy-efficient sequences usually start at the lowest level and feed operational requests upward. For example, zone VAV control logic determines the need for heating and cooling, which is conveyed to the air handler that serves them so that they operate as desired. The air handler control logic, in turn, conveys the need for chilled and hot water to the central cooling and heating plants. In this way, systems operate efficiently and only when needed.
c. Use tables and diagrams where possible to assist in conveying sequencing logic.
d. Show formulas in the sequences if they are to be used in calculations.
e. Write the sequences in such a way that it will make it easy to use the document to verify system functionality during construction and testing.
f. Control loop initial or default setpoints should be provided.
g. Keep the sequences as simple as reasonably possible, but without compromising energy conservation and other performance goals.
h. Use sequences that have been used successfully on similar projects as a template. Sample control sequences for several common HVAC system types are available on a CD published by ASHRAE called *Sequences of Operation for Common HVAC Systems*. Sequences for common systems are also available from control system manufacturers.
i. Show what objects (points) may be shared by other systems. For example, the vacancy/occupancy sensors may be installed by the lighting system contractor. The state of these sensors may be used by the HVAC system contractor to control the VAV-box damper position. When the vacancy/occupancy sensor considers the room to be unoccupied during the day, the VAV-box controller can put the airflow to a minimum position, thus creating part-load occupancy savings for the owner.
j. Global sequences may also exist that affect all systems that need to be included in the contract documents. Military or detention facilities may have a lockdown mode that is manually activated when a threat is detected. If there are networked fire systems, the fire alarm may override air handlers and exhaust fans in a UL-approved manner to control smoke or pressurize stairwells. With the advent of automated demand response (OpenADR), there may be sequences to respond to power outages or real time electrical price increases. When these events occur, lights may be dimmed slightly, space temperatures may be raised in cooling mode, and fan variable-frequency drives (VFDs) may deliver less air. These systems return to normal when the event is over.

5.3.4.2 Organizing Control Sequences. There are two basic methods of organizing a sequence of operation: by operating mode or by component. In a sequence that is structured by operating mode (Table 5.3.4.2-1), the major paragraphs are broken into operating modes (such as occupied, unoccupied, and morning startup), with descriptions of how each component of the system behaves in that mode. In a sequence that is structured by component (Table 5.3.4.2-2), the major paragraphs are broken into components (such as valves and dampers), with descriptions of how the component behaves in each operating mode.

Composed correctly, both formats provide the same information. Sequences that are organized by operating mode are generally easier to understand because they describe how the entire system will operate under a given set of conditions. The drawback to this format is that it can be difficult to program a controller from this sequence as details about how each component should operate are scattered throughout the sequence. Sequences that are organized by component may be easier for a programmer to use because most control programs are structured by component. Similarly, many technicians find the component structure more useful as a troubleshooting tool because they are generally troubleshooting a specific component. The question, "why is the heating valve open?" is easier to answer if all information about the heating valve is contained in one section.

The decision of which format to use should primarily be determined by the intended use of the sequence. If the intent is to explain operating concepts and highlight differences between the operating modes, the sequence should be organized by operating mode. If the intent is to provide specific programming instructions and to provide maintenance documentation, the component approach should be used. As a secondary consideration, if the designer needs to provide sequences for multiple variations of a piece of equipment (e.g., unit ventilators with hot- water heat, gas heat, or electric heat), the component approach may be easier to produce since only the affected component needs to be rewritten.

5.3.5 Object List. The object list is a tabulation of all system hardware and software points (see Table 5.3.5). Since these points can be physical points that are wired to the system or virtual software points, they are modeled using objects. This is a method often used to model data in the software standards. The BAS designer cannot possibly list all of the software objects since they will tend to be specific to the manufacturer and system installer. If a specific object is required for interoperable operations, sequences of operation, or other system functions, then it must be included in the object list. For example, if runtime is desired on a chiller, then this object should be included on the system object list.

Several features associated with the objects are defined in the object list, including the following:

a. *Hardware point type:* The type of point must be noted (analog or binary, input or output).
b. *Software point type:* Listing software points is optional, but doing so will ensure proper graphical displays and trending. The type of point should be noted (analog value, binary value, or schedule).
c. *Trend:* If the object is to be sampled in a trend log, then this should be noted. List either the desired trending time interval (for analog points), change of value (COV, for binary points), or a differential value change (for analog points).
d. *Graphic assignment:* If the object is to appear on a graphic, then this should be indicated.

5.3.6 Specification. The example specification follows the format determined by the CSI. Under the 1995 CSI Master Format, a controls specification will typically be placed in Division 15 for mechanical systems. While the exact placement varies, it is usually in Section 15900 or 15950. Under the 2004 CSI Master Format, control specifications are typically in Division 23, "Heating Ventilating and Air Conditioning," Section 23 09 00, or in Division 25, "Integrated Automation."

The CSI format for specification sections produces a consistent organization, appearance, and completeness from one specification section to another. Any specification section must answer three questions:

a. What interrelationships exist between the work of this section and the remainder of the project?
b. What materials and products are involved?
c. How are they incorporated into the work?

Section format presents the answers by grouping the information into three distinct categories, or parts:

Part 1: "General"
Part 2: "Products"
Part 3: "Execution"

These three parts are fixed in name and order, thus introducing another level of standardization into specification writing. A consistent format for the sections simplifies the BAS designer's task and makes information retrieval by the reader much easier. Each part is divided into articles, which are then further divided into paragraphs and, on occasion, subparagraphs.

It is important to note that the specification created for BASs will need to be well coordinated with the other sections. For example, Division 0 specifies how the contracts will be administered, along with general terms and conditions. This language also will apply to the systems and contractors addressed in the relevant section. Work provided in other sections also requires coordination. For a more complete discussion, refer to Clause 7.

5.3.7 Editing a Specification. When editing a master specification, it is important to refer back to the project criteria that were collected at the beginning of the process. A large project with critical needs may require a more complex sequence, submittal, and checkout. A small project may not require an on-site user interface or extensive sequences. Clauses 7, 8, and 9 of this guideline will help in creating a specification to meet the needs of a particular project.

5.4 Special Considerations for Retrofit Projects. Often the design of a BAS will be for use in an existing building. This retrofit work will require some special effort on the part of the BAS designer. On new construction, the controls system will be installed in concert with a number of other trades. Wires and raceway can be installed easily while the walls and ceilings are open. The responsibility for cleanup and painting are clearly assigned to other subcontractors on the site.

Installation during a retrofit project is complicated since the walls, floors, and ceilings are all in place. In addition, the building often will be occupied, requiring careful scheduling, night work, thorough and frequent cleaning, and continued comfort control. Retrofit also may mean that the BAS supplier may be able to reuse certain existing control components and possibly replace or refurbish others.

When designing a retrofit project, the BAS designer will have to address the following issues:

TABLE 5.3.4.2-1 Example Sequence of Operation—Mode Style

Sequence of control written in the mode style

A. General

1. The occupancy mode (occupied or unoccupied) shall be determined through a user-definable time schedule.

2. Whenever the supply fan is de-energized, as sensed by the status switch, the outside and exhaust air dampers shall be closed and the return air damper shall be open, the heating and cooling valves shall be closed or positioned as described below.

B. Occupied Mode

1. The supply fan shall be energized. There shall be adjustable minimum on and off times initially set at 5 min. Safety trips shall override the minimum on and off times.

2. There shall be separate heating and cooling space temperature setpoints. The setpoints shall be initially set at 23°C (74°F) cooling and 21°C (70°F) for heating. The occupant shall be able to adjust the zone temperature heating and cooling setpoints at the zone sensor.

3. The heating coil valve, economizer, and cooling coil valve shall modulate in sequence to maintain space temperature setpoint. The cooling valve shall be enabled only when the outside air temperature is above 15.5°C (60°F) (adjustable), the fan status is on, and the zone is calling for cooling and heating is not active. The heating valve shall be enabled whenever the outside air temperature is less than 18.3°C (65°F), the fan status is on, the zone is calling for heating, and cooling is not active.

4. Whenever the outside air temperature is less than 18.3°C (65°F) (adj.) (see ANSI/ASHRAE/IES Standard 90.1 for setpoint appropriate for climate), the outside air temperature is less than the return air temperature, and the fan status is on, modulation of the economizer dampers shall be enabled. There shall be a mixed air low limit function to close the economizer dampers to prevent the mixed air temperature from dropping below 1.7°C (35°F) (adj.).

5. When in the occupied mode, the controller shall measure the airflow and modulate the economizer dampers to maintain the minimum airflow setpoint (adj.), overriding normal economizer damper control.

C. Unoccupied Mode

1. Unoccupied OFF: The supply fan shall be de-energized except when operation is called for as described below. Outside air dampers and exhaust dampers shall be closed and return air damper open. Heating and cooling valves shall be closed except as described below.

3. Unoccupied setback heating: The supply fan shall cycle on with the outside and exhaust dampers closed when the space temperature drops below the unoccupied space temperature setpoint of 18.3°C (65°F) (adjustable). When the fan is energized, the heating valve shall modulate to maintain space temperature. The cooling valve shall be closed. The unit shall cycle to the unoccupied OFF mode when the space temperature is –16.1°C (3°F) degrees above the unoccupied space temperature heating setpoint.

3. Unoccupied setup cooling: The supply fan shall cycle on when the space temperature is above the unoccupied space temperature cooling setpoint of 29.4°C (85°F) (adjustable). When the fan is energized, the economizer and cooling valves shall be sequenced to maintain space temperature. The heating valves shall be closed. The fan unit shall cycle to the unoccupied OFF mode when the space temperature is –16.1°C (3°F) degrees below the unoccupied space temperature cooling setpoint.

4. Optimum start. The unit shall use an optimal start algorithm to minimize the unoccupied warm-up or cool-down period while still achieving comfort conditions by the start of scheduled occupied period.

D. Safety Shutdowns

1. Duct smoke detection, and low temperature limit trips shall de-energize the supply fan and close the outside air dampers. Manual reset of the tripped device shall be required to restart the system

2. The cooling valve shall open 50% when ever the low temperature limit is on.

3. The heating valve shall open 100% whenever the supply air temperature is less than 1.7°C (35°F) (adj.).

TABLE 5.3.4.2-1 Example Sequence of Operation—Mode Style *(Continued)*

E.		Alarms
	1.	Alarm the following conditions
		a. High zone temp: If the zone temperature is 2.8°C (5°F) greater than the cooling setpoint.
		b. Low zone temp: If the zone temperature is 2.8°C (5°F) less than the heating setpoint.
		c. Supply fan failure: Commanded on, but the status is off.
		d. Supply fan in hand: Commanded off, but the status is on.
		e. Supply fan runtime exceeded: Status runtime exceeds a user definable limit.
		f. High mixed air temp: Mixed air temperature greater than 32.2°C (90°F).
		g. Low mixed air temperature: mixed air temperature less than 7.2°C (45°F).
		h. High discharge air temp: If the discharge air temperature is greater than setpoint by 2.8°C (5°F) (adj.) after the unit has been operating for a minimum of 15 min.
		i. Low discharge air temp: If the discharge air temperature is less than setpoint by 2.8°C (5°F) (adj.) after the unit has been operating for a minimum of 15 min.
		j. Filter alarm: If the filter differential pressure switch exceeds its setpoint.
		k. Smoke detection.
		l. Low temperature limit.

a. Who has responsibility for cutting, patching, cleaning, and repairing damaged finishes?
b. The existing system will need to be evaluated for potential reuse of components. For example, can wiring or raceway be reused? Are the existing valves usable? This evaluation can be performed either by the BAS designer before the design or by the contractor as part of the contracted work.
c. If the building will stay occupied, does the work need to be performed at night? How will tenant complaints be handled?
d. Who is responsible for demolition? Who disposes of material that is removed? Does it remain the property of the owner?
e. Can materials and tools be stored on site?
f. Do existing services need to be maintained? This would require installing all of the new components, then switching over to the new system at night or on a weekend.
g. If an existing system is to be updated, who has the responsibility for this?
h. Are existing drawings to be updated to show new controls?

The answers to all of these issues will need to be addressed in the contract documents. If the retrofit is part of a larger project, then many of these already will have been addressed. If the project involves only controls, then additional effort will be required to properly design the project.

5.5 Bidding the Project. Once the contract documents—including the drawings, sequences, I/O list, and specification—are complete, they can be incorporated into the general contract documents. These compose a complete set of contract documents, which are typically distributed to contractors in order to obtain bids.

There are many methods of organizing and bidding a construction project. While a complete discussion of these is beyond the scope of this guideline, there are certain elements that should be considered. The selection of the BAS supplier may have a considerable impact on the comfort and operation of a facility. Therefore, it is helpful to know the major methods of selecting the supplier and installer of the BAS.

5.5.1 Open Bid. This method allows the BAS supplier to be selected through the conventional purchasing channel. This typically means that the listed and other preapproved controls subcontractors will submit a bid to the mechanical subcontractor, who, in turn, bids to the general contractor. The general contractor will compile the bids from the mechanical, electrical, concrete, and other subcontractors and submit a price for the project. The low general contractor is typically selected and, in turn, selects the lowest-priced mechanical subcontractor, who selects the lowest-priced controls subcontractor. This method results in the lowest price for the overall project, but takes away from the owner and BAS designer the ability to choose the BAS supplier.

5.5.2 Alternative Bidding Methods. There are a number of alternative bidding methods that will allow the owner and BAS designer to determine which suppliers are used for the project. While this will not necessarily result in the lowest price, it will allow for the selection of the desired supplier—often at the same cost or at a modest premium. These alternative methods will require documentation in Division 0 of the specification. These approaches include the following.

5.5.2.1 Flat Specification. This approach does not require changes in Division 0. It simply lists the desired supplier as the only valid selection. While this approach will ensure that the desired supplier is provided, it will not provide competitive bids.

5.5.2.2 Base Bid/Alternative. The base bid approach requires the general contractor to list base bid prices for the desired supplier and alternative bids for all other choices. This approach shows all of the prices to the owner and BAS designer and allows them to select the desired supplier. This results in some added effort for the mechanical subcontractor and general contractor.

5.5.2.3 Technical Proposal. This approach is typically used for a project that only entails a BAS. The BAS suppliers provide a technical proposal along with a price. The content of the technical proposal would be outlined in Division 0 and may include experience, service capabilities, key staff

TABLE 5.3.4.2-2 Example Sequence of Operation—Component Style

Sequence of Control written in the component style

Run Conditions:

The unit shall run according to a user-definable time schedule in the following modes:

Occupied Mode: The unit shall maintain the zone cooling setpoint of 23.3°C (74°F) (adj.) and the zone heating setpoint of 21.1°C (70°F) (adj.). The occupant shall be able to adjust the zone temperature heating and cooling setpoints at the zone sensor.

Unoccupied Mode (night setback): The unit shall cycle on and off to maintain the zone cooling setpoint of 29.4°C (85°F) (adj.) and the zone heating setpoint of 18.3°C (65°F) (adj.) with a 1.7°C (3°F) dead band.

Optimal Start: The unit shall use an optimal start algorithm for morning start-up. This algorithm shall minimize the unoccupied warm-up or cool-down period while still achieving comfort conditions by the start of scheduled occupied period.

Alarms shall be provided as follows:

High Zone Temp: If the zone temperature is 2.8°C (5°F) greater than the cooling setpoint.

Low Zone Temp: If the zone temperature is 2.8°C (5°F) less than the heating setpoint.

Freeze Protection:

The unit shall shut down and generate an alarm upon receiving a freeze-stat low temperature limit status. Manual reset shall be required to restart the system.

Smoke Detection:

The unit shall shut down and generate an alarm upon receiving a smoke detector status. Manual reset shall be required to restart the system.

Supply Fan:

The supply fan shall run anytime the unit is commanded to run. The fan shall run for a minimum of 5 min (adj.) and be off a minimum of 5 min (adj.) unless shutdown on safeties.

Alarms shall be provided as follows:

Supply Fan Failure: Commanded on, but the status is off.

Supply Fan in Hand: Commanded off, but the status is on.

Supply Fan Runtime Exceeded: Status runtime exceeds a user definable limit.

Cooling Coil Valve:

The controller shall measure the zone temperature and modulate the cooling coil valve open on rising temperature to maintain its cooling setpoint.

The cooling coil valve shall be enabled whenever:

Outside air temperature is greater than 15.6°C (60°F) (adj.).

AND the zone temperature is above cooling setpoint.

AND the fan status is on.

AND the heating is not active.

The cooling coil valve shall open to 50% (adj.) whenever the low temperature limit is on.

Heating Coil Valve:

The controller shall measure the zone temperature and modulate the heating coil valve open on dropping temperature to maintain its heating setpoint.

The heating coil valve shall be enabled whenever:

Outside air temperature is less than 18.3°C (65°F) (adj.).

AND the fan status is on.

AND the zone temperature is below heating setpoint.

AND the cooling is not active.

The heating coil valve shall open to 100% (adj.) whenever:

Supply air temperature is less than 1.7°C (35°F) (adj.).

OR the low temperature limit is on.

Economizer Dampers:

The controller shall measure the zone temperature and modulate the economizer dampers and cooling coil valve in sequence to maintain space temperature at the zone cooling setpoint.

The outside and exhaust air dampers shall close and the return air damper shall open when the unit is off.

The economizer shall be enabled whenever:

Outside air temperature is less than 18.3°C (65°F) (adj.) (see Standard 90.1 for setpoint appropriate for climate)

AND the outside air temperature is less than the return air temperature.

AND the fan status is on.

TABLE 5.3.4.2-2 Example Sequence of Operation—Component Style *(Continued)*

The economizer shall close to 0% (adj.) whenever:

Mixed air temperature is less than 1.7°C (35°F) (adj.).

OR on loss of fan status.

OR the low temperature limit is on.

Alarms shall be provided as follows:

High Mixed Air Temp: If the mixed air temperature is greater than 32.2°C (90°F) (adj.).

Low Mixed Air Temp: If the mixed air temperature is less than 7.2°C (45°F) (adj.).

Minimum Outside Air Ventilation:

When in the occupied mode, the controller shall measure the air flow and modulate the economizer dampers to maintain the minimum air flow setpoint (adj.), overriding normal economizer damper control.

Alarms shall be provided as follows when unit has operated for a minimum of 15 minutes:

High Discharge Air Temp: If the discharge air temperature is greater than setpoint by 2.8°C (5°F) (adj.).

Low Discharge Air Temp: If the discharge air temperature is less than setpoint by 2.8°C (5°F) (adj.).

Filter:

An alarm shall be generated if the filter differential pressure switch exceeds its setpoint.

TABLE 5.3.5 Sample BAS Control System Object List for AHU Described in Figure 5.3.2 and Tables 5.3.4.2-1 and 5.3.4.2-2

	Hardware Points				Software Points				
Point Name	**AI**	**AO**	**BI**	**BO**	**AV**	**BV**	**Sched**	**Trend**	**Show on Graphic**
Zone Temperature	×							15 min	×
Zone Setpoint Adjust	×								×
Return Air Temperature	×							15 min	×
Outdoor Air Temperature	×							15 min	×
Mixed Air Temperature	×							15 min	×
Outdoor Airflow (cfm)	×							15 min	×
Discharge Air Temp	×							15 min	×
Cooling Valve		×						15 min	×
Heating Valve		×						15 min	×
Economizer Dampers		×						15 min	×
Low Temperature Limit			×					COV	×
Smoke Detector			×					COV	×
Supply Fan Status			×					COV	×
Filter Status			×						×
Supply Fan Start/Stop				×				COV	×
Outdoor Airflow Minimum Setpoint					×				×
Schedule							×		×
Heating Setpoint					×			±0.6°C (1°F)	×
Cooling Setpoint					×			±0.6°C (1°F)	×
High Zone Temperature						×			
Low Zone Temperature						×			
Supply Fan Failure						×			
Supply Fan in Hand						×			
Supply Fan Runtime Exceeded						×			
High Mixed Air Temperature						×			
Low Mixed Air Temperature						×			
High Discharge Air Temperature						×			
Low Discharge Air Temperature						×			

resumes, and other criteria. The successful supplier can then be selected by evaluating these proposals. Often a series of points (or scores) are assigned to each area of the proposal. The supplier with the highest overall score is selected.

5.6 Submittals. Once the BAS supplier has been selected, the submittal process begins. The first step in the submittal process is design work by the BAS supplier. This consists of interpretations of the contract documents and creation of shop drawings and a submittal package. The purpose of the submittal package is to document what will be provided on the project. Submittal details are discussed in depth in Clause 7.10 of this guideline.

It is usually the responsibility of the BAS designer to review the submittal package for accuracy and conformance to the project documents. Components need to be examined for conformance to Part 2, "Products," of the specification. Riser diagrams need to be reviewed for proper network and wiring details. Valve and damper schedules must be checked to ensure that the selected valve flow coefficient (C_v) will produce the expected pressure drop at design flow. If the submittals are in agreement with the design, then they will be returned to the contractor and installation work can begin. If there is a problem with the submittal, then the problem should be noted and the package should be returned for correction and resubmittal before installation can begin.

5.7 Project Installation and Checkout. Once the submittals are successfully reviewed, the BAS supplier is able to begin the installation, programming, and checkout of the system. This typically will coincide with the work of the other project subcontractors. The BAS designer usually monitors the work for compliance with the specification. On most projects, this will mean regular job-site visits and observations of system installation and operation.

Note on Commissioning: For all BASs, checkout and testing is required for the system to perform properly. On certain projects, a commissioning agent may be employed. The requirement for a separate commissioning agent is specified in its own separate section of the specification (typically in Division 1).

5.8 Project Completion and Warranty. Before installation is complete and immediately thereafter, the operators of the system are to be trained to proficiently operate the system. When the system is completely installed and operating, the warranty period begins. At this time, the BAS supplier is responsible for providing record drawings.

5.9 Closing Comments. This clause provided an introduction to BASs and issues to consider when specifying these systems. The following clauses provide an example specification in a three-part CSI format. Explanatory notes accompany this specification language.

6. ABOUT CLAUSES 7, 8, AND 9

The next three clauses provide a detailed discussion using example specification language. These paragraphs form one complete specification section. Its outline is found in Annex A of this guideline. Analysis of each paragraph or group of paragraphs within the example specification is presented. The detailed discussion covers issues such as the following:

a. The background and technology of the item(s) covered by the specification
b. What portion of a control system project is being specified
c. What purpose this portion of the specification serves
d. Why the specification language is written in the manner shown
e. Any cautions concerning the approach taken by the specification
f. Guidance on how to select and/or size the product or system types described
g. Other documents that the reader should consult for more information

The above issues concern the specification example as written. However, a specification must always be edited for the specific needs of a given project. Therefore, this guideline also discusses issues that the reader should consider when editing a control system specification. These issues follow the phrase "Project Considerations" to draw the reader's attention to their importance. These issues include the following:

a. What values within a specification should be modified (e.g., the quantity of submittals required)
b. What else might be specified for other types of projects or special situations
c. For what projects or special situations this specification paragraph should be deleted
d. Other approaches that the BAS designer might want to consider
e. The costs and benefits associated with design choices to be made by the BAS designer

It should be noted that the purpose of the example specification is to provide a point of discussion for guiding the reader on the design and specification of a BAS. The example specification is not intended to be used for an actual project without modification. Additionally, the system architecture, communication, and DDC products described in Article 2.2, "Communication," in the specification Part 2, "Products," is just one approach of many available in the market and does not represent a preference.

Immediately following each discussion is the referenced specification article or paragraph(s) reproduced verbatim. In certain clauses, it is left to the BAS designer to replace [bracketed] wording with project-specific wording. Clause 7.13.4 provides some detail on the [bracketed] terms and instructions.

7. SPECIFICATION PART 1: GENERAL

This part of the specification covers administrative issues such as system performance, approvals, and submittals. The subsequent parts of the specification—products and execution—are discussed in Clauses 8 and 9, respectively.

This specification section must be edited to reflect paragraphs and titles used in an actual project specification.

7.1 Products Furnished but not Installed under this Section. A variety of products are furnished by a controls sub-

PART 1—GENERAL	
1.0	SECTION INCLUDES
.1	Products Furnished but not Installed Under this Section
.2	Products Installed but not Furnished under this Section
.3	Products not Furnished or Installed under but Integrated with the Work of this Section
.4	Related Sections
.5	Description
.6	Approved Control System Primary Manufacturers
.7	Quality Assurance
.8	Codes and Standards
.9	BAS Performance
.10	Submittals
.11	Warranty
.12	Ownership of Proprietary Material

contractor that are best installed by another subcontractor within the construction team. "Best installed" means that the cost of installation and/or coordinating labor is typically reduced if specified for installation by another. These products include pipe-mounted devices that are best installed by the piping subcontractor and certain duct devices (e.g., dampers) that are best installed by the sheet metal subcontractor. This specification paragraph should be edited to list only those other specification sections that include installation instructions for the products involved. (See Clause 10, "Instructions to Other Contractors," for more information on these installation instructions.)

7.1.1 Project Considerations. This specification paragraph should be stricken for projects in which the controls subcontractor may be the prime contractor (e.g., a controls upgrade project). Also, the BAS designer must complete the CSI section numbers (shown below as "xxxxx") and edit the titles to match the actual sections used within the remainder of the specification.

1.1 PRODUCTS FURNISHED BUT NOT INSTALLED UNDER THIS SECTION

A. Section xxxxx—Hydronic Piping
   1. Control Valves
   2. Flow Switches
   3. Temperature Sensor Wells and Sockets
   4. Flowmeters
B. Section xxxxx—Refrigerant Piping
   1. Pressure and Temperature Sensor Wells and Sockets
C. Section xxxxx—Ductwork Accessories
   1. Automatic Dampers
   2. Airflow Stations
   3. Terminal Unit Controls

7.2 Products Installed but not Furnished under this Section. A variety of HVAC equipment can be specified with manufacturer-furnished controls. This approach will become more common as the use of standard protocols permits integration of manufacturer-furnished BAS controllers into a single system. (Refer to Clause 10 for further discussion of the integration of these controls with the rest of the communication network.) Some of the controls furnished by an HVAC equipment manufacturer may require field installation efforts—for example, a space thermostat provided with a packaged air handler.

7.2.1 Project Considerations. This specification paragraph should be edited to list only those other specification sections that include products for installation under this section. The paragraph should be stricken for projects in which the controls subcontractor is the prime contractor (e.g., a controls upgrade project). Finally, the BAS designer must complete the listed section numbers (shown below as "xxxxx") and edit the titles to match the actual sections used within the remainder of the specification.

1.2 PRODUCTS INSTALLED BUT NOT FURNISHED UNDER THIS SECTION

A. Section xxxxx—Refrigeration Equipment
   1. Refrigerant Leak Detection System
B. Section xxxxx—Rooftop Air-Handling Equipment
   1. Thermostats
   2. Duct Static Pressure Sensors

7.3 Products not Furnished or Installed under but Integrated with the Work of this Section. BASs increasingly rely on controls provided by a variety of subcontractors and/or suppliers. These controls range from chiller and boiler controls to non-HVAC controls, such as fire alarm systems, fire/smoke dampers, and lighting control systems. If the BAS design requires functions that involve the sharing of information between these various controls—or just some type of simple interlock—then it can be said that the BAS is integrated with these other controls. The following are examples of functions that require integration:

a. A boiler plant can use a digital output from the BAS to enable/disable a boiler sequencing controller provided by the boiler manufacturer.
b. Chiller setpoint reset can involve the output of an analog signal from the BAS to the chiller controller provided by the chiller manufacturer. With an open protocol this can be handled through a communications network. See Informative Annex F for a reference to open-protocol guideline specification language.
c. A variable-air-volume (VAV) terminal unit can be provided with a cross-flow velocity sensor that is used with a field-installed DDC controller for pressure-independent control.
d. Duct smoke detectors are typically interlocked by the controls subcontractor to the air handler for life safety shutdown.
e. Fire/smoke dampers may be supplied with pneumatic actuators and therefore require control air to be supplied by the controls subcontractor.
f. Smoke control can require extensive integration between the BAS system and the fire alarm system if the HVAC system is involved in smoke control.
g. An HVAC system can be started and stopped based on a security system's card reader transactions.

h. HVAC and lighting controls can be operated from the same time schedule residing in either system.

The suppliers and/or subcontractors involved with the other systems should be both supplying and installing these systems. However, the various members of the construction team need to coordinate their efforts to successfully integrate the controls. The purpose of this paragraph is merely to direct the reader to these other controls. Other portions of the project design need to provide the details of this integration, including

a. this specification, Article 3.3, "Coordination";
b. the BAS drawings and sequences of operation, which should describe the functions required; and
c. the other sections of the specification (including other divisions), which should be edited to include reciprocal discussions of the integration required (again, refer to Clause 10 for discussion about wording to be included in these sections).

7.3.1 Project Considerations. The following specification paragraph should be edited to include only the other specification sections that apply to the integration involved. Also, the BAS designer needs to complete the CSI section numbers (shown below as "xxxxx") and edit the titles to match the actual sections used within the remainder of the specification. Finally, a detailed discussion of the integration required should be included in specification Article 3.22.

1.3 PRODUCTS NOT FURNISHED OR INSTALLED UNDER BUT INTEGRATED WITH THE WORK OF THIS SECTION

A. Section xxxxx—Heat Generation Equipment
   1. Boiler Controls
B. Section xxxxx—Refrigeration Equipment
   1. Chiller Controls
C. Section xxxxx—Rooftop Air-Handling Equipment
   1. Discharge Air Temperature Control
   2. Economizer Control
   3. Volume Control
D. Section xxxxx—Unit Ventilators and Fan-Coil Units
   1. Setpoint Reset
   2. Day and Night Indexing
E. Section xxxxx—VAV Terminal Units
   1. Cross-Flow Velocity Sensor
F. Section xxxxx—Variable-Frequency Drives

7.4 Related Sections. Controls are typically field-installed on a variety of mechanical and other equipment. The installation efforts of other subcontractors must be coordinated with the efforts of the controls subcontractor. Therefore, this section should be used to direct the reader to all other portions of the specification that include equipment to be controlled by—or coordinated with—the BAS. There may be a variety of specification sections outside the mechanical and electrical divisions that should be identified here, including kitchen equipment, fume hoods, irrigation systems, etc. These will depend on the level of building automation and integration desired. This section also reminds the controls subcontractor that it is also subject to the general project terms and conditions found in Divisions 0 and 1.

7.4.1 Project Considerations. The BAS designer must edit this section to list the actual CSI sections and their titles used within the remainder of the project specification.

1.4 RELATED SECTIONS

A. The general conditions of the contract, supplementary conditions, and general requirements are part of this specification and shall be used in conjunction with this section as part of the contract documents.
B. The following sections constitute related work:
   1. Section xxxxx—Submittal Requirements
   2. Section xxxxx—Commissioning
   3. Section xxxxx—Security Access and Surveillance
   4. Section xxxxx—Detection and Alarm
   5. Section xxxxx—Basic Mechanical Materials and Methods
   6. Section xxxxx—Heat Generation Equipment
   7. Section xxxxx—Refrigeration Equipment
   8. Section xxxxx—Heating, Ventilating, and Air-Conditioning Equipment
   9. Section xxxxx—Air Distribution
   10. Section xxxxx—Testing, Adjusting, and Balancing
   11. Section xxxxx—Basic Electrical Materials and Methods
   12. Section xxxxx—Wiring Methods
   13. Section xxxxx—Electrical Power
   14. Section xxxxx—Low-Voltage Distribution

7.5 Description of BAS. This section should contain a narrative description of the system. This description could include the type of architecture, communication technology, panel layout, use of DDC versus conventional controls, operator interfaces, and any special or unusual hardware or operating features. In addition, if performance monitoring or event response are to be included as described in Annex E, descriptions of these capabilities should be included. The purpose is to provide the reader with insight into the design intent. This section should be an overview of the project, highlighting any special requirements associated with its implementation. It is not meant to describe every detail of the control system design and installation.

Included in this section is a description of the architecture with respect to Internet accessibility. Many vendors have developed BASs that allow communications via Internet protocol. This allows users to access DDC data using a standard Web browser. The implementation of Internet technology chosen by the various vendors typically falls into one of two categories: Web-based systems or Web-compatible systems. Understanding the differences between the two types will aid the designer in the specification process.

Web-based BASs are developed as true Web applications. These systems are designed to be interfaced using only a standard Web browser. The BAS files are typically housed on a dedicated server (loaded with the vendor's Web-based system software) that is not used as an operator interface. The operator interface can be any computer using a standard Web browser that is able to communicate to the server over the Internet/intranet. Since the BAS is designed to operate as a Web application, all system data are Web-accessible.

Web-compatible systems serve up data from the BAS to the Web. These systems can be accessed using a standard Web browser, but still require the use of the vendor's proprietary software on dedicated computers for advanced functions or to view all system data. In many cases additional software must be used in conjunction with a standard Web browser for users to interrogate the system over the Internet. BAS files typically reside on a dedicated server and/or operator workstation(s) running the vendor's proprietary software. A gateway or Web-enabled controller is used to convert specific data to Internet format. Therefore, the BAS as a whole is not Web-accessible (only the data that have been designated for conversion). Because only data that are specifically designated for Web accessibility can be served up via the Web, the designer must carefully specify the system functionality that will be available to Web users.

For applications where Internet users will simply be viewing BAS data or making setpoint changes, the Web-compatible system may be a good fit. This may be a good alternative for projects where there is an existing BAS that offers a Web-compatible product. For facilities where multiple users need to access all aspects of the BAS (scheduling, trend analysis, loop tuning, etc.), Web-based systems may be a better fit. A Web-based system may be more attractive for larger projects or facilities with multiple buildings, since the system files and Web interface reside in a single server (or group of servers) as opposed to being distributed between multiple gateways, Web-enabled controllers, and/or servers and workstations. IT departments are often very protective of allowing Internet access, and the fewer ports open to the Internet the better.

Specifying the performance required by the Internet user will define the type of system that can be used for the project. If the user is only required to view system data and have the ability to change setpoints, either Web-accessible system type will be acceptable. If the user is required to have access to all system data including the manipulation of adjustable parameters, scheduling, trend data, tuning parameters, etc., then a Web-based system is implied. The designer should also consider how many different users will be accessing the BAS and how often. Some vendors (Web-based and Web-compatible) restrict the number of simultaneous Web users or charge extra for additional users above a preset minimum.

It is not enough to specify that the BAS be Web-accessible. The designer must determine what level of Web interface is required for the specific project and define it clearly in the specifications. See additional requirements in Clause 12.

7.5.1 Project Considerations. This first example is generic and may or may not result in a Web-based interface.

1.5 DESCRIPTION

A. General. The control system shall consist of a high-speed, peer-to-peer network of DDC controllers and an operator workstation. The operator workstation shall provide for overall system supervision and configuration, graphical user interface, management report generation, and alarm annunciation.

B. Performance Monitoring. The BAS will provide the specified performance monitoring functionality, including required monitoring points and performance metrics, improved through system accuracy, data acquisition and data management capabilities, and required graphical and data displays.

C. Event Response. The BAS will provide the specified operational changes based on event response from the energy service provider.

This second example is for a full Web-based interface with performance monitoring and event response.

1.5 DESCRIPTION

A. General. The control system shall consist of a high-speed, peer-to-peer network of DDC controllers, a control system server, and an operator workstation.

B. System software shall be based on a server/thin-client architecture, designed around the open standards of web technology. The control system server shall be accessed using a Web browser over the control system network, the owner's local area network, and remotely over the Internet (through the owner's LAN).

C. The intent of the thin-client architecture is to provide operators complete access to the control system via a Web browser. No special software other than a Web browser shall be required to access graphics, point displays, and trends, configure trends, configure points and controllers, or to edit programming.

D. Performance Monitoring. The BAS will provide the specified performance monitoring functionality, including required monitoring points and performance metrics, improved through system accuracy, data acquisition and data management capabilities, and required graphical and data displays.

E. Event Response. The BAS will provide the specified operational changes based on event response from the energy service provider.

This third example is for a Web-compatible interface with performance monitoring and event response.

1.5 DESCRIPTION

A. General. The control system shall consist of a high-speed, peer-to-peer network of DDC controllers, a control system server, and/or an operator workstation.

B. The control system server and/or operator workstation shall provide for overall system supervision and configuration, graphical user interface, management report generation, and alarm annunciation.

C. The system shall support Web browser access to the building data. A remote user using a standard Web browser shall be able to access the control system graphics and change adjustable setpoints with the proper password.

D. Performance Monitoring. The BAS will provide the specified performance monitoring functionality, including required monitoring points and performance metrics, improved through system accuracy, data acquisition and data management capabilities, and required graphical and data displays.

E. Event Response. The BAS will provide the specified operational changes based on event response from the energy service provider.

7.6 Approved Control System Contractors and Manufacturers

7.6.1 General. The controls subcontractor chosen for the project is perhaps the single most important factor in the successful implementation of a BAS. This is contrary to other specification sections where the emphasis is placed on manufacturers. Therefore, to help control the quality of the subcontractor chosen, it is good practice to limit the list of allowable bidders. Prequalification efforts can range from using a list of familiar subcontractors to undertaking a major prequalification effort. The issues considered might include the subcontractor's reputation, the quality of the subcontractor's documentation, the level of customer training provided, and history of service performance. Be advised that these issues can change over time for a specific subcontractor.

The list of approved controls subcontractors does not preclude the possibility that other controls subcontractors or BAS manufacturers may win the project. The BAS designer should review other sections or divisions of the specification for the rules concerning substitutions and prior approvals.

7.6.2 Technical Proposals. An alternative approach to controlling subcontractor quality is to request technical proposals from potential subcontractors and/or manufacturers. This is best used when price alone is not the sole issue in selecting the controls subcontractor. Such situations might include

a. the first project in a campus upgrade,

b. a client interested in learning more about DDC technology prior to selecting the control system contractor, or

c. critical applications where success cannot be entrusted to the low bid.

Be aware that this approach must be handled separately from a bid process. Once the control system contractor is selected and the price determined, the contract value may be assigned to the project. Once again, consult and review other sections or divisions of the specification concerning assignment of preselected subcontractors.

Technical proposals can be specified to include a wide variety of subcontractor and product information, including the following:

a. A profile of the controls subcontractor and manufacturer
b. A profile of the product line, including its age and number of installations
c. The control system contractor's approach to project planning and management
d. Resumes of personnel
e. References
f. Examples of project documentation
g. A proposed system architecture diagram
h. Data sheets for major components
i. Examples of actual system graphic screens for other projects
j. Examples of actual custom application programs for other projects
k. Samples of shop drawings for other projects
l. A list of exceptions, clarifications, or deviations from the specification
m. Proposed alternative methods of approach
n. A sample of a typical service agreement
o. Product list prices and discounts to be offered for the purposes of this project
p. A demonstration of system operation
q. A tour of a completed system installation

Once the technical proposals are received, an evaluation process must be undertaken to select the controls subcontractor. This process may involve a team of evaluators with a formal scoring method or something less formal. Either way, it should be clear that the technical proposal approach can involve extensive specification and evaluation efforts. Clause 12 has additional requirements if a facility master system integrator (FMSI) is used for the project.

7.6.3 Listing BAS Contractors or Manufacturers in the Specification. While it is desirable to specify approved contractors in a specification, it is not always practical and it is sometimes not allowed by clients, particularly government or institutional bodies where doing so can be considered anticompetitive. In the sample specification language below, it is assumed that only the primary BAS manufacturer can be listed in the specification but that specific local dealers or contractors cannot be specified. The last statement in the specification paragraph is provided to clarify that not all components of a BAS are produced by the manufacturers listed.

1.6 APPROVED CONTROL SYSTEM PRIMARY MANUFACTURERS

A. The following are approved BAS manufacturers and product lines:

Manufacturer	Product Line
Manufacturer A	
Manufacturer B	
Manufacturer C	

Note:

1. The order of the above list of manufacturers does not indicate preference. Inclusion on this list does not guarantee acceptance of products or installation. BASs shall comply with the terms of this specification.
2. Use operator workstation software, controller software, custom application programming language, building controllers, custom application controllers, and application-specific controllers only from one of the manufacturers and product lines listed.
3. Other products specified herein (such as sensors, valves, dampers, and actuators) need not be manufactured by the above manufacturers.

7.7 Quality Assurance. These paragraphs can provide a variety of requirements concerning the standards of practice that should apply to the controls subcontractor and his/her products and installation practices.

7.7.1 Project Considerations. This paragraph should only be used if the BAS designer is seeking additional bidders beyond those listed in the above discussion on "Approved BAS Contractors and Manufacturers." The example specification paragraph lists some of the items that might be considered for selecting additional bidders. The BAS designer may choose to add other requirements, depending on the need for more rigorous qualifications, such as the criteria discussed in Article 1.6, "Approved Control System Primary Manufacturers."

1.7 QUALITY ASSURANCE

A. Installer and Manufacturer Qualifications
   1. Installer shall have an established working relationship with BAS manufacturer of not less than three years.
   2. Installer shall have successfully completed BAS manufacturer's control system training. Upon request, Installer shall present certification of completed training including hours of instruction and course outlines.

7.8 Codes and Standards. This paragraph should list only those codes and standards, along with the specific sections, used in the BAS design. The paragraph should not be used for an exhaustive list of all codes and standards that might conceivably have something to do with controls. Also, the contractor should not be expected to determine what sections of a building (as opposed to mechanical) code apply to a project. Therefore, the specification lists the specific sections of the building code referenced. If this approach is not used, the specification will be difficult to enforce.

7.8.1 Project Considerations. The codes and standards that apply to a given project will vary with the application and jurisdiction. ICC (International) Codes are listed in the example; however, the project might be in a jurisdiction that is covered by the BOCA or Standard Building Codes or the National Building Code of Canada. Also, the specific sections of a building code will vary with the code used, the application, and the edition of the code used. Therefore, the list must be edited for each project. Change "state" to "provincial" or remove as required for location of the project.

1.8 CODES AND STANDARDS

A. Work, materials, and equipment shall comply with the most restrictive of local, state, and federal authorities' codes and ordinances or these plans and specifications. As a minimum, the installation shall comply with current editions in effect 30 days prior to receipt of bids of the following codes:
   1. *National Electric Code* (NEC)
   2. International Building Code (IBC)
   3. International Mechanical Code (IMC)
   4. [Local codes]

7.9 System Performance. The BAS designer is always faced with the choice of being prescriptively detailed versus less exact in describing what is required for any system component. Sensors, for example, call for more detail than components whose desired results might be met by a wide range of products. When prescriptive language is used, it should

a. be recognized by the client as important;
b. cite realistic, deliverable values;
c. not conflict with any products specified in Article 1.6, "Approved Control System Primary Manufacturers," and Part 2, "Products"; and
d. be used sparingly or not all; unless you know for certain that a specific performance standard is vital, do not use prescriptive language.

The BAS designer will need to determine with the client what the desired system performance should be and what elements are important. A project that is controlling a critical process may need much quicker system reactions than one simply used for comfort cooling. The BAS designer should only state the required level of performance for the project. Specifying a higher level of performance may result in increased job costs for additional hardware or higher-grade devices than the client requires.

7.9.1 Graphic Display and Refresh. These factors impact how rapidly the system operator sees data on the screen. These rates also may impact the selection of PC hardware and network loading.

7.9.2 Object Command. This measures how long it takes for a commanded output to react to an operator-entered change.

7.9.3 Object Scan. Systems that implement a master/slave architecture typically scan the controllers periodically and store this information at the building controller level. This means that the operator may be looking at data that are only as current as the last time the controller was scanned. "Object scan" is the time it takes for any building controller to register and react to a change of state or value of any point, variable, or alarm on the system. It is a function of the communication network's throughput and may be critical for reactions where a controller may be monitoring conditions caused by systems that are controlled by another controller.

7.9.4 Alarm Response Time. This is how long it takes for the operator to see an alarm. It might take up to a minute to see the alarm at the workstation or front end. Most front ends will log all alarms. The user may only want critical alarms sent to a cell phone as an e-mail.

7.9.5 Program Execution Frequency. Many HVAC applications, such as time-of-day scheduling and demand limiting, do not need to run more often than once per minute. A system with sophisticated custom control, however, may need to run once every five seconds. Shorter frequencies will use additional system resources and may result in increased costs.

7.9.6 DDC Loop Frequency. DDC loops for most HVAC processes do not need to run more often than once every 30 seconds. If a project has a critical process, such as system static pressure control, then a shorter frequency (1–5 s) may be required.

7.9.7 Multiple Alarm Annunciation. This determines how quickly alarms are distributed. On a dial-up system, this number should be in the range of 1–5 min.

7.9.8 Project Considerations. All of the performance values (e.g., times and accuracy) should be reviewed and possibly edited for a given project. In particular, the performance values may not be achievable by the product lines that are listed in Article 1.6, "Approved Control System Primary Manufacturers," or Part 2, "Products." Even if they are achievable, the system required may be more expensive than a typical BAS or that covered by the project budget.

1.9 BAS PERFORMANCE

A. Performance Standards. System shall conform to the following minimum standards over network connections:

1. Graphic Display. A graphic with 20 dynamic points shall display with current data within 10 s.
2. Graphic Refresh. A graphic with 20 dynamic points shall update with current data within 8 s.
3. Object Command. Devices shall react to command of a binary object within 2 s. Devices shall begin reacting to command of an analog object within 2 s.
4. Object Scan. Data used or displayed at a controller or workstation shall have been current within the previous 6 s.
5. Alarm Response Time. An object that goes into alarm shall be annunciated at the workstation within 45 s.
6. Program Execution Frequency. Custom and standard applications shall be capable of running as often as once every 5 s. Select execution times consistent with the mechanical process under control.
7. Performance. Programmable controllers shall be able to completely execute BAS PID control loops at a frequency adjustable down to once per second. Select execution times consistent with the mechanical process under control.
8. Multiple Alarm Annunciation. Each workstation on the network shall receive alarms within 5 s of other workstations.

7.9.9 Reporting Accuracy. Reporting accuracy per application is listed for end-to-end performance. These include the effects of device accuracy, analog to digital (A/D) conversion in the controller, and any loss in data transmission. The values shown in Table 7.9.9 of the system performance excerpt below are shown for typical HVAC applications. Industrial and process applications may require higher accuracy. For example, the typical accuracy listed for a relative humidity sensor is ±5% in a comfort cooling and monitoring application. This can be met with a standard commercial-grade device. However, a printing plant application may require humidity control of ±1%. Specifying this greater accuracy will result in the selection of an industrial-grade device that may cost five to ten times more than the commercial sensor used for space monitoring.

7.9.10 Control Stability and Accuracy. The stability and accuracy of the controlled variable (e.g., temperature, pressure, humidity) is a function of the programming and tuning of the control loops of the working BAS. The stability is also dependent on properly sized and installed mechanical components.

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9. Reporting Accuracy. System shall report values with minimum end-to-end accuracy listed in 1.9.A.10, Table 1.
10. Control Stability and Accuracy. Control loops shall maintain measured variable at setpoint within tolerances listed in 1.9.A.10, Table 1 under "Accuracy Required for Control."

7.9.11 Performance Monitoring. Specifying higher-quality sensors may be required when implementing a performance monitoring system in order to obtain desired accuracy and repeatability of measured and calculated performance metric indices. Levels 1 and 2 as described in Informative Annex E can be accomplished with the instrumentation typically installed in a BAS, as shown in Table 7.9.9. In the example below, Table 7.9.11 reflects the required reporting accuracy for a Level 3 system as described in Informative Annex E. Special consideration should also be given to communication for performance monitoring applications, due to the additional bandwidth that may be required to provide the required sampling rate for all objects.

11. Reporting Accuracy. System shall report values with minimum end-to-end accuracy listed in 1.9.A.10, Table 1. (Note to BAS designer: Use the second Table 1 for performance monitoring.)
12. Control Stability and Accuracy. Control loops shall maintain measured variable at setpoint within tolerances listed in Table 1 under "Accuracy Required for Control."

7.10 Submittals. In general, submittals provide the BAS designer an opportunity to review the work of the contractor before construction begins or any control components are installed. Submittals also include the requirements of the contract closeout documentation. A submittal may be viewed as any documentation required from the contractor.

The submittal process should be familiar to anyone involved with construction. It is a standard requirement of most projects, with the example specification providing a typical description of those requirements.

Completion of a BAS submittal requires detailed interface information for the HVAC equipment to be controlled. Therefore, a controls subcontractor needs copies of the appropriate equipment submittals to determine equipment connections, choose appropriate controllers, and provide accurate programming. In a sense, the BAS designer becomes the information transfer hub between equipment manufacturers, suppliers, and subcontractors. The BAS designer should make sure that submittals are processed in a timely manner so that copies can be made and distributed to those needing this information for their own submittals and designs.

7.10.1 Project Considerations. Different types of submittal packages can be requested. The example specification represents the typical submittal for a BAS. It is a package of information that completely describes the components and system to be provided. The submitting contractor should not start any installation work until the BAS designer grants approval. For large, fast-track, or design-build projects, the total submittal package can be broken down into partial (or early) submittals to accommodate the lead times that suppliers need to order material and gather the correct manpower. For projects where alternative approaches are available, presubmittals provide a method for allowing the BAS designer to formally choose an alternative. More discussion of these two types of submittals is as follows:

a. *Partial submittals:* These contractor-initiated submittals usually include items of long delivery lead time or items that are installed first in the project sequence. Valves, dampers, and rough-in material fall into this category. Once approval is granted on these items, that part of the submittal is complete.
b. *Presubmittals*: Information given in a presubmittal is meant for complete approval. A submittal package of the complete system at a later date will again include this information for overall system approval. This allows the BAS designer to consider different approaches and give initial approval to an alternative approach but not approve the overall concept until the whole system is reviewed. This can be used to qualify systems (or system-level components) with which the BAS designer is not familiar, and it should occur early in the procurement process.

BASs that use color graphics to mix data with system schematics, color photos, floor plans, etc., may benefit from an additional component to the submittal: storyboards of the proposed color graphics. These provide conceptual sketches of each screen plan to be generated. They also commit the supplier to a certain number and quality of graphics to be generated. Each sketch should include the following:

a. *Conceptual screen layout of data and pictures:* Blocks with a text descriptor (e.g., AHU-1 diagram) may be used to represent the picture. Blocks with a text descriptor (e.g., AHU-1 control points) also may be used for text area locators.
b. *How one screen relates to another:* Indications should be given as to how specific screens can be accessed from other screens. This gives the BAS designer a sense of how a system operator will use the graphics for additional information.

Subparagraphs A.1 and A.2 of the example specification below concern the submittal of manufacturers' information and product data for the BAS's central and field hardware. Subparagraph A.3 requests the contractor submit information to confirm that the controlled systems will perform in accordance with the requirements of the contract documents. This information must be submitted in time for adequate review and comment by the BAS designer. Take care to set a reasonable time for this review to take place. In the example below, the time allowed for submittal is 12 weeks after contract award. For smaller or fast-track projects, this time may be much shorter. Please edit for the requirements of the specific project.

The articles under Paragraph B and C involve project closeout materials. Once again, submittal of these items is central to the benchmark of project final completion, and final payment should be contingent upon their satisfactory delivery.

Other items for editing based on a specific project include the following:

a. The Division 1 section governing submittals, the quantity of submittal copies requested, and the times allowed for submittal due dates.
b. The type of specific electronic media (e.g., magnetic/optical) desired for copies of drawing files and software.
c. Which release of AutoCAD should be used for shop drawings.
d. BIM (Building Information Modeling) is to be used, define the tool set, such as REVIT or other, and the file formats required.
e. Part 3, "Execution," may not involve a system demonstration, so the submittal required for this process should be deleted.
f. The system demonstration process described in Part 3, "Execution," may be more extensive than that described in the example specification. Therefore, the submittals discussed in the example may need to be modified to correspond.
g. Delete the pressure test certification for projects that do not include pneumatics.

1.10 SUBMITTALS

A. Product Data and Shop Drawings. Meet requirements of Section 01xxx on shop drawings, product data, and samples. In addition, the contractor shall provide shop drawings or other submittals on all hardware, software, and installation to be provided. No work may begin on any segment of this project until submittals have been successfully reviewed for conformity with the design intent. Six copies are required. Provide drawings as compatible files on optical disk (file format: .dwg, .dxf, .vsd, or comparable) with three ANSI B (11 × 17 in.) prints of each drawing. When manufacturer's cutsheets apply to a product series rather than a specific product, the data specifically applicable to the project shall be highlighted or clearly indicated by other means. Each submitted piece of literature and drawing shall clearly reference the specification and/or drawing that the submittal is to cover. General catalogs shall not be accepted as cut sheets to fulfill submittal requirements. Submittals shall be provided within 12 weeks of contract award. Submittals shall include:

1. BAS Hardware
   a. A complete bill of materials of equipment to be used indicating quantity, manufacturer, model number, and other relevant technical data.
   b. Manufacturer's description and technical data, such as performance curves, product specification sheets, and installation/maintenance instructions for the items listed below and other relevant items not listed below:
      1. DDC (controller panels)
      2. Transducers/transmitters
      3. Sensors (including accuracy data)
      4. Actuators
      5. Valves
      6. Relays/switches
      7. Control panels
      8. Power supply
      9. Batteries
      10. Operator interface equipment
      11. Wiring
   c. Wiring diagrams and layouts for each control panel. Show all termination numbers.
   d. Schematic diagrams for all field sensors and controllers. Provide floor plans of all sensor locations and control hardware.
2. BAS Hardware
   a. A complete bill of material of equipment used, indicating quantity, manufacturer, model number, and other relevant technical data.
   b. Manufacturer's description and technical data, such as product specification sheets and installation/maintenance instructions for the items listed below and other relevant items not listed below:
      1. Central processing unit
      2. Monitors
      3. Printers
      4. Keyboard
      5. Power supply
      6. Battery backup
      7. Interface equipment between CPU and control panels
      8. Operating system software
      9. Operator interface software
      10. Color graphic software
      11. Third-party software
   c. Schematic diagrams for all control, communication, and power wiring. Provide a schematic drawing of the central system installation. Label all cables and ports with computer manufacturers' model numbers and functions. Show all interface wiring to the control system.
   d. Riser diagrams of wiring between central control unit and all control panels.
   e. A list of the color graphic screens to be provided. For each screen, provide a conceptual layout of pictures and data and show or explain which other screens can be directly accessed.
3. Controlled Systems
   a. Riser diagrams showing control network layout, communication protocol, and wire types.
   b. A schematic diagram of each controlled system. The schematics shall have all control points labeled with point names shown or listed. The schematics shall graphically show the location of all control elements in the system.
   c. A schematic wiring diagram for each BAS. Each schematic shall have all elements labeled. Where a control element is the same as that shown on the BAS schematic, it shall be labeled with the same name. All terminals shall be labeled.
   d. An instrumentation list for each controlled system. Each element of the BAS shall be listed in table format. The table shall show element name, type of device, manufacturer, model number, and product data sheet number.

e. A mounting, wiring, and routing plan-view drawing. The drawing shall be done in 1/4-in. scale. The design shall take into account HVAC, electrical, and other systems' design and elevation requirements. The drawing shall show the specific location of all concrete pads and bases and any special wall bracing for panels to accommodate this work.
f. A complete description of the operation of the control system, including sequences of operation. The description shall include and reference a schematic diagram of the controlled system.
g. A point list for each system controller including both I/O, point number, the controlled device associated with the I/O point, and the location of the I/O device. Software flag points, alarm points, etc.

4. Quantities of items submitted shall be reviewed but are the responsibility of the contractor.
5. A description of the proposed process along with all report formats and checklists to be used in Article 3.19, "BAS Demonstration and Acceptance."
6. See Informative Annex F for a reference to open-protocol guideline specification language relating to device conformance statements and/or device profiles required for the submittal process
7. Instrumentation and data point summary Table. Contractor shall submit in table format with the following information for each instrument and data point. The table is to be reviewed and approved by the owner's representative prior to hardware and software installation and programming.
   a. Point name
   b. Point description: Provide building designation, system type, equipment type, engineering units, and functionality; include a description of its physical location
   c. Expected range (upper and lower limit)
   d. Instrumentation (as applicable): Manufacturer, model number, range, and accuracy specification
   e. Type
      1. AI: Analog Input
      2. BI: Binary Input
      3. NAI: Network Analog Input
      4. NBI: Network Binary Input
      5. NVI: Network Variable Input
      6. NVO: Network Variable Output
      7. CP: Configuration Property
      8. P: Programmed (e.g., soft or virtual point in control sequence such as a PID input or output)
      9. C: Calculated Value; a soft or virtual point. If calculated value, provide logic diagrams or code and any constants used in formula. If time-based integrated values are required, provide time periods: minutes, daily, weekly, monthly, and yearly. Also indicate if it is a running average.
   f. Input resolution
   g. Graphic display resolution
   h. Data trend interval
   i. Number of samples stored in local controller before transfer to host computer/server database
   j. Data point address

B. Schedules
   1. Within one month of contract award, provide a schedule of the work indicating the following:
      a. Intended sequence of work items
      b. Start dates of individual work items
      c. Duration of individual work items
      d. Planned delivery dates for major material and equipment and expected lead times
      e. Milestones indicating possible restraints on work by other trades or situations
   2. Provide monthly written status reports indicating work completed, revisions to expected delivery dates, etc. An updated project schedule shall be included.

C. Project Record Documents. Upon completion of installation, submit three copies of record (as-built) documents. The documents shall be submitted for approval prior to final completion and shall include:
   1. Project Record Drawings. As-built versions of the submittal shop drawings provided as compatible files on optical media and as ANSI B (11 × 17 in.) prints
   2. Testing and Commissioning Reports and Checklists. Completed versions of reports, checklists, and trend logs used to meet requirements of Article 3.19, "BAS Demonstration and Acceptance"
   3. Certification of pressure test required in Article 3.10, "Control Air Tubing"
   4. Operation and Maintenance (O & M) Manual
   5. As-built versions of submittal product data
   6. Names, addresses, and 24-hour telephone numbers of installing contractors and service representatives for equipment and control systems

7. Operator's manual with procedures for operating control systems: logging on and off, handling alarms, producing point reports, trending data, overriding computer control, and changing setpoints and variables
8. Programming manual or set of manuals with description of programming language and syntax, of statements for algorithms and calculations used, of point database creation and modification, of program creation and modification, and of editor use
9. Engineering, installation, and maintenance manual or set of manuals that explains how to design and install new points, panels, and other hardware; how to perform preventive maintenance and calibration; how to debug hardware problems; and how to repair or replace hardware
10. Documentation of all programs created using custom programming language including setpoints, tuning parameters, and object database
11. Graphic files, programs, and database on magnetic or optical media
12. List of recommended spare parts with part numbers and suppliers
13. Complete original-issue documentation, installation, and maintenance information for furnished third-party hardware, including computer equipment and sensors
14. Complete original-issue copies of furnished software, including operating systems, custom programming language, operator workstation software, and graphics software.
15. Licenses, guarantees, and warranty documents for equipment and systems
16. Recommended preventive maintenance procedures for system components, including schedule of tasks such as inspection, cleaning, and calibration; time between tasks; and task descriptions

D. Training Materials. Provide course outline and manual for each class at least six weeks before first class. The BAS designer will modify course outlines and manuals if necessary to meet the owner's needs. The BAS designer will review and approve course outlines and manuals at least three weeks before first class.

7.11 Warranty. The warranty is usually a written guarantee of the integrity of a product and/or service and the good faith of the manufacturer and/or installer given to the purchaser. It generally specifies that the manufacturer and/or installer will, for a period of time, be responsible for the repair or replacement of defective parts and will sometimes also provide periodic servicing.

When preparing the warranty section for your project, the following should be included and/or referenced in describing the terms and conditions.

7.11.1 The General Conditions of the Specification. The general conditions define the warranty terms and conditions for the entire project and should be referenced in any warranty conditions listed in the controls specification.

7.11.2 The Guarantee. A guarantee that the BAS will be "free from defects in workmanship and material."

7.11.3 Warranty Period. The warranty period will vary with the type of project and the owner's requirements. A typical warranty period is one year after system acceptance, although some owners may desire up to five years. After the first year of acceptance, each additional year may increase the cost of the project. It is generally observed that malfunctions and problems in electronic equipment occur in the first year after installation. Thus, the economic value of extending the warranty may not be justified. However, an owner may have other financial considerations that justify an extended warranty. If the BAS capabilities include performance monitoring, additional calibration or sensor warranty services outside of the standard manufacturer's warranty may be required. Consider the number of years following substantial completion required to achieve and sustain the performance goals of the BAS.

7.11.4 Commencement of the Warranty. The BAS warranty begins upon acceptance of the system. The system can be accepted through one of three common methods:

a. The owner uses the system before the completion of the project, thereby receiving beneficial use from the system. This can constitute acceptance.
b. The system can be accepted after the completion of each phase of a multiphase project.
c. Acceptance occurs after an agreed-upon completion of a demonstration or acceptance test of the system. An "acceptance test" could include an endurance test, commissioning, and/or some other means of testing the performance of the system.

After any of the above methods of acceptance, written documentation is initiated by the manufacturer and/or installer, placing the system and its components into warranty. The document should stipulate the start date and duration of the warranty period, as well as any additional services and/or support provided to the purchaser that may exceed the terms and conditions of the project. The warranty document may include warranty registration cards covering various pieces of hardware (to be completed and returned to the manufacturer and/or installer) and any software licensing agreements required by the manufacturer and/or installer. In addition, the warranty may include a recommended spare parts list for the owner.

7.11.5 Notification of Failure and/or Defects. The owner should contact the (prime) contractor during the contract warranty period. If the BAS warranty exceeds the contract's warranty, calls made after the contract's warranty expires should be made to the extended warranty provider.

7.11.6 Response Time to Correct Failures and/or Defects. Response time to a warranty call shall indicate the time required to reach the job site following a call from the owner to the contractor. A typical response time to a job site is 24 hours during normal business hours, with exceptions being 1 hour, 24 hours a day, 7 days a week, for critically operated facilities. Different response times could be established for

TABLE 7.9.9 Sensors, Meters, Calculated Values, and Required Accuracies

#	Object Description and Location if Applicable	Sensor or Value Type	Sensor Type or Calculation Method	Expected Range	Required End-to-End Accuracy	Display Resolution	Refresh Interval, min	Trend Interval, min	Accuracy Required for Control
S1	Ambient dry-bulb temperature	AI	Locate in weather station or ventilated enclosure in fully shaded location away from thermal mass bodies	–29°C to 40°C (–20°F to 120°F)	±0.5°C (±0.1°F)	±0.25°C (±0.5°F)	1	10	±1.0°C (±2°F)
S2	Ambient wet-bulb temperature	AI	Locate in weather station or ventilated enclosure in fully shaded location away from thermal mass bodies	–29°C to 40°C (–20°F to 120°F)	±1.5°C (±3.0°F)	±0.25°C (±0.5°F)	1	10	±1.5°C (±3°F)
S6	Building main meter power	AI/BI (pulse)	True RMS	—	±.0% of reading	1.0 kW	1	1	1.0 kW
S8	Zone (space) temperatures	AI	10000 ohm thermistor or 1000 ohm RTD	–1°C to 38°C (30°F to 100°F)	±0.5°C (±0.1°F)	±0.25°C (±0.1°F)	1	1	±0.5°C (±1°F)
S9	Carbon dioxide	AI	Nondispersive infrared sensor technology	0 to 2000 ppm	±50 ppm	50 ppm	1	1	50 ppm
S10	Carbon monoxide	AI	Electrochemical sensor	0 to 100 ppm	±5ppm	50 ppm	1	1	50 ppm
S11	Air pressure (ducts)	AI	Variable capacitance	0 to 2 kPa (0 to 8 in. wg)	±25 Pa (±0.1 in. wg)	125 Pa (±0.5 in. wg)	1	1	25 Pa (0.1 in. wg)
S12	Air pressure (space)	AI	Variable capacitance	–25 to 25 Pa (–0.1 to 0.1 in. wg)	±3 Pa (±0.01 in. wg)	3 Pa (±0.01 in. wg)	1	1	1.3 Pa (0.005 in. wg)
S13	Water pressure	AI	—	0 to 1 kPa (0 to 150 psi)	±2% of full scale	7 kPa (1 psi)	1	1	3.5 kPa (0.5 psi)
S14	Water temperature	AI	—	(0°C to 107°C) (32°F to 225°F)	±0.5°C (±1°F)	±0.5°C (±1°F)	1	1	±0.5°C (±1°F)
S15	Delta-T	AI	10000 ohm thermistor or 1000 ohm RTD matched pair	—	±0.15°C (±0.25°F)	±0.25°C (±0.5°F)	1	1	±0.15°C (±0.25°F)
S16	Relative humidity (RH)	AI	—	0% to 100%	±5% RH	5%	1	1	±5% RH
S17	Water flow	AI	—	—	±2% of reading	1000 L/s (5 gpm)	1	1	0.005 L/s (0.1 gpm)
S18	Ducted air temperature	AI	10000 ohm thermistor or 1000 ohm RTD	7°C to 60°C (45°F to 140°F)	±0.5°C (±1°F)	±0.5°C (±1°F)	1	1	±0.5°C (±1°F)
S19	Electrical (A, V, W, power factor not specified elsewhere)	AI/BI (pulse)	True RMS, three-phase, stand-alone analog or pulse output or networked meter; use maximum resolution if pulse output	—	±1% of full scale	0.1	1	1	1/100 s or less
S28	Airflow rate (measuring stations)	AI	Electronic or differential pressure	—	±5% of reading down to 0.75 m/s (150 ft/min)	0.05 L/s (0.1 cfm)	1	1	±5% of reading down to 0.75 m/s (150 ft/min)
S30	Airflow (Terminal)	AI	Electronic or differential pressure	—	±10% of reading	47 L/s (100 cfm)	1	1	±10% of reading
S31	Airflow (pressurized spaces)	AI	Electronic or differential pressure	—	±3% of reading	24 L/s (50 cfm)	1	1	±3% of reading

AI = analog input; BI = binary input; calculated = value calculated by the DDC hardware or BAS software

TABLE 7.9.11 Sensors, Meters, Calculated Values, and Required Accuracies

#	Object Description and Location if Applicable	Sensor or Value Type	Sensor Type or Calculation Method	Expected Range	Required End-to-End Accuracy	Display Resolution	Refresh Interval, min	Trend Interval, min	Accuracy Required for Control
S1	Ambient dry-bulb temperature	AI	Locate in weather station or ventilated enclosure in fully shaded location away from thermal mass bodies	(–20°F to 120°F)	±0.2°C (±0.35°F)	±0.01°C (±0.02°F)	1	10	±1.0°C (±2°F)
S2	Ambient wet-bulb temperature	AI	Locate in weather station or ventilated enclosure in fully shaded location away from thermal mass bodies	–29°C to 40°C (–20°F to 120°F)	±0.3°C (±0.5°F)	±0.01°C (±0.02°F)	1	10	±1.5°C (±3°F)
S3	Dew point	AI	Chilled mirror, infrared, capacitive	–12°C to 38°C (10°F to 100°F)	±1.5°C (±3°F)	±0.05°C (±0.1°F)			±1.5°C (±3°F)
S4	Building main natural gas meter	BI	Positive displacement—pressure compensated; continuous output		±1% of reading, >10:1 turndown	0.05 L/s (0.1 scfm)	1	1	0.05 L/s (0.1 scfm)
S5	Natural gas flow rate (e.g., boiler)	AI/BI (pulse)	Positive displacement—pressure compensated; continuous output		±2% of reading, >10:1 turndown	0.05 L/s (0.1 scfm)	1	1	0.05 L/s (0.1 scfm)
S6	Building main meter power	BI	True RMS to 50th harmonic		±1.0% of reading	0.1 kW	1	1	0.1 kW
S7	Electric power submeter (e.g., lighting circuits)	AI/BI (pulse)	True RMS to 50th harmonic		±1.0% of reading	0.001 kW			0.001 kW
S8	Zone (space) temperatures	AI	10000 ohm thermistor or 1000 ohm RTD	–23°C to 38°C (30°F to 100°F)	±0.3°C (±0.5°F)	±0.05°C (±0.1°F)	1	1	±0.5°C (±1°F)
S9	Carbon dioxide	AI	Nondispersive infrared sensor technology	0 to 2000 ppm	±3% of reading, ±40 ppm	50 ppm	1	1	40 ppm
S10	Carbon monoxide	AI	Electrochemical sensor	0 to 100 ppm	±5 ppm	50 ppm	1	1	50 ppm
S11	Air pressure (ducts)	AI	Variable capacitance	0 to 2 kPa (0 to 8 in. wg)	±25 Pa (±0.1 in. wg)	125 Pa (±0.5 in. wg)	1	1	25 Pa (0.1 in. wg)
S12	Air pressure (space)	AI	Variable capacitance	–25 to 25 Pa (–0.1 to 0.1 in. wg)	±3 Pa (±0.01 in. wg)	3 Pa (±0.01 in. wg)	1	1	1.25 Pa (0.005 in. wg)
S13	Water pressure	AI		0 to 1 kPa (0 to 150 psi)	±2% of reading	7 kPa (1 psi)	1	1	3.5 kPa (0.5 psi)
S14	Water temperature	AI		–5°C to 107°C (32°F to 225°F)	±0.5°C (±1°F)	±0.05°C (±0.1°F)	1	1	±1.5°C (±3°F)
S15	Delta-T	AI	10000 ohm thermistor or 1000 ohm RTD matched pair		±0.15°C (±0.25°F)	±0.25°C (±0.5°F)	1	1	±0.15°C (±0.25°F)
S16	Relative humidity (RH)	AI		0% to 100%	±5% RH	5%	1	1	±5% RH
S17	Heating hot-water flow	AI			±2% of reading	1000 L/s (5 gpm)	1	1	±0.032 L/s (.5 gpm)
S18	Ducted air temperature (not specified elsewhere)	AI	10000 ohm thermistor or 1000 ohm RTD	7°C to 60°C (45°F to 140°F)	±0.5°C (±1°F)	0.5°C (1°F)	1	1	±0.5°C (±1°F)
S19	Electrical (A, V, W, power factor not specified elsewhere)	AI/BI (pulse)	True RMS, three-phase, stand-alone analog or pulse output or networked meter; use maximum resolution if pulse output		±1% of full scale	0.1	1	1	0.001 kW

TABLE 7.9.11 Sensors, Meters, Calculated Values, and Required Accuracies *(Continued)*

#	Object Description and Location if Applicable	Sensor or Value Type	Sensor Type or Calculation Method	Expected Range	Required End-to-End Accuracy	Display Resolution	Refresh Interval, min	Trend Interval, min	Accuracy Required for Control
S20	Chiller power	AI	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading	0.01 kW	1	1	0.001 kW
S21	Primary chilled-water pump power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.01 kW	1	1	0.001 kW
S22	Chiller condenser water pump power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.01 kW	1	1	0.001 kW
S23	Cooling tower fan power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.01 kW	1	1	0.001 kW
S24	Secondary chilled-water pump power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.01 kW	1	1	0.001 kW
S25	Chilled-water plant chilled-water supply temperature	AI	10000 ohm thermistor or 1000 ohm RTD (matched with S26)		±0.05°C (±0.1°F)	±0.005°C (±0.01°F)	1	1	±0.5°C (±1°F)
S26	Chilled-water plant chilled-water return temperature	AI	10000 ohm thermistor or 1000 ohm RTD (matched with S25)		±0.05°C (±0.1°F)	±0.005°C (±0.01°F)	1	1	±0.5°C (±1°F)
S27	Chilled-water plant chilled-water flow rate	AI	Full-bore magnetic flowmeter (preferred) Hot tapped insertion flowmeter (alternate if location permits)		±0.75% of reading ±2.0% of reading	0.005 L/s (0.1 gpm)	1	1	±0.75% of reading ±2.0% of reading
S28	Air-handling unit supply fan airflow rate	AI	Vortex shedding sensor on fan inlet		±5% of reading down to 0.75 m/s (150 ft/min)	0.05 L/s (0.1 cfm)	1	1	±5% of reading down to 0.75 m/s (150 ft/min)
S29	Airflow (measuring stations)	AI	Electronic or differential pressure		±5% of reading	47 L/s (100 cfm)	1	1	±5% of reading
S30	Airflow (terminal)	AI	Electronic or differential pressure		±10% of reading	47 L/s (100 cfm)	1	1	±10% of reading
S31	Airflow (pressurized spaces)	AI	Electronic or differential pressure		±3% of reading	24 L/s (50 cfm)	1	1	±3% of reading
S32	Air-handling unit supply fan power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.1 kW	1	1	0.001 kW

TABLE 7.9.11 Sensors, Meters, Calculated Values, and Required Accuracies *(Continued)*

#	Object Description and Location if Applicable	Sensor or Value Type	Sensor Type or Calculation Method	Expected Range	Required End-to-End Accuracy	Display Resolution	Refresh Interval, min	Trend Interval, min	Accuracy Required for Control
S33	Air-handling unit return fan power	AI/BI (pulse)	True RMS, three-phase, integrated equipment, stand-alone analog or pulse output or networked power meter; use maximum resolution if pulse output		±1.5% of reading; ±3.0% of reading if from VFD	0.1 kW	1	1	0.001 kW
S34	Air-handling unit supply air temperature	AI		7°C to 49°C (45°F to 120°F)	±0.2°C (±0.35°F)	0.01°C (0.02°F)	1	10	±0.5°C (±1°F)
S35	Air-handling unit mixed air temperature	AI	Locate in air handler's mixed air section; to minimize effects of stratification use averaging sensor if possible	4°C to 38°C (40°F to 100°F)	±0.2°C (±0.35°F)	0.01°C (0.02°F)	1	10	±0.5°C (±1°F)
S36	Air-handling unit return air temperature	AI	Locate upstream of air handler's return air damper	16°C to 32°C (60°F to 90°F)	±0.2°C (±0.35°F)	0.01°C (0.02°F)	1	10	±0.5°C (±1°F)
S37	Air-handling unit outdoor air demanded damper position	AI	Virtual point that commands the damper position	0% to 100%	N/A	0.1%	1	10	0.1%
S38	Air-handling unit return air demanded damper position	AI	Virtual point that commands the damper position	0% to 100%	N/A	0.1%	1	10	0.1%
S39	Whole-building total water flow rate	AI	Hot tapped insertion flowmeter		±2% of reading, >20:1 turndown	0.005 L/s (0.1 gpm)	1	1	0.005 L/s (0.1 gpm)
M1	Whole-building peak power	AI/BI (pulse)	Maximum of measured value S6 over a given time interval		±1%	0.1 kW	1	10	1 kW
M2	Whole-building area-normalized electric energy-use intensity	Calculated	Measured value S6 integrated over a given interval divided by a constant #C1 = building area, m^2 (ft^2)		±1%	1.8 kWh/m^2 (0.1 kWh/ft^2)	1	10	±1%
M3	Whole-building natural gas heat rate	Calculated	Measured value S4 divided by a constant #C2 = 0.01 therm/standard cubic feet		±1.5%	1.8 kW/s (0.1 therms/min)	1	10	±1.5%
M4	Whole-building area-normalized gas energy-use intensity	Calculated	Calculated value M3 integrated over a given interval divided by a constant #C1 = building area, m^2 (ft^2)		±1.5%	315 kW/m^2 (0.1 $therms/ft^2$)	1	10	±1.5%
M5	Average daily outdoor ambient temperature	Calculated	Average of instantaneous measured values (S1)		±0.2°C (±0.35°F)	±0.01°C (±0.02°F)	1	10	±0.2°C (±0.35°F)
M6	Chilled-water plant chilled-water supply-return temperature difference	Calculated	Calculated difference of two measured values (S25 – S26); sensors should be a matched pair		2% of reading or ±0.08°C (±0.15°F)	±0.005°C (±0. 01°F)	1	1	±0.08°C (±0.15°F)
M7	Chilled-water plant power	Calculated	Sum of measured values S20, S21, S22, S23, S24		±1.5%	0.1 kW	1	10	±1 kW
M8	Chilled-water loop thermal cooling output	Calculated	Calculated value M6 multiplied by measured valued S27 multiplied by a constant #C3 = 1.0 kW (500 min-tons/°F·gal)		±3%	0.3 kW (0.1 tons)	1	10	±3%
M9	Chilled-water plant efficiency	Calculated	Calculated value M7 divided by calculated value M8		±4%	0.03 COP (0.01 kW/ton)	1	10	±4%

TABLE 7.9.11 Sensors, Meters, Calculated Values, and Required Accuracies *(Continued)*

#	Object Description and Location if Applicable	Sensor or Value Type	Sensor Type or Calculation Method	Expected Range	Required End-to-End Accuracy	Display Resolution	Refresh Interval, min	Trend Interval, min	Accuracy Required for Control
M10	Total air-handling unit power	Calculated	Sum of calculated values S32x		±1.5%	0.1 kW	1	10	±1.5%
M11	Total air-handling unit flow	Calculated	Sum of measured values S28x		±5%	0.05 L/s (0.1 cfm)	1	10	±5%
M12	Total air-handling unit specific power	Calculated	Calculated value M10 divided by calculated value M11		±6%	0.0002 kW/(L/s) (0.0001 kW/cfm)	1	10	±6%
M13	Air-handling unit percentage outdoor air	Calculated	Instantaneous difference of two measured values (S35 – S36)/(S1 – S36); this can be used as an estimate of outdoor air percentage of total airflow, provided that the air temperature difference between the outdoor air and the return air is at least 5°C (11°F)	0% to 100%	N/A	0.001	1	1	0.1%

AI = analog input; BI = binary input; calculated = value calculated by the DDC hardware or BAS software

business hours, after hours, weekends, holidays, etc. To avoid any confusion, establish one acceptable response time within a specific time frame.

7.11.7 Cost. To avoid additional cost to the owner, state that a warranty response and the repair or replacement of a defective or failed component should be made at no charge to the owner.

7.11.8 Software/Firmware Updates. To ensure that the owner will have the most current operating system provided by the manufacturer, it should be stated in the specification that the manufacturer/installer shall provide and install, at no charge to the owner, the latest firmware and software applicable for this project before the expiration of the warranty period. Including this statement may increase the cost of a project. See additional requirements in Clause 12 for software/firmware updates.

7.11.9 Periodic Preventive Maintenance Service. Depending upon the owner's needs and requirements for the project, regular preventive maintenance of the system may be necessary during the warranty period to ensure the proper operation of the system. If regular maintenance is required, it should be stated in the specification that during the warranty period, the contractor shall provide normal maintenance service as recommended by the manufacturer. Maintenance shall include, but not be limited to, control components/instruments, accessories, hardware, and software. The addition of preventive maintenance will increase the cost of a project. See additional requirements in Clause 12 for software/firmware updates.

7.12 Ownership of Proprietary Material. The purpose of this paragraph is to cover ownership of the items developed for or supplied as part of a BAS project that go beyond the BAS hardware, including software and documentation. Unless there is a clear requirement to the contrary, a contractor may retain ownership of some of these items. Without full

1.11 WARRANTY

A. Warrant Work

1. Warrant labor and materials for specified BAS free from defects for a period of 12 months after final acceptance. BAS failures during warranty period shall be adjusted, repaired, or replaced at no additional cost or reduction in service to the owner. Respond during normal business hours within 24 hours of the owner's warranty service request.
2. Work shall have a single warranty date, even if the owner receives beneficial use due to early system start-up. If specified work is split into multiple contracts or a multiphase contract, each contract or phase shall have a separate warranty start date and period.
3. If the BAS designer determines that equipment and systems operate satisfactorily at the end of final start-up, testing, and commissioning phase, the BAS designer will certify in writing that BAS operation has been tested and accepted in accordance with the terms of this specification. Date of acceptance shall begin warranty period.
4. Provide updates to operator workstation software, project-specific software, graphic software, database software, and firmware that resolve the contractor-identified software

deficiencies at no charge during warranty period. If available, the owner can purchase in-warranty service agreement to receive upgrades for functional enhancements associated with above-mentioned items. Do not install updates or upgrades without the owner's written authorization.

5. Exception: Contractor shall not be required to warrant reused devices except those that have been rebuilt or repaired. Installation labor and materials shall be warranted. Demonstrate operable condition of reused devices at time of BAS designer's acceptance.

B. Special Warranty on Instrumentation

1. All instrumentation shall be covered by manufacturer's transferable [one-year] "No Fault" warranty. If manufacturer warranty is not available, the BAS installer shall provide the same.

ownership, the owner may experience unexpected costs when future modifications to the system are undertaken. Therefore, it is important to explicitly state that all materials developed specifically for this project become the property of the owner upon completion of the project. The owner should also be consulted regarding his/her desire to retain any or all tools required for system maintenance or modification.

It is neither reasonable nor important for the owner to obtain ownership of all software, such as the source code for the operating systems and standard BAS software. These items will rarely be useful to anyone other than the manufacturer and therefore may be of little value to the owner. On the other hand, this source code is proprietary material of significant commercial value to the manufacturer and may be the source of a competitive advantage in the market. However, it *is* important for the owner to be provided with the source code of all application programming created specifically for this project (e.g., custom control or energy management sequences), a requirement covered in the following specification by the item "project-specific application programming code."

1.12 OWNERSHIP OF PROPRIETARY MATERIAL

A. Project-specific software and documentation shall become the owner's property. This includes but is not limited to the following:

1. Graphics
2. Record drawings
3. Database
4. Application programming code
5. Documentation

7.13 Definitions and Acronyms for BAS Device Network Design

7.13.1 Definitions

7.13.1.1 BAS Server. A computers that maintains the systems configuration and programming database.

7.13.1.2 Binding. A process that takes place during network design and installation. The device firmware is configured to know the logical address of the other devices or group of devices in the network expecting that network variable, and it assembles and sends the appropriate packets to these devices. Similarly, when the device firmware receives an updated value for an input network variable required by its application program, it passes the data to the application program. The binding process thus creates logical connection between an output network variable in one device and an input network variable in another device or group of devices. Connections may be thought of as "virtual wires."

7.13.1.3 Bridge. A device that routes messages or isolates message traffic to a particular segment subnet or domain of the same physical communication media.

7.13.1.4 Client. An IT term that refers to a software application that requires access to a source of data, typically hosted on a remote or local computer (see Clause 7.13.1.23).

7.13.1.5 Controller. Intelligent stand-alone control device. *Controller* is a generic reference to building controllers, custom application controllers, and application-specific controllers.

7.13.1.6 Direct Digital Control. Microprocessor-based control including analog/digital conversion and program logic.

7.13.1.7 Domain Network Server (DNS). An Internet-based server that provides a lookup table resource linking logical domain names to the domain IP address. Web sites typically use a language-based name, such as www.google.com, for identification. This common name includes enough information for a DNS server to look it up and extract its IP address. Every registered domain is assigned a domain address and is registered with several world-wide top-level servers.

7.13.1.8 Gateway. Bidirectional protocol translator connecting control systems that use different communication protocols.

7.13.1.9 Hub. An IT hardware device that allows for multiple IP devices to connect to a single uplink channel. Hubs pass all information from the uplink to all downlink ports and therefore do not isolate network traffic. A *switch* (see Clause 7.13.1.25) is the preferable device to extend the number of IP devices on a network.

7.13.1.10 Local Area Network (LAN). Computer or control system communications network limited to local building or campus.

7.13.1.11 Master-Slave/Token Passing. Data link protocol as defined by the open-protocol standard. See Informative Annex F for a reference to open-protocol guideline specification language.

7.13.1.12 Network Data Objects/Network Variables. A term used to define the logical (networked) data on a controls network. Data is determined to be either an input or an output data point or object on a device, depending on whether the device creates or sets the data point and sends a network message (output) or if it receives a message from an external device on the network and then acts upon it (input).

7.13.1.13 Node. An intelligent device, such as a BAS controller, computer, or other device, attached to the network.

7.13.1.14 Open-Protocol Definitions. See Informative Annex F for a reference to open-protocol guideline specification language.

7.13.1.15 Peripheral. External devices used to communicate to and from a computer. Peripherals include monitors, network printers, etc.

7.13.1.16 Point-to-Point. Serial communication as defined in the open-protocol standard. See Informative Annex F for a reference to open-protocol guideline specification language.

7.13.1.17 Ports, Port Blocking, Port Trunking, Port Bindings. IP-based routers and firewalls allow access to certain higher-level protocols by assigning a port address or number to the protocol. For example, HTTP (Web pages) typically uses Port 80. Routers can open or close (block) certain ports in order to improve security. IT administrators are typically responsible for providing or blocking ports associated with an IP network. In certain cases, BASs may need to have certain ports open on certain servers. Coordination with the IT group is essential to provide the necessary access and security requirements. Port trunking is used to open and close a certain port for a short duration for information flow of a certain application and is a method of balancing security and information access. Ports can be linked or bound to certain applications for further security and are controlled by IT managers.

7.13.1.18 Primary Controlling LAN. High-speed, peer-to-peer controller LAN connecting BCs and optionally AACs and ASCs. (Refer to Clause 8.3.5 for more information.)

7.13.1.19 Protocol Implementation Conformance Statement. A written document that identifies the particular options specified by the open protocol that are implemented in a device. See Informative Annex F for a reference to open-protocol guideline specification language.

7.13.1.20 Repeater. A hardware device that repeats network communication messages on a channel without filtering. Repeaters are typically used to extend the wire length of a channel.

7.13.1.21 Router. A device that routes or forwards messages destined for a node on another subnet or domain of the control network. The device controls message traffic based on node address and priority. Routers may also serve as communication bridges between different channel media (i.e., power line, twisted pair, radio frequency, and Ethernet). Multiple channels can be connected using routers. Routers are used to manage network message traffic, extend the physical size of a channel (both length and number of devices attached), and to connect channels that use different media (transceiver types) together. Unlike other devices, routers are always attached to two channels.

7.13.1.22 Segment. A set of channels connected by bridges or repeaters. A node sees every packet from every other node on its segment.

7.13.1.23 Server. Typically a computer with the ability to share data with applications either locally or remotely and that hosts a central database of information. Servers provide fast, reliable access to computer data and information and are housed in a data center or other IT secure environment where reliability is ensured using backup, mirroring, or other mechanism to ensure performance and accessibility.

7.13.1.24 Subnet. A subnet is a logical collection of nodes within a domain. Multiple subnets can be defined within a single domain. All nodes in a subnet must be on the same segment. Subnets cannot cross intelligent routers.

7.13.1.25 Switch. An IT hardware device that allows multiple IP devices to connect to and transfer information on an IP network and that is used to extend the number of IP devices on a network. A switch will segment traffic between uplink and down link channels whereas a hub will forward all traffic to all channels. Switches are preferred over hubs as they help control network bandwidth traffic.

7.13.1.26 Terminator. A device comprising a capacitor and a resistive element that provides electrical termination for signals on a given channel type. Almost all networks require a specific type of terminator depending on the channel type—e.g., twisted pair—and the network topology—e.g., free or bus.

7.13.1.27 Wiring. Raceway, fittings, wire, boxes, and related items.

7.13.2 Acronyms

7.13.2.1 BAS	building automation system
7.13.2.2 DDC	direct digital control
7.13.2.3 EEMS	enterprise energy management system
7.13.2.4 EIMS	energy/enterprise information management system
7.13.2.5 EMS	enterprise management system or energy management system

7.13.3 System

7.13.3.1 FMSI	facility master system integrator
7.13.3.2 HTML	hypertext markup language
7.13.3.3 HTTP	hypertext transfer protocol
7.13.3.4 LAN	local area network
7.13.3.5 REST	representational state transfer (Devices that support this capability are referred to as RESTful devices.)
7.13.3.6 SOAP	simple object access protocol
7.13.3.7 SME	subject matter expert
7.13.3.8 SQL	structured query language
7.13.3.9 TCP/IP	transmission control protocol/ Internet protocol
7.13.3.10 UDP	user datagram protocol
7.13.3.11 VLAN	virtual local area network
7.13.3.12 VPN	virtual private network
7.13.3.13 XML	extensible markup language

7.13.4 Specification Editable Terms

7.13.4.1 "[open protocol]" is used to annotate a section of the specification where a specific open-protocol name is to be inserted. A search/replace function can simplify this process.

7.13.4.2 "[media type]" is used to annotate a section of the specification where a specific device physical/link media type or types is to be inserted and will be dependent on which open protocol is selected.

7.13.4.3 "[local codes]" is used to annotate a section of the specification where a specific listing of local, regional, or other required codes is to be inserted into the specification.

7.13.4.4 "[open-protocol body]" is used to define the certification or conformance body responsible for the associated protocol.

8. SPECIFICATION PART 2: PRODUCTS

8.1 This clause of the guideline provides description and explanation of specific articles that would appear in the products part of a BAS specification. The guideline discusses the rationale for including (or excluding) particular specification wording, notes to the designer, other approaches, related costs/benefits, and project considerations. Example specification language follows the guideline text.

The products part includes specification of the materials that are to be provided under the requirements of this section.

8.1.1 Project Considerations. The BAS designer should take care to include only products that will be used in his/her project. Do not include products that will not be part of the project.

PART 2—PRODUCTS

2.0 SECTION INCLUDES

.1 Materials
.2 Communication
.3 Operator Interface
.4 Controller Software
.5 Building Controllers
.6 Custom Application Controllers
.7 Application-Specific Controllers
.8 Input/Output Interface
.9 Power Supplies and Line Filtering
.10 Auxiliary Control Devices
.11 Wiring and Raceways
.12 Fiber Optic Cable System
.13 Compressed Air Supply—Pneumatic

8.2 Materials. In general, it is important to specify that the products and materials that are provided should be new and part of the manufacturer's current product line and that they will be supported for at least five years.

8.2.1 Project Considerations. The requirement for the use of new materials and equipment in this article should be reviewed and coordinated with the requirements of Part 3, "Execution," especially the article on existing equipment that is reused in retrofit or renovation projects. This example also requires that the systems installed use technology that has been used on a minimum of 25 installations. The technology used in this industry changes rapidly, so it may be worthwhile to consider reducing this quantity. The BAS designer should strive to review the technology offerings available before the specification is out for bid to avoid the embarrassment of specifying systems or equipment that may no longer be available.

2.1 MATERIALS

A. Use new products that the manufacturer is currently manufacturing and that have been installed in a minimum of 25 installations. Do not use this installation as a product test site unless explicitly approved in writing by the owner or the owner's representative. Spare parts shall be available for at least five years after completion of this contract.

8.3 Communication

8.3.1 Network Arrangement. The arrangement of the controllers and how they are linked together in a network is called *system architecture* or *network topology.* Selection of the physical media (wires) and data link layers (called *communication buses*) is very much an individual choice at each installation.

There are generally three types of communication buses related to building BASs:

a. Communication between workstations
b. Communication between controllers (and the workstation-to-controller communication)
c. Communication between secondary level controllers (such as terminal unit controllers or interfaces to third-party equipment such as switchgears, packaged HVAC equipment, etc.) that provide communication to the workstation, routed through a primary controller (or other interface)

Note that while the different functions of these three buses reside within all BAS systems, some systems accomplish these functions with two or even one bus.

Many BASs use commercially available local area network (LAN) technologies (e.g., Ethernet) for system communication. These LAN technologies are also popular for use in office or factory automation communication, sometimes referred to as an *intranet* or local data network. Therefore, the designer has the option of specifying a dedicated LAN for the BAS or allowing the BAS to share the facility LAN with other systems. Consideration should be given to the pros and cons of sharing the facility LAN versus using a dedicated LAN.

a. *Pros:* The major benefit of using the facility LAN is that the network infrastructure, including routers and interconnecting cabling, is already in place. This eliminates a significant material and installation expense. There is typically a network administrator or IT department responsible for managing and maintaining the network. Because the network is already extended to all users in the facility, any connected computer will have access to the BAS data. (Depending on the format of the data, proprietary software may be required to view it.)
b. *Cons:* There are security concerns involved with deploying the BAS over a network shared by other users. Since many systems use Windows-based technology, they are susceptible to viruses, worms, or hacking over the network. Educational facilities are notorious for having connected users with the time and ability to improperly use

the network. Fortunately, most IT departments are savvy to these risks, but for smaller facilities this could be a concern. Also, when the facility LAN is down for maintenance, there is no access to BAS data. In some cases, remote access to the facility LAN may not be possible or allowed; this eliminates the possibility for remote monitoring and troubleshooting. For new construction projects, the installation and startup of the facility LAN may be on a schedule that does not allow for timely installation and startup of the BAS. Another concern is that of available bandwidth. Excessive network traffic can reduce the available bandwidth, resulting in slower communication, delayed alarm reporting, or possibly lost data. Although security issues imposed by the BAS on the network are unlikely and bandwidth use by BASs is typically very low, some IT managers are hesitant to allow BASs to share the LAN.

The designer should weigh these pros and cons based on the project-specific parameters. If the choice is made to utilize the facility LAN, early coordination with IT management personnel is critical.

8.3.2 Workstation Communication. This type of communication is high speed and data rich. While communication between workstations may not be frequent, it usually involves large blocks of data, particularly file exchanges, that must occur at high speed. This bus also may be part of the facility-wide intranet, where other office or factory automation traffic occurs. The communication between controllers and workstations also can occur on this bus—alarm reporting and acknowledgement, graphic display updates, and so on. Once again, consultation with the owner and information system managers is critical if this communication is to occur on a shared intranet.

8.3.3 Controller Communication. This bus can have the greatest effect on overall system throughput. All global objects will communicate over this bus, as well as alarms. Additionally, operator-entered commands and requests for information are transmitted over this bus. This bus must be responsive enough to guarantee timely alarm reporting while still processing regular activities, such as reports and global objects. Response time in seconds is still the best measure.

8.3.4 Secondary Bus Communication. Speed for this bus must be evaluated on an application basis. The most common use for this bus is for terminal unit controllers. As space temperature has a large capacity and does not change rapidly, bus response can be relatively slow in many cases. It typically does not create large errors if the reported information is 30 or even 60 seconds old.

A building operator can work with these delays without frustration; however, some method must be provided whereby commands can be issued to (and information retrieved from) a specific controller without having to wait for the entire polling cycle. Otherwise, delays of several seconds will be extremely frustrating.

In other cases, such as when the bus is used to monitor switchgear or packaged computer room BASs, fast throughput is necessary for alarm reporting. See additional requirements in Clause 12 for BAS device network data sharing.

8.3.5 System Architecture. The system architecture, topology, or arrangement of devices on the networks that makes up a building automation system (BAS) is a function of many decisions made by the BAS designer, system supplier, and owner. No one topology is universally the best for all system applications.

When specifying a BAS, it may be necessary to determine the network architecture required to ensure that the products of several vendors on a project will be able to interoperate. This may require the use of some more definitive prescriptive language. The extent to which a specification can be performance-based or prescriptive depends on the nature of the project. Examples of this include the following:

a. *New installation, entire system provided by one vendor*: A pure performance-based specification should be used. This will allow the most economical solution to be applied.
b. *New installation, entire system provided by one vendor with intent to expand later:* A pure performance-based specification should be used. This will allow the most economical solution to be applied. Future additions to the project will follow the same network communications options as provided in the first phase.
c. *New installation, system provide by various suppliers*: For example, this might be a system where the HVAC controls are bid and provided under the relevant section, but the chillers that communicate with the system are bid in another section, and the fire alarm that also communicates with the system is bid in a third section. Make the specification prescriptive in describing the networking architecture in each of these sections.
d. *Expansion of an existing installation*: Make the specification highly prescriptive because the new equipment must connect to the existing systems. See Clause 13, where guidance on the usage of gateways and drivers for legacy systems is provided. In general, if an economical and technically viable option is available to tie in a legacy system, it should be evaluated before making the decision to completely remove the older system to replace it with something new.

The example specification illustrates a system where various suppliers may provide various systems. It uses a two-tiered topology, where the operator workstations and building controllers operate as peers on a BACnet Ethernet LAN. ASCs (see Figure 8.3.5) and custom application controllers (CAC) operate as peers on a number of subnetworks that each use a BACnet MS/TP LAN. The building controllers act as routers to connect the MS/TP subnetworks to the higher speed Ethernet LAN, forming a BACnet network.

The LON (ISO-14908, ANSI 709.1) example specification defines how the controllers, sensors, and actuators connect to the LON network via one of several media types (twisted-pair wire using ISO 14908-2 free topology, 14908-3 power line, or 14908-4 Ethernet). Each device is a peer on the network with no master required. A host PC workstation is another device on the network but is not a supervisory component such that if the PC were to go offline, the rest of the

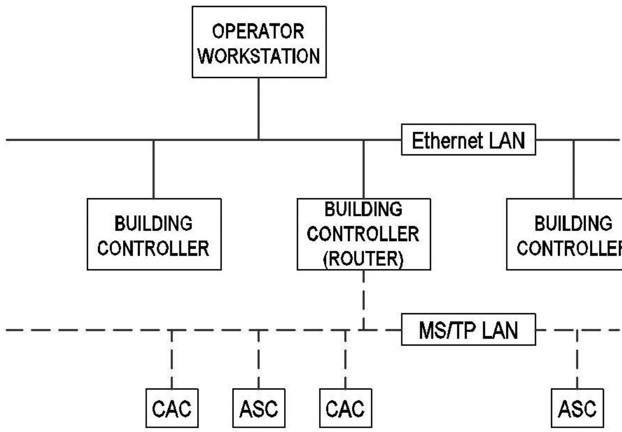

FIGURE 8.3.5 Example BAS network architecture.

network would continue to operate. Gateways and interfaces can connect to other protocols (both control and IP) and interchange data accordingly. Network routers and repeaters are used to extend the network, isolate network traffic, and convert from/to different media types. Typically, a high-speed Ethernet backbone is connected to several twisted-pair free-topology wired channels to ensure high-speed, reliable communication and optimize the system performance. IP-852 routers are used to exchange data from the control network to the data network.

A hybrid solution using LON field devices connected to a BACnet IP network is also a popular option that enables system designers and installers to take advantage of various options and features for specific projects. LON-to-BACnet interfaces are readily available to handle the protocol translation in such a way as to minimize the engineering effort and enhance the solution performance. This option is especially attractive if the existing installation has a combination of solutions that all need to be integrated, and it alleviates the need for replacing an existing control system.

It is easy to imagine many variations of this example. Each installation invariably will have unique characteristics about its network arrangement. The contract documents must clearly indicate this topology so that the proposals submitted will be evaluated fairly against each other. It is also especially important to have defined the topology and character of the network if control devices specified elsewhere, such as boiler controls and packaged chiller controllers, are to be linked to the network. If the choice of LAN types is left to the supplier of the BAS, then coordinating the connection of control devices specified elsewhere becomes problematic.

The example specification also cites the use of peer-to-peer communication, where each device on a segment of the network has the ability to communicate with any of its peers on an as-needed, as-required basis. This is in contrast to a poll-and-response communication, in which devices on the network segment cannot communicate unless polled by a master device.

See additional requirements in Clause 12 for installing and operating the BAS device network on the enterprise network.

8.3.6 Communication Performance. BAS communication is tied most directly to specification Article 2.2, "Communication," but also deals with other areas of the specification, most notably specification Article 1.9, "BAS Performance."

8.3.6.1 Project Considerations. Special consideration should be given to performance monitoring applications due to the additional bandwidth that may be required to provide the desired sampling rate for all objects.

8.3.7 Communication Protocols

8.3.7.1 Interoperability. It is important to note that the goal of interoperability between different manufacturers' BAS components is the reliable and timely function of reading and writing data between the devices. This functionality is required at all the levels of the network where different manufacturers' devices must interoperate.

Other functions, such as the exchange and manipulation of alarms, schedules, and trends, also may need to occur in the multivendor environment. Invariably, however, this communication happens at the operator workstation and building controller levels.

There is a broad range of functions for use in BASs. In an interoperable system, several of these functions may be required.

8.3.7.1.1 Data Exchange. The exchange of data between two devices (e.g., PC workstations, building controllers, custom application controllers, or ASCs) is the most basic of interoperable functions. This function allows for both the viewing (or reading) of data as well as making changes (or writing) to these data. This can be accomplished by a number of methods.

The method of exchanging data is typically protocol dependent, but the outcome of all protocols is in essence the same: transferring relevant data from the source to the destination. Key to the issue of interoperability is understanding both the data and delivery of that data. Data objects must be well defined and documented, following standard protocol rules. These apply to what's in the data packet as well as how the data packet is delivered. Hence, the value in an open-systems approach using open protocols leads to a commonality and understanding of how data is to be sent and received.

Most specifiers and system integrators no longer have to deal with the low-level details, as the controllers and the protocol used handle this internally. What is important is ensuring that the specification defines all of the relevant data sets or "points." Often a point list is developed that defines a set of variables/objects/data types that are required for both peer-to-peer and host/master-to-client/slave communication. Key to the exchange of data is understanding what's in the packet, such as a value containing temperature. As long as the sender and receiver agree on what "temperature" means, interoperability is maintained.

When a vendor decides to use its own custom definitions is when interoperability and integration problems occur. In general, it is recommended to use open standards and clearly define in the project specification what data is to be exchanged and how the information is to be structured.

See Informative Annex F for a reference to open-protocol guideline specification language. Also see Clause 12 for additional data exchange requirements.

8.3.7.1.2 Advanced Interoperable Functions. While the data exchange function is able to achieve a wide variety of functions, there are more efficient ways to accomplish a number of system functions. These are required for large installations and for use in remote operations of multiple buildings.

8.3.7.1.2.1 Alarms and Events. This function allows for the exchange of alarm information in an interoperable system. A controller that has determined that an alarm has occurred is able to send an alarm message to a predetermined location.

For example, a building controller is connected to a network of ASCs. On one of these controllers, the space temperature becomes too high. In the building controller, a program periodically compares the space temperature to a user-entered alarm limit. When the temperature exceeds that limit, the building controller generates an alarm and sends it to the PC workstation. At that workstation, an operator reads the alarm and acknowledges it.

The protocol defines how the alarms are generated, how they are sent, and what they should contain. This function is typically performed between a building controller and a PC workstation but could also occur in other controllers on the intranet. This function also might be used to trigger a control action or record an operator override.

8.3.7.1.2.2 Schedules. This set of functions allows for the editing and creation of schedules on a PC workstation that will be executed in a controller.

For example, The operator wants to change the fan's stop time in the auditorium from 6:00 p.m. to 9:00 p.m. Using the scheduling function, the operator is able to load the schedule from the controller, select the stop time, and change that parameter.

This function will typically occur between a PC workstation and a building controller, but also could occur on other controllers on the enterprise network.

8.3.7.1.2.3 Trends. The ability to sample, store, and read trends is a valuable function. Trending is a valuable tool for collecting data on system performance and energy usage. While trends are typically stored on a PC workstation, there are a number of reasons to initially store them in a controller. This will minimize network traffic and also will allow for sampling of data if a PC is not continually connected to the controller.

8.3.7.1.2.4 Network Management. Network management is an essential aspect of any networked control system. The management of data, computers, routers, and various other devices is required. Of particular importance is setting up all devices connected to the network, assigning their unique addresses and defining their input and output information (data sets), traffic flow/frequency/bandwidth requirements, and more. Additionally, network management includes adding, removing, and replacing devices on the network. Other elements of network management include naming conventions, location conventions, time synchronization, communication failure protocol, and performance information. The project specification must define some of these key elements and ensure that the system has a robust network-management platform in order to ensure reliability, performance, and efficiency.

8.3.7.2 Network Communications. While the example specification uses the BACnet standard to help define communication within the BAS network, the use of a communication protocol is a choice made by the BAS designer. See Informative Annex F for a reference to open-protocol guideline specification language. The BAS designer may find it most advantageous—either because of cost constraints, standard purchasing agreements, or other circumstances—to specify that the network communication can be conducted on a proprietary network. Or if there is no need for devices specified elsewhere to communicate on this network, it may be reasonable to leave the network type and media type completely to the discretion of the contractor.

A number of other open protocols exist in the marketplace. If the BAS designer wishes to use one of these protocols, it is strongly recommended that the BAS designer make extensive use of the resources available from the promoters of that protocol in the writing of their project-specific application. See Informative Annex F for a reference to open-protocol guideline specification language.

Any or all of these LAN types can exist in an open-protocol-compliant network, but routers are required to connect the different types of LAN segments. As mentioned above and as cited in the example specification, it is critical to specify which type of network is supported at each device in the network, including those devices mentioned elsewhere in the specification.

8.3.7.2.1 Project Considerations. Specifying an interoperable system can be a challenge. While there are many very good open-protocol options available, none is what would be considered a plug-and-play solution. In order to properly specify and apply an interoperable system, a good deal of knowledge of the protocol and network architecture is required. For example, all interoperable protocols do a good job defining how to share information (data) between systems. However, it is often not as clear how to share common alarm messages, schedules, or trends.

A BAS designer should be aware that an interoperable system should allow the user to perform a series of daily functions. However, these tasks may be more easily accomplished in a single-vendor system than in an interoperable one. Performing more advanced functions, such as configuring a controller or a network, may require several proprietary tools and specialized training.

To find more information on how to specify a particular protocol, the BAS designer should contact the sponsoring organization for that protocol. They will typically have detailed information on how to apply their protocol. See Informative Annex F for a reference to open-protocol guideline specification language.

8.3.8 Integrating a Proprietary System with an Open-Protocol System Method. The integration of open and proprietary systems might include the following scenario.

An existing building or campus that uses a single-vendor BAS energy management system, with a proprietary communication protocol, is to be expanded so that the new BAS uses an open protocol.

In practice, if the existing system uses a protocol that is not open, it may not be possible to be fully interoperable without physically changing the electronics that perform the communication in the existing devices. It is also possible that the actual physical media that connect the existing devices would not be one of the standard physical links allowed in the chosen open protocol.

The most likely solution would be to use a device that acts as a gateway between the existing proprietary network and the new open network. This gateway would possess enough memory and intelligence to translate the vocabulary and grammar rules of the open protocol to the existing proprietary protocol—and back again. The gateway also would contain a map of the existing points that were to be readable and/or writable on the open internetwork. In effect, all existing points that are of interest to the open internetwork would reside as software objects in the gateway. Use the object list to identify these objects and properties to be communicated through the gateway. The gateway would then use the proprietary protocol to query and update the actual hardware (or software) points in the existing network.

In order to make the gateway as affordable and usable as possible, the system BAS designer should limit the number of different points that the gateway must make available from the existing network to the new open network. The system BAS designer also should thoroughly describe any graphics or reporting features he/she desires that use objects (points) from the existing network.

Gateways may not conform to any present standard, so great care must be taken to fully describe the performance of information exchange between the proprietary network and the new open network. A system integrator should perform much of this work. This integrator could be a service provided by the supplier of the new open network or by a third-party consultant.

8.3.8.1 System Integrator. If using a system integrator to perform the work of integrating systems that use one communication protocol with systems using another protocol, the BAS designer will need to define the duties and functions of this service. At a minimum, the BAS designer should include the following steps:

a. Contact the existing system manufacturer to secure documentation and programming information in the existing system. The integrator also may require the existing system's protocols. The existing system's manufacturer also may be called upon to provide the hardware and software of the gateway.

b. Coordinate the assignment of device and network identification.

c. Commission the network integration up to and including the use of network sniffers to verify network message packet integrity. Sniffers, or *protocol analyzers*, are devices used to analyze the content of message packets.

d. Provide the final documentation of the integrated internetwork.

e. See Clause 12 for additional requirements for the facility master system integrator (FMSI).

8.3.8.1.1 Project Considerations

a. See Clause 12 for IP and non-IP networking requirements.

b. The future expansion capacities listed in the example reflect a relatively large single building, probably in excess of 100,000 m^2 (1,000,000 ft^2). Other projects may require a smaller number of future connections or, in the case of an extensive campus, many more. Care should be taken in choosing this number as it could have an effect on the system cost.

c. See Informative Annex F for a reference to open-protocol guideline specification language.

2.2 COMMUNICATION

A. Control products, communication media, connectors, repeaters, hubs, and routers shall compose a [open protocol] BAS. Controller and operator interface communication shall conform to [open-protocol body] conformance and/or certification requirements.

B. Each controller shall have a communication port.

C. Project drawings indicate remote buildings or sites to be connected to the enterprise network to allow for communication with each controller on the network as specified in Paragraph D.

D. Network operator interface and value passing shall be transparent to internetwork architecture.

   1. An operator interface connected to the BAS shall allow the operator to interface with each networked controller as if directly connected. BAS information such as data, status, reports, system software, and custom programs shall be viewable and editable.

   2. Inputs, outputs, and control variables used to integrate control strategies across multiple controllers shall be available on the network. Program and test all cross-controller links required to execute specified BAS operation. An authorized operator shall be able to manage, maintain, and access the BAS network of controllers.

E. System shall be expandable to at least twice the required data points with additional controllers, associated devices, and wiring. Expansion shall not require operator interface hardware additions or software revisions.

8.4 Clock Synchronization. Since most systems will have multiple devices with real-time clocks, a method of coordinating the clocks should be provided. This ensures that when a time-of-day schedule is to start a chiller at 7:00 a.m., that it starts at 7:00 a.m. and not at 7:10 a.m.

8.4.1 Project Considerations. The example specification uses the open-protocol time synchronization service to accomplish this function. When specifying a project that does not use an open protocol, use the services available in either the proprietary network or through whatever open protocol is being used in that particular instance.

F. Workstations, building control panels and controllers with real-time clocks shall use the open-protocol time synchronization service. The system shall automatically synchronize system clocks daily from an operator-designated device via the internetwork. The system shall automatically adjust for daylight savings and standard time as applicable.

8.5 Operator Interface. The operator interface section of this clause describes what the system operator will see when he/she interfaces with the system. This discussion is tightly coupled with the controller software section that follows.

8.5.1 Number of Operator Interface Devices Required. This simply sets the desired number of operator interface devices (workstations) that will be provided. The location of these devices should be clearly shown in the project plans. If portable operator devices are specified, then designate the quantities to be provided.

8.5.1.1 Project Considerations. The number of workstations is very much an individual project-specific requirement. Many projects only require one workstation, so the wording of this article should be carefully prepared to reflect that. Remember that in this example, the workstations and the building controllers are both connected to the same high-speed network. Other system architectures are possible and will require different specification descriptions.

2.3 OPERATOR INTERFACE

A. Operator Interface. PC-based workstations shall reside on a high-speed network with building controllers as shown on the system drawings. Each workstation or each standard browser connected to the server shall be able to access all BAS information.

8.5.2 Physical System Connection. Virtually all BAS projects will be connected to the enterprise network. Direct connection to a BAS controller is normally only performed by the BAS technician during the installation and commissioning phases or in emergencies when the network is not working and the BAS controller needs servicing.

On a small project, the operator interface device may be connected directly to a panel or may be remotely located and connected by dial-up phone modem. On a larger project, where several operator interface devices are required, they will typically be connected on a high-speed LAN.

8.5.2.1 Project Considerations. The example specification requires an Ethernet LAN (ISO 8802-3). Exercise caution in specifying connection via dial-up. Communication speed is much slower over a dial-up connection.

B. Workstation and controllers shall communicate using [open protocol] protocol. Workstation and control network backbone shall communicate using ISO 8802-3 (Ethernet) data link/physical layer protocol and [open protocol] addressing as specified in [open-protocol body] guidelines and requirements. See Informative Annex F for a reference to open-protocol guideline specification language.

8.5.3 System Hardware. Depending on the project, the operator may access the BAS directly via an operator workstation or across a network by connecting to a Web server. In either case, the designer must specify a PC. PCs are commonly available devices that can be used for other functions by the owner, including word processing, maintenance management, and other common functions; however, for larger projects or where recommended by the BAS manufacturer, the workstation/server should be dedicated to DDC functions only.

Specifying computers can be difficult due to rapid technology changes in that industry. The elements most subject to change are processor type and speed, as well as both memory and hard drive capacities. By specifying that the hardware meet the BAS manufacturer's recommendations along with the specified system performance requirements, the designer may avoid calling out such specifics as minimum processor speed, hard drive size, etc. Of course, if there are specific computer requirements, then this is the place to define them; just remember that these will need to be edited periodically to keep up with changes in technology (paragraph C.1.c in the example specification below illustrates specific requirements that may be added by the designer).

Any accessories required with the workstation should also be specified in this section. This may include a network printer dedicated to the BAS, or access to a network printer that is already on the enterprise network.

8.5.3.1 Project Considerations. Buildings that will have on-site operators should include at least one operator interface if a Web server configuration is not used. Larger facilities may require several operator workstations to be located throughout the building, but more than likely will utilize a Web server arrangement. Consult with the owner to verify the need and location for all operator interfaces.

Smaller buildings, those that are part of a connected campus or enterprise, and those that do not have on-site operators may not require an on-site operator workstation. For those buildings that are part of a connected campus or enterprise utilizing an existing Web server, a local PC with network access may suffice. For the other cases, several options are available. One option is to use some type of local display. This may consist of an LCD or LED display panel and a keypad, which allows operators to see objects' status, view alarms, and change setpoints and schedules. Another option would be to eschew any local operator interface and utilize a portable operator's terminal or hand-held interface device to interrogate the system. The last two options are less common and will require the designer to become familiar with the capabilities of each BAS manufacturer to be considered.

C. Hardware. Each operator workstation or Web server shall consist of the following:
   1. Computer. Hardware shall meet or exceed BAS manufacturer's recommended specifications and shall meet response times specified elsewhere in this document. The following hardware requirements also apply:
      a. The hard disk shall have sufficient memory to store
         1. all required operator workstation software,
         2. a BAS database at least twice the size of the delivered system database, and
         3. one year of trend data based on the points specified to be trended at their specified trend intervals.
      b. Provide additional hardware (communication ports, video drivers, network interface cards, cabling, etc.) to facilitate all control functions and software requirements specified for the DDC system.
      c. Minimum hardware configuration shall include the following: [This section needs to be updated continuously. The BAS Designer needs to insert the appropriate language here].
      d. See Clause 12 for additional server requirements.
      e. See Informative Annex F for a link to the protocol organizations who provide workstation interoperability guide specification language.

D. System Software
   1. Operating System. Furnish a concurrent multitasking operating system. The operating system also shall support the use of other common software applications. Examples include Microsoft Excel, Microsoft Access, or other SQL database software. Acceptable operating systems are Windows, the latest Windows Server release, Linux, and UNIX.

8.5.4 System Software. This section only details the software that runs on the PC workstation. All of the other functions described under system applications are edited and archived at the PC workstation but are actually executed at the system controllers. Refer to Clause 8.6, "Controller Software," of this guideline.

8.5.4.1 Operating System. The operating system for the PC workstation should be multitasking and support the use of other current off-the-shelf programs. This is one place where the BAS designer may want to be prescriptive in stating the allowable operating systems that will support the other programs the system operator may wish to use. Be sure that the allowable manufacturers are able to support the specified operating system.

8.5.4.2 System Graphics. The system graphics will provide the primary method of system interface for the operator. Graphics are typically created on the PC with the use of a standard graphics creation package. The example specification requires this to be furnished with each PC workstation.

8.5.4.2.1 Specifying Graphics. The graphics required on each system are specified in Article 3.17, "Programming," of the example specification. When completing the system's object list, the objects to be displayed graphically need to be clearly indicated.

2. System Graphics. The operator workstation software shall be graphically oriented. The system shall allow display of up to 10 graphic screens at once for comparison and monitoring of system status. Provide a method for the operator to easily move between graphic displays and change the size and location of graphic displays on the screen. The system graphics shall be able to be modified while online. An operator with the proper password level shall be able to add, delete, or change dynamic objects on a graphic. Dynamic objects shall include analog and binary values, dynamic text, static text, and animation files. Graphics shall have the ability to show animation by shifting image files based on the status of the object.
3. Custom Graphics. Custom graphic files shall be created with the use of a graphics generation package furnished with the system. The graphics generation package shall be a graphically based system that uses the mouse to create and modify graphics that are saved in industry standard formats such as PCX, TIFF, and GEM. The graphics generation package also shall provide the capability of capturing or converting graphics from other programs, such as Designer or AutoCAD.
4. Graphics Library. Furnish a complete library of standard HVAC equipment graphics such as chillers, boilers, air handlers, terminals, fan-coils, and unit ventilators. This library also shall include standard symbols for other equipment including fans, pumps, coils, valves, piping, dampers, and ductwork. The library shall be furnished in a file format compatible with the graphics generation package program.

8.5.4.3 System Applications

8.5.4.3.1 General. The systems applications are all edited and archived on the PC workstation but executed on the appropriate BAS controller.

8.5.4.3.2 Automatic and Manual System Database Save and Restore. This provides a method to back up BAS applications on the PC workstation. This is desirable since the system controllers will be operating off data that are stored in their system memory. While the memory in the system controllers is usually either nonvolatile or backed up, it is still a good practice to have a copy of these data stored off-line. A copy also should be stored off site. If a controller should fail, then it can be reloaded—or replaced and reloaded—using the backed up data.

E. System Applications. Each workstation shall provide operator interface and off-line storage of system information. Provide the following applications at each workstation:
   1. Automatic System Database Save and Restore. Each workstation shall store on the hard disk a copy of the current database of each building controller. This database shall be updated whenever a change is made in any system panel. The storage of these data shall be automatic and not require operator intervention. In the event of a database loss in a building management panel, the first workstation to detect the loss shall automatically restore the database for that panel. This capability may be disabled by the operator.
   2. Manual Database Save and Restore. A system operator with the proper password clearance shall be able to save the database from any system panel. The operator also shall be able to clear a panel database and manually initiate a download of a specified database to any panel in the system.

8.5.4.3.3 System Configuration. This is the low-level system setup.

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3. System Configuration. The workstation software shall provide a method of configuring the system. This shall allow for future system changes or additions by users under proper password protection.

8.5.4.3.4 Online Help. Online help provides the operator with assistance without requiring the use of reference manuals.

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4. Online Help. Provide a context-sensitive, online help system to assist the operator in operating and editing the system. Online help shall be available for all applications and shall provide the relevant data for that particular screen. Additional help information shall be available through the use of hypertext.

8.5.4.3.5 Security. Since the system's PC workstations are frequently located in nonsecure locations, a method of protecting the system from unauthorized users is required. This should require the entry of a username and password in order for the operator to perform system functions. Requiring a person to enter a username (log on) also provides a method to track and log operator actions.

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5. Security. Each operator shall be required to log on to the system with a username and password in order to view, edit, add, or delete data. System security shall be selectable for each operator. The system supervisor shall have the ability to set passwords and security levels for all other operators. Each operator password shall be able to restrict the functions accessible to viewing and/or changing each system application, editor, and object. Each operator shall automatically be logged off of the system if no keyboard or mouse activity is detected. This auto logoff time period shall be user-adjustable. All system security data shall be stored in an encrypted format.

8.5.4.3.6 System Diagnostics. BASs should be able to provide their own diagnosis of problems.

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6. System Diagnostics. The system shall automatically monitor the operation of all workstations, printers, network connections, building management panels, and controllers. The failure of any device shall be annunciated to the operator.

8.5.4.4 Alarm Processing. One of the valuable services that a BAS can provide is to notify the operator when something has gone wrong. This section of the specification provides a method to set parameters that will generate an alarm. It also should discuss what actions should occur when an alarm is detected. The object list included with the contract documents should indicate which system objects have alarm processing and, for analog objects, what the appropriate alarm limits should be.

Alarm messages should use the English language description of the object that has gone into (or out of) an alarm state. For example, "AH1RJP1 High" is not acceptable. "Air Handler 1 in the Robert James Building—High Static Pressure" *is* acceptable.

8.5.4.4.1 Project Considerations. If expanded descriptors or text describing actions to be taken by the operator upon receipt of an alarm are desired, please take care to clearly state these requirements and the text of such messages in detail. See Clause 12 for alarming requirements.

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7. Alarm Processing. Any object in the system shall be configurable to alarm in and out of normal state. The operator shall be able to configure the alarm limits, alarm limit differentials, states, and reactions for each object in the system.

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8. Alarm Messages. Alarm messages shall use the English language descriptor for the object in alarm in such a way that the operator will be able to recognize the source, location, and nature of the alarm without relying upon acronyms or other mnemonics.
9. Alarm Reactions. The operator shall be able to determine (by object) what, if any, actions are to be taken during an alarm. Actions shall include logging, printing, starting programs, displaying messages, dialing out to remote stations, paging, providing audible annunciation, or displaying specific system graphics. Each of these actions shall be configurable by workstation and time of day.

8.5.4.5 Trend, Alarm, and Event Logs. The BAS should have the capability to store data in a list or log. These are used to record occurrences, along with a record of the time and date of each occurrence. Trend logs look at system objects and record their values at specific intervals (or on change of state). Alarm and event logs store operator-specified events when they occur, along with a time and date stamp.

8.5.4.5.1 Project Considerations. What events should go into these logs? The answer depends on the application. If the BAS primarily provides comfort conditioning and has little operator interaction, then few objects should be designated for the log. Only a serious event occurrence, such as an equipment failure, should be recorded and then followed by notification of the operator (typically by pager). On the other hand, a building that requires extensive record keeping and traceability—such as a hospital, computer operations center, correctional facility, or pharmaceutical manufacturing plant—should have all BAS actions and alarms recorded. Care should be taken to clearly indicate these requirements to the controls subcontractor in the sequences of operation or object list. The information should include the number of samples and the interval between samples—or change-of-value requirements—for each object to be logged. In addition, if required for performance monitoring, the BAS designer should include that the data should be exportable and in what format.

10. Trend Logs. The operator shall be able to define a custom trend log for any data object in the system. This definition shall include interval, start time, and stop time. Trend data shall be sampled and stored on the building controller panel, be archived on the hard disk, and be retrievable for use in spreadsheets and standard database programs. Trend data shall be exportable in a standard electronic format [(.xls, .csv, .xml)] for analysis external to the BAS.

11. Alarm and Event Log. The operator shall be able to view all system alarms and change of states from any location in the system. Events shall be listed chronologically. An operator with the proper security level may acknowledge and clear alarms. All that have not been cleared by the operator shall be archived to the hard disk on the workstation.

8.5.4.6 Trend Graph Display. In addition to trend log data, visualizing trend data over time on a graph can be a useful diagnostic tool for a BAS operator. Such graphical displays can reveal unnecessary equipment operation during unoccupied hours, control instability over time, unexpected deviations from setpoint, and energy savings opportunities. Viewing multiple data points on a single graph can identify relationships between system components. For example, viewing space temperature with applicable space temperature setpoints (unoccupied or occupied heating or cooling) over time can provide valuable insight into the equipment performance and space comfort. This capability is a standard feature of most BASs.

12. Group Trend Time Series Plots
    a. Provide user-selectable Y points.
    b. Provide user-editable titles, point names, and Y axis titles.
    c. Individual trended points shall be able to be grouped in groups of up to four points per plot with up to four plots per page.

X-Y trend graphs can provide an additional level of data visualization by allowing the relationship between two variables to be viewed directly. For example, viewing outdoor air temperature against natural gas consumption may not only show that gas consumption generally increases as outdoor air temperature drops but also show interesting features of the mechanical system operations, mechanical system degradation, the building envelope, and occupancy patterns. These types of trend graphs may not be included as part of a BAS standard offering but may be available as special features of a BAS or as third-party add-ons to a BAS. These graphs should be included to perform Level 2 or Level 3 performance monitoring as described in Informative Annex E.

13. X-Y Trend Plots
    a. User-selectable X and Y trend inputs
    b. User-editable titles, point names, and X and Y axis titles
    c. User-selectable time period options:
        1. 1-day 24-hour period
        2. 1-week 7-day period
        3. 1-month period, with appropriate days for the month selected; or
        4. 1-year period

        The user shall be able to select the beginning and ending period for each X-Y chart, within the time domain of the database being used.

d. User-selectable display of up to 6 plots per screen in 2 columns

8.5.4.7 Object and Property Status and Control. In most cases, the operator will interact with the system through the BAS graphics. However, not all objects may be graphically displayed. Therefore, an alternative method of viewing and controlling system data should be provided for all projects.

14. Object and Property Status and Control. Provide a method for the operator to view, and edit if applicable, the status of any object and property in the system. The status shall be available by menu, on graphics, or through custom programs.

8.5.4.8 Reports and Logs. BASs that have a designated full-time or part-time operator may benefit from system reporting. This provides a method to have the system prepare a concise record of operating characteristics over time.

8.5.4.8.1 Project Considerations. The reports described in the sample guide specification that follow are representative of several reports that could be requested for a new project of significant size and scope. Each report and log that is requested or specified adds cost (in programming, if not in software and hardware, as well). Consult with the owner for project-specific requirements.

15. Reports and Logs. Provide a reporting package that allows the operator to select, modify, or create reports. Each report shall be definable as to data content, format, interval, and date. Report data shall be archivable on the hard disk for historical reporting. Provide the ability for the operator to obtain real-time logs of all objects by type or status (e.g., alarm, lockout, normal). Reports and logs shall be stored on the PC hard disk in a format that is readily accessible by other standard software applications, including spreadsheets and word processing. Reports and logs shall be readily printed to the system printer and shall be set to be printed either on operator command or at a specific time each day.
16. Standard Reports. The following standard BAS reports shall be provided for this project. Provide ability for the owner to readily customize these reports for this project.

This specification lists some commonly required standard reports.

a. All Objects/Points/Variables: All system (or subsystem) objects, points, variables, configuration properties, and their current values
b. Alarm Summary: All current alarms (except those in alarm lockout)
c. Disabled Objects/Points: All objects/points that are disabled
d. Alarm Lockout Objects/Points: All objects/points in alarm lockout (whether manual or automatic)
e. Alarm Lockout Objects/Points in Alarm: All objects/points in alarm lockout that are currently in alarm
f. Logs:
    1. Alarm History
    2. System Messages
    3. System Events
    4. Trends

8.5.4.9 Custom Reports. Other reports, listed below, are representative of several reports that could be specified for a new project of significant size and scope. Each report and log that is specified adds cost (in programming, if not in software and hardware as well). Consult the owner for project-specific requirements.

When specifying information management applications, it is important to identify the owner's needs as related to the following application features:

a. Security access (e.g., who has access to what information)
b. Data integrity (e.g., read-only, any modification to the data are documented)
c. Data archival and retrieval
d. Data structures (e.g., ODBC compliance)
e. Exporting data to third-party systems
f. Importing data from third-party systems
g. System configuration (e.g., single-user versus client/server)
h. Performance requirements
i. Reports

This first article is the catch-all section that allows the operator to provide any type of reporting. A schedule of reports also can be added to the system documents if the reports are to be provided by the supplier.

17. Custom Reports. Provide the capability for the operator to easily define any system data into a daily, weekly, monthly, or annual report. These reports shall be time and date stamped and shall contain a report title and the name of the facility.

8.5.4.9.1 Tenant Override Report. This report documents after-hours equipment operation (e.g., lighting, HVAC) requested by tenants. It should be specified only when after-hours services are being provided and accounted for by the operator.

18. Tenant Override Reports. Provide a monthly report showing the daily total time in hours that each tenant has requested after-hours HVAC and lighting services. Provide an annual summary report that shows the override usage on a monthly basis.

8.5.4.9.2 Electrical, Gas, and Weather Reports. These are valuable for comparing energy usage from year to year and for budgeting future energy costs. These reports should be specified when active monitoring is included as part of the system. These reports also require additional sensors to be specified for the meter points and outdoor air temperature. See Clause 12 for energy reporting requirements.

19. Electrical, Gas, and Weather Reports
    a. Electrical Meter Report: Provide a monthly report showing the daily electrical consumption and peak electrical demand with time and date stamp for each building meter.
    b. Provide an annual (12-month) summary report showing the monthly electrical consumption and peak demand with time and date stamp for each meter.
    c. Gas Meter Report: Provide a monthly report showing the daily natural gas consumption for each meter. Provide an annual (12-month) report that shows the monthly consumption for each meter.
    d. Weather Data Report: Provide a monthly report showing the daily minimum, maximum, and average outdoor air temperature, as well as the number of heating and cooling degree-days for each day. Provide an annual (12-month) report showing the minimum, maximum, and average outdoor air temperature for the month, as well as the number of heating and cooling degree-days for the month. If there is a weather station within 25 miles of the facility, provide real-time weather information via SOAP/XML. Otherwise, use weather values from the BAS.
20. Electrical, Gas, and Weather Graphic Display
    a. Provide a graphic display for each electrical meter and gas meter and weather data point(s) with a data table and a current 24-hour trend plot. Include data values for the following time periods; today, previous day, week to date, previous week, month to date, previous month, year to date, previous year.

8.5.4.9.3 ASHRAE Standard 147 Report. This is a log recommended for large chillers (>700 kW [200 ton]) on a daily basis by *ANSI/ASHRAE Standard 147-2013, Reducing the Release of Halogentated Refrigerants from Refrigerating and Air-Conditioning Equipment and Systems*. It should only be specified if large chillers are on the project.

8.5.4.9.3.1 Project Considerations. Chiller controllers are typically specified under the specification section for the chillers. Care should be taken to coordinate these two specification sections if data must be exchanged between the chiller controller and the building-wide DDC system specified here (refer to Clause 10.7, "Application-Specific Controllers for Equipment Specified Under Other Sections"). Also coordinate the object list to show the information requested in this report and how frequently it is to be sampled.

21. ASHRAE Standard 147 Report: Provide a daily report that shows the operating condition of each chiller as recommended by ASHRAE Standard 147. At a minimum, this report shall include:
    a. Chilled-water (or other secondary coolant) inlet and outlet temperature
    b. Chilled-water (or other secondary coolant) flow
    c. Chilled-water (or other secondary coolant) inlet and outlet pressures
    d. Evaporator refrigerant pressure and temperature
    e. Condenser refrigerant pressure and liquid temperature
    f. Condenser-water inlet and outlet temperatures
    g. Condenser-water flow
    h. Refrigerant levels
    i. Oil pressure and temperature
    j. Oil level
    k. Compressor refrigerant discharge temperature
    l. Compressor refrigerant suction temperature
    m. Addition of refrigerant
    n. Addition of oil
    o. Vibration levels or observation that vibration is not excessive
    p. Motor amperes per phase
    q. Motor volts per phase
    r. PPM refrigerant monitor level
    s. Purge exhaust time or discharge count
    t. Ambient temperature (dry-bulb and wet-bulb)
    u. Date and time logged

8.5.4.10 Workstation Application Editors. This section details how the applications that run on the system controllers should be set up and edited on the PC workstation.

F. Workstation Applications Editors. Each PC workstation shall support editing of all system applications. Provide editors for each application at the PC workstation. The applications shall be downloaded and executed at one or more of the controller panels.

8.5.4.11 Controller. The BAS will typically consist of a series of controllers. ASCs require operator setup of parameters such as setpoints, flow parameters, etc.

1. Controller. Provide a full-screen editor for each type of application that shall allow the operator to view and change the configuration, name, control parameters, and setpoints for all controllers.

8.5.4.12 Scheduling. The scheduling application is set up in the PC and executed on the controller.

2. Scheduling. An editor for the scheduling application shall be provided at each workstation. Provide a method of selecting the desired schedule and month. This shall consist of a monthly calendar for each schedule. Exception schedules and holidays shall be shown clearly on the calendar. Provide a method for allowing several related objects to follow a schedule. The start and stop times for each object shall be adjustable from this master schedule. Schedules shall be easy to copy to other objects and/or dates.

8.5.4.13 Custom Application Programming. Smaller and less sophisticated projects will use standard application programs for most functions. Custom programming will still be used to achieve more sophisticated control sequences. It also may be used to provide a standard application capability not provided by the vendor.

8.5.4.13.1 Project Considerations. The example specification language below allows the BAS subcontractor to provide a product that uses a text-based, graphic-based, or parameter-based programming language. If the owner expresses a distinct preference for one programming language type over the others, edit the specification accordingly.

3. Custom Application Programming. Provide the tools to create, modify, and debug custom application programming. The operator shall be able to create, edit, and download custom programs at the same time that all other system applications are operating. The BAS shall be fully operable while custom routines are edited, compiled, and downloaded. The programming language shall have the following features:
   a. The language shall be English language oriented, be based on the syntax of BASIC, FORTRAN, C, or PASCAL, and allow for free-form programming (i.e., not column-oriented or "fill in the blanks"). Alternatively, the programming language can be graphically based using function blocks as long as blocks are available that directly provide the functions listed below and that custom or compound function blocks can be created.
   b. A full-screen character editor/programming environment shall be provided. The editor shall be cursor/mouse-driven and allow the user to insert, add, modify, and delete custom programming code. It also shall incorporate word processing features such as cut/paste and find/replace. The debugger also shall provide error messages for syntax and execution errors.
   c. The programming language shall support conditional statements (IF/THEN/ELSE/ ELSE-IF) using compound Boolean (AND, OR, and NOT) and/or relations (EQUAL, LESS THAN, GREATER THAN, NOT EQUAL) comparisons.
   d. The programming language shall support floating-point arithmetic using the following operators: +, , ÷, ×, and square root. The following mathematical functions also shall be provided: absolute value and minimum/ maximum value from a list of values.
   e. The programming language shall have predefined variables that represent time of day, day of the week, month of the year, and the date. Other predefined variables shall provide elapsed time in seconds, minutes, hours, and days. These elapsed time variables shall be able to be reset by the language so that interval-timing functions can be stopped and started within a program. Values from all of the above variables shall be readable by the language so that they can be used in a program for such purposes as IF/THEN comparisons, calculations, etc.
   f. The language shall be able to read the values of the variables and use them in programming statement logic, comparisons, and calculations.
   g. The programming language shall have predefined variables representing the status and results of the system software and shall be able to enable, disable, and change the setpoints of the system software described below.
   h. The programming language shall allow independently executing program modules to be developed. Each module shall be able to independently enable and disable other modules.
   i. The editor/programming environment shall have a debugging/simulation capability that allows the user to step through the program and observe any intermediate values and/or results.

8.5.5 Portable Operator's Terminal. The function of the portable operator's terminal is to provide a convenient way to obtain BAS data at any location in the building. The operator could carry this device to a mechanical room or up to a space sensor and be able to connect and troubleshoot the system. The device could connect to the system in various ways, including

a. connecting to a controller using an EIA-232 connection,
b. connecting to a low-level network using TP/FT-10 or EIA-485, or
c. connecting to the system-level LAN.

8.5.5.1 Project Considerations. For most large installations, this terminal will be a notebook-style PC. This is how it has been described in the sample guide specification. On a smaller project, it may be more appropriate to specify software to run on the operator's PC. Other alternatives include no portable interface, the use of a smart room sensor, or the use of a keypad and LCD display. And, as with the PC workstation, the technology changes very rapidly, so care should be taken to carefully specify the speed, memory capacity, and storage requirements of the hardware.

The example specification uses protocol-agnostic general language to specify its communication requirements for interoperability. There are many methods, both proprietary and open, such as BACnet, LON, Modbus, Zigbee, multiple Ethernet/TCP/IP options, to accomplish these requirements.

G. Portable Operator's Terminal. Furnish a portable operator's terminal that shall be capable of accessing all BAS data. This device may be connected to any point on the system network or may be connected directly to any controller for programming, setup, and troubleshooting. This device may be connected to any point on the system network or it may be connected directly to controllers using [open protocol]. The portable operator's terminal shall be a notebook-style PC including all software and hardware required. The PC shall contain at minimum: [BAS designer needs to update this requirement for the project.]

8.6 Controller Software. This section concerns the software that runs the building and energy management applications. This software must reside and operate in the controllers that compose the network, not the PC operator workstations.

Regardless of the manufacturer of the BAS, the designer must customize the DDC equipment to control the building's specific equipm1ent as intended. This is accomplished through the application programming, which varies depending on the DDC controller manufacturer and type:

a. Text-based programming (also known as line-based programming and mnemonic programming)
b. Graphic-based programming
c. Menu-driven programming (parameter-based programming)

Selection of the application programming language is the province of the manufacturer and is not prescribed in this example specification. However, Part 3, "Execution," of the specification covers the requirements for documentation and performance of each programming type.

2.4 CONTROLLER SOFTWARE

A. Furnish the following applications software for building and energy management. All software applications shall reside and operate in the system controllers. Editing of applications shall occur at the operator workstation.

8.6.1 Security. The software contained in the controllers must be kept secure and protected from modification or corruption by unauthorized or poorly trained users. This should require the entry of a username and password in order for the operator to perform system functions. Requiring a person to enter a username (log on) also provides a method to track and log operator actions.

B. System Security
   1. User access shall be secured using individual security passwords and user names.
   2. Passwords shall restrict the user to the objects, applications, and system functions as assigned by the system manager.
   3. User log on/log off attempts shall be recorded.
   4. The system shall protect itself from unauthorized use by automatically logging off following the last keystroke. The delay time shall be user-definable.

8.6.2 Scheduling. System scheduling software resides on and is executed by the controllers. Scheduling setup and editing is normally done from the workstations. The following specification language represents typical scheduling programs.

8.6.2.1 Project Considerations. The "weekly schedule" subparagraph specifies requirements for ten events. The "holiday schedules" subparagraph specifies requirements for 99 special schedules. These are typical numbers and are met by most manufacturers. The BAS designer may modify these for more intricate scheduling needs.

8.6.3 Grouping. It is extremely useful to be able to group together equipment with similar functions and/or locations.

C. System Coordination. Provide a standard application for the proper coordination of equipment. This application shall provide the operator with a method of grouping together equipment based on function and location. This group may then be used for scheduling and other applications.

8.6.4 Alarm Processing. One of the valuable services that a BAS can provide is to notify the operator when something has gone wrong. The object list or the sequences of operation included with the contract documents should indicate which system objects have alarm processing, and for analog objects, what the appropriate alarm limits should be.

D. Scheduling. Provide the capability to schedule each object or group of objects in the BAS. Each schedule shall consist of the following:
   1. Weekly Schedule. Provide separate schedules for each day of the week. Each of these schedules should include the capability for start, stop, optimal start, optimal stop, and night economizer. Each schedule may consist of up to 10 events. When a group of objects are scheduled together, provide the capability to adjust the start and stop times for each member.
   2. Exception Schedules. Provide the ability for the operator to designate any day of the year as an exception schedule. Exception schedules may be defined up to a year in advance. Once an exception schedule is executed, it will be discarded and replaced by the standard schedule for that day of the week.
   3. Holiday Schedules. Provide the capability for the operator to define up to 99 special or holiday schedules. These schedules may be placed on the scheduling calendar and will be repeated each year. The operator shall be able to define the length of each holiday period.
   4. Before project close-out, the contractor shall create schedules for each piece of equipment (not just provide the capability to do so).

E. Binary Alarms. Each binary object shall be set to alarm based on the operator-specified state. Provide the capability to automatically and manually disable alarming.

F. Analog Alarms. Each analog object shall have both high and low alarm limits. Alarming must be able to be automatically and manually disabled.

G. Alarm Reporting. The operator shall be able to determine the action to be taken in the event of an alarm. Alarms shall be routed to the appropriate workstations based on time and other conditions. An alarm shall be able to start programs, print, be logged in the event log, generate custom messages, and display graphics.

8.6.5 Remote Communication. The controllers often need the ability to communicate offsite in order to automatically report a serious alarm. This specification wording requires that the communication conforms to open protocols for the work. See Informative Annex F for a reference to open-protocol guideline specification language.

8.6.5.1 Project Considerations. It is possible for the BAS to issue notifications to a variety of devices and in different formats. If this feature is desired, specify it and identify the devices that will receive these notifications.

H. Remote Communication. The system shall have the ability to transmit the alarm/event using the [open protocol] control network. See Informative Annex F for a reference to open-protocol guideline specification language.

8.6.6 Standard Application Programs. The following specification paragraphs detail the requirements for several typical application programs: demand limiting, maintenance management, sequencing, proportional-integral-derivative (PID) control, staggered start, energy calculations, anti-short cycling, on/off control with differential, and runtime totalization.

8.6.6.1 Project Considerations. This example specification represents a moderately large, complex project. Many other projects will require specification of only a few of these programs. While it is not very expensive to provide the capability to run these programs, the programming required to set up these programs to control equipment and systems is somewhat costly and will require that the BAS designer clearly indicate—in the object list or sequences of operation—which equipment and systems are to be controlled by these programs. Consult with the owner to determine the need for any or all of these programs.

8.6.7 Demand Limiting. This program is fairly limited in its application and should be specified with considerable care to avoid nuisance shutdowns and curtailment of services to critical systems. The BAS designer will need to add additional specification language if the project has to meet SmartGrid requirements such as automated demand response programs.

I. Demand Limiting
   1. The demand-limiting program shall monitor building power consumption from signals generated by a pulse generator (provided by others) mounted at the building power meter or from a watt transducer or current transformer attached to the building feeder lines.
   2. The demand-limiting program shall predict the probable power demand such that action can be taken to prevent exceeding the demand limit. When demand prediction exceeds demand limit, action will be taken to reduce loads in a predetermined manner. When demand prediction indicates the demand limit will not be exceeded, action will be taken to restore loads in a predetermined manner.
   3. Demand reduction shall be accomplished by the following means:
      a. Reset air-handling unit supply temperature setpoint up by 1°C (2°F).
      b. Reset space temperature setpoints up by 1°C (2°F).
      c. De-energize equipment based upon priority.

4. Demand-limiting parameters, frequency of calculations, time intervals, and other relevant variables shall be based on the means by which the local power company computes demand charges.
5. Provide demand-limiting prediction and control for any individual meter monitored by the system or for the total of any combination of meters.
6. Provide the means for an operator to make the following changes online:
   a. Addition and deletion of loads controlled
   b. Changes in demand intervals
   c. Changes in demand limit for meter(s)
   d. Maximum shutoff time for equipment
   e. Minimum shutoff time for equipment
   f. Select rotational or sequential shedding and restoring
   g. Shed/restore priority
7. Provide the following information and reports, to be available on an hourly, daily, and monthly basis:
   a. Total electric consumption
   b. Peak demand
   c. Date and time of peak demand
   d. Daily peak demand

8.6.8 Maintenance Management. This application is frequently handled by non-energy-management software. Consult with the owner to determine his/her needs and to coordinate with third-party software.

J. Maintenance Management. The system shall monitor equipment status and generate maintenance messages based upon user-designated runtime, starts, and/or calendar date limits.

8.6.9 Sequencing. This ensures that equipment start/stop follows a specific sequence of operation. If the sequence of operation is written correctly, the capability of this application will be provided.

K. Sequencing. Provide application software based upon the sequences of operation specified to properly sequence chillers, boilers, and pumps.

8.6.10 Proportional-Integral-Derivative (PID) Control. This control algorithm defines process feedback loop control. Most HVAC processes use only the proportional or proportional-integral features of PID loop control.

L. PID Control. A PID algorithm with direct or reverse action and anti-windup shall be supplied. The algorithm shall calculate a time-varying analog value that is used to position an output or stage a series of outputs. The controlled variable, setpoint, and PID gains shall be user-selectable.

8.6.11 Staggered Start. Another application of the sequencing program, the staggered start, is justified only if several large motor loads are under the control of the BAS. This application prevents the starting of very large motor loads simultaneously and ensures that they follow a specific sequence of operation.

M. Staggered Start. This application shall prevent all controlled equipment from simultaneously restarting after a power outage. The order in which equipment (or groups of equipment) is started, along with the time delay between starts, shall be user-selectable.

8.6.12 Energy Calculations. This application is a companion to demand limiting. It also should be specified if the owner is managing power consumption under time-of-day or real-time energy rates.

Utilities use both sliding-window and fixed-window demand intervals. Calculations should be provided for both. The fixed-window demand interval requires that the pulse accumulator or totalized value used to capture the energy consumption be synchronized with the utility meter to identify when the demand period begins and ends. Note the sliding window calculation must allow the operator to define the sample period used for the demand interval (e.g., 15 min) and sample interval (e.g., 1 min).

N. Energy Calculations.
   1. Provide software to allow instantaneous power (e.g., kW) or flow rates (e.g., L/s [gpm]) to be accumulated and converted to energy usage data.
   2. Provide an algorithm that calculates a sliding-window average (e.g., rolling average). The algorithm shall be flexible to allow window intervals to be user specified (e.g., 15 min, 30 min, 60 min).
   3. Provide an algorithm that calculates a fixed-window average. A digital input signal will define the start of the window period (e.g., signal from utility meter) to synchronize the fixed-window average with that used by the energy service provider.

8.6.13 Anti-Short-Cycling. Anti-short-cycling is a protective application to prevent accidental switching of binary outputs.

O. Anti-Short-Cycling. All binary output objects shall be protected from short cycling. This feature shall allow minimum on-time and off-time to be selected.

8.6.14 On/Off Control with Differential. This application simulates the action of a switch with an adjustable dead band in software. It can be used in a tank-filling application, for instance.

P. On/Off Control with Differential. Provide an algorithm that allows a binary output to be cycled based on a controlled variable and setpoint. The algorithm shall be direct-acting or reverse-acting and incorporate an adjustable differential.

8.6.15 Runtime Totalization. This application is frequently used in a tracking/reporting system and motor accumulated runtime—either manually or automatically—to a preventive maintenance program. This application also is used in equalizing runtime of parallel equipment or in switching lead-lag sequences.

Q. Runtime Totalization. Provide software to totalize runtimes for all binary input objects. A high runtime alarm shall be assigned, if required, by the operator.

8.7 Building Controllers

8.7.1 General. The example specification describes the characteristics of building controllers and is tightly coupled with the articles on "custom application controllers" and "application-specific controllers." Some of the information described in this and the following two sections may also be detailed in other sections.

8.7.2 Background. The primary purpose of a building controller is to facilitate global control strategies. The building controller can also provide the interface between the field points and the operator's PC workstation. The controller will communicate with the workstation (and other controllers) via the communication bus described in the section on communication. Like building controllers, custom application controllers can support custom written programs to meet specific building requirements. Building controllers may contain software optimization strategies and they may interface to input/output devices.

Two important considerations are when and why one should provide building controllers, custom application controllers, and ASCs and in what combination these should be provided to best meet the facility's BAS requirements. The right combination of controllers will provide an optimized architecture for the BAS as well as cost. The BAS designer will need to clearly define the system's architecture or the performance requirement of the system. This will ensure that the vendor provides the appropriate number and type of controllers.

In general,

a. specify building controllers for facility-wide control strategies;
b. specify to connect remote concentrations of field devices with custom application controllers networked back to building controllers; and
c. use ASCs for packaged equipment and terminal unit controls when the preprogrammed sequences match the designed needs.

If the application involves facility-wide coordination requiring controllers to share data on a real-time basis, a peer-to-peer approach is probably desirable. A peer-to-peer approach introduces more power and integrity to controller networks. This is because each device has full access to the communication bus and may be able access data from any controller. Make sure that the specified controllers can communicate in a peer-to-peer fashion.

The typical building may have only one or a few building controllers, but many custom application and ASCs. If the facility has a large central plant, large air handlers, and very complex control strategies, then a combination of building, custom application, and ASCs may be desirable. If facility-wide control is unnecessary, then a combination of custom application and ASCs will probably suffice.

The following describes some of the general characteristics of a building controller.

Typical Features

a. Fast, high-powered processor with large memory capacity (usually available in a variety of different memory configurations)
b. May have many built-in features and functions, such as control loop tuning, scheduling, history, alarming, and optimization strategies
c. Available in customizable configurations, expandable, and versatile
d. General purpose: ability to run large programs for multiple pieces of equipment or systems for facility-wide control
e. May or may not have direct coupled I/O capability; I/O may be picked up by remote LAN controllers

Cost

a. Sophisticated controller, higher priced than custom application controllers and ASCs
b. Labor-intensive to configure

Communication

c. Communicates on higher performance networks, such as Ethernet
d. Typically a peer-to-peer type device that is able to share information with other building controllers, workstations, and slave controllers

8.7.3 Internal Software. The building controller contains software and firmware that compose its operating system and internal application programs. This software is not the same as the custom operating programs used to control the facility. It is generally not acceptable for operators to have access to internal firmware programs. However, it is important to be able to update and/or upgrade these programs in the event of a software defect or to take advantage of a new enhancement.

8.7.4 Modularity. The building controller may be modular in design. This feature is generally important for two reasons: lower first cost and ease of future expansion. Modularity should be covered when specifying spare object capacity. Note that when specifying spare object capacity, it is important to specify the percentage (or quantity) of spare objects required at the controller level or system level, whichever is desired.

Another advantage of modularity is the ability to specify, cost-effectively, that a single controller will control only one or two major pieces of equipment (air-handling units, chillers, etc.). While this increases the number of possible points of failure for the system, a controller failure will have less of an impact on daily operation. Small controllers with limited I/O capacity may also meet this requirement.

8.7.5 Operator Software. It may be desirable to specify that the building operator will have the ability to make software changes to affect the control of the building, that is, modify the sequences of operation. This can be accomplished by most manufacturers. For this, the controller should be software or firmware programmable (either is generally acceptable).

Keep in mind, however, that the controller application software could be modified in such a way that it does not operate properly. Only well-trained users should undertake the modification of application programs.

8.7.6 Inputs and Outputs. The building controller will receive signals from remote building sensors, transmitters, transducers, meters, etc., and typically will accept the following inputs:

a. 0 to 10 VDC
b. 4 to 20 mA
c. Contact closure
d. Pulse inputs
e. Resistive inputs (RTD or thermistor)

Some manufacturers now offer universal-type inputs, which may be designated as either binary (on/off) or analog (proportional signal) inputs. The type of input (binary or analog) is selectable by the user without hardware modifications. Universal points tend to increase the cost of the controller; however, they allow greater flexibility in matching the point type required by the system.

The building controller will provide output signals to control remote end-devices and typically will provide the following outputs:

a. Contact closure
b. Analog outputs (0 to 10 VDC, 4 to 20 mA, pulse-width modulation, tri-state, floating control)

8.7.7 Power Supplies. Building controllers are powered by either 24 or 120 VAC sources. The variance in acceptable voltage amplitude and frequency should be specified. Controllers need to have protection from source voltage reduction (brownouts) and power surges. This protection can either be internal to the controller or be provided externally. If protection is provided externally, care must be taken to ensure that it is properly installed.

8.7.8 Listings. Listings such as UL or CSA need to be determined based upon local code and owner's requirements. Listing requirements should be specific and expressed as requirements for components or as a system. Note that field modifications to a listed component, such as the addition of a relay to a listed panel, may void the listing. If listings are not necessary, they should not be specified. If they are, it is important to ensure that the requirements are clear and enforced. This ensures that all proposals received are for comparable systems.

8.7.9 Distribution of Controllers. It is advantageous to limit the number of major systems connected to one controller. This can increase initial cost but reduces risk of downtime. All field points associated with a control loop should be monitored or controlled from a single controller. This avoids the possibility of a mechanical system going out of control from loss of network data communication or a lag in response time.

2.5 BUILDING CONTROLLERS

A. General. Provide an adequate number of building controllers to achieve the performance specified in Article 1.9, "BAS Performance." Each of these controllers shall meet the following requirements.
   1. The building automation system shall be composed of one or more independent, stand-alone, microprocessor-based building controllers to manage the global strategies described in the "System Software" section.

As was previously mentioned, building controllers are typically available with a variety of different memory capacities. The job-specific database will use up memory. Make sure there is enough memory available for programs, trend logs, and other database functions by specifying these in the object list or the sequences of operation.

8.7.9.1 Project Considerations. The BAS designer also may want to ensure that a percentage of unused memory is available for additions and expansions.

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   2. The building controller shall have sufficient memory to support its operating system, database, and programming requirements.

Controllers should be able to share global information with other controllers or workstations for control strategies and event notification. Outdoor air temperature is one such value that is typically shared between controllers on a high-speed network. If global objects (such as outdoor air temperature) are used within the controller, care should be taken to specifically exclude using inputs from one controller to directly control output in another controller if any delay could cause control loop instability. Acceptable uses could be the outdoor air temperature reset of an air-handling unit's discharge air temperature setpoint.

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   3. Data shall be shared between networked building controllers.
   4. The operating system of the building controller shall manage the input and output communication signals to allow distributed controllers to share real and virtual object/variable information and allow for central monitoring and alarms.

The controller should have its own internal clock to keep track of time.

8.7.9.2 Project Considerations. It may be desirable for the controller's clock to be synchronized with a master timekeeper so all controllers stay on the same time. Time could be synchronized on a regular basis or upon the event of a time change or power loss.

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5. Controllers that perform scheduling shall have a real-time clock.

The building controller should be able to fail gracefully to prevent inadvertent equipment damage. Most controllers have an internal heartbeat that regularly signals to the network that the controller is online. If this signal fails, then a notification would be automatically communicated to the network and be displayed at a workstation as an alarm.

The BAS designer should ensure that appropriate equipment failure modes are determined in the event of a loss of the BAS. In addition, a "backup" mode of control should be specified in the event that communication is lost and the global object is not received. Controllers should have power fail auto restart. This needs to be specified to ensure proper safety during a power failure and a safe orderly recovery after power restoration. Restoration after power returns can only be automatic, staged restart, or manually initiated (via workstation). The failure of any one controller should not adversely affect the ability of the rest of the system to operate.

If a controller loses its program, it should be capable of being down-line loaded in less than two minutes. This ensures that in case of memory loss the controller can be made operational again very quickly. Firmware-based controllers will not lose memory, so this feature may not always be necessary.

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6. The building controller shall continually check the status of its processor and memory circuits. If an abnormal operation is detected, the controller shall
   a. assume a predetermined failure mode, and
   b. generate an alarm notification.

In Clauses 4.4 and 8.3, the arrangement of devices on the networks and the protocol to be used are a function of many decisions made by the BAS designer and were driven by the needs and goals of the owner and user. The BAS designer, based on these decisions, may opt to use an open-protocol strategy. The example specification assumes an open-protocol strategy is to be used. The BAS designers should modify and remove the following specification sections on communications if an open-protocol strategy is not selected.

In a new system, the BAS designer may have the freedom to specify a particular communication protocol. If the new system is being integrated into an existing system, the choices may be limited by what the existing system supports. In this case, a gateway could be used to connect the existing system to the new open system network. Of course, the designer could choose not to have the existing and new systems communicate at all, in which case a gateway would not be necessary.

There are endless ways to accomplish an open system strategy. The BAS designer needs to select a method that will yield the best combination of competition, choice, and cost that uses an open protocol. Clause 13 provides some guidance on dealing with legacy systems. See Informative Annex F for a reference to open-protocol guideline specification language.

8.7.9.3 Project Considerations. Depending on the desired outcome, other approaches could be selected. A discussion of an alternative follows.

8.7.9.3.1 For Information Exchange at the Management or Supervisory Level. A network of controllers that serve a common function (an entire building, a new wing, or a lab BAS) could be connected to a higher-level open network using a gateway. This serves to isolate islands of systems that use other protocols. This also provides a way to segment responsibility. The protocol and architecture from the gateway to the lower-level controllers would be determined, and the vendor would then supply the products (including the gateway). This allows a vendor to be creative and offer value-engineering ideas. The BAS designer need not specify the protocol at this level. However, the BAS designer needs to indicate what information is required at the higher level of the network in the object list described in Clause 5.3.5.

The BAS designer will need to ensure these protocols are appropriate for this level of communication. In addition, the system architecture may be affected by this decision. See Informative Annex F for a reference to open-protocol guideline specification language.

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7. The building controller shall communicate with networked BAS devices on the network using the protocol-specific communication requirements. Controller-to-controller communication shall be peer-to-peer and not require a master or host server for communication.

Each protocol standards organization has a compliance testing program. See Informative Annex E for a reference to open-protocol guideline specification language. The BAS designer needs to select the appropriate LAN technologies that are available from the open protocols selected for the work. See Annex F for a reference to open-protocol guideline specification language. The building controller shall be listed by or submitted for testing to a testing laboratory approved by the open protocol selected for the work.

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8. The building controller shall be certified, listed by or submitted for testing to a testing laboratory approved by [open-protocol body].

The BAS designer needs to select the appropriate LAN technologies that are available from the open protocol selected for the work. See Informative Annex F for a reference to open-protocol guideline specification language. The building controller may also serve as the router to other networks where the custom application and ASCs reside. It is also possible to have the router functionality in another dedicated device.

8.7.9.4 Project Considerations. Recall that for this example we chose to have the building controller linked with other building controllers on an Ethernet LAN and to have the building controller act as a router to the BAS device network, connecting it to a subnetwork of custom application and ASCs.

It also may be desirable to have a service port available for connection by a portable operator's terminal.

B. Communication.
   1. Each building controller shall reside on the [open-protocol network].
   2. The controller shall provide a communication port connection or network interface for a portable operator's terminal.
   3. Network routers/repeaters/bridges shall be used to extend communications, change media type, or extend the network in order to ensure proper communication for the entire BAS.

Building controllers are typically not placed outdoors or in extremely harsh climates. However, they should be able to endure typical equipment room climates. These climates can be damp and sometimes very hot and dusty.

C. Environment. Controller hardware shall be suitable for the anticipated ambient conditions.
   1. Controllers used outdoors and/or in wet ambient conditions shall be mounted within waterproof enclosures and shall be rated for operation at 40°C to 65°C (40°F to 150°F).
   2. Controllers used in conditioned space shall be mounted in dust-proof enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

Some building controllers are equipped with a keypad. In addition, most building controllers have the ability to communicate to a laptop for servicing or gaining online access to information. The BAS designer should make sure that the system supports password protection to prevent unauthorized access to the system.

8.7.9.5 Project Considerations. A keypad costs extra and its availability is limited by manufacturer. If the manufacturer is already supplying a laptop, the keypad may be unnecessary.

D. Keypad. A local keypad and display shall be provided for each controller. The keypad shall be provided for interrogating and editing data. An optional system security password shall be available to prevent unauthorized use of the keypad and display. If the manufacturer does not provide this keypad and display, provide a portable operator terminal (optional at BAS designer's discretion).

A visual indication is useful in determining building controller failure. This could be recognized or noticed by a building operator while making service rounds. It may be desirable for the status LEDs to be seen without opening the front panel door. Internal components should be replaceable without the need to rewire the entire panel.

E. Serviceability. Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to field-removable, modular terminal strips or to a termination card connected by a ribbon cable.

All volatile memory should be provided with battery backup to ensure contents are protected against loss for at least 72 hours. Consider requiring emergency power if longer power outages are likely or potentially catastrophic.

F. Memory. The building controller shall maintain all BIOS and programming information in the event of a power loss for at least 72 hours.

The building controller also should be protected from process noise, electrical noise (5 to 120 Hz), and radio frequency interference (keyed radios).

G. Immunity to power and noise. Controller shall be able to operate at 90% to 110% of nominal voltage rating and shall perform an orderly shutdown below 80% nominal voltage. Operation shall be protected against electrical noise of 5 to 120 Hz and from keyed radios up to 5 W at 1 m (3 ft).

8.8 Custom Application Controllers

8.8.1 General. The following describes some of the general characteristics of a custom application controller. Refer to the discussion in Clause 8.7, "Building Controllers," comparing the building and ASCs to custom application controllers.

Typical Attributes

a. Less robust processor, and memory capacity may be limited compared to a building controller
b. Little or no built-in applications
c. Available in customizable configurations; may or may not be expandable
d. Usually oriented to control a single piece of equipment; ability to run small programs for single pieces of equipment; not suitable for facility-wide control strategies
e. Many I/O configuration options; object capacity may be more limited than building controllers
f. May be suitable for harsh environments or outdoor use

Cost

a. Generally lower priced than building controllers but more expensive than ASCs
b. Labor-intensive to configure

Communication

a. May use lower performance networks
b. May operate as a slave device to a building controller; may not communicate to other custom application controllers or ASCs

8.8.2 Internal Software. The custom application controller contains software or firmware that compose the operating system and internal application programs of the controller. This software is not the same as the custom operating programs used to control the facility. It is generally not acceptable for operators to have access to internal firmware programs. However, it is important to be able to update and/or upgrade these programs in the event of a software defect or to take advantage of a new enhancement.

8.8.3 Modularity. The custom application controller may be modular in design. This feature is generally important for two reasons: lower first cost and ease of future expansion. Modularity should be covered when specifying spare object capacity. Note that when specifying spare object capacity, it is important to specify the percentage (or quantity) of spare objects required at the controller level or system level, whichever is desired.

Another advantage of modularity is the ability to specify, cost-effectively, that a single controller will control only one or two major pieces of equipment (air-handling units, chillers, etc.). While this increases the number of possible points of failure for the system, a controller failure will have less of an impact on daily operation. Small controllers with limited I/O capacity may also meet this requirement.

8.8.4 Operator Software. It may be desirable to specify that the building operator will have the ability to make software changes to affect the control of the building, that is, modify the sequences of operation. For this, the controller should be software or firmware programmable (either is generally acceptable).

Keep in mind, however, that the controller application software could be modified in such a way that it does not operate properly. Only well-trained users should undertake the modification of application programs.

8.8.5 Inputs and Outputs. Custom application controllers will receive signals from remote building sensors, transmitters, transducers, meters, etc., and typically will accept the following inputs:

a. 0 to 10 VDC
b. 4 to 20 mA
c. Contact closure
d. Pulse inputs
e. Resistive inputs (RTD or thermistor)

Some manufacturers now offer universal-type inputs that may be designated as either binary (on/off) or analog (proportional signal) inputs. The type of input (binary or analog) is selectable by the user without hardware modifications. Universal points tend to increase the cost of the controller; however, they allow greater flexibility in matching the point type required by the system.

Custom application controllers will provide output signals to control remote end-devices and typically will provide the following outputs:

a. Contact closure
b. Analog outputs (0 to 10 VDC, 4 to 20 mA, pulse-width modulation, tri-state, floating control)

8.8.6 Power Supplies. Custom application controllers are powered by either 24 or 120 VAC sources. The variance in acceptable voltage amplitude and frequency should be specified. Controllers need to have protection from voltage reduction (brownouts) and power surges. This protection can either be internal to the controller or provided externally. If protection is provided externally, care must be taken to ensure that it is properly installed.

8.8.7 Listings. Listings such as UL or CSA need to be determined based upon local code and owner requirements. Listing requirements should be specific and expressed as requirements for components or as a system. Note that field modifications to a listed component, such as the addition of a relay to a listed panel, may void the listing. If listings are not necessary, they should not be specified. If they are, it is important to ensure that the requirements are clear and enforced. This ensures that all proposals received are for comparable systems.

8.8.8 Distribution of Controllers. It is advantageous to limit the number of major systems connected to one controller. This can increase initial cost but it reduces risk of downtime. All field points associated with a control loop should be monitored or controlled from a single controller. This avoids the possibility of a mechanical system going out of control from loss of network data communication or a lag in response time.

2.6 CUSTOM APPLICATION CONTROLLERS

A. General. Provide an adequate number of Custom Application Controllers to achieve the performance specified in Article 1.9, "BAS Performance." Each of these panels shall meet the following requirements.

As was previously mentioned, controllers are typically available with a variety of different memory capacities. The job-specific database will use up memory. Make sure there is enough memory available for programs, trend logs, and other database functions by specifying these in the objects list or the sequences of operation.

8.8.8.1 Project Considerations. The BAS designer also may want to ensure that a percentage of additional unused memory is available for additions and expansions.

1. The custom application controller shall have sufficient memory to support its operating system, database, and programming requirements.

Controllers should be able to share global information with other controllers or workstations for control strategies and event notification. Outdoor air temperature is one such value that is typically shared between controllers on a high-speed network. If global objects (such as outdoor air temperature) are used within the controller, care should be taken to specifically exclude using inputs from one controller to directly control output in another controller if any delay could cause control loop instability. Acceptable uses could be outside air temperature reset of an air-handling unit's discharge air temperature setpoint.

2. Data shall be shared between networked custom application controllers.
3. The operating system of the controller shall manage the input and output communication signals to allow distributed controllers to share real and virtual object information and allow central monitoring and alarms.

The controller should have its own internal clock to keep track of time. It may be desirable for the controller's clock to be synchronized with a master timekeeper so all controllers stay on the same time. Time could be synchronized on a regular basis or upon the event of a time change or power loss.

4. Controllers that perform scheduling shall have a real-time clock.

The controller should be able to fail gracefully to prevent inadvertent equipment damage. Most controllers have an internal heartbeat that regularly signals to the network that the controller is on-line. If this signal fails, then a notification would be automatically communicated to the network and be displayed at a workstation as an alarm.

The BAS designer should ensure that appropriate equipment failure modes are determined in the event of a loss of automation control. In addition, a backup mode of control should be specified in the event that communication is lost and the global object is not received. Controllers should have power fail auto restart. This needs to be specified to ensure proper safety during a power failure and a safe orderly recovery after power restoration. Restoration after power returns can only be automatic, staged restart, or manually initiated (via workstation). The failure of any one controller should not adversely affect the ability of the rest of the system to operate.

If a controller loses its program, it should be capable of being down-line loaded in less than two minutes. This ensures that, in case of memory loss, the controller can be made operational again very quickly. Firmware-based controllers will not lose memory, so this feature may not always be necessary.

5. The custom application controller shall continually check the status of its processor and memory circuits. If an abnormal operation is detected, the controller shall
   a. assume a predetermined failure mode and
   b. generate an alarm notification.

The same discussion applies here as in Clause 8.7 for building controllers. Clauses 4.4 and 8.3 discuss how the arrangement of devices on the networks and the protocol to be used are functions of many decisions made by the BAS designer and were driven by the needs and goals of the owner and user. The BAS designer, based on these decisions, may opt to utilize an open-protocol strategy. The example specification assumes an open-protocol strategy is being used. The BAS designer should modify and remove the following specification sections on communications if an open-protocol strategy is not selected.

In a new system, the BAS designer may have the freedom to specify a particular communication protocol. If the new system is being integrated into an existing system, the choices may be limited by what the existing system supports. In this case, a gateway could be used to connect the existing system to the new open system network. Of course, the designer could choose not to have the existing and new systems communicate at all, in which case a gateway would not be necessary.

There are endless ways to accomplish an open system strategy. The BAS designer needs to select the appropriate open protocol suitable for the project. See Informative Annex F for a reference to open-protocol guideline specification language.

8.8.8.2 Project Considerations. Depending on the desired outcome, other approaches could be selected. A discussion of an alternative follows.

8.8.8.2.1 For Information Exchange at the Management or Supervisory Level. A network of controllers that serve a common function (an entire building, a new wing, or a lab BAS) could be connected to a higher-level open network using a gateway. This serves to isolate islands of systems that use other protocols. This also provides a way to segment responsibility. The protocol and architecture from the gateway to the lower-level controllers would be determined, and the vendor would then supply the products (including the gateway). This allows a vendor to be creative and offer value-engineering ideas. The BAS designer need not specify the protocol at this level. However, the BAS designer needs to indicate what information is required at the higher-level open network in the object list described in Clause 5.3.5.

Keep in mind that there are various open protocols suitable for the task. See Informative Annex F for a reference to open-protocol guideline specification language.

6. The custom application controller shall communicate with other open-protocol devices on the network using the protocol-specific services.

Each protocol standards organization has a compliance testing program. See Informative Annex F for a reference to open-protocol guideline specification.

7. All network controllers shall be tested and certified or listed by an official open-protocol testing laboratory as being compliant with the standardized open-protocol device capabilities.

See Informative Annex F for a reference to open-protocol guideline specification language for the LAN technologies that are available.

In this example, the custom application controllers communicate on the relatively lower speed device-level network. Please refer Figure 8.3.5 and the discussion on the use of building controllers as routers between the device-level LAN and the Ethernet LAN.

It also may be desirable to have a service port available for connection by a portable operator's terminal.

B. Communication.
1. Each custom application controller shall reside on a control network using the device-level protocol.
2. The controller shall provide a service communication port or network interface using an open-protocol for connection to a portable operator's terminal.

Custom application controllers should be able to endure typical equipment room climates. These climates can be damp and sometimes very hot and dusty.

C. Environment. Controller hardware shall be suitable for the anticipated ambient conditions.
1. Controllers used outdoors and/or in wet ambient conditions shall be mounted within waterproof enclosures and shall be rated for operation at 40°C to 65°C (40°F to 150°F).
2. Controllers used in conditioned space shall be mounted in dustproof enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

Some building controllers are equipped with a keypad. In addition, most custom application controllers have the ability to communicate to a laptop for servicing or gaining on-line access to information. The BAS designer should make sure that the system supports password protection to prevent unauthorized access to the BAS.

8.8.8.3 Project Considerations. A keypad costs extra and its availability is limited by manufacturer. If the manufacturer is already supplying a laptop, the keypad may be unnecessary.

D. Keypad. A local keypad and display shall be provided. The keypad shall be provided for interrogating and editing data. An optional system security password shall be available to prevent unauthorized use of the keypad and display.

A visual indication is useful in determining custom application controller failure. This could be recognized or noticed by a building operator while making service rounds. It may be desirable for the status LEDs to be seen without opening the front panel door. Internal components should be replaceable without the need to rewire the entire panel.

E. Serviceability. Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to field-removable, modular terminal strips or to a termination card connected by a ribbon cable.

All volatile memory should be provided with battery backup to ensure contents are protected against loss for at least 72 hours. Consider requiring emergency power if longer power outages are likely or potentially catastrophic.

F. Memory. The custom application controller shall maintain all BIOS and programming information in the event of a power loss for at least 72 hours.

The custom application controller also should be protected from process noise, electrical noise (5 to 120 Hz), and radio frequency interference (from keyed radios).

G. Immunity to power and noise. Controller shall be able to operate at 90% to 110% of nominal voltage rating and shall perform an orderly shutdown below 80% nominal voltage. Operation shall be protected against electrical noise of 5 to 120 Hz and from keyed radios up to 5 W at 1 m (3 ft).

8.9 Application-Specific Controllers

8.9.1 General. The following describes some of the general characteristics of an application-specific controller (ASC):

Typical Attributes

a. Lower performance processor, memory capacity may be limited
b. Usually oriented to control a single piece of equipment (VAV box, unit ventilator, chiller, boiler, packaged rooftop unit, etc.) and contains a fixed program (not user-modifiable) optimized to control the equipment to which it is connected
c. Not suitable for general building control applications
d. Usually located on the equipment it is controlling
e. Limited I/O and object capacity (usually dedicated to the equipment)

Cost

a. Generally lowest priced controller
b. Easier to configure

Communication

c. Typically operates as a slave device to a building controller on a lower-level network and does not communicate directly to other higher-level controllers or workstations.

8.9.2 Background. The typical building will usually contain more ASCs than any other type of controller. These controllers are used for specific applications, such as zone, rooftop, heat-pump, unit ventilator, chiller, and boiler control. These controllers are relatively inexpensive when compared to building and custom application controllers. These controllers are not feature-rich but are optimized to do a specific job. These controllers generally have fixed programs and I/O object allocation to control the specific equipment to which they are connected. Some of the equipment-related building sequences that may reside in these controllers are as follows:

a. Night cycle setup/setback/shutdown
b. Temperature and humidity-based economizers
c. Warm-up and purge sequences
d. Setpoint reset
e. Start/stop optimization
f. Diagnostics
g. Data sharing
h. Status and safety alarms

Typically, networks of ASCs are connected to building controllers that direct the facility-wide control strategies and initiate the strategies listed above. ASCs are sometimes used to connect remote I/O concentrations that would not be practical to wire to a building or custom application controller. Facility-wide control is not suitable for an ASC.

To reiterate, an important consideration is when and why one should provide building controllers, custom application controllers, and ASCs and in what combination these should be used to best meet the facility's BAS requirements. The right combination of controllers will provide an optimized architecture for control as well as cost. The BAS designer will need to clearly define the system's architecture or the performance requirement of the system. This will ensure that the vendor provides the appropriate number and type of controllers.

In general,

a. specify building controllers for facility-wide control strategies;
b. specify to connect remote concentrations of field devices with custom application controllers networked back to building controllers; and
c. use ASCs for packaged equipment and terminal unit controls when the preprogrammed sequences match the designed needs.

A recent trend has emerged concerning packaged equipment. In order to optimize costs and provide the best solution for the equipment and the customer, most packaged equipment is delivered with ASCs factory-mounted by the manufacturer. A problem may exist if the BAS and packaged equipment are supplied by different or multiple vendors, as is common on most jobs. The problem will be in interconnecting these ASCs and the BAS controllers to create a cohesive system. A few years ago, this was done through expensive hardwired inputs and outputs.

If most packaged equipment is to be supplied with factory-mounted microprocessor controls, it makes sense to use a common communication methodology to interconnect all controllers in a facility to create a cohesive building management system optimized for facility-wide control. Recently, many building automation companies have begun supplying proprietary interfaces or gateways to individual equipment suppliers. While these interfaces are functional, they can be expensive. Not all BASs are equipped to tackle this task. In addition, the variety of interfaces available will be manufacturer-dependent.

See Informative Annex F for a reference to open-protocol guideline specification language. Clause 10.7, "Application-Specific Controllers for Equipment Specified Under Other Sections," of this guideline, addresses particular specification language to be used in the specifications for the other equipment to ensure that communication issues are adequately covered. See Clause 12 for additional building-wide control strategies.

2.7 APPLICATION-SPECIFIC CONTROLLERS

A. General. Application-specific controllers (ASCs) are microprocessor-based BAS controllers, which through hardware or firmware design are dedicated to control a specific piece of equipment. They are not fully user-programmable but are customized for operation within the confines of the equipment they are designed to serve. ASCs shall communicate with other BAS open-protocol devices on the network using the open-protocol-specific read (execute) property service.

1. Each ASC shall be capable of stand-alone operation and shall continue to provide control functions without being connected to the network.
2. Each ASC will contain sufficient I/O capacity to control the target system.
3. Each ASC shall be certified or listed for compliance to the [open-protocol body] standards.

Each protocol standards organization has a compliance testing program. See Informative Annex F for a reference to open-protocol guideline specifications and for open-protocol guideline specification language for the LAN technologies that are available.

8.9.2.1 Project Considerations. As described earlier, many BAS suppliers have direct-connect solutions to other systems where ASCs are used. These connections could be used as alternatives to having the ASCs directly connect to the open network. Allowing this type of solution may help reduce cost and provide the vendors with some additional options. Again, support for this type of solution will vary by BAS supplier.

In a new system, the BAS designer may have the freedom to specify a particular communication protocol. If the new system is being integrated with an existing system, the choices may be limited by what the existing system supports.

B. Communication.

1. The controller shall reside on the [open protocol] network using [media type] physical media. Each network of controllers shall be connected to one building controller.
2. Each controller shall have an [open protocol] [media type] compatible connection for a laptop computer or a portable operator's tool. This connection shall be extended to a space temperature sensor port where shown.

Terminal unit controller parameters should be viewed and manipulated from an accessible space temperature sensor port.

ASCs should be able to endure typical equipment room climates or outdoor environments (e.g., rooftop air handlers). These climates can be damp and sometimes very hot and dusty.

C. Environment. The hardware shall be suitable for the anticipated ambient conditions.
   1. Controllers used outdoors and/or in wet ambient conditions shall be mounted within waterproof enclosures and shall be rated for operation at 40°C to 65°C (40°F to 150°F).
   2. Controllers used in conditioned space shall be mounted in dust-proof enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

A visual indication is useful in determining ASC failure. This could be recognized or noticed by a building operator while making service rounds. It may be desirable for the status LEDs to be seen without removing the enclosure cover. Internal components should be replaceable without the need to rewire the entire panel.

D. Serviceability. Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to field-removable, modular terminal strips or to a termination card connected by a ribbon cable.

ASCs should hold programming information in nonvolatile memory.

E. Memory. The ASC shall use nonvolatile memory and maintain all BIOS and programming information in the event of a power loss.

The applications specific controller also should be protected from process noise, electrical noise (5 to 120 Hz), and radio frequency interference (from keyed radios).

F. Immunity to power and noise. Controllers shall be able to operate at 90% to 110% of nominal voltage rating and shall perform an orderly shutdown below 80%. Operation shall be protected against electrical noise of 5-120 Hz and from keyed radios up to 5 W at 1 m (3 ft).

Controllers are powered by either 24 or 120 VAC sources. The variance in acceptable voltage amplitude and frequency should be specified. Controllers need to have protection from voltage reduction (brownouts) and power surges. This protection can either be internal to the controller or provided externally. If protection is provided externally, care must be taken to ensure that it is properly installed.

G. Transformer. Power supply for the ASC must be rated at a minimum of 125% of ASC power consumption and shall be of the fused or current limiting type.

8.10 Input/Output Interface

8.10.1 General. Input objects and output objects interface with a BAS by wiring a remote device to be controlled and/or monitored directly to the building, custom, and/or ASCs.

8.10.1.1 Project Considerations. Inputs and outputs may be arranged on interchangeable modules or circuit boards to allow the replacement of a damaged module or board without replacing the entire controller. While this may be beneficial, note that modularity does not necessarily mean that protection is provided for the main board or its components. A requirement for removable wire terminals or terminal strips does simplify the process of replacing a board or module that has failed.

2.8 INPUT/OUTPUT INTERFACE

A. Hardwired inputs and outputs may tie into the BAS through building, custom application, or ASCs.

B. All input points and output points shall be protected such that shorting of the point to itself, to another point, or to ground will cause no damage to the controller. All input and output points shall be protected from voltage up to 24 V of any duration, such that contact with this voltage will cause no damage to the controller.

8.10.2 Binary Inputs. A binary input may be a dry contact closure by a remote device or may be a voltage level change impressed upon a control relay holding coil, magnetic starter coil, pilot light, etc. When the device is connected to a binary input on the BAS's building, custom application, and/or application-specific controller, the controller can monitor the device's two-position state and, through its program, can respond to the device's "change of state." A binary input must sense "dry contact" closure without external power (other than that provided by the controller) being applied. The following are examples of various devices:

Device	**Monitored Action**
Temperature switch	Normal-alarm
Humidistat	Normal-high (or low)
Pressure switch	Normal-high (or low)
Current switch	On/Off
Door contact	Open-closed
Motion detector	Normal-alarm
CO detector	Normal-alarm
Smoke detector	Normal-alarm
Flow switch	On/Off
Level switch	Normal-alarm

Refer to the discussion on "Equipment Status Sensing" later in this section under "Auxiliary Control Devices."

Supervised binary inputs are commonly used in fire detection and security systems and occasionally in HVAC systems for critical alarm circuitry verification. Supervised circuits normally have three states: normal, alarm, and trouble. "Trouble" is an indication that the supervised circuit has failed (the wiring to the alarm contact has shorted or open-circuited). Since circuit supervision is accomplished with different methods, no specification language is offered in the example.

C. Binary inputs shall allow the monitoring of on/off signals from remote devices. The binary inputs shall provide a wetting current of at least 12 mA to be compatible with commonly available control devices and shall be protected against the effects of contact bounce and noise. Binary inputs shall sense "dry contact" closure without external power (other than that provided by the controller) being applied.

8.10.3 Pulse Accumulation Inputs. Pulsed inputs are commonly used with devices that use contact closures to determine a specific quantity of a measured medium. For example, an electric meter's two-position contact closure represents a specific quantity or consumption of electricity (in kWh) and, when divided by the time interval, provides the demand or rate of consumption (in kW). It is important to specify the maximum sensing frequency, usually 60 pulses per second or less. The following are examples of pulsed input devices:

Device	Measured Variable
Electrical meter	kW and kWh
Liquid flowmeter	gpm
Gas meter	MCF

D. Pulse accumulation input objects. This type of object shall conform to all the requirements of binary input objects and also accept up to 10 pulses per second for pulse accumulation.

8.10.4 Analog Inputs. An analog input is a remote device generating a varying (proportional) signal that is interpreted by the building, custom application, or application-specific controller over a range applicable to the device's application. The types of proportional signals are voltage, current, and resistance. These are provided by thermistors, resistance temperature detectors (RTDs), thermocouples, and various types of transducers. Typical voltage signals are 0 to 5 VDC and 0 to 10 VDC. The most common current signal is 4 mA to 20 mA. Some of the resistance-type sensors are 1000 ohm platinum, 3000 ohm platinum, 100 ohm platinum, and 1000 ohm nickel RTDs, 4.7 K ohm thermistors, and 10 K ohm thermistors. An example of an analog sensor would be a 4 to 20 mA temperature sensor with a temperature range of –17°C to 38°C (0ºF to 100°F). The temperature at 12 mA would be 10°C (50°F). Other examples of analog input devices, along with their engineering units, are as follows:

Device	Engineering Unit
Duct temperature sensor	°C (°F)
Liquid flow	L/s (gpm)
Airflow	L/s (cfm)
Humidity	% RH
Dew point	°C (°F)
Light level	Lux (foot-candles)
Natural gas flow rate, standardized	Standard L/s (scfm)

E. Analog inputs shall allow the monitoring of low-voltage (0 to 10 VDC), current (4 to 20 mA), or resistance signals (thermistor, RTD). Analog inputs shall be compatible with—and field configurable to—commonly available sensing devices.

8.10.5 Binary Outputs. Binary outputs are basically "contact" closures (i.e., the DDC output is binary on/off type). When the output is on, current may flow up to the maximum rating of the output circuit (usually two amps or less). When the output is off, current flow is interrupted. The switching device may be either a relay contact or a solid-state switch (triac), which is usually limited to low voltage (24 VAC or less). When the circuit to be controlled exceeds the binary output rating (such as magnetic starter coils or small motors), a secondary control relay is normally installed between the BAS controller and the load.

8.10.5.1 Project Considerations. Some BAS controllers are available with a manual on-auto-off override switch on each binary output, as well as an LED indicator for visual indication of the output status. These items could be specified to facilitate start-up, commissioning, and troubleshooting procedures. These override switches are an expensive option, however. Consult with the owner before specifying.

Switching devices: Start/Stop

Actuating devices: Open/Closed

a. Control of minimum outdoor air dampers
b. Summer-winter control of changeover valves
c. Control of two-position shutoff valves on chillers, cooling towers, boilers, etc.
d. Control of shutoff dampers in air-handling systems
e. Control of refrigerant shutoff valves in direct-expansion (DX) systems

Time proportioned devices: Cycling on/off

a. Fin-tube radiation and convectors
b. Radiant floor, wall, or ceiling panels

F. Binary outputs shall provide for on/off operation or a pulsed low-voltage signal for pulse width modulation control. Binary outputs on building and custom application controllers shall have three-position (on/off/auto) override switches and status lights. Outputs shall be selectable for either normally open or normally closed operation.

8.10.6 Analog Outputs. Analog outputs are generally continuously variable voltage or current signals, used to vary the position of air and water flow, and pressure control devices, such as dampers, valves, variable-speed drives, inlet vanes, etc. These output signals are generally industry standard, i.e., 0 to 5 VDC, 0 to 10 VDC, or 4 to 20 mA, but also may be unique to the manufacturer (such as 1 to 15 VDC or phase-cut AC signals). When the output signal is low (0 V, 4 mA, etc.), the controlled device will be at one end of its stroke (full open, full closed, minimum RPM, etc.). As the signal increases from the low end, the controlled device is modulated toward the opposite end (closed, open, high rpm, etc.). The output level is generally determined by a feedback control loop.

8.10.6.1 Project Considerations. Some BAS controllers are available with a manual "hand-auto" override switch and a manual positioning potentiometer for each analog output furnished as an option. This feature is relatively expensive on a per-point basis. It should only be specified when there is a need on the owner's part to position the controlled device electronically should the BAS controller fail. This feature becomes less important as more and more damper and valve actuators incorporate hand-crank or pushbutton manual override devices.

G. Analog outputs shall provide a modulating signal for the control of end devices. Outputs shall provide either a 0 to 10 VDC or a 4 to 20 mA signal as required to provide proper control of the output device. Analog outputs on building or custom application controllers shall have status lights and a two-position (AUTO/MANUAL) switch and manually adjustable potentiometer for manual override. Analog outputs shall not exhibit a drift of greater than 0.4% of range per year.

8.10.7 Tri-State Outputs. Through the building, custom application, and/or application-specific controller, the tri-state outputs permit the controller to control bidirectional motors and actuators or ON/OFF devices. A typical tri-state output consists of two Form C relays and/or two triacs that function as one output. Each output is capable of pulse width modulation (PWM). Typical tri-state (three-point floating) devices are damper motors and valve actuators. Presently, tri-state actuation is less expensive than true analog-actuated devices.

H. Tri-State Outputs. Provide tri-state outputs (two coordinated binary outputs) for control of three-point floating type electronic actuators without feedback. Use of three-point floating devices shall be limited to zone control and terminal unit control applications (VAV terminal units, duct-mounted heating coils, zone dampers, radiation, etc.). Control algorithms shall run the zone actuator to one end of its stroke once every 24 hours for verification of operator tracking.

8.10.8 Universal I/Os. Some manufacturers provide for universal-type I/Os that may be designated as either binary (digital) or analog (proportional) input/output. The type of I/O is programmed by the user without hardware modifications.

8.10.8.1 Project Considerations. The requirement for universal-type I/O points may add to the cost of the controller.

I. I/O points shall be the universal type, i.e., controller input or output may be designated (in software) as either a binary or analog type point with appropriate properties. Application-specific controllers are exempted from this requirement.

J. System Capacity. The system size shall be expandable to at least twice the number of input/output objects/points required for this project. Additional controllers (along with associated devices and wiring) shall be all that is necessary to achieve this capacity requirement. The operator interfaces installed for this project shall not require any hardware additions or software revisions in order to expand the system.

8.11 Power Supplies and Line Filtering

8.11.1 Control Transformers. Step-down control transformers with 24 VAC secondary voltage are normally provided as the AC power source for BAS controllers, I/O modules, application-specific (zone) controllers, and electronic actuators. Control transformers should be UL listed for Class 2 current-limited service or should be provided with over-current protection on both primary and secondary circuits for Class 2 current-limited service. Connected loads should not exceed 80% of the transformer's rated capacity.

Use of larger 24 VAC transformers (100 VA or greater) for providing power to a number of application-specific controllers and actuators is not recommended unless secondary circuits are divided and subfused to limit available short-circuit current to NEC Class 2 specifications. It will usually be less expensive to use multiple Class 2 transformers than using larger transformers with subfusing.

8.11.2 DC Power Supplies. DC power supplies for BAS controllers and I/O modules are normally incorporated into the control device so that the power requirement is for unregulated 24 VAC. However, humidity sensors, transmitters, and transducers often require a separate 24 VDC power source.

Separate DC power supplies should be selected to match the voltage and current requirements of the connected loads. Units should be selected to limit connected loads to 75% of rated output capacity to allow for extended life and/or future expansion. Power supplies should be full-wave rectifier types with regulated output to minimize transmitter or transducer inaccuracies due to voltage ripple or drift.

When AC input voltage is 24 VAC Class 2 current-limited, UL or CSA listing is not necessary. When AC input is Class 1 (120 VAC or greater), UL recognition and/or CSA listing is recommended.

2.9 POWER SUPPLIES AND LINE FILTERING

A. Control transformers shall be UL listed. Furnish Class 2 current-limiting type or furnish over-current protection in both primary and secondary circuits for Class 2 service in accordance with NEC requirements. Limit connected loads to 80% of rated capacity.
   1. DC power supply output shall match output current and voltage requirements. Unit shall be full-wave rectifier type with output ripple of 5.0 mV maximum peak-to-peak. Regulation shall be 1.0% line and load combined, with 100-microsecond response time for 50% load changes. Unit shall have built-in overvoltage and overcurrent protection and shall be able to withstand a 150% current overload for at least three seconds without trip-out or failure.
      a. Unit shall operate between 0°C and 50°C (32°F and 120°F). EM/RF shall meet FCC Class B and VDE 0871 for Class B and MIL-STD 810C for shock and vibration.
      b. Line voltage units shall be UL recognized and CSA approved.

8.11.3 Power Line Filtering. It can be desirable to provide for transient voltage and surge suppression (TVSS) on all power sources for DDC workstations and control equipment. Suppressors can be provided at individual 120 VAC power connections to the control devices. The preferred approach is to provide TVSS protection at the power connection to local electrical distribution panels (in Division 16 of the specification).

8.11.3.1 Project Considerations. Provide surge protection in areas where lightning strikes are frequent and/or power reliability and quality is questionable.

B. Power Line Filtering
   1. Provide transient voltage and surge suppression for all workstations and controllers either internally or as an external component. Surge protection shall have the following at a minimum:
      a. Dielectric strength of 1000 V minimum
      b. Response time of 10 nanoseconds or less
      c. Transverse mode noise attenuation of 65 dB or greater
      d. Common mode noise attenuation of 150 dB or better at 40 Hz to 100 Hz

8.12 Auxiliary Control Devices

8.12.1 Motorized Control Dampers. Please refer to Clause 11 of this guideline and the ASHRAE *Handbook—Fundamentals*, as well as the ASHRAE *Handbook—HVAC Applications* and ASHRAE *Handbook—HVAC Systems and Equipment* (I-P and SI) for a complete discussion on the sizing and selection of control dampers. The following specification wording is typical for most BAS applications.

2.10 AUXILIARY CONTROL DEVICES

A. Motorized control dampers, unless otherwise specified elsewhere, shall be as follows:
   1. Control dampers shall be the parallel or opposed blade type as below or as scheduled on drawings.
      a. Outdoor and/or return air mixing dampers and face and bypass (F&BP) dampers shall be parallel blade, arranged to direct airstreams toward each other.
      b. Other modulating dampers shall be the opposed blade type.
      c. Two-position shutoff dampers may be parallel or opposed blade type with blade and side seals.
   2. Damper frames shall be 13 gage galvanized steel channel or 3.2 mm (1/8 in.) extruded aluminum with reinforced corner bracing.
   3. Damper blades shall not exceed 20 cm (8 in.) in width or 125 cm (48 in.) in length. Blades are to be suitable for medium velocity performance (10 m/s [2000 fpm]). Blades shall be not less than 16 gage.
   4. Damper shaft bearings shall be as recommended by manufacturer for application, oil impregnated sintered bronze or better.
   5. All blade edges and top and bottom of the frame shall be provided with replaceable butyl rubber or neoprene seals. Side seals shall be spring-loaded stainless steel. The blade seals shall provide for a maximum leakage rate of 50 L/s·m^2 (10 cfm per ft^2) at 1000 Pa (4 in. wg) differential pressure. Provide air foil blades suitable for a wide-open face velocity of 7.5 m/s (1500 fpm).
   6. Individual damper sections shall not be larger than 125 × 150 cm (48 × 60 in.). Provide a minimum of one damper actuator per section.
   7. Modulating dampers shall provide a linear flow characteristic where possible.
   8. Dampers shall have exposed linkages.

8.12.2 Damper/Valve Actuators. All actuators have several distinct purposes. They all must

a. move the actuated device (valve or damper) to the desired position. The actuator must provide enough thrust or torque to move the closure member under the most severe conditions.

b. hold the actuated device in the desired position. Particularly in throttling conditions where fluids may create dynamic forces, actuators must have adequate spring, mechanical, or fluid power to overcome these forces.
c. provide adequate force to fully seat the valve or damper.
d. provide the proper failure mode positioning in the event of system failure. This may be fully closed, fully open, or as is, depending on the application. Certain failure mode requirements may eliminate electric actuators yet be ideal for pneumatic units.
e. provide the proper length of stroke or degree of rotational travel.
f. provide the required operating speed.

It is necessary to make a decision about whether to select electric or pneumatic actuators. There are advantages to both types. Points to consider are as follows:

a. Power source availability
b. Torque or force required
c. Failure mode
d. Control accessories (e.g., the need for auxiliary contacts; requirements of transducers for pneumatic valves)
e. Speed of operation
f. Frequency of operation
g. Operating environment
h. Cost
i. Maintenance

8.12.2.1 Electric Actuators. Electric actuators are often used with 110 VAC power; however, actuators are available in a wide variety of AC and DC voltages.

Two-position motors generally require only the power input. Motors used for floating-point (tri-state) control may require only the power wiring but will require three wires, as they are powered in either the open or closed direction as directed. Fully proportioning motors require power as well as either a 0 to 10 VDC or 4 to 20 mA control signal input.

Smaller electric actuators may be less expensive to install and maintain than pneumatic actuators. Many electric actuators only use power when they are in operation, and there is no need for compressed air—an expensive source of energy.

Electric actuators are available with an operating temperature range of –40°C to 65°C (–40ºF to 150ºF). When used outdoors, the electric actuator should be sealed from the environment to prevent the introduction of moisture into the internal workings of the actuator. Condensation may still form inside or be drawn in from the electrical conduit. Another source of condensation is a result of environmental "breathing." This is caused by expansion of the motor housing when it warms up from use and the contraction of the housing when it cools off. This can be prevented by the installation of heaters (when the actuators are used outdoors) in the actuator housing to maintain a constant temperature.

Almost all manufacturers of electric actuators have a version that conforms to NEMA 7 for installation in hazardous locations.

Fail-safe operation is often desirable (i.e., the actuator returns to a normal position on power failure). With electric actuators up to a certain size, this is normally accomplished utilizing a built-in spring for return to a given position on power failure. The fail-safe position (normally open or normally closed) must be specified, as the normal positions are often specified for outdoor, return, and exhaust control dampers and for steam and/or water control valves. Particular attention is needed when two or more actuators are to be controlled in sequence, such as a heating valve (N.O.), outdoor air damper (N.C.), and a cooling valve (N.C.) on an air-handling unit, for example.

Most electric actuators for modulating service are available with a feedback circuit that indicates actuator position. This circuit may be connected to an analog input on the controller, which can have the same end result as incorporating a "positive positioned" on a pneumatic actuator. The actuator control signal can then be adjusted to obtain a certain actuator position regardless of load, friction, or hysteresis. This can be especially advantageous when controlling large dampers or valves with excessive shaft or sealing friction.

8.12.2.2 Performance Characteristics of Electric Actuators. Electric actuators that are most commonly available for use within the industry are rated for 100% duty cycle. However, if the application calls for a larger-than-usual two-position motor, care must be taken to ensure that the rated duty cycle of the motor is appropriate for the application.

As electric actuators are basically geared motors, it is impossible to increase the speed of the actuator without changing the gears. The speed can be decreased by adding an algorithm in the controller.

Electric actuators interface well with the controllers without the requirement of transducers. The net sensitivity of a voltage or current input actuator is the output resolution of the controller (A/D converter) or the sensitivity of the electric actuator, whichever is least sensitive. The sensitivity of a tri-state motor is a factor of the motor speed and the minimum effective output pulse duration. One of the life expectancy ratings for modulating electric actuators is generally the number of repositionings. Care should be taken during the selection (or commissioning process) to ensure that the controller does not excessively reposition the actuator with incremental values at the limits of its sensitivity. This can be accomplished by providing a small dead band for fully proportioning actuators and by ensuring that floating actuators do not receive control pulses of excessively short duration. (Very short pulses do little more than take up slack in the gear train and accomplish no repositioning of end equipment.)

B. Electric damper/valve actuators.
   1. The actuator shall have mechanical or electric stall protection to prevent damage to the actuator throughout the rotation of the actuator.
   2. Where shown, for power-failure/safety applications, an internal mechanical, spring-return mechanism shall be built into the actuator housing. Alternatively, an uninterruptible power supply (UPS) may be provided.
   3. Proportional actuators shall accept a 0 to 10 VDC or 0 to 20 mA control signal and provide a 2 to 10 VDC or 4 to 20 mA operating range.

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4. All 24 VAC/VDC actuators shall operate on Class 2 wiring.
5. All non-spring-return actuators shall have an external manual gear release to allow manual positioning of the damper when the actuator is not powered. Spring-return actuators with more than 7 N·m (60 in.·lb) torque capacity shall have a manual crank for this purpose.

8.12.2.3 Pneumatic Damper/Valve Actuators and Positioners. Most pneumatic actuators use the control air signal of 20 to 100 kPa (3 to 15 psi) to actuate. If they are equipped with pilot positioners, a main air supply is also required.

A standard operating temperature range is –20°C to 80°C (–4°F to 175°F). If control accessories such as limit switches are used, they may not have the same temperature range as the actuator.

Pneumatic actuators are inherently explosion-proof. Pneumatic actuators are generally more cost-effective than electric actuators when used in hazardous areas. If limit switches or other electrical control accessories are used, these must be housed in a NEMA 7 enclosure.

Most pneumatic actuators are spring-return (for fail-safe operation). Where springs are not practical due to actuator size or weight, an accumulator tank can be installed to store air pressure for emergency operation.

8.12.2.4 Performance Characteristics of Pneumatic Actuators. Pneumatic actuators have a 100% duty cycle. In fact, the harder they work, the better they work. Pneumatic actuators may be stalled indefinitely without damage.

The ability to control the speed of a pneumatic actuator (with positioning) is one of the most underused advantages of the design. Speeds from two seconds to 20 minutes are easily achieved. The most simple method is to install a variable orifice on the exhaust port of the actuator.

For modulating service, pneumatic actuators are infinitely adjustable. The limitation is the A/D converter in the controller and the sensitivity of the transducer. For example, if you have an 8-bit A/D converter and a 0 to 10 VDC output signal (from the controller to the transducer), the output resolution would be 39 mV.

C. Pneumatic damper/valve actuators and positioners.
   1. Pneumatic actuators shall be piston-rolling diaphragm type or diaphragm type with easily replaceable, beaded, molded neoprene diaphragm.
   2. Actuator housings may be molded or die-cast zinc or aluminum. Exception: Actuator housings for terminal unit zone control dampers or valves may be of high-impact plastic construction with an ambient temperature rating of 10°C to 60°C (50°F to 140°F) minimum. However, any plastic devices located in return air (ceiling) plenums shall be isolated from plenums with an auxiliary metal enclosure having a quick-opening access panel.
   3. Actuator size and spring ranges selected shall be suitable for intended application.
   4. Rate pneumatic actuators for a minimum 140 kPa (20 psig).
   5. Damper actuators shall be selected in accordance with manufacturer's recommendations to provide sufficient close-off force to effectively seal damper and to provide smooth modulating control under design flow and pressure conditions. Furnish a separate actuator for each damper section.
   6. Valve actuators shall provide tight close-off at design system pressure and shall provide smooth modulation at design flow and pressure conditions.
   7. On sequencing applications, valve and damper actuators shall be sized for a maximum of 14 kPa (2 psi) shift in nominal spring range. Spring ranges shall be selected to prevent overlap or positive positioners shall be provided.
   8. Positive positioners to have the following performance characteristics:
      a. Linearity: ±10% of output signal span
      b. Hysteresis: 3% of the span
      c. Response: 1/4 psig input change
      d. Maximum pilot signal pressure: 140 kPa (20 psig)
      e. Maximum control air supply pressure: 420 kPa (60 psig)
   9. Positive positioners shall be provided on actuators for inlet vane control and on any other actuators where required to provide smooth modulation or proper sequencing.
   10. Positive positioners shall be high-capacity force balance relay type with suitable mounting provisions and position feedback linkage tailored for particular actuator.
   11. Positive positioners shall use full control air pressure at any point in stem travel to initiate stem movement or to maintain stem position. Positioners shall operate on a 20 to 100 kPa (3 to 15 psig) input signal unless otherwise required to satisfy the control sequences of operation.

8.12.3 Control Valves. Please refer to Clause 11 of this guideline and to the ASHRAE *Handbook—Fundamentals*, ASHRAE *Handbook—HVAC Applications*, and ASHRAE *Handbook—HVAC Systems and Equipment* for a complete discussion on the sizing and selection of control valves. The following specification wording is typical for most BAS applications.

8.12.3.1 Project Considerations. Verify the pressure class ratings of valves used in special applications. For instance, Class 125 or 250 may not be appropriate for some high-rise applications.

D. Control Valves
   1. Control valves shall be two-way or three-way type for two-position or modulating service as shown.
   2. Close-off (differential) Pressure Rating. Valve actuator and trim shall be furnished to provide the following minimum close-off pressure ratings:
      a. Water Valves
         1. Two-way: 150% of total system (pump) head.
         2. Three-way: 300% of pressure differential between ports A and B at design flow or 100% of total system (pump) head.
      b. Steam Valves. 150% of operating (inlet) pressure.
   3. Water Valves
      a. Body and trim style and materials shall be in accordance with manufacturer's recommendations for design conditions and service shown, with equal percentage ports for modulating service.
      b. Sizing Criteria
         1. Two-position service: Line size.
         2. Two-way modulating service: Pressure drop shall be equal to twice the pressure drop through heat exchanger (load), 50% of the pressure difference between supply and return mains, or 34.5 kPa (5 psi), whichever is greater.
         3. Three-way modulating service: Pressure drop equal to twice the pressure drop through the coil exchanger (load), 34.5 kPa (5 psi) maximum.
         4. Valves DN 15 (1/2 in.) through DN 50 (2 in.) shall be bronze body or cast brass ANSI Class 250, spring-loaded, PTFE packing, quick opening for two-position service. Two-way valves to have replaceable composition disc or stainless steel ball.
         5. Valves DN 65 (2 1/2 in.) and larger shall be cast iron ANSI Class 125 with guided plug and PTFE packing.
      c. Water valves shall fail normally open or closed, as scheduled on plans, or as follows:
         1. Water zone valves—normally open preferred
         2. Heating coils in air handlers—normally open
         3. Chilled-water control valves—normally closed
         4. Other applications—as scheduled or as required by sequences of operation
   4. Steam Valves
      a. Body and trim materials shall be in accordance with manufacturer's recommendations for design conditions and service with linear ports for modulating service.
      b. Sizing Criteria
         1. Two-position service: pressure drop 10% to 20% of inlet psig
         2. Modulating service: 100 kPa (15 psig) or less; pressure drop 80% of inlet psig
         3. Modulating service: 101 to 350 kPa (16 to 50 psig); pressure drop 50% of inlet psig
         4. Modulating service: over 350 kPa (50 psig); pressure drop as scheduled on plans

8.12.4 Temperature Devices

8.12.4.1 Binary Temperature Devices. A variety of temperature-sensing devices with a binary (on/off) output are available. These devices will close (or open) a contact upon a temperature rise (or drop). In a common application, these devices directly control equipment such as unit heaters to start and stop based on the space temperature.

When the device contact is connected to a binary input on the BAS controller, the controller can then be programmed to respond to a sensor "change of state" (i.e., closing or opening of the device's contact). The contact change of state may be programmed as a two-position control function and/or a high-limit or low-limit alarm function. An example would be to index the BAS to summer or winter mode, depending on the contact position of a two-position thermostat sensing outdoor ambient temperature.

Some of these devices are furnished with an adjustable differential, and others are fixed. If a specific differential is required for a particular application, it should be noted. The differential is the difference between the cut-in and cut-out of the contacts, expressed in the engineering units of the measured variable.

Low-limit thermostats, also known as *freezestats*, are primarily used as a safety device. As the temperature of the sensed medium drops below the condensing temperature of the vapor in the capillary tube, the vapor condenses, thus reducing the pressure in the tube and tripping the switch. For most applications, as this is a safety device, manual reset is recommended; automatic restart may damage the mechanical system. Often these devices are connected directly to the starter of the equipment. In order to provide indication at the BAS of the low-limit switch tripping, a second electrical contact is required. This may be accomplished by either an external associated double-pole relay or by specifying the low-limit switch as a double-pole device.

E. Binary Temperature Devices

1. Low-voltage space thermostat shall be 24 V, bimetal-operated, mercury-switch type, with either adjustable or fixed anticipation heater, concealed setpoint adjustment, 13°C to 30°C (55°F to 85°F) setpoint range, 1°C (2°F) maximum differential, and vented ABS plastic cover.
2. Line-voltage space thermostat shall be bimetal-actuated, open contact type, or bellows-actuated, enclosed, snap-switch type or equivalent solid-state type, with heat anticipator, UL listed for electrical rating, concealed setpoint adjustment, 13°C to 30°C (55°F to 85°F) setpoint range, 1°C (2°F) maximum differential, and vented ABS plastic cover.
3. Low-limit thermostats. Low-limit airstream thermostats shall be UL listed, vapor pressure type, with an element of 6 m (20 ft) minimum length. Element shall respond to the lowest temperature sensed by any 30 cm (1 ft) section. The low-limit thermostat shall be manual reset only.

8.12.4.2 Resistance Temperature Detectors (RTDs). RTDs are temperature sensors containing either a fine wire or a thin metallic element whose resistance increases with temperature. A small current is passed through the element and its resistance is measured. Following are the standard types of RTDs:

a. 1000 ohm platinum
b. 3000 ohm platinum
c. 100 ohm platinum
d. 1000 ohm nickel

RTDs are well suited for single-point measurements of temperatures below 1000°C (1832°F). RTDs exhibit long-term stability and traceable accuracy.

Sensitivity (the change in resistance per unit temperature change) is low (especially for the 100 ohm devices) but fairly linear. This linearity and the stability of the device over time (there is essentially no drift) make it the preferred sensor where accuracy and low maintenance are required.

RTDs are characterized by their high degree of linearity, good sensitivity, and excellent stability.

8.12.4.3 Thermistors. Thermistors are temperature-sensitive resistors whose resistance varies inversely with temperature. The resistance of a 5000 ohm thermistor may change by 20 Ω/°C (11.1 Ω/°F). Thermistors are frequently used where high sensitivity is required. It is important to note that higher sensitivity only means that the temperature can be read to greater precision. It should not be inferred that these sensors are accurate to that precision. The sensitivity of thermistors varies significantly with temperature, being the highest at lower temperatures.

Thermistors have a strongly nonlinear output. Nonlinearity is not a significant issue since a controller will linearize the data. The thermistor type must be matched to the controller linearization table.

Thermistors have relatively low thermal conductivity and are frequently encapsulated in epoxy, glass, or vinyl—substances that also have low thermal conductivity.

8.12.4.4 Sensor Accuracy. It must be understood that the first step in accuracy is the sensor itself. However, factoring in an offset in the controller (calibration) can compensate for this. The overall goal is reported accuracy, and the dominant requirement should be expressed in those terms.

Other factors include the following:

a. Sensor accuracy
b. Analog-to-digital conversion in the controller
c. Error due to sensor self-heating
d. Any conversion in the workstation
e. Wire resistance (length of run)

Accuracy needs to be expressed either in terms of full-scale range or current reading, as desired. Other factors that can be important include the following:

a. Repeatability
b. Drift (as in drift shall not exceed accuracy requirements over a five-year period)
c. Response (time constant)

8.12.4.4.1 Sensor Construction. Strain-minimizing construction is necessary to prevent tension from pulling leads out of sensors.

8.12.4.4.2 Immersion Sensors. In some instances (such as performing Btu calculations for chillers), the supply and return water temperature sensors could be required to match, to have similar characteristics, and be calibrated to within 0.1°C (0.2°F) of each other. Wells for immersion sensors have to withstand the pressures of the system. Installation of wells is important with respect to length of sensor and how the well is installed.

8.12.4.4.3 Outdoor Air Sensors. Outdoor air sensors should be located on the north or east side of the building with a waterproof enclosure and sun shield to minimize the effects of solar loading.

8.12.4.4.4 Duct-Mounted Sensors. When the sensor is used for control, it must be installed to minimize the effects of stratification. Averaging sensors are best, but there is a cost impact. Sensor length is important as well. The sensing element is located on the tip of the sensor; therefore, longer sensors should be used on wider ducts to get the element into the airstream. Several sensors can be wired in series/parallel to get more complete coverage. Averaging sensors can be specified if required for more accurate control.

Temperature sensors should not be installed close to heating coils because they will pick up radiant heating from the coil.

8.12.4.4.5 Space Temperature Sensors. Space temperature sensors allow the selection of the following:

a. Covers/enclosures
b. Setpoint adjustment, if desired
c. Temperature indication
d. Mounting height and orientation

F. Temperature Sensors
1. Temperature sensors shall be RTD or thermistor.
2. Duct sensors shall be single point or averaging as shown. Averaging sensors shall be a minimum of 1.5 m (5 ft) in length per 1 m^2 (10 ft^2) of duct cross section.
3. Immersion sensors shall be provided with a separable stainless steel well. Pressure rating of well is to be consistent with the system pressure in which it is to be installed. The well must withstand the flow velocities in the pipe.
4. Space sensors shall be equipped with setpoint adjustment, override switch, display, and/or communication port as shown.
5. Provide matched temperature sensors for differential temperature measurement.

8.12.5 Humidity Devices

8.12.5.1 Polymer Film Element Humidity Devices. These devices have a hygroscopic organic polymer deposited on a water-permeable substrate. The polymer film absorbs moisture until it is in balance with the ambient air. This causes a change in resistance or capacitance.

Typically, these devices have built-in circuitry to provide temperature compensation and signal conditioning. The advantages of this type of sensor are low cost and fast response times (1 to 120 seconds for a 64% change in relative humidity).

8.12.5.2 Binary Humidity Devices. Duct and/or space humidity sensors are also available with a binary (contact) output. These devices may be connected to BAS controller binary inputs and programmed as two-position control functions and/or high-limit or low-limit alarm functions. An example would be a duct-mounted return air humidistat connected to a binary input, programmed as a high limit to stop a direct evaporative cooler when the humidity setpoint is exceeded. Other examples would be high (or low) room humidity, high (or low) duct humidity, and high (or low) outdoor air humidity.

G. Humidity Sensors
1. Duct and room sensors shall have a sensing range of 20% to 80%.
2. Duct sensors shall be provided with a sampling chamber.
3. Outdoor air humidity sensors shall have a sensing range of 20% to 95% rh. They shall be suitable for ambient conditions of 40°C to 75°C (40°F to 170°F).
4. Humidity sensor's drift shall not exceed 1% of full scale per year.

8.12.6 Flow Switches. Flow switches are used to positively sense a moving medium. The two common options for assessing flow are a sail- or paddle-type switch in the fluid and a differential pressure switch.

Paddle/sail switches are used to measure the flow directly. However, since they are placed in the medium and have moving components, they require maintenance and have a limited lifetime. Pressure switches are not directly in the fluid being sensed and they have no moving parts. Therefore, their long-term reliability is higher.

H. Flow Switches
1. Flow-proving switches shall be either paddle or differential pressure type, as shown.
2. Paddle type switches (water service only) shall be UL listed, SPDT snap-acting with pilot duty rating (125 VA minimum) and shall have adjustable sensitivity with NEMA 1 enclosure unless otherwise specified.
3. Differential pressure type switches (air or water service) shall be UL listed, SPDT snap-acting, pilot duty rated (125 VA minimum), NEMA 1 enclosure, with scale range and differential suitable for intended application or as specified.

8.12.7 Relays. Relays provide a means for one electrical source to switch a separate electrical circuit at the same or different voltage. The number of separate contacts on the device is known as *poles*; the number of connections each pole can make is known as *throw*. A double-pole, double-throw relay (DPDT) has two separate contacts that can close a circuit under two conditions: energized and de-energized.

Relay configuration includes several physical and electrical characteristics:

a. Shape and number of electrical connections
b. Override button and/or LED indication can be included
c. Base or panel mount
d. Electromechanical or solid state
e. Normally open or normally closed contacts (or both)

8.12.7.1 Project Considerations. Maintenance consideration may influence panel mounting or base mounting in that base mounting allows easy replacement of a defective relay.

I. Relays
1. Control relays shall be UL listed plug-in type with dust cover and LED "energized" indicator. Contact rating, configuration, and coil voltage shall be suitable for application.
2. Time delay relays shall be UL listed solid-state plug-in type with adjustable time delay. Delay shall be adjustable ±200% (minimum) from setpoint shown on plans. Contact rating, configuration, and coil voltage shall be suitable for application. Provide NEMA 1 enclosure when not installed in local control panel.

8.12.8 Override Timers. Override timers are typically used to allow a building operator to override the "unoccupied" operation mode for a predetermined amount of time. These timers come in many forms, some more complicated than others. The specification language below specifies an electromechanical timer.

J. Override Timers
   1. Override timers shall be spring-wound line voltage, UL Listed, with contact rating and configuration as required by application. Provide 0-to-6-hour calibrated dial unless otherwise specified. Timer shall be suitable for flush mounting on control panel face and located on local control panels or where shown.

8.12.9 Power Monitoring

8.12.9.1 Current Sensing. Current transformers can be used to reduce the measured current to a lower, proportional current. A transmitter then produces a signal that can be read directly by the controller. The current transmitter must be sized such that the output (in milliamperes) will approach the full range of the controller input as the primary current varies over the anticipated range. This will provide maximum sensitivity.

Current transformers are available in “split-core” so they can be installed and removed from, or around, existing cable.

It is important that the secondary of the current transformer be shorted, when the device is not connected, to prevent failures. Otherwise, dangerously high voltage may exist across the terminals of the secondary.

The following characteristics should also be considered when specifying current devices:

a. Voltage output and current output
b. Amperage rating
c. Output signal
d. Temperature rating
e. Frequency range
f. UL listing, CSA approval

K. Current Transmitters
   1. AC current transmitters shall be the self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4 to 20 mA two-wire output. Unit ranges shall be 10 A, 20 A, 50 A, 100 A, 150 A, and 200 A full scale, with internal zero and span adjustment and ±1% full-scale accuracy at 500 ohm maximum burden.
   2. Transmitter shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA Recognized.
   3. Unit shall be split-core type for clamp-on installation on existing wiring.

L. Current Transformers
   1. AC current transformers shall be UL/CSA Recognized and completely encased (except for terminals) in approved plastic material.
   2. Transformers shall be available in various current ratios and shall be selected for ±1% accuracy at 5 A full-scale output.
   3. Transformers shall be fixed-core or split-core type for installation on new or existing wiring, respectively.

8.12.9.2 Voltage Sensing. Voltage transformers can be connected across the higher voltage to be measured. The secondary will provide a lower voltage output, proportional to the higher voltage, which can be read directly by the controller. The voltage transformer also must be sized to provide an appropriate output voltage based on anticipated input voltages.

Unlike the current transformer, it is important that the secondary terminals are not shorted.

M. Voltage Transmitters
   1. AC voltage transmitters shall be self-powered single-loop (two-wire) type, 4 to 20 mA output with zero and span adjustment.
   2. Ranges shall include 100 to 130 VAC, 200 to 250 VAC, 250 to 330 VAC, and 400 to 600 VAC full-scale, adjustable, with ±1% full-scale accuracy with 500 ohm maximum burden.
   3. Transmitters shall be UL/CSA Recognized at 600 VAC rating and meet or exceed ANSI/ISA S50.1 requirements.

N. Voltage Transformers
   1. AC voltage transformers shall be UL/CSA Recognized, 600 VAC rated, complete with built-in fuse protection.
   2. Transformers shall be suitable for ambient temperatures of 4°C to 55°C (40°F to 130°F) and shall provide ±0.5% accuracy at 24 VAC and a 5 VA load.
   3. Windings (except for terminals) shall be completely enclosed with metal or plastic material.

8.12.9.3 Power Sensing. Wattmeters measure both current and voltage to determine the consumption (kWh) and demand (kW) of electrical loads (e.g., equipment, building service, electric panels). Wattmeters may be either a standalone device or a virtual device created by a custom application controller that takes a signal (pulse, voltage, or current) and then calculates the total energy and peak demand. Standalone wattmeters come in several different versions, depending upon the features desired; for example, some units read only kWh and kW while others provide expanded point information such as kWh, kW, PF, V, A, and kVA.

Wattmeters come in two types:

a. Integrated into the current transducer (CT): This type supports applications with a voltage range from 100 to 480 V and current range from 0 to 2400 amps.
b. Panel-mounted: This type supports applications with a voltage range of 100 to 600 V and a current range from 0 to 5000 amps.

The advantage of the integrated CT wattmeter is lower installation cost, as the wattmeter is integrated into the CT and no power or signal wiring needs to be run.

The following characteristics should be considered when specifying power-monitoring devices:

a. Required accuracy (nonrevenue or revenue grade). For most submetering applications, an acceptable accuracy is ±1%.
b. Input resolution of each pulse
c. Three-phase (wye or delta) or single-phase system
d. Voltage (120-600 V)
e. Current transformers (100-5000 amps), high accuracy, split-core
f. UL listing, CSA approval
g. Memory: Nonvolatile EEPROM memory retains last known values in the event of power loss.
h. Programming: Factory programmed or not
i. Manual readout: None or LED display
j. Communication protocols supported
k. Outputs:
   1. Pulse signal for kWh (optional)
   2. Analog signal (0 to 10 V or 4 to 20 mA) for demand kW
   3. Sub-LAN output points
      i. Total energy (kWh)
      ii. Energy rate (kW)
      iii. Reactive power (kVAR)
      iv. Apparent power (kVA)
      v. Power factor
      vi. Voltage: line–line, line–neutral, A–B, B–C, A–C, A–N, B–N, C–N
      vii. Current total: A, B, C

O. Power Monitors
   1. Selectable rate pulse output for kWh reading, 4–20 mA output for kW reading, N.O. alarm contact, and ability to operate with 5.0 amp current inputs or 0–0.33 volt inputs.
   2. 1.0% full-scale true RMS power accuracy, +0.5 Hz, voltage input range 120–600 V, and auto range select.
   3. Under voltage/phase monitor circuitry.
   4. NEMA 1 enclosure.
   5. Current transformers having a 0.5% FS accuracy, 600 VAC isolation voltage with 0–0.33 V output. If 0–5 A current transformers are provided, a three-phase disconnect/shorting switch assembly is required.

8.12.9.4 Hydronic Flowmeters. Flowmeters commonly used for commercial HVAC applications include the following types:

a. Turbine
b. Full-bore magnetic
c. Single point magnetic
d. Vortex shedding
e. Transit time ultrasonic

The features, advantages, and disadvantages of these meters are summarized in Table 8.12.9.4, with application issues summarized as follows:

a. The turbine meter is perhaps the most common for HVAC applications because of its low cost, but it is prone to clogging on open systems such as condenser water systems. Because of the moving parts, routine maintenance is required.
b. Full-bore magnetic flowmeters are the best type of hydronic flowmeter from an accuracy standpoint (very accurate even at very low flow rates) and operational standpoint (lowest maintenance costs, longest lasting), but they are expensive. Until recently they were extremely expensive because most manufacturers designed the meters for the more demanding industrial market, but commercial-quality meters are now available at much lower cost. Because the full-bore meter senses the entire water flow (not just a single point), they are much less sensitive to installation problems; as long as turbulence does not cause reversing eddy currents within the flow tube, the meter will be accurate.
c. Single-point magnetic meters are often used for large piping when the cost of full-bore meters becomes prohibitive, but because they measure flow at only a single point in the pipe, they are much less accurate than full bore meters.
d. Vortex shedding meters were more common before magnetic meters came down in price. They are now more commonly used on gas and steam flow. A significant limitation is that they are not very accurate at low flow.
e. Ultrasonic meters are noninvasive, i.e., they do not require any openings into the pipe, and were initially used for ad hoc flow measurements such as for test and balance. Installation details are critical. Manufacturers provide jigs and assemblies to ensure that the sensors are accurately installed, but they are still prone to inaccuracies from installation error. Because they are noninvasive, ultrasonic meters are particularly applicable to retrofit applications.

For metering chilled- and hot-water flows at buildings, particularly for revenue purposes, the full-bore magnetic flowmeter may be the best option. The pipe sizes are generally small enough at building connections that these meters are affordable. Full-bore magnetic flowmeters may also be the best choice for metering total central-plant output of variable-flow chilled water and for heating hot-water systems. If budget constraints are such that full-bore magnetic flowmeters are cost prohibitive, dual turbine meters may be an acceptable second choice. They are relatively inexpensive and reasonably accurate if well maintained.

8.12.9.5 Thermal Energy (Btu) Meter. Thermal energy meters (often called *Btu meters* when the output is measured in British thermal units) measure flow, supply temperature, and return temperature to determine the thermal energy consumption (kWh [Btu]) and demand (kW [Btu]) of thermal energy loads (e.g., hot water, chilled water, and steam). Btu meters may be either a stand-alone device or a virtual device created by a custom application controller that takes flow and temperature signals and then calculates the total consumption and peak demand.

TABLE 8.12.9.4 HW and CHW Flowmeter Comparison

Type	Configuration	Typical Accuracy/ Minimum Flow	Advantages	Disadvantages
Turbine (single for small pipes, dual for pipes DN 65 [2.5 in.] and larger)	Insertion	±2% 0.15 m/s (0.5 ft/s)	• Usually least expensive • Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement	• Can be fouled by contaminants in water; not recommended for open circuit systems • Moving parts result in lower operating life, possibly degrading accuracy • Requires correct installation depth to be accurate • Sensitive to installation details – long straight inlet and outlet runs required
Full-bore magnetic	Flow tube	±0.5% 0.015 m/s (0.05 ft/s)	• Most accurate meter • Lowest minimum flow rate • Least sensitive to installation problems and requires least amount of straight piping runs at inlet and discharge • Very little maintenance required; no moving parts • Long life with little calibration required	• Most expensive meter, and especially expensive for large pipes (>DN 300 [12 in.]) • Cannot be removed without shutting off system or providing an expensive bypass
Single-point magnetic	Insertion	±1% 0.06 m/s (0.2 ft/s)	• Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement • Very little maintenance required; no moving parts • Long life with little calibration required	• Relatively expensive for small pipe sizes • Requires correct installation depth to be accurate • Sensitive to installation details – long straight inlet and outlet runs required
Vortex shedding	Insertion	±2% 0.3 m/s (1 ft/s)	• Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement	• Not accurate at low flows • Can be fouled by contaminants in water; • Requires correct installation depth to be accurate • Sensitive to installation details – long straight inlet and outlet runs required
Transit time ultrasonic	External	±0.5% 0.3 m/s (1 ft/s)	• External mount allows easy retrofit and replacement • No moving parts and no parts exposed to fluid so maintenance costs are low	• Relatively expensive for small pipe sizes • Not accurate at low flows or quick rate of change • Requires correct configuration to be accurate – sensitive to configuration details such as pipe dimensions and wall thickness • Sensitive to installation details—long straight inlet and outlet runs and precise mounting required

The advantage of the stand-alone Btu wattmeter is lower installation cost because a thermal energy meter is factory programmed, tested, and calibrated, making start-up and commissioning of the thermal energy meter less time consuming.

The accuracy of the thermal energy meter is directly related to the accuracy of the temperature sensors. A ±1.0°F error and a 5°F temperature differential can cause an error of 20% in the energy calculation in addition to any error introduced by the flowmeter.

The following characteristics should be considered when specifying energy-monitoring devices:

a. Required accuracy
b. Accuracy of temperature sensors (RTDs, solid-state sensors, or thermistors): ±0.25%, matched or calibrated with respect to one another
c. Accuracy of flowmeter: See “Hydronic Flowmeters” section.
d. UL listing, CSA approval
e. Factory calibration: traceable to NIST with certification
f. Memory: Nonvolatile EEPROM memory retains values in the event of power loss
g. Programming: Factory programmed or user programmed

P. Hydronic Flowmeters
1. Insertion-Type Turbine Meter
   a. Dual counter-rotating axial turbine elements, each with its own rotational sensing system, and an averaging circuit to reduce measurement errors due to swirl and flow profile distortion. Single turbine for piping DN 50 (2 in.) and smaller. Flow sensing turbine rotors shall be nonmetallic and not impaired by magnetic drag.
   b. Insertion type complete with hot-tap isolation valves to enable sensor removal without water supply system shutdown.
   c. Sensing method shall be impedance sensing (non magnetic and non-photo-electric)
   d. Volumetric Accuracy
      1. ±0.5% of reading at calibrated velocity
      2. ±1% of reading from 0.9 to 9 m/s (3 to 30 ft/s) (10:1 range)
      3. ±2% of reading from 0.12 to 6 m/s (0.4 to 20 ft/s) (50:1 range)
   e. Each sensor shall be individually calibrated and tagged accordingly against the manufacturer's primary standards which must be accurate to within 0.1% of flow rate and traceable to the National Institute of Standards and Technology (NIST).
   f. Maximum operating pressure of 2758 kPa (400 psi) and maximum operating temperature of 93.3°C (200°F) continuous (104.4°C [220°F] peak).
   g. All wetted metal parts shall be constructed of 316 stainless steel.
   h. Analog outputs shall consist of non-interactive zero and span adjustments, a DC linearly of 0.1% of span, voltage output of 0–10 Vdc, and current output of 4–20 mA.
2. Magnetic Flow-Tube Type Flowmeter
   a. Sensor shall be a magnetic flowmeter, which utilizes Faraday's Law to measure volumetric fluid flow through a pipe. The flowmeter shall consist of two elements, the sensor and the electronics. The sensor shall generate a measuring signal proportional to the flow velocity in the pipe. The electronics shall convert this EMF into a standard current output.
   b. Electric replacement shall not affect meter accuracy (electric units are not matched with specific sensors).
   c. Four-wire, externally powered, magnetic type flow transmitter with adjustable span and zero, integrally mounted to flow tube. Output signal shall be a digital pulse proportional to the flow rate (to provide maximum accuracy and to handle abrupt changes in flow). Standard 4–20 mA or 0–10 Vdc outputs may be used provided accuracy is as specified.
   d. Flow tube
      1. ANSI class 1034 kPa (150 psig) steel
      2. ANSI flanges
      3. Protected with PTFE, PFA, or ETFE liner rated for 118.3°C (245°F) minimum fluid temperature
   e. Electrode and grounding material
      1. 316L stainless steel or Hastelloy C
      2. Electrodes shall be fused to ceramic liner and not require o-rings.
   f. Electrical enclosure. NEMA 4, 7
   g. Approvals
      1. UL or CSA
      2. NSF Drinking Water approval for domestic water applications
   h. Performance
      1. Accuracy shall be ±0.5% of actual reading from 0.9 to 9 m/s (3 to 30 ft/s) flow velocities, and 2% from 0.012 to 0.9 m/s (0.04 to 3 ft/s).
      2. Stability. 0.1% of rate over six months.
      3. Meter repeatability shall be ±0.1% of rate at velocities >3 ft/s.
3. Magnetic Insertion-Type Flowmeter
   a. Magnetic Faraday point velocity measuring device
   b. Insertion type complete with hot-tap isolation valves to enable sensor removal without water supply system shutdown
   c. 4-20 mA transmitter proportional to flow or velocity
   d. Accuracy. Larger of 1% of reading and 0.6 m/s (0.2 ft/s)
   e. Flow range. 0.06 to 6 m/s (0.2 to 20 ft/s), bidirectional
   f. Each sensor shall be individually calibrated and tagged accordingly against the manufacturer's primary standards which must be accurate to within 0.1% of flow rate and traceable to the National Institute of Standards and Technology (NIST)
4. Vortex Shedding Flowmeter
   a. Output. 4–20 mA, 0–10 Vdc, 0–5 Vdc
   b. Maximum fluid temperature: 800°F (427°C).
   c. Wetted parts. Stainless steel
   d. Housing. NEMA 4X
   e. Turndown: 25:1 minimum

f. Accuracy: 0.5% of calibrated span for liquids, 1% of calibrated span for steam and gases
g. Body. Wafer style or ANSI flanged to match piping specification

5. Transit-Time Ultrasonic Flowmeter
    a. Clamp-on transit-time ultrasonic flowmeter
    b. Wide-beam transducer technology
    c. 4–20 mA transmitter proportional to flow or velocity
    d. Accuracy. 0.5% of reading in range 0.3 to 9 m/s (1 to 30 ft/s), 0.0003 m/s (0.001 ft/s) sensitivity.

h. Communication protocols display units: I-P, SI, or the capability to select either units
i. Compensation: Built-in tables for density and pressure
j. Calculation modes: Heat, cool, heat and cool, charge/discharge
k. Panel display: None or LED display
l. Security for LED display models: password protection
m. Inputs:
    1. Flow
    2. Entering temperature
    3. Leaving temperature
    4. Pressure (for steam applications)
n. Outputs:
    1. Pulse signal for energy (optional)
    2. 4–20 mA signal for power (optional)
    3. Sub-LAN output points
        i. Total energy
        ii. Power
        iii. Flow
        iv. Density
        v. Delta temperature
        vi. Energy consumption: hour, day, month, year (optional)

Q. Thermal Energy Meters
    1. Matched RTD, solid-state, or thermistor temperature sensors with a differential temperature accuracy of ±0.0833°C (0.15°F).
    2. Flowmeter: See "Hydronic Flowmeters" section.
    3. Unit accuracy of ±1% factory calibrated, traceable to NIST with certification
    4. NEMA 1 enclosure
    5. Panel mounted display
    6. UL listed
    7. Isolated 4–20 mA signals for energy rate and supply and return temperatures and flow
    8. Energy meter shall be equipped with an instantaneous flow and a totalized flow with a totalizer that can hold one month of data.

8.12.10 Equipment Status Sensing

8.12.10.1 Analog Feedback from System. The status of system components may be determined either by a feedback signal from the electronic transducer or by sensing the medium directly. The actual position is not important, but the resulting reaction is important. For example, the fact that the damper is 20% open is not significant, but the fact that 20% outside air is introduced may be critical.

A feedback signal from the transducer requires an additional wire pair and an additional analog input point on the controller. The only information this provides is the output pressure in the case of a pneumatic transducer or the actual position in the case of an electronic motor. It does not provide information on the position of the mechanical device, nor does it provide information on the work done (how much heating, cooling, or air is provided).

A feedback signal from the device requires an additional wire pair and an additional analog input point on the controller. The only information this provides is the position of the damper or valve. It does not provide information on the position of the mechanical device, nor does it provide information on the work done (how much heating, cooling, or air is provided).

A temperature sensor (or flow sensor) provides the information that the system actually requires. These sensors need to be provided for feedback control of the mechanical system and to provide adequate indication of the operation of the movement of the valve or damper. Using these will require no additional wiring or additional input points. However, when the system (mechanical and/or control) is not working properly, the system will require further testing to determine if the controlled component is actually responding.

8.12.10.2 Determination of On/Off Condition of Equipment

8.12.10.2.1 Status Relays. Energize a relay powered through the auxiliary switch of the contactor when the starter's contactor closes. This tells the system and operator that the contactor is energized; it does not provide information on the actual state of the fan or pump. A remote disconnect switch may be open or a belt may be broken to prevent the equipment from running. The relay is an inexpensive device to purchase and install.

8.12.10.2.2 Differential Pressure. This measures the condition of the actual medium to determine proper functioning of the equipment. It is the only method that provides information on what is actually happening by measuring pressure differences caused by the operation of the fan or pump. The devices are more expensive than relays. The wiring run is usually longer than that of relays or other electrical switches, so proper installation is critical. These devices tend to fail more frequently and require more maintenance than electrical relays and switches.

8.12.10.2.3 Current Switch. This senses current to the motor and is a better indication of the field condition than the relay, as it monitors the actual current draw of the motor. Current-sensing switches are now widely available at reasonable prices. These current switches are more dependable than differential-pressure type switches, which may be erratic due to turbulence or other factors at the chosen sensing location. Also, installation is simplified, as the current switch may be installed to sense current in a motor lead at the magnetic starter or disconnect switch rather than at the motor location.

Current switches should have an adjustable set (trip) point, and should be adjusted at start-up so that if the fan belt or pump motor coupling breaks, the current switch does not indicate "on" status.

8.12.10.2.4 Adjustable Current Switch. Senses current to the motor. May be used as a better indication of the field condition than a fixed current switch when it is adjusted to close only at proper running current. A lesser current, such as when a belt or shaft is broken, will not close the switch. Cannot be used for this purpose on a variable-volume system.

8.12.10.2.5 Analog Current Sensor. This provides the most comprehensive feedback without measuring the actual medium. It provides an indication of the system's current from which the state of the equipment may be derived and also provides information for variable-volume systems. The device's price is close to that of an adjustable-current switch, but it requires an analog input object at the controller.

Remember to specify the setup of the adjustable-current switch or the analog current sensor in Part 3, "Execution" of the specification to achieve the desired result.

R. Current Switches
   1. Current-operated switches shall be self-powered, solid-state with adjustable trip current. The switches shall be selected to match the current of the application and output requirements of the DDC system.

8.12.11 Pressure Devices

8.12.11.1 Space Static Pressure Sensors. Outputs of 4 to 20 mA or 0 to 10 VDC and inputs of –60 to 60 Pa (–0.25 to 0.25 in. wg) are standard. The input range needs to be negative to read accurately to zero. The range should be selected to make maximum use of full span while affording an accurate indication of all conditions. The subcontractor will select the proper range to fulfill the performance criteria defined in the specification.

Specification of output variations (e.g., less than 0.3% of full-scale range for supply voltage variations of ±10%) is a requirement for accuracy based upon voltage changes. Include a definition of required accuracy, such as "Combined hysteresis, repeatability, and nonlinearity effects should not exceed ±1.0% of full-scale range." Characteristics such as an operating temperature range of 0°C to 60°C (32°F to 140°F) and 10% to 90% rh (noncondensing) need to be defined to include likely ambient conditions. An example of the effect on accuracy due to ambient conditions is ±1.0% of full-scale range per 28°C (50°F) change in temperature.

The overpressure input protection should be included to protect the device from damage or inaccuracies due to application of excessive pressure. Zero and span should be field adjustable. This allows for on-site recalibration for critical applications.

8.12.11.2 Duct Static Pressure Sensors. The points covered in the discussion of the space static pressure sensor apply here. In addition, it should be ensured that the reading goes to zero when the fan is off. This helps gain customer confidence and is a measure of calibration.

8.12.11.3 Differential Pressure—Hydronic. Outputs of 4 to 20 mA or 0 to 10 VDC and input ranges of –0.25 to 0.25 in. wg are standard. The input range needs to be negative to read accurately to zero. The range should be selected to make maximum use of full span while affording an accurate indication of all conditions.

Specification of output variations (e.g., less than 0.3% of full-scale range for supply voltage variations of ±10%) is a requirement for accuracy based upon voltage changes. Include a definition of required accuracy, such as: "Combined hysteresis, repeatability, and nonlinearity effects should not exceed ±1.0% of full-scale range." Characteristics such as an operating temperature range of 0°C to 60°C (32°F to 140°F) and 10% to 90% rh (noncondensing) need to be defined to include likely ambient conditions. An example of the effect on accuracy due to ambient conditions is ±1.0% of full-scale range per 28°C (50°F) change in temperature.

Overpressure input protection should be included to protect the device from damage or inaccuracies due to application of excessive pressure. Additionally, the device must be rated to withstand the pressures of the system in which it is to be installed.

Zero and span should be field adjustable. This allows for on-site recalibration for critical applications.

S. Pressure Transducers
   1. Transducer shall have linear output signal. Zero and span shall be field adjustable.
   2. Transducer sensing elements shall withstand continuous operating conditions of positive or negative pressure 50% greater than calibrated span without damage.
   3. Water pressure transducer shall have stainless steel diaphragm construction, proof pressure of 1034 kPa (150 psi) minimum. Transducer shall be complete with 4 to 20 mA output, required mounting brackets, and block and bleed valves.
   4. Water differential pressure transducer shall have stainless-steel diaphragm construction, proof pressure of 1034 kPa (150 psi) minimum. Over-range limit (differential pressure) and maximum static pressure shall be 2068 kPa (300 psi). Transducer shall be complete with 4 to 20 mA output, required mounting brackets, and five-valve manifold.

8.12.11.4 Pressure Switches. Various types of pressure-sensing devices with contact outputs are available. Some examples are water or air type differential pressure switches used to sense operation of a pump or fan or to act as a high-limit alarm for pressure drop across system filters. Gage pressure switches are often used for high- and/or low-pressure alarms for compressed air, gases, and/or closed water system pressures.

Some of these devices are furnished with an adjustable differential, while others are fixed. If a specific differential is required for a particular application, it should be noted. The differential is the difference between the cut-in and cut-out of the contacts, expressed in the engineering units of the measured variable.

T. Differential Pressure Type Switches (Air or Water Service)
   1. Shall be UL listed, SPDT snap-acting, pilot duty rated (125 VA minimum), NEMA 1 enclosure, with scale range and differential suitable for intended application or as shown.

U. Pressure-Electric (PE) Switches
   1. Shall be metal or neoprene diaphragm actuated, operating pressure rated 0–175 kPa (0–25 psig), with calibrated scale setpoint range of 14–125 kPa (2–18 psig) minimum, UL listed.
   2. Provide one- or two-stage switch action SPDT, DPST, or DPDT, as required by application. Electrically rated for pilot duty service (125 VA minimum) and/or for motor control.
   3. Shall be open type (panel-mounted) or enclosed type for remote installation. Enclosed type shall be NEMA 1 unless otherwise specified.
   4. Shall have a permanent indicating gage on each pneumatic signal line to PE switches.

8.12.12 Electropneumatic Transducers. All modulated signals to pneumatic equipment from DDC controllers are produced by electropneumatic transducers. These convert the analog voltage or current signal by operating electric solenoid switches or valves to pass and restrict control airflow. Considerations are as follows:

a. The transducers pass a limited quantity of air, and the control airflow rate will determine how fast the actuator strokes. Ensure that the capacity of the device is adequate for the actuator used. Alternately, provide a pilot positioner or a pneumatic relay in conjunction with the transducer. Higher capacity transducers tend to cost more.
b. Method of operation—Some units consume air by bleeding air to the atmosphere to achieve the prescribed pressure. The quantity of air consumed (wasted) may add up to a significant quantity on large installations.
c. Pressure adjustment—The output of the device may be adjusted to match the spring range of the actuator. As such, the input signal (4 to 20 mA or 0 to 10 V) will convert to the actuator's 20 to 90 kPa (3 to 13 psig), 55 to 90 kPa (8 to 13 psig), or any other range. Alternately, a similar effect may be achieved by setting the BAS's software to convert a representative 0% to 100% to its actuator pressure equivalent. In this latter method, the resolution of the output is more limited as only a portion of its range is used.
d. Pressure gage—This simple, inexpensive component is valuable in troubleshooting and assessing the function of the system by the operator and service technician. It is well worth the additional cost. It also may be installed in the branch tubing rather than be incorporated into the transducer body.
e. Lock up—Upon the loss of electrical power, the transducer will remain in its last position, unless bleed-off is specified.

8.12.12.1 Project Considerations. Return to a fail-safe position is usually not important on a typical zone control reheat valve. However, mission critical zones (an animal laboratory, for instance) require that the valve returns to the fail-safe position.

V. Electropneumatic (E/P) Transducers
   1. Electronic/pneumatic transducer shall provide a proportional 20 to 100 kPa (3 to 15 psig) output signal from either a 4 to 20 mA or 0 to 10 VDC analog control input.
   2. E/P transducer shall be equipped with the following features:
      a. Separate span and zero adjustments
      b. Manual output adjustments
      c. Pressure gage assembly
      d. Feedback loop control
      e. Air consumption of 0.05 L/s (0.1 scfm) at mid-range

8.12.13 Local Control Panels. While the BAS's building, custom application, and application-specific controllers are housed in their own control panels, auxiliary control devices, such as relays and transducers, also should be housed in local control panels. The enclosure must meet electrical code requirements for the equipment and voltages that it contains. The enclosure also must protect its contents from external elements: mechanical damage, weather, dust, and pests. These panels may be NEMA 1 (general purpose), NEMA 12 (dust-proof), NEMA 4 (weatherproof), or NEMA 7 (explosion-proof).

W. Local Control Panels
   1. All indoor control cabinets shall be fully enclosed NEMA 1 construction with (hinged door) key-lock latch and removable subpanels. A single key shall be common to all field panels and subpanels.
   2. Interconnections between internal and face-mounted devices shall be prewired with color-coded stranded conductors neatly installed in plastic troughs and/or tie-wrapped. Terminals for field connections shall be UL listed for 600 volt service, individually identified per control/ interlock drawings, with adequate clearance for field wiring. Control terminations for field connection shall be individually identified per control drawings.
   3. Provide on/off power switch with overcurrent protection for control power sources to each local panel.

8.13 Wiring and Raceways. Copper wiring, plenum cable, and raceway are normally specified in great detail in Division 16, "Electrical." Consistency in product specification of the wiring and raceway used by the controls subcontractor and the electrical subcontractor is desirable, and reference to the Division 16 specifications for these materials will ensure this consistency.

8.13.1 Project Considerations. The selection of wire and cabling types is only a consideration if connecting to or extending an existing wire plant. The example specification is based on a new construction project. Specifications for retrofits or renovations require much more prescriptive language.

2.11 WIRING AND RACEWAYS

A. General. Provide copper wiring, plenum cable, and raceways as specified in the applicable sections of Division 16.

B. All insulated wire to be copper conductors, UL labeled for 90°C (194°F) minimum service.

8.14 Fiber Optic Cable System. Fiber optics is an alternative to a copper-wire-based communication media. Fiber optic media can communicate farther and faster than copper. It is also immune to electrical noise, ground potential differences, and lightning strikes and is a good choice for use outdoors. The drawback of fiber optics is that it has a significantly higher installed cost. A fiber optic installation requires more expensive transceivers, media, and connections. It should only be specified where the benefits justify the cost. For most BAS applications, the higher speed of fiber optics is not realized over that of the less expensive copper media.

8.14.1 Project Considerations. If a project includes long cabling runs between buildings (>50 m [165 ft]), consider the use of fiber optic cable for these runs. Note Article 3.9, "Fiber Optic Cable" of the specification (see Clause 9.9 of this guideline) will specify the locations where this fiber optic cabling is to be installed.

2.12 FIBER OPTIC CABLE SYSTEM

A. Optical Cable. Optical cables shall be duplex 900 mm tight-buffer construction designed for intra-building environments. The sheath shall be UL Listed OFNP in accordance with NEC Article 770. The optical fiber shall meet the requirements of FDDI, ANSI X3T9.5 PMD for 62.5/125 μm.

B. Connectors. All optical fibers shall be field-terminated with ST type connectors. Connectors shall have ceramic ferrules and metal bayonet latching bodies.

8.15 Compressed-Air Supply—Pneumatic. Compressed air supply systems are not required when there is no pneumatic control and actuation.

8.15.1 General. A pneumatic compressed air system furnishes clean, dry air at the proper pressure to all pneumatic control devices. Clean air prevents clogging of control devices. Most devices contain filters, orifices, nozzles, and valve mechanisms, which are affected by dirt and/or oil accumulation.

Air should be dry enough to prevent condensation anywhere in the pneumatic system. Condensation causes corrosion. Products of corrosion cause blockage of orifices and valve mechanisms. Dry air aids a filter's ability to remove oil or dirt. Dry air also is important to prevent freezing of the outdoor lines in cold climates.

It is important that oil be removed from compressed air. Oil in compressed air mixes with fine dirt particles, acting as a bonding agent. This causes a buildup of contamination.

Air is normally compressed to a high-pressure average of 550 kPa (80 psi) to allow efficient storage, drying, and filtering. The air pressure is then reduced and distributed throughout the system. Normally, main-air distribution systems are operated between 100 and 170 kPa (15 and 25 psi) pressure, depending upon type of control.

The compressed-air system normally will include an air compressor unit with intake air filters, high-pressure air storage tank, an air dryer, central station particulate and aerosol filters, as well as pressure-reducing relief, and condensate drain valves.

8.15.2 Air Volume. The air supply requirement of a pneumatic system is the sum of the air consumption of all consuming devices (controllers, transducers, positioners, etc.) in the system. Air consumption of a device is a function of the design and is the maximum continuous consumption as it operates normally in a system. Air consumption is measured in liters per second (L/s) or cubic feet of air per minute at standard atmospheric pressure (scfm).

8.15.3 Clean-Air Requirement. Contaminants in the air require that a compressor air intake filter be installed to remove particles that would interfere with clearances in the compressor pump.

Warm compressed air from the compressor pump discharge is routed into a receiver or storage tank where flow rate fluctuations are smoothed out. Cooling and settling actions condense some of the excess moisture and allow fallout of the larger oil droplets carried over from the compressor pump.

The high-pressure air from the storage tank flows through the air dryer, the central station air filter, and the pressure-reducing valve (PRV) and then into the air distribution system at reduced pressure.

Informative Note: In high-rise structures, it is generally more economical to distribute high-pressure air and locate pressure-reducing stations where needed.

The air filter is located just before the PRV for removal of any remaining liquids or particulates generated by the compressing and moisture-condensing functions. It is important to properly maintain this filter for maximum operating efficiency. All harmful air contaminants must be removed by the discharge filter.

Informative Note: In high-rise structures, there is a central distribution filter and a secondary filter located at each PRV.

8.15.4 Dry-Air Requirement. Pneumatic air distribution tubing runs throughout the building and sometimes outdoors. The coldest ambient temperature to which tubing is exposed must be considered the criterion for required dryness (dew point) of the compressed air supply. This is normally the coldest winter outside air temperature if the tubing runs outside.

If condensation occurs in the air line, the downstream controls may not function properly. If freezing of this condensation occurs, controls will not function properly.

8.15.5 Air Compressors. The most commonly used temperature control air compressors are the electrically driven simplex (one compressor) and duplex (two compressors) reciprocating compressors. The duplex provides for standby or alternate compressor operation with overload capacity. The compressor should be completely assembled with an ASME receiver tank.

Compressors are rated for delivery rate of air (calculated on the basis of standard atmospheric conditions) at a selected discharge pressure. First, the total air consumption of the system must be calculated. The air compressor size is then selected to operate at a 33% to 50% duty cycle (percent runtime). This means that the rated compressor output has to be three times system consumption for a 33% runtime or two times consumption for a 50% runtime. At higher altitudes, the compressor pumps less air (L/s [cfm]) and the controls consume more air. Altitude compensation is required according to manufacturer's recommendations above 600 m (2000 ft).

The air storage tank should provide sufficient capacity to carry peak air consumption loads and to minimize the number of starts per hour. The number of starts per hour is affected by the system air consumption, the rated output of the air compressor, and the size of the storage tank. Generally, the storage tank is sized large enough to result in a maximum of six starts per hour. Excessive starts per hour will result in excessive wear and tear on the air compressor and motor and may result in motor burnout.

Duplex compressor units are somewhat more expensive, but they provide for automatic backup should one compressor fail. Also, as the two compressors alternate, the number of individual compressor starts per hour is reduced by 50%, resulting in longer compressor life.

Oil-lubricated compressors last longer due to the continuous lubrication but require proper maintenance, such as periodic oil changes. If this maintenance does not occur, oil eventually will be introduced into the air distribution system. Oil-less compressors require less periodic maintenance and avoid the problem of oil introduction into the air lines; however, major compressor overhaul service can be expected for every three to five years of service.

Intake filters are used to protect the compressor pump from particulates and are sized to match the compressor. As the intake filter accumulates dirt, increased pressure drop occurs and can result in excessive compressor oil usage and air contamination, along with a reduction in air compressor capacity. Periodic filter changeout is required for efficient operation. A reduction in air delivery also occurs.

2.13 COMPRESSED AIR SUPPLY—PNEUMATIC

A. Air Compressor
1. Furnish and install a duplex temperature control type air compressor where indicated on plans. Oil carryover shall not exceed 4 ppm.
2. Both compressors shall be mounted on a single ASME receiver tank, with the tank sized according to manufacturer's recommendations, 115 L (30 gal) minimum, six starts per hour maximum. Each compressor is to be sized for no more than 33% runtime.
3. Provide factory-installed duplex starter/automatic alternator package with separate motor feeds, arranged for automatic start of standby compressor.
4. Provide OSHA belt guards, operating pressure switches, tank pressure gage, intake filters, ASME safety relief valves, check valves, shutoff valve, and vibration isolation pads for each air compressor unit.
5. Provide electric solenoid type (normally closed) automatic receiver tank drain valve with built-in timers for operating frequency and duration.

8.15.6 Air Dryers

8.15.6.1 General. The selection of an air dryer is based on expected job conditions of moisture in the air and the lowest temperature to which an air line will be exposed. There are two methods of drying compressed air: condensing drying and desiccant drying. Refrigerated dryers and water-cooled aftercoolers are examples of condensing drying.

8.15.6.2 Condensing Dryers. Moisture in compressed air is removed either by an increase in pressure, a decrease in temperature, or both. When air is compressed and/or cooled beyond its saturation point, moisture condenses. Draining this condensate causes some drying of the air supply.

The amount of drying is determined by the compressed air pressure and temperature. Application considerations depend primarily on these factors.

8.15.6.3 Refrigerated Air Dryers. The refrigerated air dryer is the most common means of removing vapor that may condense from the compressed air system. It provides the greatest system reliability and requires the least amount of maintenance. The refrigerated dryer uses noncycling compressor operation with hot-gas bypass control of refrigerant flow, providing a constant dew-point temperature of approximately 2°C (35°F) at the tank pressure. Direct, air-to-refrigerant exchangers provide efficient operation. The dryer includes a prefilter/separator for efficient liquid removal and condenses both water and oil. An automatic drain exhausts the generated condensate.

With a dew point of 2°C (35°F) and an average compressor-tank pressure of 520 kPa (80 psi), air is dried to a dew point of –11°C (12°F) at 140 kPa (20 psi). However, in many northern climates—under severe winter conditions, where piping and devices are exposed to outside temperatures—the –11°C (12°F) is not low enough.

The dryer also must be sized to meet the system air consumption requirements.

8.15.6.4 Desiccant Dryers. There may be some applications in northern climates where the dew point of a refrigerated dryer is insufficient to prevent condensation in the air lines. It may be necessary to install a desiccant or chemical dryer to provide adequate drying. A desiccant dryer should be installed following a refrigerated dryer. Dew points down to –40°C (–40°F) are possible with this combination.

The desiccant dryer most applicable to BASs uses the absorbent principle of operation. The drying occurs as long as the absorbent material is not saturated.

The regeneration of a desiccant is generally accomplished either by heating the desiccant bed or removing the resulting water vapor from the desiccant chamber. In order to provide a continuous supply of dry air, a desiccant dryer has two desiccant chambers. While one chamber is being regenerated, the other supplies dry air to the system.

To prevent damage to air lines and control components, a fine filter is used after the desiccant dryer to filter out any desiccant discharged into the air supply.

When specifying air dryers, provide for a condensate drain location and provide AC power at the location where the dryer is to be mounted.

B. Refrigerated Air Dryer
   1. Provide continuously operating, hermetic compressor refrigerated type air dryer, UL Listed, sized for maximum dew point of 9.5°C (15°F) with 38°C (100°F) saturated inlet air at 550 kPa (80 psig) at maximum rated flow.
   2. Dryer package shall include operating/failure status indication, manual bypass service valve, inlet and outlet pressure gages, and automatic condensate drain trap with manual override.

C. Regenerative Desiccant Compressed Air Dryer
   1. Unit shall be wall-mounted, complete with two drying towers containing desiccant beds sized to ensure that air velocity across the desiccant bed is not greater than 0.3 m/s (60 fpm) at 700 kPa (100 psig). Bed shall be sized so that the effects of desiccant aging during the first year are negated. Each tower shall be furnished with fill and drain ports to facilitate desiccant replacement.
   2. Unit shall be complete with on/off switch, solid-state timer, control valves, and check valves. Purge air shall be exhausted through mufflers to reduce noise levels.
   3. Unit shall have a 20.7 kPa (3 psi) maximum pressure drop and provide dry air with a 40°C (40°F) dew point.
   4. Unit shall be sized to match required air consumption, 2.5 L/s (5 cfm) minimum.

8.15.7 Filters. A central station filter filters out solid particulate matter and aerosols so the air-using control devices can function properly throughout their normal life. Air quality required for normal commercial control devices is a maximum of 50 micrograms per cubic centimeter (0.04 parts per million) of 0.3 micron or larger particles.

Oil contamination of compressed air appears in aerosol form. These coalesce and collect in device filters, orifices, and small passages, resulting in device failure.

Numerous filters are available to satisfactorily filter out solids. The only way to filter out aerosols is to use an oil coalescing filter. This acts to coalesce the small particles of oil mist into larger droplets that drop off into a sump. There they are discharged either automatically or drained manually.

Filters must be sized for the maximum normal delivery of the compressor. This allows good efficiency for about one year before the filter must be replaced. Placing the filter ahead of the PRV eliminates pressure drop considerations.

8.15.8 Pressure-Reducing Valves (PRV). A PRV is required to reduce the compressed air pressure to that used by the system (typically 200 kPa [30 psig]). One PRV is normally provided and installed after the dryer; on larger projects, it is less expensive and easier for maintenance to run high-pressure mains to various building zones (such as each level on a high rise) and reduce the air pressure at each zone. This reduces the overall pipe size required and reduces the possibility of excessive pressure losses in the main.

The PRV must be sized based on the maximum air consumption of the system. This is less than the full output of the compressor (because of the duty cycle); however, sizing the PRV for greater than system air consumption provides reserve capacity. PRVs are normally selected to reduce from 700 to 140 kPa (100 to 20 psig) for system control devices and 700 to 400 kPa (100 to 60 psig) for large valve/damper positioners.

8.15.9 Relief Valves. The relief valve on the compressor receiver tank relieves air at a pressure lower than the rated pressure of the tank and is normally specified to be supplied with the air compressor assembly.

A second relief valve is normally positioned downstream of the PRV to protect equipment from damage in the event of PRV failure. These relief valves must be sized to safely pass the amount of air supplied by the compressor.

8.15.10 Condensate Drains. Accumulated condensate (water/oil) within the air supply must be discharged to maintain continuous clean and dry air to the system. Condensate is discharged either manually or automatically as it accumulates.

The receiver tank and central station filter periodically can be drained manually. Automatic drains are recommended for greater system reliability.

Normally, the refrigerated dryer has an automatic drain due to the large amount of water and oil generated. The addition of an automatic drain should be considered for the air storage tank and central station filter.

The automatic drain should be checked periodically either by visual inspection or by manually blowing it down to determine proper functioning.

D. Filter and PRV Station

1. Provide aerosol coalescing type auto-drain, submicron air filter assembly with replaceable element, 98% efficient for solids 0.3 micron and larger, with 99% efficient oil removal at rated capacity. Furnish with manual filter bypass and shutoff valves, upstream and downstream pressure gages, and one spare filter element.
2. Provide relieving type pressure-reducing valves suitable for temperature control service sized for rated system capacity, with the following:
    a. ASME-rated safety relief valve on low-pressure side, factory set at 172.4 kPa (25 psig) maximum
    b. Control pressure gage on inlet and outlet
    c. Valved bypass
    d. Particle filter

8.15.11 Tubing. While local codes and practices vary, the use of either hard copper or polyethylene tubing is generally acceptable. Copper tubing is neater in appearance, is more rugged and less susceptible to cutting, and has lower friction losses. Polyethylene tubing is less expensive and easier to install.

Copper tubing should be the hard-drawn seamless type. This sets a minimum standard for the quality of the tubing and eliminates the use of soft-drawn copper. Soft copper tubing is less expensive to install; however, it is very soft and susceptible to compression damage.

It is preferable that all exposed tubing be copper. This affords protection from damage and is worth the extra expense. A less expensive alternative is to install polyethylene tubing in conduit. This still protects the tubing, but it is easier to install than copper. The conduit should be installed with the same constraints as conduit for electrical wiring.

Standard requirements for polyethylene tubing require a maximum operating pressure of 200 kPa (30 psig) at 80°C (175°F), with an ambient operating temperature range of –23°C (–10°F) to 65°C (150°F). This covers most commercial applications and is readily available. If the expected operating temperatures exceed this range, they must be specified.

E. Tubing

1. Copper. Provide ACR hard-drawn seamless copper tubing.
2. Polyethylene. Provide type FR plenum rated polyethylene tubing. Tubing shall be rated for a maximum operating pressure of 200 kPa (30 psi) at 80°C (175°F), with an ambient operating temperature range of 13°C (10°F) to 65°C (150°F). Plastic tubing shall have the burning characteristics of linear low-density polyethylene tubing, shall be self-extinguishing when tested in accordance with ASTM D 635, shall have UL 94 V-2 flammability classification and shall withstand stress cracking when tested in accordance with ASTM D 1693. Plastic-tubing bundles shall be provided with mylar barrier and flame-retardant polyethylene jacket.

9. SPECIFICATION PART 3: EXECUTION

This clause of the guideline provides descriptions and explanations of specific articles that would appear in the "Execution" part of a BAS specification. These articles tell the contractor what to do with the products and devices. Where the product part describes the components, this section outlines how they will be installed to meet the sequences of operation and performance criteria. It also describes the installation practices that should be adhered to for a quality installation. The guideline discusses the rationale for including (or excluding) particular specification wording, notes to the designer, other approaches, related costs/benefits, and project considerations. Example specification articles or paragraphs follow the guideline text.

PART 3—EXECUTION

3.0 SECTION INCLUDES

.1 Examination
.2 Protection
.3 Coordination
.4 General Workmanship
.5 Field Quality Control
.6 Existing Equipment
.7 Wiring
.8 Communication Wiring
.9 Fiber Optic Cable System
.10 Control Air Tubing
.11 Installation of Sensors
.12 Flow Switch Installation
.13 Actuators
.14 Warning Labels
.15 Identification of Hardware and Wiring
.16 Controllers
.17 Programming
.18 BAS Checkout and Testing
.19 BAS Demonstration and Acceptance
.20 Cleaning
.21 Training
.22 Sequences of Operation
.23 Control Valve Installation
.24 Control Damper Installation
.25 Smoke Damper Installation
.26 Duct Smoke Detection
.27 Controls Communication Protocol
.28 Start-Up and Checkout Procedures

9.1 Examination. The contractor is not responsible for the resolution of project problems due to discrepancies, conflicts, or omissions in the design. A good contractor will endeavor to find such problems as soon as possible so that they can be corrected prior to or early in the construction phase.

A clarification in a contractor's bid concerning possible problems will aid in the process of contractor selection and contract negotiation. Because the strategy of the bid process sometimes suppresses these efforts, it is important that an open process be in place to answer questions and resolve problems.

Obviously, care must be taken to ensure that the plans and specifications are accurate because these are what the project bid will be based upon. All stakeholders are negatively impacted by change orders resulting from this type of oversight.

The purpose of these paragraphs is to direct the contractor to examine the following:

a. *Construction documents*: The contractor is satisfied that the design is sufficiently clear and complete to allow the installation to be successfully completed.
b. *Construction site prior to BAS installation*: No conditions have changed or occurred that might prevent the completion of the control installation. This is important since other contractors may have installed equipment as part of this project that might interfere with control device installation. Also, for example, the controls subcontractor needs to examine the installation of valves by the piping subcontractor to ensure that they were properly installed or piped.
c. *Construction documents for other work that might need careful coordination with the controls system to ensure a successful project*: An example would be providing sufficient straight runs of duct or pipe for the installation of air or water flow sensors.

9.1.1 Project Considerations. Additional specification language must be inserted for projects involving an existing building. Conditions hidden by walls and/or other structures, along with the use of existing controls, all make the design of a retrofit project more challenging. Care also must be taken to specify the work that is to be demolished and for proper disposal of existing equipment (for retrofit projects).

3.1 EXAMINATION

A. The project plans shall be thoroughly examined for control device and equipment locations. Any discrepancies, conflicts, or omissions shall be reported to the architect/BAS designer for resolution before rough-in work is started.
B. The contractor shall inspect the site to verify that equipment may be installed as shown. Any discrepancies, conflicts, or omissions shall be reported to the BAS designer for resolution before rough-in work is started.
C. The contractor shall examine the drawings and specifications for other parts of the work. If head room or space conditions appear inadequate—or if any discrepancies occur between the plans and the contractor's work and the plans and the work of others—the contractor shall report these discrepancies to the BAS designer and shall obtain written instructions for any changes necessary to accommodate the contractor's work with the work of others. Any changes in the work covered by this specification made necessary by the failure or neglect of the contractor to report such discrepancies shall be made by—and at the expense of—this contractor.

9.2 Protection. The "protection" section reinforces the need for the contractor to turn over a system to the owner that is in new condition. During the construction process, the site is frequently not secured and is subject to dirt, weather, and theft. This section requires the contractor to take appropriate steps to protect the equipment he/she has installed against accidental damage. The contractor must take adequate measures to protect this equipment until it is accepted by the owner.

3.2 PROTECTION

A. The contractor shall protect all work and material from damage by his/her work or employees and shall be liable for all damage thus caused.
B. The contractor shall be responsible for his/her work and equipment until finally inspected, tested, and accepted. The contractor shall protect any material that is not immediately installed. The contractor shall close all open ends of work with temporary covers or plugs during storage and construction to prevent entry of foreign objects.

9.3 Coordination. This section summarizes the responsibilities of the different subcontractors who provide any service or interface to the controls subcontractor during the course of installation and checkout. These traditional responsibilities include the following:

a. 120 VAC or greater wiring
b. Wiring of controls in mechanical equipment supplied by the manufacturer
c. Installation of dampers and flow measuring stations
d. Installation of valves and immersion wells
e. Provision for smoke detectors
f. Provision for smoke and fire/smoke dampers and actuation
g. Logic for smoke control and fire/smoke damper actuator

Project coordination and planning is important to everyone. Since the controls subcontractor's work typically occurs at the end of the project, there is little opportunity to accelerate the work to meet the planned schedule if there are delays. Additionally, much of the controls subcontractor's work cannot be performed until after the mechanical and electrical work has been substantially completed in a particular area or system.

Another difficulty stems from the differences in the BAS hardware from vendor to vendor. It is difficult to precisely schedule wall space for control and interface panels.

The amount of effort required to coordinate these activities will vary depending on the scope and complexity of the project.

3.3 COORDINATION

A. Site

1. Where the mechanical work will be installed in close proximity to, or will interfere with, work of other trades, the contractor shall assist in working out space conditions to make a satisfactory adjustment. If the contractor installs his/her work before coordinating with other trades, so as to cause any interference with work of other trades, the contractor shall make the necessary changes in his/her work to correct the condition without extra charge.
2. Coordinate and schedule work with all other work in the same area, or with work that is dependent upon other work, to facilitate mutual progress.

B. Submittals. Refer to the Article 1.10, "Submittals," of this specification for requirements.

The following paragraphs describe the coordination that must take place between the test and balance subcontractor and controls subcontractor. The BAS designer must look at the test and balance section of the project specification to determine with whom the test and balance subcontractor has a contract. The test and balance subcontractor and the controls subcontractor may be working for different individuals. If so, extra project coordination may be necessary to ensure that the test and balance subcontractor actually receives the necessary tools and training and that the tools are returned to the controls subcontractor when the project is completed.

Also discussed is the coordination that must take place for products provided by different vendors. If these products are to communicate and operate as a cohesive system, then each must support the appropriate interoperable functions. These functions are described in Part 2, "Products". Additionally, Clause 10, "Instructions to Other Contractors," of this guideline ensures that all products provided by different vendors are coordinated appropriately.

Remember that there is only one prime contractor on the job. If a task is indicated anywhere in the project documents, the prime contractor must make sure it is performed. It is not the intent of the specification to assign responsibility to a specific subcontractor.

9.3.1 Project Considerations. Delete the subparagraphs on smoke detectors, smoke dampers, and fire/smoke dampers if they do not apply. Delete the requirement for control air to fire/smoke dampers should they be provided with electric actuation. Be sure to describe all sequences for the above items in specification Article 3.22, "Sequences of Operation." Finally, add requirements for coordination on smoke control, should it be part of the project.

Change the number of hours in the following subparagraph to specify the applicable number of hours for training. Also, change the number of terminal units that call for the assistance of a qualified technician in the following subparagraph to reflect a reasonable number for the project being specified.

C. Test and Balance

1. The contractor shall furnish a single set of all tools necessary to interface to the BAS for test and balance purposes.
2. The contractor shall provide training in the use of these tools. This training will be planned for a minimum of 4 hours.
3. In addition, the contractor shall provide a qualified technician to assist in the test and balance process, until the first 20 terminal units are balanced.
4. The tools used during the test and balance process will be returned at the completion of the testing and balancing.

D. Life Safety

1. Duct smoke detectors required for air handler shutdown are supplied under Division 16 of this specification. The contractor shall interlock smoke detectors to air handlers for shutdown as described in Article 3.22, "Sequences of Operation."
2. Smoke dampers and actuators required for duct smoke isolation are provided under a Section of Division 15. The contractor shall interlock these dampers to the air handlers as described in Article 3.22, "Sequences of Operation."
3. Fire/smoke dampers and actuators required for fire rated walls are provided under another Section of Division 15. Control of these dampers shall be by Division 16. The contractor shall provide control air to the dampers.

E. Coordination with Controls Specified in Other Sections or Divisions. Other sections and/or divisions of this specification include controls and control devices that are to be part of or interfaced to the BAS specified in this section. These controls shall be integrated into the system and coordinated by the contractor as follows:

1. All communication media and equipment shall be provided as specified in Article 2.2, "Communication," of this specification.
2. Each supplier of a controls product is responsible for the configuration, programming, start-up, and testing of that product to meet the sequences of operation described in this section.
3. The Contractor shall coordinate and resolve any incompatibility issues that arise between the control products provided under this section and those provided under other sections or divisions of this specification.
4. The contractor is responsible for providing all controls described in the contract documents regardless of where within the contract documents these controls are described.

5. The contractor is responsible for the interface of control products provided by multiple suppliers regardless of where this interface is described within the contract documents.

9.4 General Workmanship. This section delineates the minimum acceptable standards for the installation of the BAS. This requires that all of the controls subcontractor's work—and any work of his/ her subcontractors—be performed in a neat, workmanlike manner so that the final installed project is completed to provide a properly working system, as well as a neat and orderly installation. This should be in line with the installation required by other related trades (such as Division 16 of this specification for electrical installation). This should include any general requirements and guidelines that are expected of the controls subcontractor. The requirement to install all wiring, tubing, and piping parallel to building lines allows for an aesthetically pleasing installation and maximizes the use of wall space, etc.

3.4 GENERAL WORKMANSHIP

A. Install equipment, piping, and wiring/raceway parallel to building lines (i.e., horizontal, vertical, and parallel to walls) wherever possible.
B. Provide sufficient slack and flexible connections to allow for vibration of piping and equipment.
C. Install all equipment in readily accessible locations as defined by Chapter 1, Article 100, Part A of the National Electrical Code (NEC).
D. Verify integrity of all wiring to ensure continuity and freedom from shorts and grounds.
E. All equipment, installation, and wiring shall comply with acceptable industry specifications and standards for performance, reliability, and compatibility and be executed in strict adherence to local codes and standard practices.

9.5 Field Quality Control. It has been customary to include the requirement that all aspects of an installation be monitored for conformance to the specification and codes. The method of monitoring and types of corrective actions are left up to the contractor. Documentation of those standard procedures can be made a requirement of this section so that overall project management personnel can understand and better coordinate with other subcontractors for better, faster, and more complete problem resolution. Such documentation should be requested to be a part of the submittal documentation. The BAS designer may desire that the contractor submit documentation detailing field quality control. If so, this requirement should be added to Article 1.10, "Submittals," and it should detail the steps to be taken by the personnel to

a. identify, investigate, and analyze the occurrence of nonconforming products or installation;
b. act to avoid recurrence of a problem;
c. apply quality controls to ensure corrective actions are taken and are effective; and
d. implement and record changes in procedures resulting from corrective actions.

9.5.1 Project Considerations. Remove "state," or replace with "provincial," as applicable to the location of the project in the subparagraph below.

3.5 FIELD QUALITY CONTROL

A. All work, materials, and equipment shall comply with the rules and regulations of applicable local, state, and federal codes and ordinances as identified in Part 1, "General," of this specification.
B. Contractor shall continually monitor the field installation for code compliance and quality of workmanship.
C. Contractor shall have work inspected by local and/or state authorities having jurisdiction over the work.

9.6 Existing Equipment. This section is only applicable to those projects involving renovations to existing facilities. In specifying the method of construction involved in renovation or retrofit, the BAS designer's most important consideration is the identification of which devices and materials are to be new, which are to be salvaged, and which are to be reused. In the following suggested specification language, the BAS designer must make this choice on an item-by-item basis.

9.6.1 Project Considerations. This article applies only to projects involving existing buildings. Delete this article for new construction.

Note that Article 2.1, "Materials," of this specification states that all products shall be new. If this article is to be used, edit that article appropriately.

The items within the brackets {} are options to be selected as applicable to an individual project. Delete the options that are not appropriate.

3.6 EXISTING EQUIPMENT

A. Wiring. {The contractor may reuse any abandoned wires. The integrity of the wire and its proper application to the installation are the responsibility of the contractor. The wire shall be properly identified and tested in accordance with this specification. Unused or redundant wiring must be properly identified as such.} {Interconnecting control wiring shall be removed and become the property of the contractor, unless specifically noted or shown to be reused.}
B. Pneumatic Tubing. {The contractor may reuse any redundant pneumatic tubing. The integrity of the tubing and its proper application to the installation are the responsibility of the contractor. The tubing shall be properly identified and tested in accordance with this specification. Unused or redundant tubing must be removed or, where this is not possible, properly identified.} {Interconnecting pneumatic control tubing

shall be removed and become the property of the contractor, unless specifically noted or shown to be reused.}

C. Local Control Panels. {The contractor may reuse any existing local control panel to locate new equipment. All redundant equipment within these panels must be removed. Panel face cover must be patched to fill all holes caused by removal of unused equipment or replaced with new.} {Remove and deliver to owner.} {Existing panels become the property of the contractor.} {Salvage, recondition, and reuse existing devices and cabinets as noted. Relocate as shown.}

D. Unless otherwise directed, the contractor is not responsible for the repairs or replacement of existing energy equipment and systems, valves, dampers, or actuators. Should the contractor find existing equipment that requires maintenance, the BAS designer is to be notified immediately.

E. Temperature Sensor Wells. The contractor may reuse any existing wells in piping for temperature sensors. These wells shall be modified as required for proper fit of new sensors.

F. Indicator Gages. Where these devices remain and are not removed, they must be made operational and recalibrated to ensure reasonable accuracy. Maintain the operation of existing pneumatic transmitters and gages.

G. Room Thermostats. {Salvage, recondition, and reuse} {Deliver to Owner} {Shall be removed and become the property of the contractor, unless otherwise noted}.

H. Electronic Sensors and Transmitters. Unless specifically noted otherwise, {remove and deliver to the Owner} {become the property of the contractor}.

I. Controllers and Auxiliary Electronic Devices. {Deliver to the owner} {Salvage, recondition, and reuse} {Become the property of the contractor}.

J. Pneumatic Controllers, Relays and Gages: {Deliver to owner} {Become the property of the contractor}.

K. Damper Actuators, Linkages, and Appurtenances. {Deliver to owner} {Salvage, recondition, and reuse} {Become the property of the contractor}.

L. Control Valves. {Replace with new} {Salvage, recondition, and reuse} {Become the property of the contractor}.

M. Control Compressed Air System {Deliver to owner and replace with new system} {Salvage, recondition, and reuse} {Becomes the property of the contractor, unless otherwise noted}.

Cut-over of controls to the new BAS must be considered and coordinated carefully. As an existing system is presently running under the old BAS, the switchover must be performed so as to minimize the disruption to building occupants. This is often performed by switching control from one system to another while the building is unoccupied, at night, or by specifying the maximum duration that the system may be off-line to perform these changes. Each facility will have its own priorities in determining acceptable procedures, and consultation with the owner before issuing the specification is recommended. Typically, cut-over in unoccupied periods is more expensive for a contractor, but it reduces the chances for problems to occur that would be noticed by building occupants.

9.6.2 Project Considerations. Edit the hours of occupancy in the paragraph below to define the time in which it is unacceptable for the systems to be off and the maximum length of time that the system may be off. If there is no limitation, remove the paragraph.

N. The mechanical system must remain in operation between the hours of 6 a.m. and 6 p.m., Monday through Friday. No modifications to the system shall cause the mechanical system to be shut down for more than 15 minutes or to fail to maintain space comfort conditions during any such period. Perform cut-over of controls that cannot meet these conditions outside of those hours.

The building's system may be operated during scheduled hours by time-clock devices or an existing BAS. It is important that the systems continue to operate under the programmed schedule while the installation of the new BAS is in progress.

O. The scheduling of fans through existing or temporary time clocks or BAS shall be maintained throughout the BAS installation.

Location of new equipment in existing buildings and mechanical rooms is often a passionate personal concern of the operating personnel. It may be important either to explicitly define where this equipment shall be located or to allow the contractor to select the most suitable location but have this selection approved by the owner's representative before installation.

9.6.3 Project Considerations. The location of the new equipment should be shown on the drawings. If left to the subcontractor's discretion, the BAS designer may require a proposal for the location of new equipment. Include this requirement in Article 1.10, "Submittals" of this specification.

P. Install control panels where shown.

Older buildings and small mechanical systems may have motor control starters that are not wired for hand/off/auto control. Each of these starters must be modified for interconnection to the new BAS.

Q. Modify existing starter control circuits, if necessary, to provide hand/off/auto control of each starter controlled. If new starters or starter control packages are required, these shall be included as part of this contract.

Work in an existing building will require wire penetration through existing walls. The BAS designer must ensure that there is a mechanism for fixing penetrated areas to the owner's satisfaction.

R. Patch holes and finish to match existing walls.

9.7 Wiring

9.7.1 General. Division 16 of the specification should be the primary guide for wiring and installation of wiring for the project. This section should require compliance with Division 16 and define requirements that are peculiar to the BAS that are in addition to, or override, those of Division 16.

The BAS designer will need to consider the myriad of available wiring options. The following text discusses some of these options. For example, raceway will be discussed. The use of raceway is often mandatory. However, cable tray and/or plenum cable can be used in certain situations. The ability to use plenum cable can greatly affect wiring costs and provide a level of cost savings. It can only be used in accordance with the proper codes.

The next choice a BAS designer must make concerning wiring is whether to recommend solid or stranded wire. The BAS designer may not care and may leave it up to the contractor to decide. Generally, stranded wire has better electrical characteristics. Solid wire can be more aesthetically pleasing when terminated in a panel because it tends to hold its shape. Stranded wire, however, provides a better electrical connection when used in a terminal block. If you are not sure what to recommend, leave the choice to the contractor. See Clause 12 for additional wiring requirements.

9.7.2 Need for Raceway. Raceway provides mechanical protection of BAS wiring. It also enhances the aesthetic quality of the installation. Local codes may not require conduit for low voltage, although some do. As such, the use of conduit may be considered optional.

The use of raceway for all wiring runs does, however, increase the cost of the installation.

As a compromise of cost versus mechanical reliability and appearance, it is recommended to use raceway where the wires are likely to be subject to mechanical damage, such as in mechanical rooms at levels below 3 m (10 ft), and in any occupied areas of the building. Where concealed in ceiling space or at high elevations, its use may be considered unnecessary.

9.7.3 Wire Termination. To maintain the reliability of system performance, good quality connections are required. Terminal blocks and soldered, crimped, or wire nut connections could be used. A screw-type terminal block is recommended. Its use also provides a quick method of system checkout. Wire nuts are not considered reliable or aesthetically pleasing. The following lists the pros and cons of each.

Terminal Blocks

a. Must purchase and therefore provide extra expense
b. Provide flexibility; wiring can be easily removed for troubleshooting purposes
c. Provide a good electrical connection
d. Excellent aesthetic quality

Soldered Connections

a. Very expensive to install
b. Do not provide much flexibility and must be cut or unsoldered for troubleshooting purposes
c. Provide the best electrical connection
d. Poor aesthetic quality

Crimped Connections

a. Expensive to install
b. Do not provide much flexibility and must be cut for troubleshooting purposes
c. Must be used correctly to get a good electrical connection
d. Good aesthetic quality

Wire Nuts

a. Inexpensive to install
b. Provide flexibility and can be easily removed for troubleshooting purposes
c. Cannot guarantee a good electrical connection
d. Poor aesthetic quality

9.7.4 Use of Shielded Wire. Shielded wire is used to limit the induction of noise onto the system's conductors. Some manufacturers of BASs may recommend its use. Some systems only require the shielding for communication wiring. However, some also require a shield for input and output devices. It also should be noted that shielding can affect allowable wiring distances and installed cost.

9.7.5 Power Quality. Electromagnetic noise in the power system, excessively high voltage, abnormally low voltage, and fluctuating voltages may cause problems in the BAS, as well as many other systems in the building. Typically this is not a problem—and the power requirements listed under each of the controller types in Part 2, "Products," are adequate protection from oversensitive devices. If the power quality is suspect, it should probably be addressed by the BAS designer or owner on a building-wide basis. Alternatively, the BAS designer may include a paragraph in this article requiring filters, inductors, transformers, etc., to ensure the power supply quality for the products supplied under this section. This may be an expensive addition to the specification, as the contractor may add a considerable allowance for the unknown.

9.7.5.1 Project Considerations. The specification calls for use of terminal blocks for all connections. To allow for alternatives—soldered or crimped connections or wire nuts—edit accordingly. See Clause 12 for additional IP and non-IP networking requirements.

3.7 WIRING

A. All control and interlock wiring shall comply with national and local electrical codes and Division 16 of this specification. Where the requirements of this section differ from those in Division 16, the requirements of this section shall take precedence.

B. All NEC Class 1 (line voltage) wiring shall be UL Listed in approved raceway according to NEC and Division 16 requirements.

C. All low-voltage wiring shall meet NEC Class 2 requirements. (Low-voltage power circuits shall be subfused when required to meet Class 2 current limit.)

D. Where NEC Class 2 (current-limited) wires are in concealed and accessible locations, including ceiling return air plenums, approved cables not in raceway may be used provided that cables are UL Listed for the intended application. For example, cables used in ceiling plenums shall be UL Listed specifically for that purpose.

E. All wiring in mechanical, electrical, or service rooms—or where subject to mechanical damage— shall be installed in raceway at levels below 3 m (10 ft).

F. Do not install Class 2 wiring in raceway containing Class 1 wiring. Boxes and panels containing high-voltage wiring and equipment may not be used for low-voltage wiring except for the purpose of interfacing the two (e.g., relays and transformers).

G. Do not install wiring in raceway containing tubing.

H. Where Class 2 wiring is run exposed, wiring is to be run parallel along a surface or perpendicular to it and neatly tied at 3 m (10 ft) intervals.

I. Where plenum cables are used without raceway, they shall be supported from or anchored to structural members. Cables shall not be supported by or anchored to ductwork, electrical raceways, piping, or ceiling suspension systems.

J. All wire-to-device connections shall be made at a terminal block or terminal strip. All wire-to-wire connections shall be at a terminal block.

K. All wiring within enclosures shall be neatly bundled and anchored to permit access and prevent restriction to devices and terminals.

L. Maximum allowable voltage for control wiring shall be 120 V. If only higher voltages are available, the contractor shall provide step-down transformers.

M. All wiring shall be installed as continuous lengths, with no splices permitted between termination points.

N. Install plenum wiring in sleeves where it passes through walls and floors. Maintain fire rating at all penetrations.

O. Size of raceway and size and type of wire shall be the responsibility of the contractor, in keeping with the manufacturer's recommendations and NEC requirements, except as noted elsewhere.

P. Include one pull string in each raceway 2.5 cm (1 in.) or larger.

Q. Use coded conductors throughout with conductors of different colors.

R. Control and status relays are to be located in designated enclosures only. These enclosures include packaged equipment control panel enclosures unless they also contain Class 1 starters.

S. Conceal all raceways, except within mechanical, electrical, or service rooms. Install raceway to maintain a minimum clearance of 15 cm (6 in.) from high-temperature equipment (e.g., steam pipes or flues).

T. Secure raceways with raceway clamps fastened to the structure and spaced according to code requirements. Raceways and pull boxes may not be hung on flexible duct strap or tie rods. Raceways may not be run on or attached to ductwork.

U. Adhere to this specification's Division 16 requirements where raceway crosses building expansion joints.

V. Install insulated bushings on all raceway ends and openings to enclosures. Seal top end of all vertical raceways.

W. The contractor shall terminate all control and/or interlock wiring and shall maintain updated (as-built) wiring diagrams with terminations identified at the job site.

X. Flexible metal raceways and liquid-tight, flexible metal raceways shall not exceed 1 m (3 ft) in length and shall be supported at each end. Flexible metal raceway less than 16 mm (1/2 in.) electrical trade size shall not be used. In areas exposed to moisture, including chiller and boiler rooms, liquid-tight, flexible metal raceways shall be used.

Y. Raceway must be rigidly installed, adequately supported, properly reamed at both ends, and left clean and free of obstructions. Raceway sections shall be joined with couplings (according to code). Terminations must be made with fittings at boxes, and ends not terminating in boxes shall have bushings installed.

9.8 Communication Wiring. Communication wiring standards differ by manufacturer. Different manufacturers have their own topology, design, and methodology to follow. Generally, the manufacturer must take responsibility for proper installation of wiring. General information can be found in the *National Electrical Code Handbook* article on communications circuits. It will be impossible for the BAS designer to cover all scenarios. However, the BAS designer may specify and insist on a few basic guidelines and practices such as the following:

a. Ensure the installation is completed by skilled, experienced installers familiar with the physical media.

b. Ensure the communication wiring is installed in a dedicated raceway.

c. Improper grounding causes many communication problems. Insist that proper grounding principles are followed (reference the *NEC Handbook*) and that additional hardware may be necessary. This is especially important where communication wiring is extended between buildings that may have different ground potentials.

d. Maximum-distance limitations and number of drops must be within the manufacturer's specifications. Additional shorter networks may be better than one very long network, even if additional controllers or hardware are necessary.
e. Splices should be eliminated. If this is not possible, they should be kept to a minimum.

The installing subcontractor must be made responsible for the integrity of the network. The complete network shall be tested for shorts and opens. Additional tests using electronic equipment may be required for coaxial and fiber optic cabling. Follow the recommended manufacturer's guidelines.

Practices for the installation of twisted-pair and coaxial cabling may differ by manufacturer. Follow their recommendations and use this communication wiring article as a guide. See Clause 12 for additional IP and non-IP networking requirements.

9.8.1 Project Considerations. Some owners and BAS designers consider the communication wiring to be critical to the uninterrupted operation of the BAS. To ensure the continuous operation of the system, they require the communication wiring be installed within raceway throughout its length, including where wiring is in a concealed accessible space such as a ceiling plenum. Such a requirement may add substantial cost to the project. If this is considered a cost-justifiable addition, add the following paragraph to this article: "All communication wiring shall be UL listed in approved raceway according to NEC and Division 16 requirements."

3.8 COMMUNICATION WIRING

A. The contractor shall adhere to the items listed in Article 3.7, "Wiring," of the specification.
B. All cabling shall be installed in a neat and workmanlike manner. Follow manufacturer's installation recommendations for all communication cabling.
C. Do not install communication wiring in raceway and enclosures containing Class 1 or other Class 2 wiring.
D. Maximum pulling, tension, and bend radius for cable installation, as specified by the cable manufacturer, shall not be exceeded during installation.
E. Contractor shall verify the integrity of the entire network following the cable installation. Use appropriate test measures for each particular cable.
F. When a cable enters or exits a building, a lightning arrestor must be installed between the lines and ground. The lighting arrestor shall be installed according to the manufacturer's instructions.
G. All runs of communication wiring shall be unspliced length when that length is commercially available.
H. All communication wiring shall be labeled to indicate origination and destination data.
I. Grounding of coaxial cable shall be in accordance with NEC regulations article on "Communications Circuits, Cable, and Protector Grounding."

9.9 Fiber Optic Cable System. Fiber optic cabling requires special installation practices beyond what is specified here. The BAS designer may want to specify and insist on a few basic guidelines and practices. For example, ensure that the installation is completed by skilled, experienced installers familiar with the physical media. The BAS designer may want to reference the NEC article on optical fiber cables.

The installing subcontractor must be made responsible for the integrity of the network. Additional tests using electronic equipment may be required for this type of cabling. Follow the recommended manufacturer's guidelines.

The maximum pulling tensions specified by the fiber optic cable manufacturers are very important. If pulling tensions are exceeded when pulling wire, degradation of the wire occurs. If they are exceeded while pulling the cable, it will break.

9.9.1 Project Considerations. The use of fiber optics is commonly not required in most systems and projects. Remember also that this article relates to Article 3.9, "Fiber Optic Cable" specifying the cable in Part 2, "Products," of this specification. If not required, do not include these articles.

3.9 FIBER OPTIC CABLE SYSTEM

A. Maximum pulling tensions as specified by the cable manufacturer shall not be exceeded during installation. Post-installation residual cable tension shall be within cable manufacturer's specifications.
B. All cabling and associated components shall be installed in accordance with manufacturers' instructions. Minimum cable and unjacketed fiber bend radii, as specified by cable manufacturer, shall be maintained.

9.10 Control Air Tubing

9.10.1 General. Include this section only if there will be pneumatic components on this project.

For aesthetic considerations and maximization of available wall space, the contractor is asked to run all pneumatic tubing parallel to the building lines. Oblique angles in the installation usually appear as sloppy or of poor quality.

Copper tubing should not be attached to ductwork because of unnecessary vibration and the potential for galvanic reaction.

Polyethylene tubing should be supported at intervals of no greater than 75 cm (30 in.) to prevent sag (unless installed in conduit). Polyethylene tubing should be kept separated from hot piping and equipment. When polyethylene tubing penetrates a firewall, it should be installed in a section of close-fitting pipe or conduit extending 0.46 mm (18 in.) on either side of the wall.

All tubing mounted on the inside of outdoor walls (or roofs) should be mounted with the building insulation between the tubing and the outer building surface, and the tubing should be installed clear of the wall to isolate the tubing from the effects of outdoor air temperatures.

Grommets should be provided where tubing passes through ductwork or plenum walls.

Note that Article 1.10, "Submittals," requires certification of pressure testing of the pneumatic system.

9.10.2 Main Air Tubing. Main air tubing must be sized by the contractor, based upon the air consumption of the system and the length of the run, to provide adequate pressure at all points.

If main air pressure is required at points scattered over a broad area (such as variable-air-volume boxes on a floor), it is recommended that the main air be looped around the floor as opposed to a series of straight main air runs. This reduces the effective length of the run and the effects on pressure drop.

Vertical risers should be copper rather than polyethylene. This is because the copper is easier to support for distances (less sag) and is more durable. Also, there is less pressure drop due to friction and there is no possibility of the plastic tubing pulling off from the barbed fittings where these are used.

When high-pressure mains are used (in excess of 200 kPa [30 psi]), tubing should be copper.

9.10.3 Sensor Tubing. Sensor tubing must be sized by the contractor. This can be critical because sensor tubing that is improperly sized will affect the accuracy and repeatability of the measurement. It is especially true of a sensor such as a flow-through static pressure transducer.

9.10.3.1 Project Considerations. Include this control air tubing article only if there will be pneumatic components on this project.

It is generally better to locate the sensor in such a way as to minimize the tubing runs at the expense of increased wiring distances. Where accurate readings from pitot-tube arrays are required, specify equal lengths of tubing from the high-pressure and low-pressure ports of the sensor.

When specifying pressure-reducing valves, typically these are located after the dryer. On larger projects, it is less expensive and easier for maintenance to run high-pressure mains to various building zones (such as each level in a high rise) and reduce the air pressure at each zone. This reduces the overall pipe size required and reduces the possibility of excessive pressure losses in the main.

One filter for the system may be sufficient if the total air consumption in each zone is very low; however, it is generally preferable to filter the high-pressure air at the dryer and at each pressure-reducing valve.

3.10 CONTROL AIR TUBING

A. Main air tubing shall be sized by the contractor. Main air runs on a floor shall be looped, as opposed to a series of straight air runs.
B. Vertical risers shall be copper.
C. Sensor tubing shall be sized by the contractor. Locate sensors to minimize tubing runs at the expense of increased wiring distances.
D. Locate air dryer in discharge air line from tank. Wall-mount dryer on rubber in shear mounts. Install pressure regulator downstream of dryer. Pipe automatic drains to nearest floor drain.
E. Use copper tubing in mechanical rooms where subject to damage or temperatures in excess of 95°C (200°F), where adjacent to heating pipes passing through common sleeve, and where not readily accessible. In mechanical rooms, bundled plastic tubing with suitable junction boxes or single plastic tubing with tray or raceway may be used.
F. Mechanically attach tubing to supporting surfaces. Sleeve through concrete surfaces in minimum 1 in. sleeves, extended 15 cm (6 in.) above floors and 3 cm (1 in.) below bottom surface of slabs.
G. Purge tubing with dry, oil-free compressed air before connecting control instruments.
H. All control air piping shall be concealed except in equipment rooms or unfinished areas. Installation methods/materials are as follows:
    1. Concealed and inaccessible. Use FR plastic in metal raceway. Room thermostat drops in stud walls in areas with lay-in ceiling may be FR plastic tubing.
    2. Concealed and accessible tubing (including ceiling return air plenums) shall be ACR copper tubing or FR plastic tubing, subject to the following limitations:
        a. FR tubing shall be enclosed in metal raceway when required by local code.
        b. Quantity of FR tubing per cubic foot of plenum space shall not exceed manufacturer's published data for Class 1 installation.
        c. Exposed. Use hard-drawn ACR copper or FR plastic in metal raceway.
        d. Where copper tubing is used, a section 0.5 m (18 in.) or less of FR plastic tubing is acceptable at final connection to control device.
I. Pneumatic tubing shall not be run in raceway containing electrical wiring.
J. Where FR tubing exits the end of raceway or junction box, provide snap-in nylon bushing. Where pneumatic tubing exits control panels, provide bulkhead fittings. Where copper tubing exits junction boxes or panels, provide bulkhead fittings.
K. All control air piping shall be installed in a neat and workmanlike manner parallel to building lines with adequate support.
L. Piping above suspended ceilings shall be supported from or anchored to structural members or other piping and/or duct supports. Tubing shall not be supported by or anchored to electrical raceways or ceiling support systems.

M. For air pressures greater than 200 kPa (30 psig), compression or solder type connection shall be used.
N. When FR tubing is used for pressures 200 kPa (30 psig) or less, brass-barbed fittings may be used. Plastic fittings are not acceptable.
O. Brass-barbed fittings shall be used at copper-to-FR tubing junctions. Plastic slipped-over copper tubing is not acceptable.
P. Perform a pressure test on the entire pneumatic system as follows:
   1. Test high-pressure air piping at 1000 kPa (150 psig) air pressure. Maintain this pressure for two hours without loss of pressure. If loss of pressure is indicated, correct and retest until the system shows no loss of pressure for two hours.
   2. Test low-pressure air tubing at 200 kPa (30 psig) air pressure. Maintain this pressure for 2 hours without pumping, during which time the pressure shall not drop more than 7 kPa (1psi). Should pressure loss occur, determine the leak, repair with new equipment or piping, and retest until the system shows no more than 7 kPa (1 psi) pressure drop in two hours.
   3. Leaks at pipe and tube joints shall be corrected by remaking of the joints.

9.11 Installation of Sensors. The sensor installation can have a direct and harmful effect on sensor accuracy. Care must be taken to ensure that the sensor is installed as recommended by the manufacturer for the application.

9.11.1 Project Considerations. A display of the temperature or pressure of the air or liquid is often useful for the operator, and in some cases the display is used to ensure that the device is functioning correctly. Providing gages at pressure and differential pressure sensors is especially useful—but often expensive. Some owners will be interested in having this level of instrumentation. In that case, decide whether the gages should be located at the device or on a panel face at a central location. Piping water to a gage in a panel is usually not practical. In all cases, test ports should be added to the piping or tubing to allow test and calibration of the devices. Particular attention should also be paid to sensor location and potential thermal stratification, as it can impact the quality of the measurement.

3.11 INSTALLATION OF SENSORS

A. Install sensors in accordance with the manufacturer's recommendations.
B. Mount sensors rigidly and adequately for the environment within which the sensor operates.
C. Room temperature sensors shall be installed on concealed junction boxes properly supported by the wall framing.
D. All wires attached to sensors shall be air sealed in their raceways or in the wall to stop air transmitted from other areas affecting sensor readings.
E. Sensors used in mixing plenums and hot and cold decks shall be of the averaging type. Averaging sensors shall be installed in a serpentine manner vertically across the duct. Each bend shall be supported with a capillary clip.
F. Low-limit sensors used in mixing plenums shall be installed in a serpentine manner horizontally across duct. Each bend shall be supported with a capillary clip. Provide 3 m of sensing element for each 1 m^2 (1 ft of sensing element for each 1 ft^2) of coil area.
G. All pipe-mounted temperature sensors shall be installed in wells. Install all liquid temperature sensors with heat-conducting fluid in thermal wells.
H. Install outdoor air temperature sensors on north wall, complete with sun shield at designated location
I. Differential Air Static Pressure
   1. Supply Duct Static Pressure. Pipe the high-pressure tap to the duct using a pitot tube. Pipe the low-pressure port to a tee in the high-pressure tap tubing of the corresponding building static pressure sensor (if applicable) or to the location of the duct high-pressure tap and leave open to the plenum.
   2. Return Duct Static Pressure. Pipe the high-pressure tap to the duct using a pitot tube. Pipe the low-pressure port to a tee in the low-pressure tap tubing of the corresponding building static pressure sensor.
   3. Building Static Pressure. Pipe the low-pressure port of the pressure sensor to the static pressure port located on the outside of the building through a high-volume accumulator. Pipe the high-pressure port to a location behind a thermostat cover.
   4. The piping to the pressure ports on all pressure transducers shall contain a capped test port located adjacent to the transducer.
   5. All pressure transducers, other than those controlling VAV boxes, shall be located in field device panels, not on the equipment monitored or on ductwork. Mount transducers in a location accessible for service without use of ladders or special equipment.
   6. All air and water differential pressure sensors shall have gage tees mounted adjacent to the taps. Water gages shall also have shutoff valves installed before the tee.

9.12 Flow Switch Installation

9.12.1 Airflow. Care must be taken to install the switch properly with the direction of flow. Flow switches work best when installed in a horizontal duct; however, if installation in a vertical duct is necessary, flow switches should be installed in the vertical duct with an upward direction of flow. This will reduce false readings.

9.12.2 Hydronic Flow. A fitting (generally, DN25 [1 in.] NPT) is provided in the pipe by the mechanical subcontractor. Specification language for flow switch installation is found in Article 3.12, "Flow Switch Installation." This language can be inserted into the section "Instructions to other Contractors," addressed in Clause 12. The controls subcontractor must indicate the location of the device.

Flow switches are available for DN25 (1 in.) and larger pipes (with a lesser selection for DN15 and DN 20 [1/2 and 3/4 in.] pipe). The flow vane needs to be adjusted in size for the diameter of the pipe.

3.12 FLOW SWITCH INSTALLATION

A. Use correct paddle for pipe diameter.
B. Adjust flow switch in accordance with manufacturer's instructions.

9.13 Actuators. Actuators must be installed with enough clearance to allow for removal and servicing. When actuators are mounted in parallel, they should be actuated by the same signal or slaved such that there is no lag between the positioning. Damper actuators mounted in the airstream or above the ceiling must be rated for that application in consideration of fire and smoke spread regulations.

When determining a location for mounting the actuators, consider the problems caused by condensation of moisture in the air within the actuator. When outside, or in an outside airstream, this moisture may freeze. In an electric actuator, it may cause corrosion. Some manufacturers of electric actuators have designed features into their products that help eliminate the moisture within the actuator, but this problem clearly should be considered in the design of the system.

If the drive rotation time of direct-coupled electric actuators is not a limiting factor, specifying one actuator per damper section (thereby eliminating jackshafting) is not only affordable but can eliminate damper lag and allow for more flexible damper applications.

3.13 ACTUATORS

A. Mount and link control damper actuators according to manufacturer's instructions.
   1. To compress seals when spring-return actuators are used on normally closed dampers, power actuator to approximately 5 degrees open position, manually close the damper, and then tighten the linkage.
   2. Check operation of damper/actuator combination to confirm that actuator modulates damper smoothly throughout stroke to both open and closed positions.
   3. Provide all mounting hardware and linkages for actuator installation.
B. Electric/Electronic
   1. Dampers. Actuators shall be direct-mounted on damper shaft or jackshaft unless shown as a linkage installation. For low-leakage dampers with seals, the actuator shall be mounted with a minimum 5 degrees available for tightening the damper seals. Actuators shall be mounted following manufacturer's recommendations.
   2. Valves. Actuators shall be connected to valves with adapters approved by the actuator manufacturer. Actuators and adapters shall be mounted following the actuator manufacturer's recommendations.
C. Pneumatic Actuators
   1. Size pneumatic damper actuator to operate the related control damper(s) with sufficient reserve power to provide smooth modulating action or two-position action. Actuator also shall be sized for proper speed of response at the velocity and pressure conditions to which the control damper is subject.
   2. Pneumatic damper actuators shall produce sufficient torque to close off against the maximum system pressures encountered. Size the pneumatic damper actuator to close off against the fan shutoff pressure, as a minimum.
   3. Where two or more pneumatic damper actuators are installed for interrelated operation in unison, such as dampers used for mixing, provide the dampers with a positive pilot positioner. The positive pilot positioner shall be directly mounted to the pneumatic damper actuator and have pressure gages for supply input and output pressures.
   4. The total damper area operated by an actuator shall not exceed 80% of the manufacturer's maximum area rating. Provide at least one actuator for each damper section. Each damper actuator shall not power more than 2 m^2 (20 ft^2) of damper.
   5. Use line shafting or shaft couplings (jackshafting) in lieu of blade-to-blade linkages or shaft coupling when driving axially aligned damper sections.

9.14 Warning Labels. Mechanical equipment (fans, pumps, chillers, boilers, compressors, etc.) operates under automatic remote control from the BAS or other remote control devices. It may start or stop without any warning and represents a potential hazard to operating and service personnel. It is mandatory that labels warning of this danger be attached to both the equipment and the motor starter to minimize the hazard to operating/service personnel.

Electrical control devices (motor starters, power contactors, control panels, etc.) are often served by more than one power source with multiple disconnect switches. A common example is a three-phase magnetic motor starter with a local three-phase power disconnect switch and with a remotely powered low-voltage (120 VAC or 24 VAC) coil control circuit. Other examples are boilers or chillers with separate three-phase power and single-phase control circuits with separate disconnects. Labels warning of multiple power sources with separate disconnects should be attached to this equipment.

3.14 WARNING LABELS

A. Permanent warning labels shall be affixed to all equipment that can be automatically started by the BAS.
   1. Labels shall use white lettering (12-point type or larger) on a red background.
   2. Warning labels shall read as follows:

CAUTION

This equipment is operating under automatic control and may start or stop at any time without warning. Switch disconnect to off position before servicing.

B. Permanent warning labels shall be affixed to all motor starters and all control panels that are connected to multiple power sources utilizing separate disconnects.
   1. Labels shall use white lettering (12-point type or larger) on a red background.
   2. Warning labels shall read as follows:

CAUTION

This equipment is fed from more than one power source with separate disconnects. Disconnect all power sources before servicing.

9.15 Identification of Hardware and Wiring. Identification of hardware provides owners and operators of a system with an efficient method of identifying systems, equipment, and components for maintenance. Identification also enhances safety and allows for easier troubleshooting and modifications of a system.

Labeling should be visible, permanent, and understandable and should relate to the engineering as-built drawings, BAS's database naming descriptions, and to the systems/devices being interfaced, controlled, and monitored.

Labels for panels should be laminated, engraved labels that can be affixed to a panel by glue and/or rivets or screws.

Labels for room sensors should be laminated labels affixed to the outside of a baseplate or cover of a sensor. As an alternative, if a label is unappealing, affix the label to the inside of the cover.

All field devices, including duct sensors, transducers, valves, and actuators, should be tagged with labels attached directly to the device.

Wire and pneumatic tubing should be labeled with tie-wraps, shrink-wraps, brass tags, crackback labels, and/or color-coded prenumbered labels.

While good labeling increases installation cost, it is generally accepted in the industry today that labeling is important. Most projects are installed with labels that are either incorrect or that use a labeling system that is awkward and of little use. The net result is that the contractor expends additional effort and the owner incurs increased price. Labeling that actually benefits the owner must be specified. During the design process, verify the labeling approach with the owner. These labels must be presented on the drawings and kept current as the project progresses.

9.15.1 Project Considerations. The following additional items may be added to the specification to further identify a project's equipment:

a. All wiring and conduit, including wire within panels, shall be labeled on both ends with the device name or BASS address location or terminal block number.
b. All straight runs should be labeled at least every 15 m (50 ft) and at all junction boxes and branches. A label/tag should be provided within 1 m (3 ft) of any penetration of floor, wall, or ceiling. All tags/labels shall be easily read and within view in concealed areas such as ceiling plenums, shafts, and chases.
c. All electrical devices such as transformers and power supplies shall be labeled with supply voltage and power circuit number.
d. Terminal blocks shall be labeled to match the connected device.
e. Panel-mounted devices shall be labeled to match as-built drawings.
f. Pneumatic tubing shall be labeled at least every 15 m (50 ft) for straight runs, at least one label/tag for each branch, and within 1 m (3 ft) of any tee. In addition, a label/tag should be provided within 1 m (3 ft) of any penetration of floor, wall, or ceiling. All tags/labels should be easily readable and within view in concealed areas such as ceiling plenums, shafts, and chases. All pneumatic devices, such as valves, filters, and pressure-reducing valves, should be labeled.
g. All wire and tubing labels shall be clearly indicated on the control drawings. The method of labeling shall be logical and intuitive.

3.15 IDENTIFICATION OF HARDWARE AND WIRING

A. All wiring and cabling, including that within factory-fabricated panels, shall be labeled at each end within 5 cm (2 in.) of termination with the BAS address or termination number.
B. All pneumatic tubing shall be labeled at each end within 5 cm (2 in.) of termination with a descriptive identifier.
C. Permanently label or code each point of field terminal strips to show the instrument or item served.

D. Identify control panels with minimum 1 cm (1/2 in.) letters on laminated plastic nameplates.
E. Identify all other control components with permanent labels. All plug-in components shall be labeled such that removal of the component does not remove the label.
F. Identify room sensors relating to terminal box or valves with nameplates.
G. Manufacturers' nameplates and UL or CSA labels are to be visible and legible after equipment is installed.
H. Identifiers shall match record documents.

9.16 Controllers

9.16.1 General. This section of the specification describes the requirements for installing and loading controllers, as well as spare point capacity. The BAS designer may want to insist on a few key requirements for the installation of controllers. These are as follows:

a. It may be desirable to mount controllers offset from the wall by 1 cm (1/2 in.), which will reduce the risk of water damage during the construction phase of the project. This may be an additional expense, but one that is easily justified.
b. Various controller manufacturers test controller operation with different types of wire, especially for communication. As an example, some controllers require shielded wire and some do not, while others allow either. It is therefore possible to specify a wire type that will allow the system to function and yet not be supported by the manufacturer. It is important to keep in mind that the overriding requirement is system performance. The BAS designer should defer to the manufacturer's recommended wiring practices.
c. Potential problems often can be avoided by ensuring that power wiring is not mixed with communication and I/O wiring. Wiring and communication wiring installation requirements are listed in Part 3, "Execution," of the specification.
d. All controllers require some method of grounding. It can be beneficial, especially in areas where the quality and stability of power is suspect, either to provide or require a separate ground loop (riser) for the BAS. Different controller manufacturers may have different grounding requirements or recommendations. It is generally best to defer to these recommendations.

9.16.2 Controller Loading. It is advantageous for some users to limit the number of major systems connected to one controller (e.g., two air-handling units or one chiller per controller). This can increase initial cost but reduce the risk of equipment downtime in the event of controller failure. In addition, all field points associated with a control loop must be monitored or controlled from a single controller. This avoids the possibility of a system going out of control from loss of data communication or a lag in response time.

Spare point capacity is an extra expense. Do not specify spare point capacity if it is really not desired. However, if this extra expense can be justified, then make sure that the spare points are usable. Some of the situations that might warrant spare point capacity are as follows:

a. The owner wishes to be prepared for expansion in the future and wants to provide extra capacity for it now.
b. The owner wishes to do the expansion work with his/her own employees.
c. The owner wishes to be prepared for an emergency situation that would warrant extra capacity.

It is generally best to specify that spare points be provided in terms of a percentage of total points per location. Providing spare points on a system-wide basis does not ensure that the points will be located where they are needed. Requiring spare points per controller will accomplish this but may require either the manipulation of point assignment to a less than optimum configuration for control or the addition of an unnecessary controller, which increases cost. If several controllers are located in a mechanical room, the primary concern is that the proper percentages of spare points be available within the location.

Spare point capacity also should be specified on the basis of point type. If the installed controllers differentiate between digital and analog points (as well as input and output), the DDC system should be expected to receive the required percentage of all point types.

9.16.2.1 Project Considerations. If spare point capacity is considered cost-justified, then edit the paragraph that lists this capacity requirement for the amount required. To reduce project cost, delete this requirement.

It is not good practice to split the input and output of a control loop between two controllers. Any delay in communication may render the control loop unstable, and loss of communication may cause the mechanical system to function improperly due to lack of a feedback signal.

3.16 CONTROLLERS

A. Provide a separate controller for each AHU or other HVAC system. A BAS controller may control more than one system provided that all points associated with the system are assigned to the same BAS controller. Points used for control loop reset, such as outside air or space temperature, are exempt from this requirement.
B. Building Controllers and Custom Application Controllers shall be selected to provide a minimum of 15% spare I/O point capacity for each point type found at each location. If input points are not universal, 15% of each type is required. If outputs are not universal, 15% of each type is required. A minimum of one spare is required for each type of point used.
    1. Future use of spare capacity shall require providing the field device, field wiring, point database definition, and custom software. No additional controller boards or point modules shall be required to implement use of these spare points.

9.17 Programming

9.17.1 Project-Specific Programming. Regardless of the manufacturer of the system, the contractor must customize the BAS equipment to control the building's specific equipment as intended. The application programming does this. The application programming may take on one of several shapes, depending on the BAS controller manufacturer and type. The three common types are as follows:

a. Text-based programming (also known as line-based programming and mnemonic programming)
b. Graphic-based programming
c. Menu-driven programming (also known as parameter-based programming)

The menu-driven programming method differs from the other two in that the strategies or algorithms used to meet the sequences of operation have been preprogrammed and must simply be selected. Text-based and graphic-based programming are more flexible, and thus usually more powerful, but also require more care. Some elements to consider are:

a. *Comprehensiveness*: The programming should incorporate all elements of the installed BAS and should tie in all elements that are functionally related.
b. *Robustness*: A program must take into account all possibilities for events—even ones that should not happen. Experience has shown that even unlikely conditions and events, or unexpected states of control, will eventually occur. This may be due to equipment shutdown, components being manually commanded by an operator to some state of operation, or for some other reason. The result is that the program temporarily will react abnormally and not regain control of the mechanical equipment without manual intervention or until conditions change drastically.

9.17.1.1 Text-Based Programming. This form is usually based on a high-level programming language, such as BASIC, C, or Pascal, and is generally the most comprehensive and flexible for complete configuration of the BAS. With this power comes the disadvantage of requiring the user to know how to program and how to do so effectively.

Important factors in having a complete and robust installation include:

a. *Structured code:* Most advanced high-level languages have developed a structured format; that is, the use of IF-THEN-ELSE blocks and subroutines are preferred over the use of the GOTO statement. Most languages allow both forms, and the skill and style of the programmer determine the best form to use. The structured form is preferred by most experienced programmers. The advantage of structured code is clarity, allowing a person examining the code to find the relevant information and instructions to the system in one place in a readily understandable format.
b. *Documentation:* Many programming languages have a capability to insert English-language text (comments) into the program to describe the desired function of the section of code. A good programmer uses comments to make the program easy to read and understand. While many programmers avoid this as unnecessary because they already understand the program's purpose, it aids in troubleshooting and comprehension for others examining the system. After the job is installed and time has passed, programming is no longer intuitively obvious to understand. Many consider clearly commented code a staple of good programming. Use comment statements liberally to enhance the clarity of the program and the system.

There are other factors to consider when selecting and programming a text-based system. Another issue concerns whether the code exists on-line or off-line. In some systems, all of the programming resides in the field control panel; in others, the program code exists in the user interface workstation and only the "compiled" machine language exists in the field device. The latter method optimizes the memory requirements of the field device and also may increase the execution speed of the program by the processor. However, if the code is likely to be modified by persons in more than one location, this creates a problem in that each location may have a different version of the program and neither will know which is the most recent or the correct version. Diligent management of the documentation and versions of code among all operators and locations may help reduce the problem of different version of programs residing and operating on the system.

Programs are often divided into modules by systems or by component. System-type programming commands all of the components of the system in one block of code that may depend on the season or time of day. In component-style programming, each block of code deals with one element of the system (e.g., a cooling coil valve or fan start/stop). The program will define what conditions or modes will affect the element. Component-style programs typically involve smaller and more numerous modules.

Component-style programming is generally regarded as the preferable type. It allows a user or programmer to quickly determine why and when a system element is performing the way it is. It also allows the programmer to be thorough and robust, as described above, as he/she would know that all possibilities are covered.

Typically, systems are controlled to maintain setpoint or target values. For example, the system attempts to maintain the room temperature at a setpoint value (such as 21°C [72°F]) determined by the operator or occupants of the space. While it is easy to insert these values directly into the program code, it is usually desirable to set these up as variables so that system operators may reset them in the future. This will allow slight modification and tuning of the system to best match the building condition and occupants without the need to reprogram.

While it is useful to code these constants into the program, do not bury the values in the code. It is often best to define the values as variables and to set their value within the program, but at only one location so that values may be easily altered by a programmer in the future.

9.17.1.2 Guideline for Programming Style for Text-Based Systems. The point name (mnemonic or descriptor) is to be used in programming code, not the hardware/software point addresses. This allows the operator to use a name that he/she can select or that makes sense logically.

Where a language allows the IF-THEN-ELSE structure, programming must incorporate properly nested IF-THEN-ELSE statements. BRANCH/JUMP/GOTO statements will only be acceptable in systems that do not allow IF-THEN-ELSE program structure. The IF-THEN-ELSE structure, or DO-WHILE, is a more efficient use of programming space than BRANCH/JUMP/GOTO.

Where a block of code is to be repeated in multiple locations in a program, a subroutine structure should be used. This increases the efficient use of available programming space. It also allows for verification of only one block of code rather than numerous occurrences of similar code.

Statements within "if," "do," or "subroutine" blocks should be properly indented (by two blank spaces) to allow easy identification and understanding of such block structure.

Control of any point or device should occur in only one program. For example, the secondary pumps should not be controlled by both the chiller and boiler programs.

Where declaration of variable types is required (local, global, real, integer, etc.), these statements should appear at the beginning of the program. The declaration should occur in the program where the variable is set.

The program should be liberally and adequately covered with descriptive comments that will include the intent of the section of code and the methodology used to accomplish the control strategy. Comments also should be included within "if" and "do" statements to properly describe under what conditions the events will occur and what those events are.

9.17.1.3 Graphic-Based Programming. Graphic-based programming was developed to eliminate the need for system users and for the person setting up the system to know how to program a high-level computer language. The user must still be computer literate and must understand what he/she wants the program to accomplish.

Words such as "intuitive" are often used to describe the programming process. The process typically entails placing and arranging "function blocks" on the computer screen and connecting these blocks with lines to indicate the relationship between the various blocks. A block may consist of a BAS point or element or may be a calculation, action, or logical evaluation. These more complex blocks usually will have a number of parameters that must be entered in order to tell the computer how to interpret the block and what to do with it.

A person who understands controls should be able to become proficient in graphic-based programming in just a few days, as opposed to the few months required to become proficient in a high-level programming language. The converse of this feature is that it often requires slightly more time to program the system. Programming also may be slower where complex strategies are used or in large systems where not all interacting components of the system may be viewed on one screen and time is required to navigate the physical screen display to associate the relevant components.

One advantage of graphic-based programming is that a flowchart of the system's sequences of operation is produced as part of the programming process. The usefulness of the flowchart often depends on the ability to display the entire building's sequences, as interaction between the components may be missed when only a small portion of the strategy is displayed in isolation.

Also, the usefulness of the display may be diminished when the actual parameters of the function block are not readily visible in large function blocks. In these cases, one knows that something is there but may not know what the factors are. This is generally a function of the type of graphic-based programming tool used. These disadvantages are offset by the fact that it is more difficult to follow a program written in a high-level language (even properly commented) than it is to write it oneself.

9.17.1.4 Menu-Driven Programming. This style of system configuration requires the installer/programmer to enter parameters, definitions, conditions, requirements, and constraints to the field controller in order to tell it how to perform the control function. This type of device configuration is typically fast and easy and requires neither a high-level computer programming language nor the need to set up logic blocks on a screen.

The sequences are preprogrammed by the manufacturer and only need to be selected by the user. The greatest advantage is that a programmed sequence of operation with proven performance and reliability is immediately produced. The ability to use this type of device is limited only by the range of sequences that are preprogrammed by the manufacturer.

The interaction between devices that use parameter-based programming requires either a text-based or graphic-based programming language on other devices to relay information and evaluate external factors. Usually, the parameters that are entered may be modified by these external programs in order to customize the action of the preprogrammed controller.

9.17.2 Point Naming. The ability of any text-based or graphic-based program to control devices is dependent on its ability to reference that device or "point." Typically, each physical device or variable is given a unique identifier name. While there are few limitations imposed by the system on this name, its selection is important to facilitate ease of understanding of the programming, especially in large or complex systems.

The system operator's reference to points by their name has been reduced by the introduction of the graphic terminal, which produces system schematics and displays the actual values of the points and variables in their representative place without referring to the actual name. Nevertheless, a good naming convention greatly enhances troubleshooting of installed systems because programs are made readable and easy to comprehend.

There are several methods of naming points. The key elements in virtually all of them are the modular structure of the name and the consistency with which it is used throughout an installation. Consult with the owner to determine a desirable method. The sample specification recommends a naming convention; the BAS designer should modify the naming convention if a different one is desired.

The modular nature of a name allows a particular name to identify the function of a point, the physical device or environment it is in, the type of system to which it belongs, and its location in the building or the system identification. In some cases, with larger systems, the actual building or portion of the building must be identified.

Naming consistency is important. This will facilitate ease of report generation by allowing regular expressions in requests—for example, all temperatures, everything in the South Wing, or every element associated with air-handling system A01. It also allows any operator or service technician to identify the elements of the BAS in the building without requiring intimate knowledge of it.

9.17.3 Other Programming and Database Setup. This article is the proper location to specify the appearance, makeup, and navigation route for graphic screens of the operator interface. For example, one may specify color, menus, and type of animation, if any. Actions to occur in a graphic display—such as pop-up screen messages, a change to a specific screen graphic, or other notification based on equipment runtime or alarm—are specified here.

Most manufacturers' equipment can perform almost anything imaginable. The result is the product of the creativity and artistic talent of the programmer and the time and cost invested in producing the final product.

Also, this article is the place to specify any action to be initiated by the system under special conditions, such as alarm annunciation and prioritization. User access, special trend logging requirements, and other additional system functions should be added to this article.

9.17.3.1 Project Considerations. Modify the naming convention to be used if the owner has a preferred naming system.

If the composition of the operator interface is important, add a paragraph to specify the appearance, makeup, and navigation route for graphic screens of the operator interface.

Add a paragraph to specify any special action to be initiated by the BAS, user access, special trend logging requirements, and other additional BAS functions.

3.17 PROGRAMMING

A. Provide sufficient internal memory for the specified sequences of operation and trend logging. There shall be a minimum of 25% of available memory free for future use.

B. Point Naming. System point names shall be modular in design, allowing easy operator interface without the use of a written point index. Use the following naming convention: AA.BBB.CCDDE where

1. AA is used to designate the location of the point within the building, such as mechanical room, wing, or level, or the building itself in a multibuilding environment,
2. BBB is used to designate the mechanical system with which the point is associated (e.g., A01, HTG, CLG, LTG),
3. CC represents the equipment or material referenced (e.g., SF for supply fan, RW for return water, EA for exhaust air, ZN for zone),
4. D or DD may be used for clarification or for identification if more than one CC exists (e.g., SF10, ZNB),
5. E represents the action or state of the equipment or medium (e.g., T for temperature, H for humidity, C for control, S for status, D for damper control, I for current).

C. Software Programming

1. Provide programming for the system and adhere to the sequences of operation provided. All other system programming necessary for the operation of the system, but not specified in this document, also shall be provided by the contractor. Imbed into the control program sufficient comment statements to clearly describe each section of the program. The comment statements shall reflect the language used in the sequences of operation. Use the appropriate technique based on the following programming types:
   a. Text-based
      1. Must provide actions for all possible situations
      2. Must be modular and structured
      3. Must be commented
   b. Graphic-based
      1. Must provide actions for all possible situations
      2. Must be documented
   c. Parameter-based
      1. Must provide actions for all possible situations
      2. Must be documented

D. Operator Interface

1. Standard graphics—Provide graphics for all mechanical systems and floor plans of the building. This includes each chilled water system, hot water system, chiller, boiler, air handler, and all terminal equipment. Point information on the graphic displays shall dynamically update. Show on each graphic all input and output points for the system. Also show relevant calculated points such as setpoints.
2. Show terminal equipment information on a graphic summary table. Provide dynamic information for each point shown.
3. The contractor shall provide all the labor necessary to install, initialize, start up, and troubleshoot all operator interface software and its functions as described in this section. This includes any operating system software, the operator interface database, and any third-party software installation and integration required for successful operation of the operator interface.

9.18 BAS Checkout and Testing. BAS checkout and testing must be performed by the controls subcontractor prior to acceptance by the owner. Checkout and testing verify that the system is complete and performs as designed. The contractor should

a. observe and make adjustments, calibrations, and measurements;
b. perform tests of the BAS;
c. tune the controllers;
d. set schedules; and
e. make any necessary BAS corrections to ensure that the systems function as described in the sequences of operation.

The contractor should permanently record—on system equipment schedules—the final setting of controller proportional-integral-derivative (PID) constant settings, setpoints, manual reset values, maximum and minimum controller output, and ratio and bias settings, in units and terminology specific to the controller.

During checkout, each control device (e.g., sensors and actuators) is tested to ensure that it is operating properly and is calibrated. Additionally, each piece of equipment and system shall be run through its range of operation, including part-load operation, and the results documented. It is during this phase that control loops and PID control constants are adjusted or verified and control interfaces to other building systems, such as fire and smoke BASs, are tested to ensure proper system operation.

Once all input and output points are checked for proper operation and calibration, the start-up and testing of the sequences of operation will occur. Testing of the sequences of operation should be performed methodically, from simple start/stop through all control routines.

Generally, this follows the sequences of operation step by step. For example, testing for a VAV air-handling unit may include the following steps:

a. Start/stop of equipment, including morning warm-up, night override, and shutdown
b. Duct static pressure control
c. Ventilation/economizer control
d. Cooling control
e. Heating control
f. Alarms
g. Reports

As part of the effort to start up and test the sequences or operation, the contractor shall tune all control loops. This involves an iterative determination of proportional and integral settings in each control loop, often a very time-consuming process.

3.18 BAS CHECKOUT AND TESTING

A. Start-up Testing. All testing listed in this article shall be performed by the contractor and shall make up part of the necessary verification of an operating BAS. This testing shall be completed before the owner's representative is notified of the system demonstration.

1. The contractor shall furnish all labor and test apparatus required to calibrate and prepare for service of all instruments, controls, and accessory equipment furnished under this specification.
2. Verify that all control wiring is properly connected and free of all shorts and ground faults. Verify that terminations are tight.
3. Enable the BASs and verify calibration of all input devices individually. Perform calibration procedures according to manufacturers' recommendations.
4. Verify that all binary output devices (relays, solenoid valves, two-position actuators and control valves, magnetic starters, etc.) operate properly and that the normal positions are correct.
5. Verify that all analog output devices (I/Ps, actuators, etc.) are functional, that start and span are correct, and that direction and normal positions are correct. The contractor shall check all control valves and automatic dampers to ensure proper action and closure. The contractor shall make any necessary adjustments to valve stem and damper blade travel.
6. Verify that the system operation adheres to the sequences of operation. Simulate and observe all modes of operation by overriding and varying inputs and schedules. Tune all DDC loops and optimum start/stop routines.
7. Alarms and Interlocks
   a. Check each alarm separately by including an appropriate signal at a value that will trip the alarm.
   b. Interlocks shall be tripped using field contacts to check the logic, as well as to ensure that the fail-safe condition for all actuators is in the proper direction.
   c. Interlock actions shall be tested by simulating alarm conditions to check the initiating value of the variable and interlock action.

9.19 BAS Demonstration and Acceptance. It is important to demonstrate to the owner that the system and its components as installed and previously tested meet the requirements of the contract documents in all respects. Therefore, many of the tests previously performed by the subcontractor may be repeated for demonstration and/or documentation to the owner.

The sample specification requires that the owner's representative be present to witness all tests demonstrating all aspects of system performance. The time commitment required for this will be extensive and must be anticipated by the BAS designer. If the commitment cannot be met, then the specification should be modified to clarify how much of the system should be demonstrated. Either way, all forms and checklists prepared or completed by the subcontractor are required by the specification for submission and approval.

The sample specification requires that the demonstration process be defined by the contractor for approval as part of the submittals. However, the BAS designer, owner, or a commissioning agent may prefer to define the process instead. If so, a detailed discussion of the process, including all forms and checklists to be used, must be added to the specification. Do not underestimate the detail and volume of forms/checklists required. Also, note that the project may include commissioning.

9.19.1 Project Considerations. Specification Article 1.4, "Related Sections" of the specification as written assumes that the commissioning process is defined in a separate section of the specification. However, the BAS designer may choose to define the commissioning process in this section. If so, a new paragraph needs to be added to this article.

If no demand limiting control is used in the project, delete the demand limiting paragraph.

If the time commitment by the BAS designer or owner to observe the demonstration cannot be met, then modify the subparagraph that states that the BAS designer will be present and remove the notification requirement. Where the BAS designer requires notification, modify the time required for notification as appropriate for the specific project.

3.19 BAS DEMONSTRATION AND ACCEPTANCE

A. Demonstration

1. Prior to acceptance, the BAS shall undergo a series of performance tests to verify operation and compliance with this specification. These tests shall occur after the Contractor has completed the installation, started up the system, and performed his/her own tests.
2. The tests described in this section are to be performed in addition to the tests that the contractor performs as a necessary part of the installation, start-up, and debugging process and as specified in Article 3.18, "BAS Checkout and Testing" of this specification. The BAS designer will be present to observe and review these tests. The BAS designer shall be notified at least ten days in advance of the start of the testing procedures.
3. The demonstration process shall follow that approved in Article 1.10, "Submittals." The approved checklists and forms shall be completed for all systems as part of the demonstration.
4. The contractor shall provide at least two persons equipped with two-way communication and shall demonstrate actual field operation of each control and sensing point for all modes of operation including day, night, occupied, unoccupied, fire/smoke alarm, seasonal changeover, and power failure modes. The purpose is to demonstrate the calibration, response, and action of every point and system. Any test equipment required to prove the proper operation shall be provided by and operated by the contractor.
5. As each control input and output is checked, a log shall be completed showing the date, technician's initials, and any corrective action taken or needed.
6. Demonstrate compliance with Article 1.9, "BAS Performance."
7. Demonstrate compliance with sequences of operation through all modes of operation.
8. Demonstrate complete operation of operator interface.
9. Additionally, the following items shall be demonstrated:
   a. DDC loop response. The contractor shall supply trend data output in a graphical form showing the step response of each DDC loop. The test shall show the loop's response to a change in setpoint, which represents a change of actuator position of at least 25% of its full range. The sampling rate of the trend shall be from 10 seconds to 3 minutes, depending on the speed of the loop. The trend data shall show for each sample the setpoint, actuator position, and controlled variable values. Any loop that yields unreasonably under-damped or over-damped control shall require further tuning by the Contractor.
   b. Demand limiting. The contractor shall supply a trend data output showing the action of the demand limiting algorithm. The data shall document the action on a minute-by-minute basis over at least a 30-minute period. Included in the trend shall be building kW, demand limiting setpoint, and the status of sheddable equipment outputs.
   c. Optimum start/stop. The contractor shall supply a trend data output showing the capability of the algorithm. The change-of-value or change-of-state trends shall include the output status of all optimally started and stopped equipment, as well as temperature sensor inputs of affected areas.
   d. Interface to the building fire alarm system.
   e. Operational logs for each system that indicate all setpoints, operating points, valve positions, mode, and equipment status shall be submitted to the architect/BAS designer. These logs shall

cover three 48-hour periods and have a sample frequency of not more than 10 minutes. The logs shall be provided in both printed and disk formats.

10. Any tests that fail to demonstrate the operation of the system shall be repeated at a later date. The contractor shall be responsible for any necessary repairs or revisions to the hardware or software to successfully complete all tests.

B. Acceptance

1. All tests described in this specification shall have been performed to the satisfaction of both the BAS designer and owner prior to the acceptance of the BAS as meeting the requirements of completion. Any tests that cannot be performed due to circumstances beyond the control of the contractor may be exempt from the completion requirements if stated as such in writing by the BAS designer. Such tests shall then be performed as part of the warranty.

2. The system shall not be accepted until all forms and checklists completed as part of the demonstration are submitted and approved as required in Article 1.10, "Submittals."

9.20 Cleaning. This section describes special instructions for the controls subcontractor for cleanup and disposal of materials. The contractor is responsible for daily cleanup of the work area. This will ensure that areas are kept free of debris that could potentially injure others or cause damage to equipment.

Cleaning also may be covered under the general terms and conditions for the project (Division 0). If this is the case, then it is only required in this section of the specification to note if any special cleaning is required. For example, if the general contractor has responsibility for cleaning the site and disposing of waste, then this section might be omitted. However, if this is a retrofit project and each subcontractor is responsible for cleanup on his/her own work, then special instructions are required in this section.

9.20.1 Project Considerations. Delete this article if it is covered elsewhere, such as in Division 0.

3.20 CLEANING

A. The contractor shall clean up all debris resulting from his/her activities daily. The contractor shall remove all cartons, containers, crates, etc., under his/her control as soon as their contents have been removed. Waste shall be collected and placed in a designated location.

B. At the completion of work in any area, the contractor shall clean all work, equipment, etc., keeping it free from dust, dirt, and debris, etc.

C. At the completion of work, all equipment furnished under this section shall be checked for paint damage, and any factory-finished paint that has been damaged shall be repaired to match the adjacent areas. Any cabinet or enclosure that has been deformed shall be replaced with new material and repainted to match the adjacent areas.

9.21 Training. Training requirements for the BAS are different for each owner and will vary based on the experience and background of users. The proper amount and type of training will ensure that the system operators are able to effectively operate the equipment and building the way it was envisioned. The designer is responsible for identifying the training needs of the owner's staff and tailoring the specification to reflect their requirements. The important thing to remember is that training costs money and will affect the bid price.

Following are some important criteria regarding training:

a. Training is an investment in people. As with providing the proper equipment and tools, system operators must be provided with the necessary amount of training. Management must make a commitment to train their operators.

b. Operators must be made accountable for learning. Unfortunately, the amount of knowledge gained from training is often directly related to the motivational level of the participants. More advanced training should be directed to more motivated individuals.

The following factors affect the selection and length of training classes:

a. Training based on the BAS user's job function:
    - Monitoring and operation
    - Maintenance and troubleshooting
    - Administrative and system management

b. Training based on the experience level of the BAS user:
    - No experience
    - Monitoring only
    - Advanced

c. Operators' knowledge of PCs and software

Edit this section of the example specification to tailor the classroom training sessions and hours based on the owner's needs. Do not assume that the manufacturer will provide the proper amount of training. Spell out exactly what is required.

Periods of training followed by on-the-job interaction with the actual BAS will be most effective. This will give operators a chance to work with the equipment, encounter problems, and return to the classroom where questions can be answered. Training should be timed so that system operators are competent on the first day of beneficial use of the system.

9.21.1 Project Considerations. Modify the paragraph to reflect the appropriate number of sessions, days, and hours.

3.21 TRAINING

A. Provide a minimum of four on-site or classroom training sessions, three days each, throughout the contract period for personnel designated by the owner.

It is recommended that refresher courses be given at appropriate intervals following the system's turnover or BAS's acceptance (e.g., at 6 and 12 months). This may be limited by budget constraints and should be tailored to meet the owner's requirements. The following specification item attempts to cover the refresher course requirement.

9.21.2 Project Considerations. Modify the paragraph to reflect the appropriate number of sessions, months, and days.

If the work is not part of new building construction, replace "building's turnover" with "system acceptance" or another suitable description.

B. Provide two additional training sessions at 6 and 12 months following building's turnover. Each session shall be three days in length and must be coordinated with the building owner.

The primary user is the day-to-day BAS operator. There is no need to burden the day-to-day operator with the advanced functions of the DDC system, such as programming. They need to know how to use the system as a tool for their daily activities. These activities may include checking system status using graphics or point reports, adjusting setpoints, and acknowledging and responding to alarms. Most of the training should be oriented to these individuals.

Training can be divided into three general classes:

a. *Introductory training* should be designed to introduce the BAS to the operators. The typical length of this class is two to five days.
b. *Hands-on operator training* should be designed to make the operators familiar with the sequences of operation and comfortable with operating the BAS. This class should be held on site using the BAS. The typical length of this class is three to five days.
c. *Advanced training* should be designed to make the operators comfortable with advanced functions such as programming the system. The typical length of this class is one to two weeks.

Secondary users of the BAS include system managers/administrators. Design this class to provide these individuals with an overall view of the system. The typical training class length for administrators is four to eight hours.

C. Train the designated staff of owner's representative and owner to enable them to do the following:
   1. Day-to-day Operators:
      a. Proficiently operate the system
      b. Understand BAS architecture and configuration
      c. Understand system components
      d. Understand system operation, including BAS control and optimizing routines (algorithms)
      e. Operate the workstation and peripherals
      f. Log on and off the system
      g. Access graphics, point reports, and logs
      h. Adjust and change system setpoints, time schedules, and holiday schedules
      i. Recognize malfunctions of the system by observation of the printed copy and graphical visual signals
      j. Understand system drawings and Operation and Maintenance manual
      k. Access data from controllers and ASCs
      l. Operate portable operator's terminals
   2. Advanced Operators:
      a. Make and change graphics on the workstation
      b. Create, delete, and modify alarms, including annunciation and routing of these
      c. Create, delete, and modify point trend logs and graph or print these both on an ad-hoc basis and at user-definable time intervals
      d. Create, delete, and modify reports
      e. Add, remove, and modify system's physical points
      f. Create, modify, and delete programming
      g. Add panels when required
      h. Add operator interface stations
      i. Create, delete, and modify system displays, both graphical and others
      j. Perform BAS field checkout procedures
      k. Perform BAS controller unit operation and maintenance procedures
      l. Perform workstation and peripheral operation and maintenance procedures
      m. Perform BAS diagnostic procedures
      n. Configure hardware including PC boards, switches, communication, and I/O points
      o. Maintain, calibrate, troubleshoot, diagnose, and repair hardware
      p. Adjust, calibrate, and replace system components
   3. System Managers/Administrators:
      a. Maintain software and prepare backups
      b. Interface with job-specific, third-party operator software
      c. Add new users and understand password security procedures

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Ensure that the contractor provides competent instructors to give full instruction to designated personnel in the adjustment, operation, and maintenance of the system. Instructors should be thoroughly familiar with all aspects of the subject matter they are to teach.

D. These objectives will be divided into three logical groupings. Participants may attend one or more of these, depending on level of knowledge required.

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1. Day-to-day Operators: parts 1-13
2. Advanced Operators: parts 1-29
3. System Managers/Administrators: parts 1-13 and 30-32

Classroom training should be offset with hands-on field training. The majority of the training should be hands-on, which is more effective. The hands-on training should occur on the operators' own equipment or in a lab environment where equipment is available.

E. Provide course outline and materials in accordance with Article 1.10, "Submittals," of this specification. The instructor(s) shall provide one copy of training material per student.
F. The instructor(s) shall be factory-trained instructors experienced in presenting this material.
G. Classroom training shall be done using a network of working controllers representative of the installed hardware.

9.22 Sequences of Operation. This is the most important part of the design. This section of the specification is where the sequences of operation should be inserted when they are not shown on the drawings. It is important that these sequences be clear as to what is expected to happen in all modes of operation and to be complete. See Clause 5.3, "Designing the DDC System," of this guideline for further discussion.

9.22.1 Project Considerations. Insert the sequences of operation into this article or create sequences as a project drawing.

3.22 SEQUENCES OF OPERATION

A. [Provide operation as shown on drawings].

10. INSTRUCTIONS TO OTHER CONTRACTORS

Most projects involve a variety of subcontractors for the mechanical portion of the installation. These subcontractors typically include a piping subcontractor and sheet metal subcontractor, along with the controls subcontractor. It is most efficient for these other subcontractors to install such temperature control items as valves and dampers, even if they are supplied by the controls subcontractor. Therefore, instructions for proper installation of these devices must be included in all other applicable sections of the specification. The purpose of this clause is to discuss these other sections.

There are a number of controls products provided by the controls subcontractor that are normally installed by other subcontractors. For example, dampers are usually installed by the sheet metal subcontractor and valves by the piping subcontractor. Therefore, it makes sense to show the installation requirements for these items in the appropriate other sections of the specification. The following guidelines discuss those requirements and provide specification language that can be inserted by the designer in these other sections.

Caution: It is ultimately the responsibility of the prime contractor to meet all requirements of the specification. Therefore, placement of installation instructions in other sections is not necessarily an indication of which subcontractor is to perform a task. The prime contractor must allocate the work. The designer should be careful to avoid being drawn into a conflict between subcontractors, each of whom may insist that it is not their responsibility to install a certain control device.

10.1 Control Valve Installation. A valve can be properly selected and sized and still be a failure if it is not properly installed. Globe valves and other linear-motion valves should be installed vertically. In this position, there is less bending movement and stress at the bonnet connection and less deflection at the guides. If the valve must be installed horizontally, the mass of the actuator, as well as the acceleration due to vibration and seismic forces, must be considered. If the pipe is vertical, the actuator may need to be supported by a brace or hanger from the pipe. Thermal expansion must be allowed for. The problem with mounting a linear-motion valve with the actuator below the packing box is the possibility of leakage into the actuator. Actuators are designed to drain in their normal, upright position.

A rotary-stem valve should be mounted with the valve stem horizontal to prevent the bottom bearing from being at the low point of the pipe where dirt will collect. The direction of the opening should be such that any sediment that may have settled out of the stream while the valve was closed will be swept along as the valve opens. That is, the valve on the butterfly valve should rotate upward as the valve opens. The actuator on rotary-motion valves can usually be oriented in any direction.

Some valves are constructed so that much of the maintenance can be performed while the valve is in place. In this case, the valve should be located with sufficient clearance to perform repairs and to be removed from the line, if necessary. However, performance comes first. It is better to locate the valve so that it performs well and requires little maintenance than to locate it strictly for ease of maintenance.

Avoid locating the valve where the actuator will be exposed to high temperatures. Consider 65°C (150°F) a maximum. Diaphragms, seals, and positioner parts are adversely affected by temperature.

Because pipes are known to vibrate, it is important that the air lines, hydraulic tubing, and electrical connections to actuators be sufficiently flexible.

Butterfly valves swing out into adjacent piping and therefore must clear any obstacle that may be present. For example, a butterfly valve could not be flanged directly to another butterfly valve or check valve. Lined pipe or lined butterfly valves can create special problems.

There must be adequate clearance at the adjacent fittings for the flange bolts to be installed. In this respect, eccentric reducers often become traps for the unwary. Flangeless valves require extra long studs or rods to connect the companion flanges. They also need a clearance to match.

It is important that condensate not be allowed to accumulate in a steam line either before or after a control valve.

There must be steam traps at all low points. When the valve is closed, the steam on the downstream side of the valve condenses and forms a vacuum. When this happens, the condensate cannot be discharged through an ordinary steam trap. If the trap discharges to the atmosphere, this problem can be solved by adding an air vent or vacuum breaker to the line at the highest point. This allows air to enter and the condensate to drain. An alternative is a vacuum trap that uses live steam to force the condensate out despite the pressure difference. This is a costly and complex measure. Another way to overcome the problem is to design the system so that any condensate that gathers is drained to the end of the system in a vertical line at a location where it is swept along by the high-velocity steam when the valve reopens. The downstream piping should never flow upward in such cases. If the trap discharges to a condensate header that is elevated or at a pressure above atmospheric, special care must be taken.

The reason why all of this is so important is that a small amount of condensate can be accelerated to rifle-bullet velocity when steam is introduced to a line under vacuum. The forces can be great enough to destroy the piping system. There are other reasons for concern. Steam should never be turned into a cold line suddenly because thermal shock can cause pipe failure. It is common practice to install a small bypass line around large steam block valves to warm up the line slowly. There are many ways that a control valve can open suddenly before the line has been warmed. To be safe, it is wise to allow a small amount of steam to bleed through a warm-up line.

Place the following specification language in Part 3, "Execution," of the specification section that deals with valves and appurtenances or, if a separate section is written, in control valves.

3.23 CONTROL VALVE INSTALLATION

A. Valve submittals shall be coordinated for type, quantity, size, and piping configuration to ensure compatibility with pipe design.

B. Slip-stem control valves shall be installed so that the stem position is not more than 60 degrees from the vertical up position. Ball type control valves shall be installed with the stem in the horizontal position.

C. Valves shall be installed in accordance with the manufacturer's recommendations.

D. Control valves shall be installed so that they are accessible and serviceable and so that actuators may be serviced and removed without interference from structure or other pipes and/or equipment.

E. Isolation valves shall be installed so that the control valve body may be serviced without draining the supply/return side piping system. (Note to designer: This must also be shown.) Unions shall be installed at all connections to screw-type control valves.

F. Provide tags for all control valves indicating service and number. Tags shall be brass, 1 1/2 in. in diameter, with 6.4 mm (1/4 in.) high letters. Securely fasten with chain and hook. Match identification numbers as shown on approved controls shop drawings.

10.2 Hydronic Pressure Sensor Installation. The mechanical subcontractor typically provides fittings and valves for pressure transducers. The controls subcontractor must provide locations for these devices.

The valve arrangement is as shown in Figure 10.2. Use this diagram to create or edit a detail for the piping installation. No specification language is required. Five valves are required. Two valves are used for isolation, one each on the high and low side to the transducer. These can be used to close the flow to the sensor. A crossover valve must be provided for calibration. The remaining two valves vent the high and low sides.

The taps for the liquid service lines should be at or below the horizontal midline of the pipe and the slope of the sensing lines should be down from the isolation valves to the sensor so that any vapor will not be trapped in the sensor lines. Tap gas or steam lines on top of the pipe and slope the sensor lines up from the isolation valves to the sensor so that any liquid or condensate will drain back into the service lines. Provide drip or dirt legs on the isolation lines as required to keep the sensor clean.

When the transducer is in service, the two vent valves and the crossover valve are closed and the two isolation valves are open. To service the sensor, the isolation valves are closed, then the vent valves are opened to relieve pressure. For calibration, the isolation valves are closed, the crossover valve is opened, and the vent valves are closed. This ensures equal pressure on the high and low ports.

To place the unit back into service, slowly open both isolation valves with open vent valves to bleed air from all lines. Then close the vent valves and open the isolation valves fully. Finally, close the crossover valve.

Snubbers should be used on all steam pressure sensors to isolate the sensor from the steam itself.

10.3 Control Damper Installation. The control dampers are typically installed by the sheet metal subcontractor but are supplied by the controls subcontractor. This work needs to be coordinated between the sheet metal subcontractor and the controls subcontractor to ensure that properly sized control dampers and ductwork are effectively handled. Also, the coordination should ensure that the control dampers are supplied to the sheet metal subcontractor at the appropriate time during the project to meet the sheet metal installation schedule. This section of the specification is typically inserted under the sheet metal section of the specification. The BAS designer should ensure that the dampers' sizes and types are clearly shown on the drawings and properly listed in the damper table on the drawings.

Improperly installed dampers and damper sections prevent blades from sealing properly. Gaps between the blades and frame indicate a damper installed out-of-flat (twisted). Misalignment of the damper or damper sections can cause a

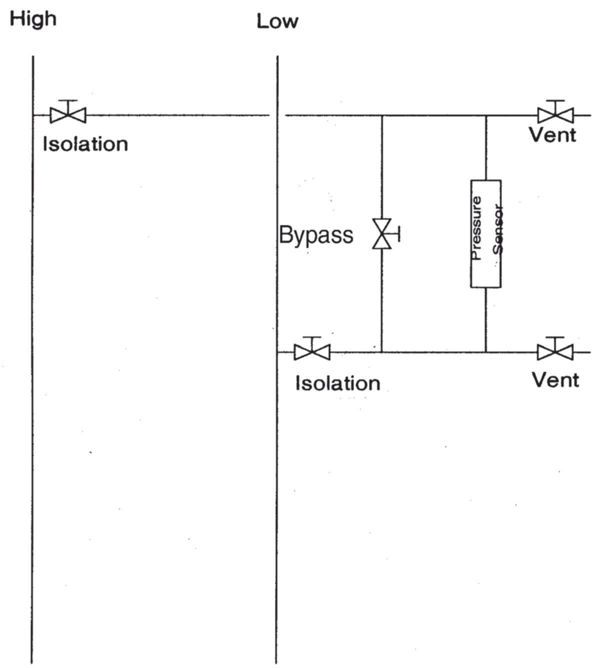

FIGURE 10.2 Valve arrangements.

twist in the frame, resulting in blade to linkage binding. This overloads the damper section and can render it inoperable.

When tightening the mounting screws, first start on one side by tightening the top and bottom and then finish with the other side. This will help keep the damper square. Stressing the damper by trying to compress the duct wall with the mounting screws can cause binding and an inoperative damper. Fill any gaps at the top and sides with a filler strip.

The following language is typically inserted in Part 3, "Execution," of the sheet metal specification.

3.24 CONTROL DAMPER INSTALLATION

A. Damper submittals shall be coordinated for type, quantity, and size to ensure compatibility with sheet metal design.
B. Duct openings shall be free of any obstruction or irregularities that might interfere with blade or linkage rotation or actuator mounting. Duct openings shall measure 6.4 mm (1/4 in.) larger than damper dimensions and shall be square, straight, and level.
C. Individual damper sections, as well as entire multiple section assemblies, must be completely square and free from racking, twisting, or bending. Measure diagonally from upper corners to opposite lower corners of each damper section. Both dimensions must be within 0.3 cm (1/8 in.) of each other.
D. Follow the manufacturer's instructions for field installation of control dampers. Unless specifically designed for vertical blade application, dampers must be mounted with blade axis horizontal.
E. Install extended shaft or jackshaft according to manufacturer's instructions. (Typically, a sticker on the damper face shows recommended extended shaft location. Attach shaft on labeled side of damper to that blade.)
F. Damper blades, axles, and linkage must operate without binding. Before system operation, cycle damper after installation to ensure proper operation. On multiple section assemblies, all sections must open and close simultaneously.
G. Provide a visible and accessible indication of damper position on the drive shaft end.
H. Support ductwork in area of damper when required to prevent sagging due to damper weight.
I. After installation of low-leakage dampers with seals, caulk between frame and duct or opening to prevent leakage around perimeter of damper.

10.4 Fire/Smoke Damper Coordination. The application of smoke and combination smoke/fire dampers must be carefully considered and coordinated in order for these devices to accomplish their intended functions. Two major applications are:

a. Isolation of a smoke zone from adjacent zones by installing smoke-event-actuated dampers in ducts and/or openings that pass through barrier walls and/or floors separating one zone from another. (The barriers may also be fire-rated, in which case a combination smoke/fire damper would be used.) Smoke/fire dampers are also often required to protect rated exit corridors.
b. Installation of smoke-event-actuated dampers in duct and wall openings for smoke management purposes in "engineered smoke control" applications. (Refer to NFPA and appropriate building code sections.)

To properly apply and select these devices, consider the following items:

a. Location of the smoke damper
b. Type of damper actuator (pneumatic or electronic)
c. Normal position of the damper (open or closed)
d. Leakage class (I, II, III, or IV)
e. Temperature rating (121°C [250°F] or 177°C [350°F])
f. What will actuate the damper on an alarm condition (local detector, zone detector, general alarm, HVAC interlock, etc.)
g. Local codes that may have special supervision requirements and/or UL listings

Generally, application of smoke and combination smoke/fire dampers will involve the architectural, HVAC, and electrical design teams and the sheet metal, electrical, and controls subcontractors' construction and commissioning teams. The local code authority and/or the fire marshal often will be involved. It is essential that all parties involved understand and agree to the intended function of these dampers so that they will be properly specified, installed, connected, and tested.

Close coordination between design teams and installation subcontractors is essential for these dampers to function properly. Normally, the architect and HVAC design teams identify the dampers' functions and locations. Then the fire detection and alarm system designer provides for the actuation signal (and sometimes for the actuator power source) or provides for passing the information to the BAS.

The dampers are installed (and sometimes furnished) by the sheet metal subcontractor and are connected to the control signal by the electrical, fire detection system, or controls subcontractor. Testing becomes a joint effort between the fire detection system subcontractor, the HVAC subcontractor, the controls subcontractor, the testing and balancing agency, and/or a separate commissioning agent.

10.4.1 Project Considerations

a. Damper functions and locations (e.g., smoke only or combination smoke/fire dampers)
b. Functional considerations such as leakage class, temperature rating, normal position, etc.
c. Type of actuator
    1. *Pneumatic actuators* are simpler and easier to construct for higher temperature ratings. However, if a control air source is not already in place for other purposes, this option may be more costly. If the fire alarm system drives the dampers, a solenoid air valve (low or line voltage) will be required for each interface with the fire alarm system.

       Some building codes (e.g., *International Building Code*) require that all pneumatic air piping associated with smoke dampers be metallic (not plastic) and that if plastic piping is used in other parts of the pneumatic system, the smoke control portion will be isolated such that it will not be affected by failure of a plastic pipe or fitting in other parts of the BAS.
    2. *Electric actuators* may be less expensive for some applications, but the design team must be careful to provide a power source for these actuators in addition to the alarm system control interface. Actuator power (whether line voltage or low voltage) is often provided by a specification's electrical sections, especially if the controls subcontractor does not furnish the smoke dampers. However, close coordination between the disciplines is required to ensure that both actuator power and the fire alarm interface are provided in the contract documents and that the required sequence of operation is clearly described. If numerous smoke or smoke/fire dampers and fans are involved, a control matrix (fire zone or detector trip versus damper position and/or fan operation) may be needed to describe the desired sequences of operation.

The following language is typically inserted in Part 3, "Execution," of the sheet metal accessories specification (or wherever the smoke dampers are specified):

3.25 SMOKE DAMPER INSTALLATION

A. The contractor shall coordinate all smoke and smoke/fire damper installation, wiring, and checkout to ensure that these dampers function properly and that they respond to the proper fire alarm system general, zone, and/or detector trips. The contractor shall immediately report any discrepancies to the BAS designer no less than two weeks prior to inspection by the code authority having jurisdiction.

10.5 Duct Smoke Detection. Duct smoke detectors are required by most codes on air-handling equipment with capacities over 56.6 m^3/min (2000 cfm). When there is a fire alarm system in the building, the duct detection system is required to be connected to the fire alarm system. If no fire alarm system is required in the building, the duct detectors may be stand-alone units that de-energize the fan upon detection of smoke.

When there is a fire alarm system in the building, the fire alarm system subcontractor should supply the duct detector and any required accessories. This ensures that the duct detectors will be compatible with the alarm system. Underwriters Laboratories requires that detectors used on a fire alarm system be cross-listed for use with that system. If the controls subcontractors were to provide the detectors, there would be no way during the bidding process to know which brand of detectors will need to be furnished. This leads to higher pricing and frustration for all parties.

In buildings where there is no fire alarm system, the detectors can be furnished by the controls subcontractor or the electrical subcontractor. Local customs should be observed so that the bidders will not be caught off guard.

Installation of the detectors can be by any of the subcontractors. The controls and fire alarm subcontractors may have more familiarity with the installation requirements. When the controls subcontractor installs the detectors, its work is limited to mounting the detector and wiring the fan interlocks. The fire alarm subcontractor retains the responsibility for the alarm loop wiring.

In the addressable type of fire alarm systems, the duct detectors may not have dry contacts for fan shutdown. In this case, a contact output module is provided that has the dry contacts for fan shutdown. The module is commanded from the fire alarm panel under program control. Alternatively, the fire alarm system provides smoke detector data to the BAS, which stops and starts fans.

The installation of the duct smoke detectors is typically the responsibility of the sheet metal subcontractor and the 120 V wiring is typically the responsibility of the electrical subcontractor. Usually the smoke detectors are supplied by the controls subcontractor to the sheet metal subcontractor for installation. This work needs to be coordinated between the sheet metal subcontractor, the electrical subcontractor, and the controls subcontractor to ensure that the smoke detectors are installed in the proper locations of the ductwork. This section of the specification is typically inserted under the sheet metal section of the specification and is referenced in the electrical section for 120 V wiring. The BAS designer should ensure that the locations are clearly shown on the drawings and properly referenced in the different specification sections.

If an engineered smoke BAS is required for a project, additional information must be included in the specification that is not a part of this guideline. The exact smoke control sequence and requirements must be coordinated by the engineers with the fire life safety engineers and the local fire marshals to ensure that all the appropriate fire codes are met.

Insert the following specification language in Article 1.10, "Submittals," of the specification section where duct smoke detectors are specified (either in Division 15 or 16):

B. Provide complete submittal data to controls system subcontractor for coordination of duct smoke detector interface to HVAC systems.

Insert the following specification language into Part 3, "Execution," of the specification section where duct smoke detectors are specified (either in Division 15 or 16):

3.26 DUCT SMOKE DETECTION

A. Submit data for coordination of duct smoke detector interface to HVAC systems as required in Article 1.10, "Submittals."

B. This Contractor shall provide a dry-contact alarm output in the same room as the HVAC equipment to be controlled.

10.6 Taps and Wells. Pressure and temperature taps are an important aspect of the ability to commission and maintain a BAS. The sensors cannot have their calibration checked in place unless the sensed media can be measured by a second instrument and compared to the DDC reading. If there is a pressure and temperature tap near each instrument in a hydronic system, such a comparison easily can be made. It is the responsibility of the piping system designer to specify and show the locations of these taps. The control BSA designer should coordinate with the piping designer during the design process to ensure that the pressure and temperature plugs are shown at the correct locations. The taps are considered piping accessories and are furnished and installed by the piping subcontractor. The controls subcontractor may assist in the location of the taps in the field so they are close to the control devices.

Temperature wells isolate the temperature sensors from process media. They protect the sensor and, more importantly, allow the sensor to be removed without draining the piping. The temperature sensor wells are specified in the controls section. The wells are provided by the controls subcontractor. This ensures that the wells are compatible with the sensors used. The well type, material, and pressure rating are important to the life of the well. The installation of the well is the responsibility of the piping subcontractor. By installing the wells, the piping subcontractor has full responsibility for the integrity of the piping. The piping subcontractor installs weld-o-lets or tees and screws in the wells. The controls subcontractor installs the heat-conductive compound in the well and mounts and wires the sensor.

Other taps in the piping are also provided by the piping subcontractor. These taps allow for connection of pressure transmitters, flow switches, and other instrumentation. Careful consideration should be given to isolation valves on these taps to allow the instruments to be serviced and calibrated without draining the pipes.

The wells must be installed in the pipe such that the bottom of the well does not touch the pipe. If the pipe diameter is smaller than the well length, this can be accomplished by installing the well in a 90 degree elbow (or a tee) such that the bottom of the well faces into the direction of flow. This is the preferred installation at all times.

If the well must be installed in a section of straight pipe, the well can be angled in the pipe installation. In this case, the well should be angled such that the bottom of the well faces into the flow.

10.7 Application-Specific Controllers for Equipment Specified Under Other Sections. Packaged systems that are specified elsewhere often come bundled with their own microprocessor-based electronic controls. Examples include chillers, boilers, unit ventilators, lighting controls, and water heaters. If it is desirable to have these other control packages exchange information with the rest of the BAS energy management BAS, it is necessary for these controllers to be specified with the appropriate compatible communication protocols. It is also critically important to list the points of information and control in these packaged systems that will need to be read and/or adjusted from the BAS energy management BAS. The most appropriate place for this point list is in the same place where the other BAS points are listed. In this way, the DDC system supplier will be aware of the total number of points in the energy management system database, as well as any requirements for display, such as graphics. The BAS supplier will be responsible for commissioning and verifying communication between the equipment packaged controls and the system.

The following is a suggested specification article to be included under other HVAC sections. Similar language can be used under the specification for lighting control and water heaters, for instance. It is important to include the section number and title of the BAS in Article 1.4, "Related Sections," of the equipment specification and, conversely, to list the equipment sections in Article 1.4, "Related Sections," of the BAS section.

10.7.1 Project Considerations. See Informative Annex F for a reference to open-protocol guideline specification language for the LAN technologies that are available. The BAS designer needs to choose one or more protocols for use in the work. See Informative Annex E for a reference to open-protocol guideline specification language for the LAN technologies that are available.

Coordinate the data that the application-specific controller provides to the building-wide DDC system to build any special trends or reports, such as the ANSI/ASHRAE Standard 147 daily chiller report.

Under Part 2, "Products," of the specification, include the following article:

3.27 CONTROLS COMMUNICATION PROTOCOL

A. General. The electronic controls packaged with this equipment shall communicate with the building BAS. The BAS shall communicate with these controls to read the information and change the control setpoints as shown in the point list, sequences of operation, and control schematics. The information to be communicated between the BAS and these controls shall be in the standard object format as defined by the open protocol. Controllers shall communicate with other open-protocol BAS objects on the network using the protocol-specific service as defined by the protocol selected. [See Informative Annex F for a reference to open-protocol guideline specification language for the LAN technologies that are available.]

B. Distributed Processing. The controller shall be capable of stand-alone operation and shall continue to provide control functions without being connected to the network.

C. I/O Capacity. The controller shall contain sufficient I/ O capacity to control the target system.

D. Communication. The controller shall reside on a BAS open protocol network using the device-level protocol. Each network of controllers shall be connected to one building controller.

E. The Controller shall have a network connection for a laptop computer or a portable operator's tool.

F. Environment. The hardware shall be suitable for the anticipated ambient conditions.

   1. Controllers used outdoors and/or in wet ambient conditions shall be mounted within waterproof enclosures and shall be rated for operation at 40°C to 65°C (40°F to 150°F).
   2. Controllers used in conditioned space shall be mounted in dust-proof enclosures and shall be rated for operation at 0°C to 50°C (32°F to 120°F).

G. Serviceability. Provide diagnostic LEDs for power, communication, and processor. All wiring connections shall be made to field-removable, modular terminal strips or to a termination card connected by a ribbon cable.

H. Memory. The Controller shall maintain all BIOS and programming information in the event of a power loss for at least 90 days.

I. Immunity to Power and Noise. Controller shall be able to operate at 90% to 110% of nominal voltage rating and shall perform an orderly shutdown below 80%. Operation shall be protected against electrical noise of 5 to 120 Hz and from keyed radios up to 5 W at 1 m (3 ft).

   1. Transformer. Power supply for the Controller must be rated at minimum of 125% of ASC power consumption and shall be fused or current limiting type.

Under Part 3, "Execution," include the following articles:

3.28 START-UP AND CHECKOUT PROCEDURES

A. Start up, check out, and test all hardware and software and verify communication between all components.

   1. Verify that all control wiring is properly connected and free of all shorts and ground faults. Verify that terminations are tight.
   2. Verify that all analog and binary input/output points read properly.
   3. Verify alarms and interlocks.
   4. Verify operation of the integrated system.

11. VALVES AND DAMPERS

11.1 General. This introduces basic concepts in the design of a BAS in considering the mechanical equipment doing the actual modulation of the flow—the valves and dampers. Variable-frequency drives are alternative methods of controlling the medium flow but are beyond the scope of this document.

11.2 Control Valves. Proper valve selection matches a valve to the requirements of the application. First consider the application, then consider the necessary valve requirements and the piping arrangement. Is the requirement for three-way valves or straight-through valves? Three-way valves require more pumping energy; however, some applications do require mixing or diverting three-way valves.

Consider the valve end connection. Flared or sweat-end connections are less expensive and easier to install in copper pipe up to about DN 20 (3/4 in). Threaded-end connections are primarily used in connections up to DN 65 (2 1/2 in.). As the size of the valve increases, the difficulty of installing the valve and sealing the joint increases. Flanged-end connections permit the valves to be easily installed and removed from the pipe; however, flanged valves are bulkier and more expensive. These are generally used for valve sizes greater than DN 65 (2 1/2 in.).

The temperature and pressure of the medium being controlled will determine the materials from which the valve should be constructed and the ratings required of the valve. All valves should be rated to match the service in which they are installed. A minimum of ANSI Class 125 bronze (for copper piping systems) or ANSI Class 125 cast iron (for steel piping systems) is typical. Higher ratings may be required for high-rise installation.

Does the application require two-position or proportional control? For two-position operation, the valve is usually the same as the line size. For proportional control, the valve should be properly sized.

Water valves should be sized such that the pressure drop through the fully open valve is equal to the pressure drop through the branch it serves. In this way, the valve—and not the controlled device—will control the flow. Valve flow characteristics need to consider system gains. System gains occur when the response of system components is nonlinear. System gains are related to the control valve, heating and cooling coils, the supply temperature of the water, the airstream, and the interaction of these and other elements.

The valve flow characteristic should be selected to linearize the total response of the system at the controlled variable (such as discharge air temperature). This generally results in the selection of equal percentage characteristics for hot-water valves (and is useful in applications where wide load variations occur). Linear valve characteristics are generally preferred for steam and chilled-water applications.

For control valve sizing, refer to the *ASHRAE Handbook—HVAC Systems and Equipment*.

11.3 Dampers

11.3.1 General. Dampers regulate the flow of air either by modulating or by two-position control. In theory, the application of dampers in HVAC systems is similar to that of control valves. Unfortunately, dampers are typically chosen based on duct size and convenience of location rather than taking the time to properly select and size a damper for its application.

Low-leakage dampers can be specified when they are to be installed in areas where leakage can affect energy efficiency. Low leakage is achieved through a variety of features including blade edge seals, blade side seals, blade linkage, blade and frame reinforcements, and seat material.

Dampers are constructed in incremental sizes up to maximum vertical and horizontal limits. Dampers larger than this size are made up of a series of smaller sections linked together. Multiple section dampers can have the drive blades linked together to ensure operation of all sections together. This also allows the use of one motor. Alternatively, one could eliminate this linkage and provide an individual, smaller actuator for each section.

For modulating control, either parallel-blade or opposed-blade dampers can be used. If the primary resistance of the system is the damper, then parallel-blade dampers are preferred; however, if a significant series resistance exists, such as a coil, opposed-blade dampers should be used.

11.3.2 Damper Characteristics. The relationship between the damper blade position and the airflow through the damper is known as the *inherent characteristic*. The inherent characteristic is defined at a constant pressure drop with no series resistance (coils, filters, louvers, diffusers, etc.).

Inherent characteristic is based upon a constant pressure drop across the damper. This is generally not the case in a real-life application. Series resistance, such as ducts, coils, and louvers, causes the pressure drop to vary as the damper changes position. This results in the *installed characteristic* and is determined by the ratio of series resistance to damper resistance. This will be different for parallel-blade and opposed-blade dampers.

Series resistance modifies the airflow characteristic. The greater the series resistance, the greater the modification. The ratio of series resistance to damper resistance is called the *characteristic ratio*.

A characteristic ratio of 2.5 for parallel-blade dampers and 10 for opposed-blade dampers will result in performance closest to ideal linear, installed characteristics. With this information, the percent of total resistance provided by the damper can be determined as follows:

Total resistance (100%) =
damper resistance + series resistance

Characteristic ratio = series resistance/damper resistance
= ([total resistance/damper resistance] – 1)

Using the above information, we can determine the percent of total resistance the damper should provide for linear operation.

For parallel-blade dampers,
2.5 = ([100/damper resistance] – 1)

Damper resistance = 29% of total resistance
or 41% of the series resistance.

For opposed-blade dampers,
10 = ([100/damper resistance] – 1)

Damper resistance = 9% of total resistance
or 10% of the series resistance.

12. BAS DEVICE NETWORK DESIGN

12.1 Overview. This section outlines the design requirements for the BAS device network. It is provided as a standalone section for easy reference.

Clause 12.10 provides guidance on the specific contractor requirements. Refer to Clauses 3 and 4 for details on these terms and their usage in this document.

12.2 General

12.2.1 Multitier Architecture. The three-tier architecture model shown in Figure 12.2 is used to delineate the system elements.

12.3 Terms. In an effort to understand the various decision factors facing the BAS designer or project manager, an understanding of the comment elements of a system is necessary. Using the three-tier architecture model as defined in Figure 12.3, each tier requires specification details.

12.4 BAS Three-Tier Architecture. Control systems have the following main components.

a. **Tier 1—Enterprise Level.** This set of components—graphical user interfaces (GUIs), applications, central servers, databases, network management tools—is commonly referred to as "system software" but also includes the physical hardware, such as computer servers, on which this software runs (see Figure 12.4-1). This software accesses data from networked controllers; has communication protocol access the control network; and stores information and data about the system such that user interfaces, management tools, and other applications can display, analyze, manipulate, and interact with the control system. Clause 13 discusses legacy systems. Legacy system software tools may use proprietary databases; older computer operating systems may be too slow to meet current standards and be unsupported by the manufacturer.
b. **Tier 2—Building Infrastructure.** Collectively, communications, wiring, and network devices are referred to as the "infrastructure" and provide the connectivity to which hardware connects in a networked control system (see Figure 12.4-2). It includes components such as routers, repeaters, gateways, interfaces, wiring, network tools (such as protocol analyzers and network wiring diagnostic tools), and related components. Legacy systems often have a proprietary suite of tools, methods, and requirements for the infrastructure connectivity. Older systems

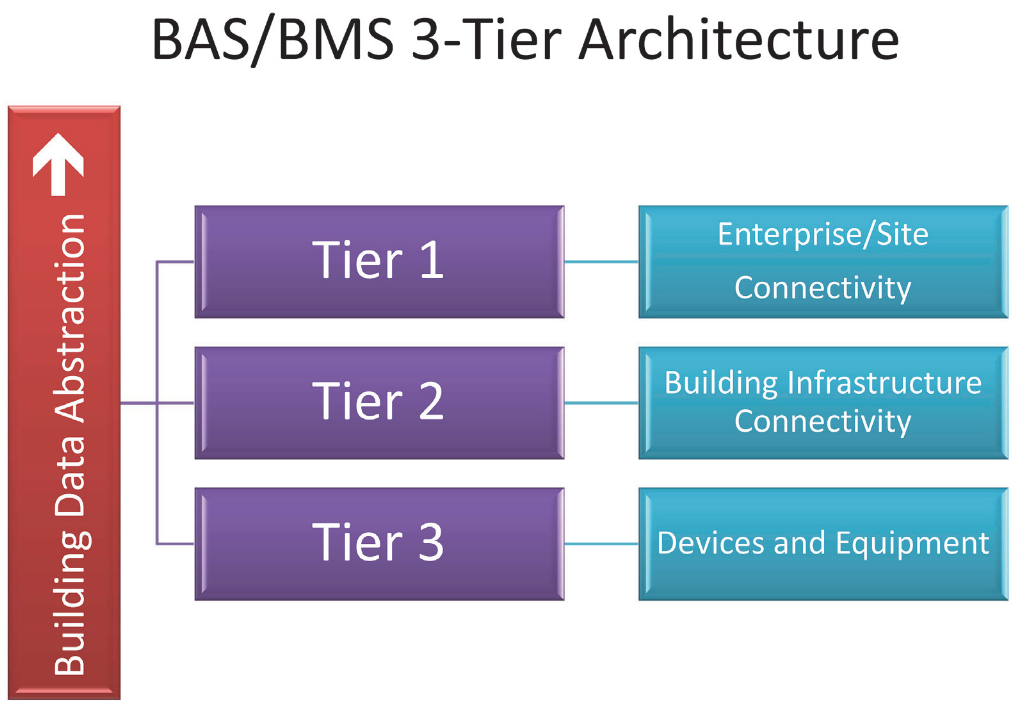

FIGURE 12.2 Building automation and building management system multitier architecture.

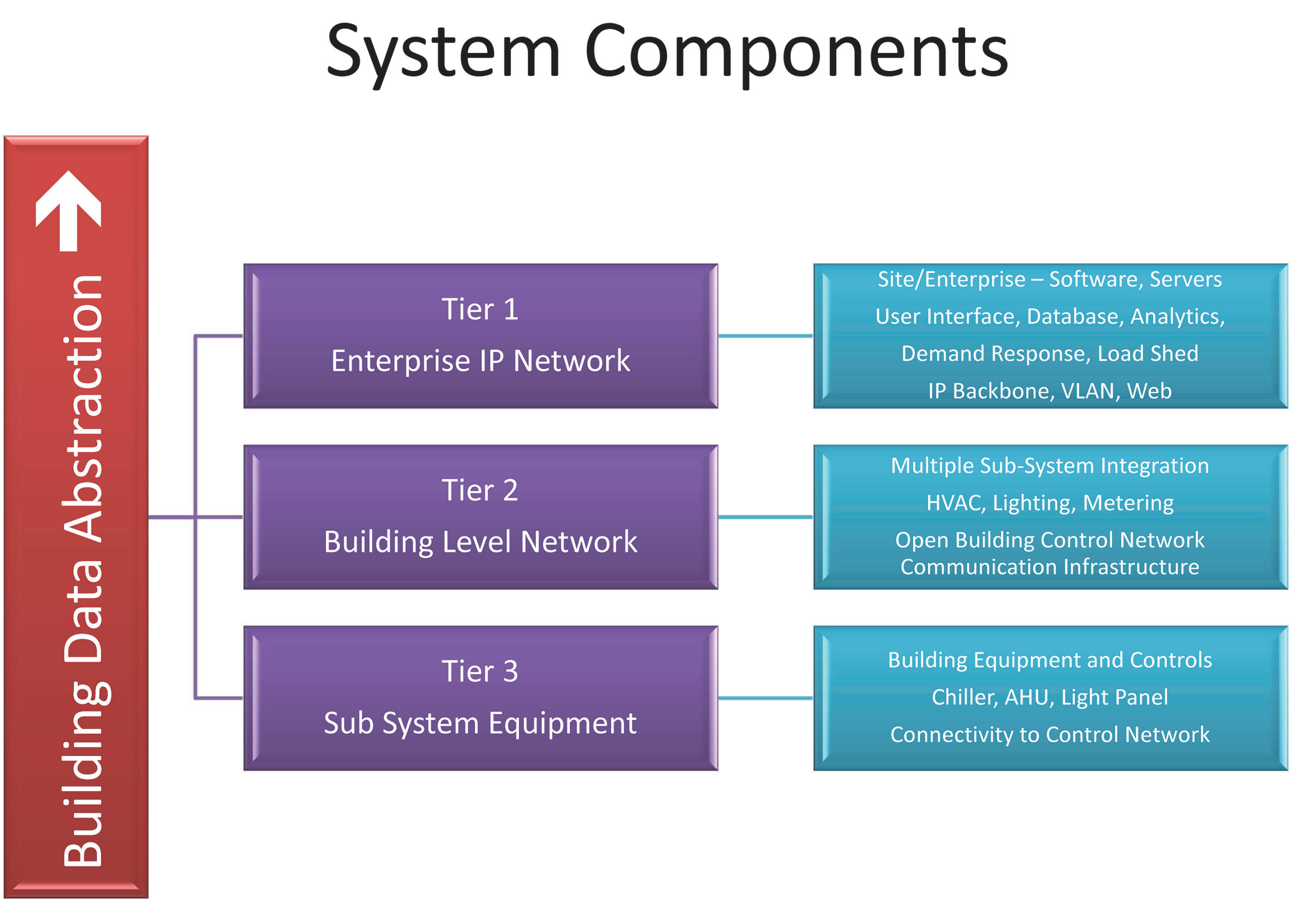

FIGURE 12.3 Three-tier building control system components.

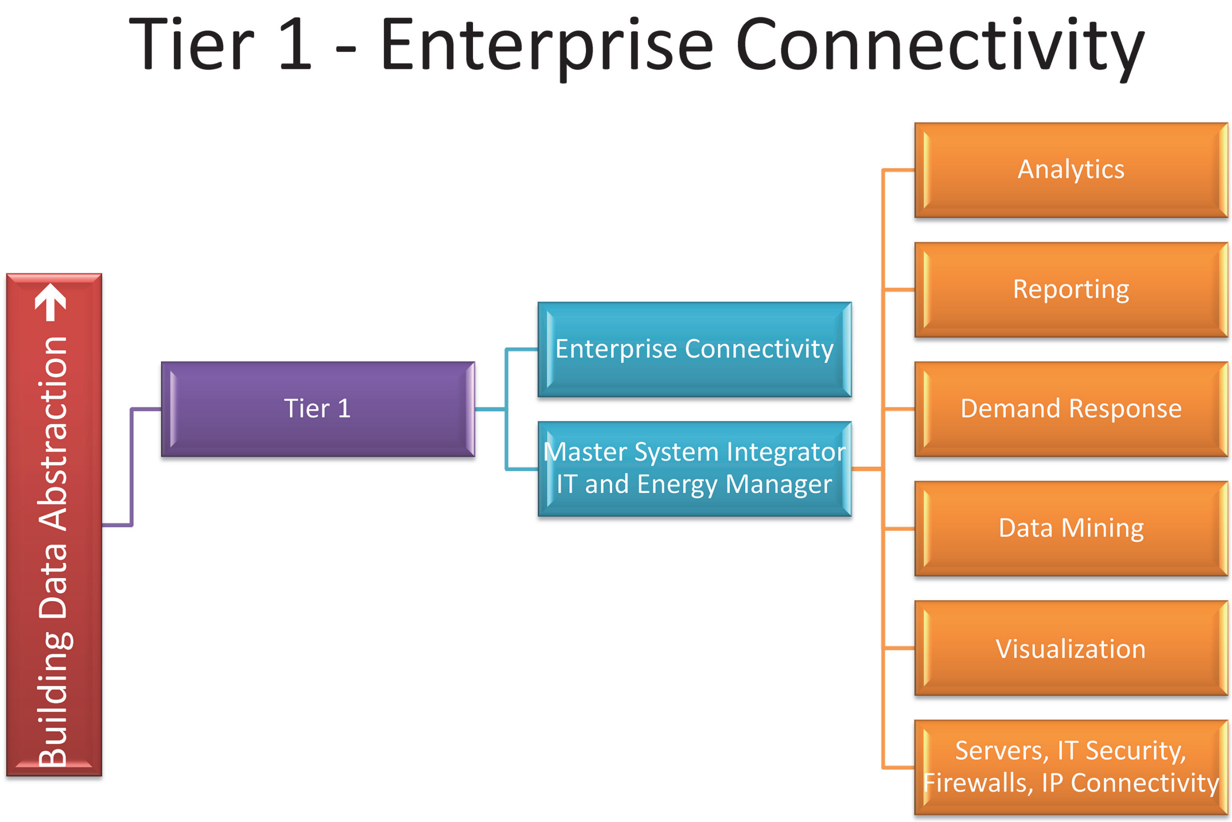

FIGURE 12.4-1 Tier 1—Enterprise connectivity.

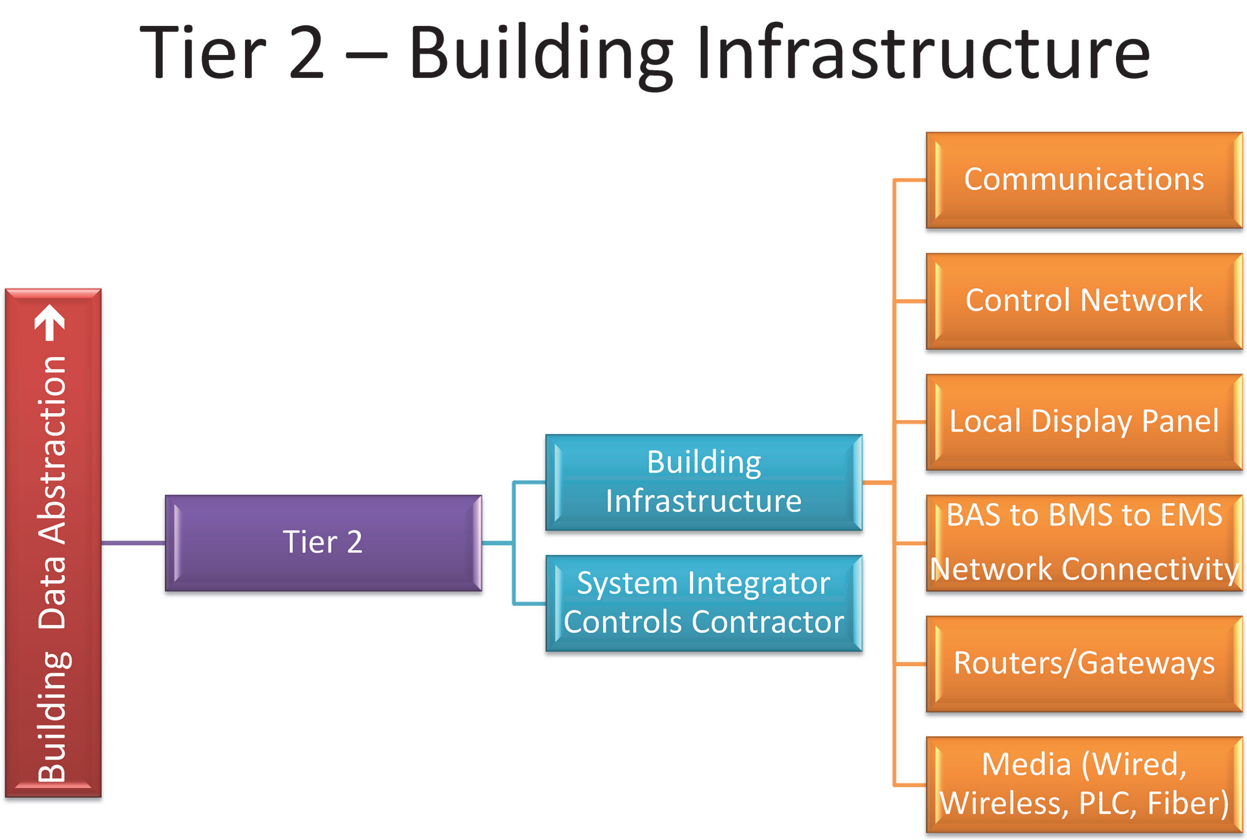

FIGURE 12.4-2 Tier 2—Building infrastructure.

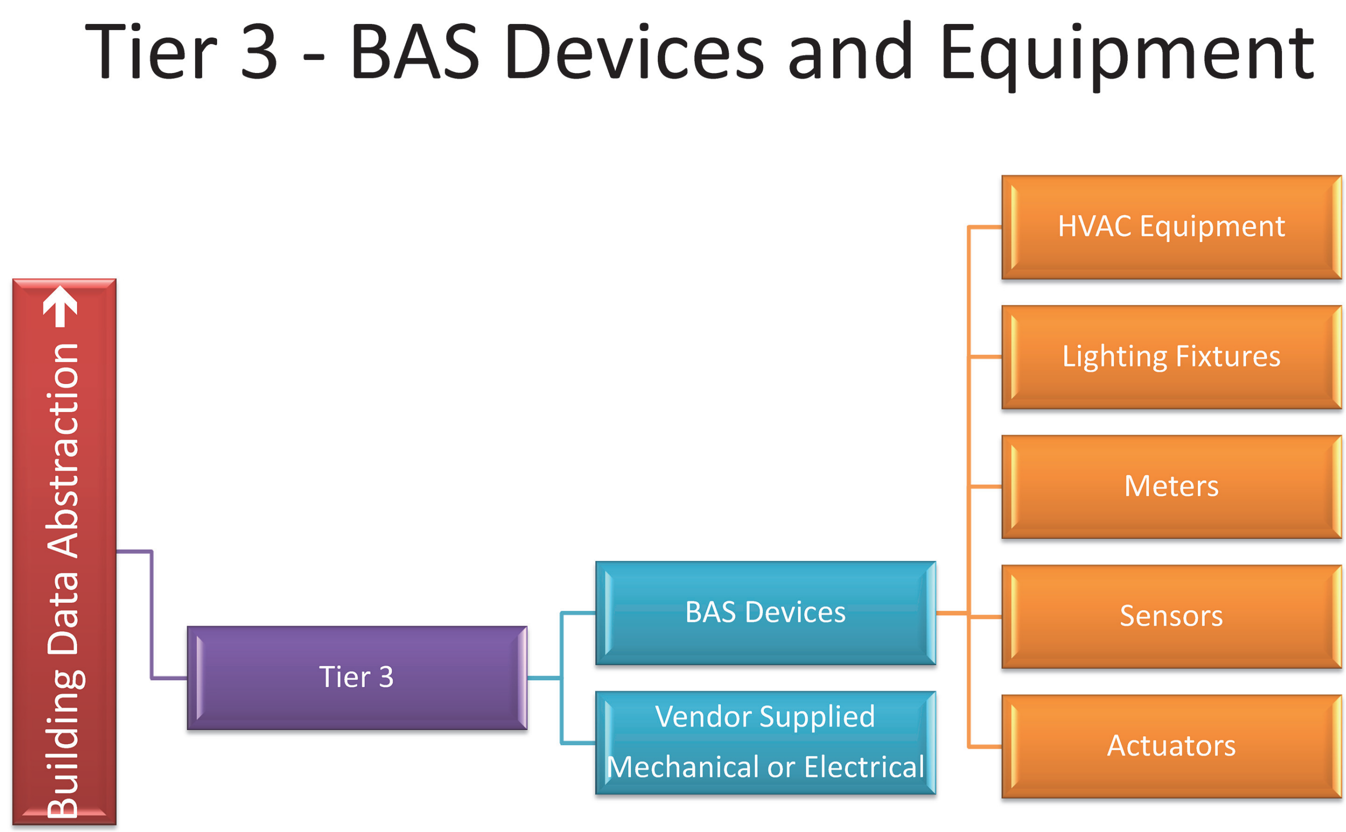

FIGURE 12.4-3 Tier 3—BAS devices and equipment.

may employ vendor-specific protocols and implementations that are no longer or are marginally supported in the industry. Training and support may no longer be widely available at a reasonable cost. The move to an open-systems approach and open-protocol control network has provided a key opportunity for vendors to prolong their systems and eliminate or significantly reduce the need for proprietary system support.

c. **Tier 3—Controllers, Devices, and Embedded Equipment.** These are referred to as the system "hardware" and typically contain electronic components based on microprocessor and microcontroller technology (see Figure 12.4-3). Hardware includes memory, code, and connections to sensors, actuators, and a communications network. As the semiconductor market changes, so do the capabilities of hardware, quickly making older technology obsolete. Obtaining the core electronics for older devices is a key issue for vendors attempting to prolong the life of legacy systems.

12.5 General System Architecture

12.5.1 The BAS shall follow the multitier architecture model that defines the interaction of devices, systems, subsystems, buildings, and the enterprise. This specification defines the interaction of the enterprise with the building infrastructure. It also delineates the data sets to be monitored and captured by the enterprise user front end.

12.5.2 Interaction between elements of the BAS follows the Common Profile Model where each element of a system can be defined by its three key elements: logical, physical, and algorithmic information as shown in Figures 12.5-1 and 12.5-2. A *logical interface* is information sent or received across the control network. A logical interface typically consists of a data point or a set of points called "network variables" or "network objects." Devices can send or receive logical data to or from other devices on the network via this logical interface. Software inside the device is referred to as "control algorithms" and is programmed by the manufacturer, by an in house technician, or by the system integrator. The control algorithms are developed such that a device can perform a defined set of functions and a sequence of operation. The physical interface refers to the physical connections to sensors and actuators such as relays, 4 to 20 mA devices, and other field-level hardware. Typically, the physical interface of the device uses digital or binary inputs and outputs and analog inputs and outputs. The point list or object schedule of a project typically defines the hardware physical set of I/O required on the device. Examples include temperature sensors, pressure sensors, switch states, and contact closures. The integrator or hardware vendor typically is responsible for ensuring that the device has the appropriate number of required I/O points to handle the physical sensors and actuators to be controlled by the device as required by the specification. A device with a well-defined set of logical, physical, and algorithmic definitions is referred to as the device's "functional profile." This device profile establishes all of the interface and operational requirements of a device and is used as the

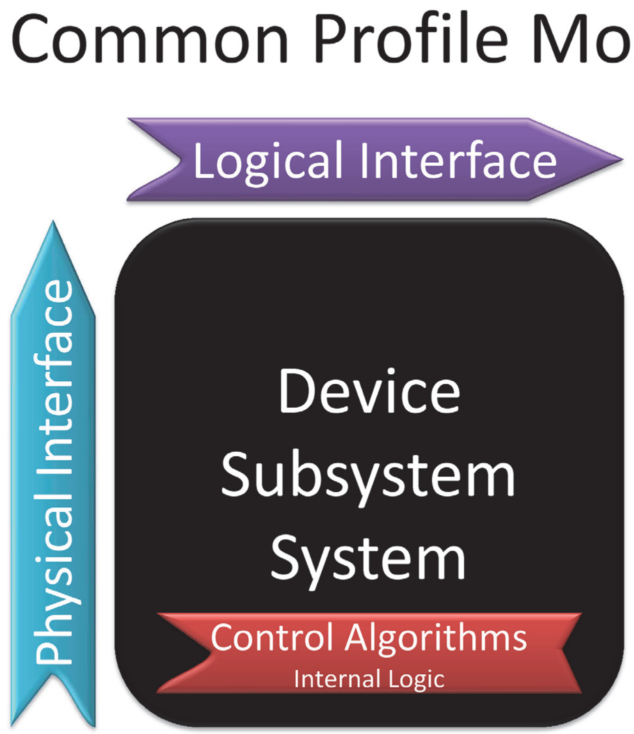

FIGURE 12.5-1 Common Profile Model—Logical, physical, and control elements.

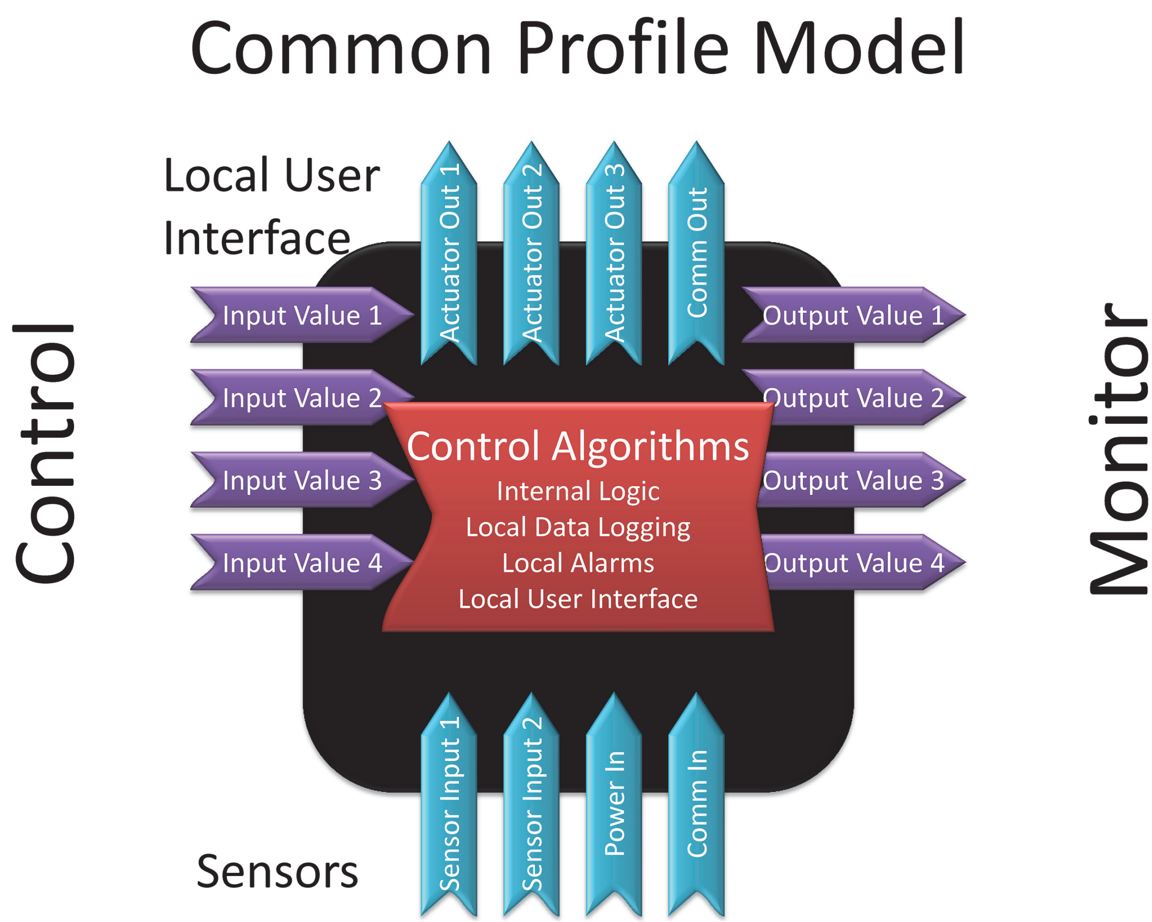

FIGURE 12.5-2 Common Profile Model Detail—Control, monitoring, sensors, and actuators.

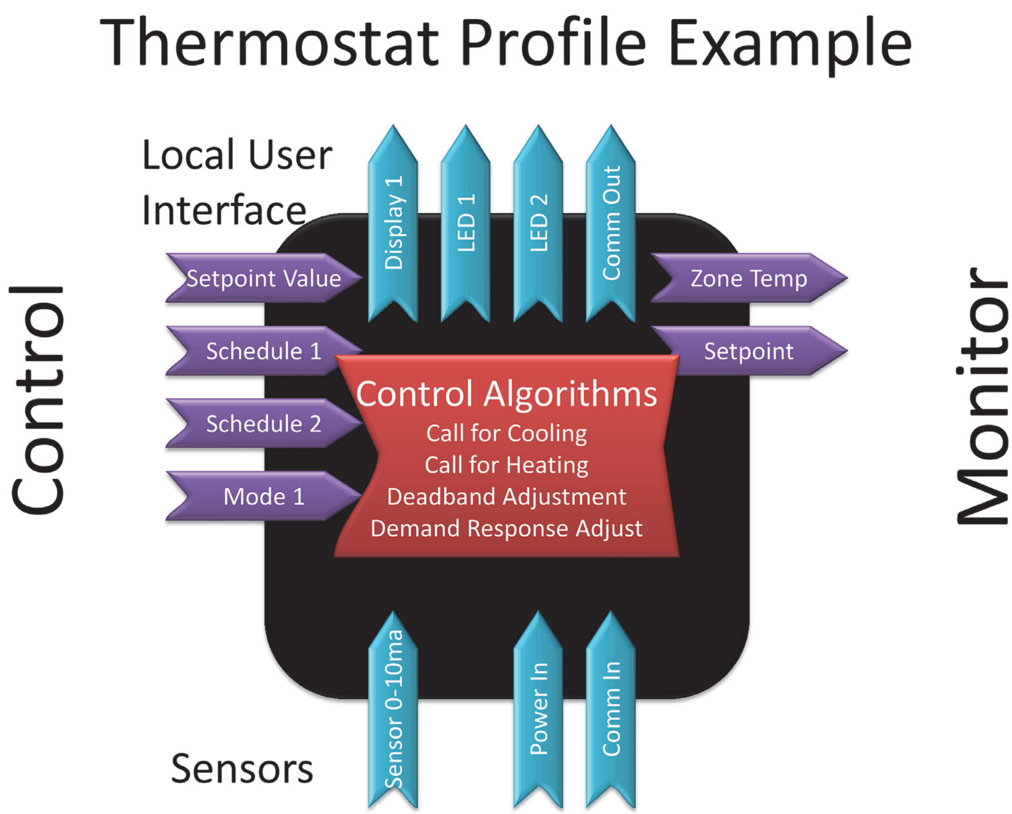

FIGURE 12.5-3 Thermostat profile example with logical and physical interfaces.

interoperable foundation of a control system. Devices from different vendors can and should have and use the same functional profile for the same device type, which simplifies the installation, integration, and commissioning of a system. It also reduces the need in the user interface and management front end for customization of graphics and other software functions to meet vender proprietary interfaces.

12.5.3 The control device has the following components:

a. Control (logical inputs)
b. Monitoring (logical outputs)
c. Sensors (physical inputs)
d. Local user interface (physical outputs)
e. Control algorithms (internal logic)

12.5.4 This model delineates the logical, physical, and internal algorithms of any device, system, or subsystem. The interaction between it and any other element is primarily through the logical interface of input and output information.

12.5.5 The BAS designer is responsible for providing the appropriate profiles that are suitable for the project. For example, a simple thermostat may have an output of "Current Temperature" as monitored internally by the sensor. This logical output shall be available to any other system element interested in the temperature of that thermostat. The structure of a thermostat in this example follows the thermostat profile (see Figure 12.5-3).

Packaged equipment produces larger collections of data and has different input requirements. Figure 12.5-4 shows an example diagram of a roof-top unit profile.

12.6 BAS Device Network Architecture. Figure 12.6 highlights the representation and interaction of the Multitier Model as described in this document. Each tier has its own scope and related contractor responsibilities. The Architecture Model has three tiers as described in the following subclauses.

12.6.1 Tier 1—Enterprise IP Network Tier or Intranet Tier. This tier includes devices directly connected to the enterprise network, including the graphical front end; peripheral devices such as printers, Web-client computers, devices such as smart cellphones or tablets; and BAS controllers and devices that have IP connectivity. Note that some sensors and actuators could be IP devices. These devices are normally not connected to the enterprise IP network.

12.6.2 Tier 2—Building- or Facility-Level IP Device Network Tier or Building IP Tier. This tier includes IP devices that normally connect to the enterprise IP network tier via a switch dedicated to the BAS device network or to enterprise switches under IT department control. This could include IP-based sensors and actuators.

12.6.3 Tier 3—Non-IP-Based BAS Controller Network Tier or BAS Controller Tier. This tier includes devices and actuators that are not IP based. These devices could be networked using non-IP wired networks such as BACnet MS/TP, LON TP/FT-10, Modbus, or proprietary media types. This tier also includes any sensors and actuators that are directly con-

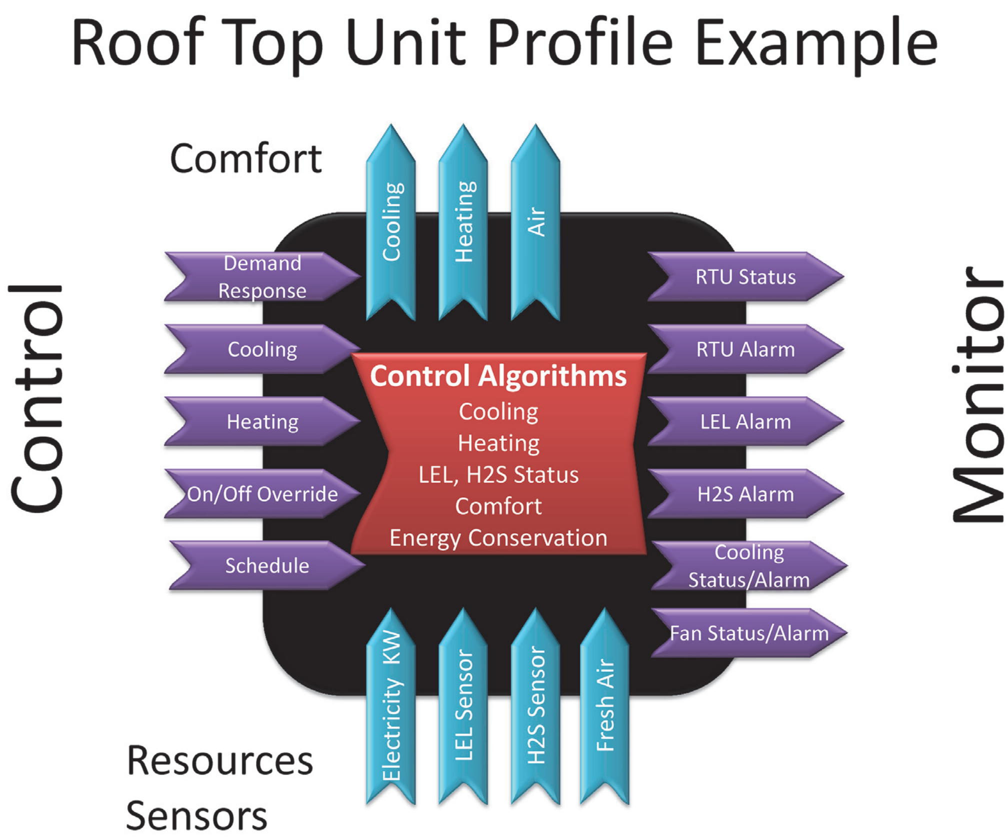

FIGURE 12.5-4 Roof-top-unit (RTU) profile example.

nected to a BAS controller or are required for a BAS device, such as a boiler or chiller, which in turn is networked into the non-IP-BAS controller network. If the chiller or boiler controller is an IP device, it would be a Tier 2 device.

12.7 Tier 1 Server—Enterprise Central Server Requirements

12.7.1 Hardware/Software. The enterprise central server shall be provided by the facility master system integrator (FMSI). The server configuration of both hardware and software shall be provided by the FMSI. The server shall, at a minimum, meet all standard IT requirements for communication, security, and connectivity to the facility LAN/WAN. Server hardware shall, at a minimum, be a current commercial grade system with enough processing power to run the required applications. It shall have all of the necessary memory and user interface requirements (mouse, keyboard, monitor, etc.) to meet or exceed the project IT requirements. The computer hardware shall be from a reputable name brand source and shall have a full factory warranty transferred to the owner. Provide all documentation; software, on optical media; and accessories necessary to run the system. Provide all necessary software, including current operating system, firewall, security, antivirus, antispam, and related software as defined in the IT standards. See project-specific IT standards for details.

12.7.2 Site Server. The central server shall be located in the site location identified by site IT and shall be in an air-conditioned, secure, controlled environment. Design criteria shall be coordinated with site facilities to designate location of the server. The FMSI shall coordinate configuration and backup requirements of the site server with the backup server.

Site server shall include a secure, reliable IT best-practice-based solution. The following are required for each site server:

a. RAID configuration for backup hard drive (RAID 0,1 or X) as defined by the IT department. Ensure no single drive failure will cause data loss. Any failed drive shall be replaced immediately to prevent loss of data.

b. For organizations accepting cloud-based backup solutions, the system design shall specify the security, reliability, and fault tolerance of cloud systems according to IT best practices.

c. Software as a service (SaaS) allows certain software and servers to be hosted by a third party accessible via the Internet. If this option is enabled, the design criteria shall establish minimum security, reliability, uptime, accessibility, and other related issues as defined by IT best practices.

d. The system shall employ strong security measures to ensure only personnel with current credentials shall have access to the system. Strong password and pass phrase access shall be employed. Multiple levels of secure access are required and shall follow the IT best practices for

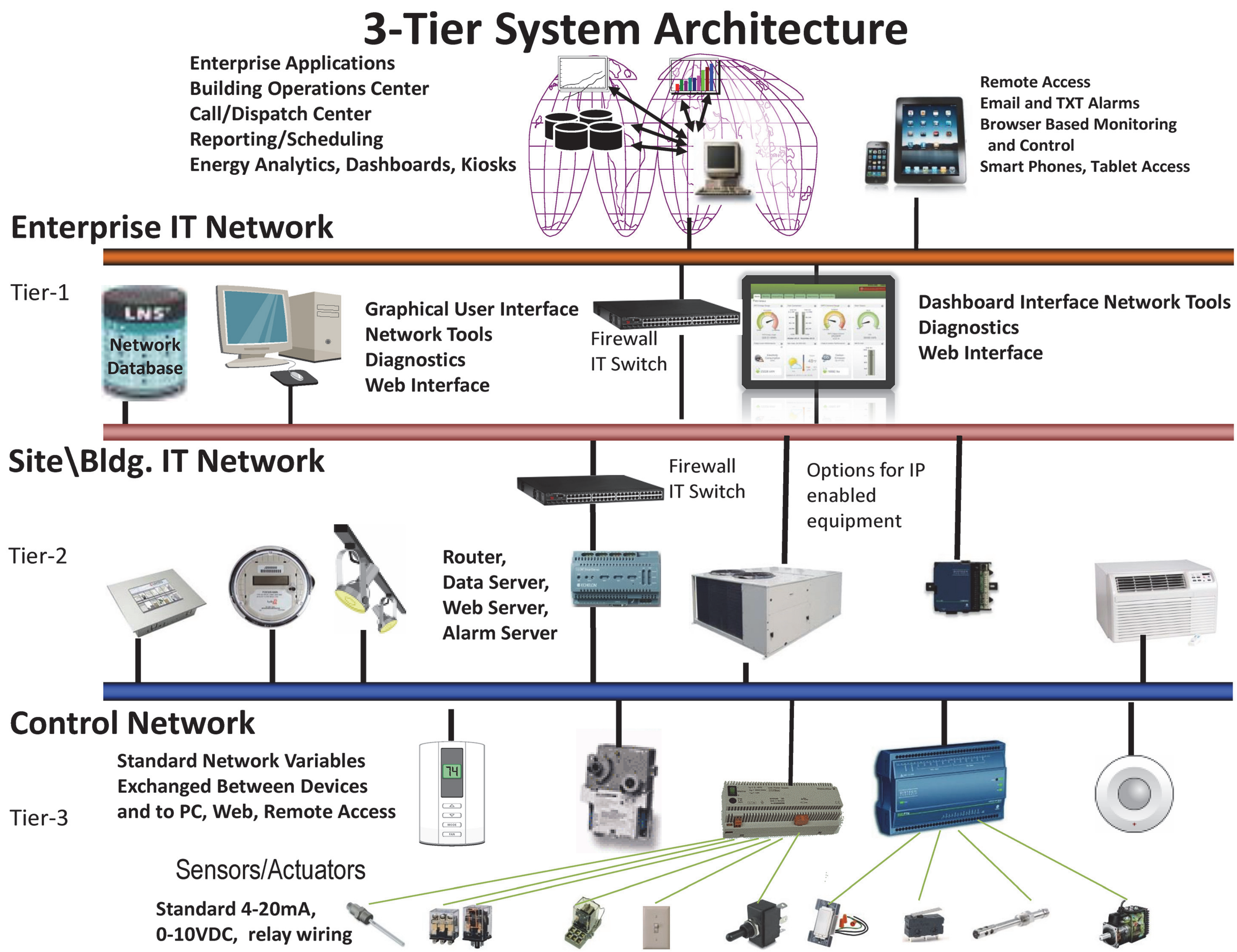

FIGURE 12.6 Three-tier system architecture.

security access (SSL, encryption, firewalls, and other measures as needed).

12.7.3 Backup Servers. If required, the backup server shall be located at the corporate central data center. Project design criteria shall incorporate IT requirements for management and maintenance of the backup server. The backup server shall adhere to the project IT workstation requirements for operating system and other software, performance, monitor, and user-interface requirements.

RAID, cloud, and SaaS options and requirements are the same as identified in Clause 12.7.2.

12.8 Enterprise IT Integration Requirements

12.8.1 Design criteria shall be coordinated with site IT manager regarding IT requirements for the following:

a. Network wiring, including requirements for CAT 6a or higher and fiber wiring
b. Network switches
c. Network routers
d. Security firewalls
e. Network IP address allocation
f. DNS requirements
g. Web hosting
h. Port blocking/unblocking/binding
i. Password/pass phrase requirements, strength, periodic changes
j. Use of antivirus, antispam, and adware blocking, and logon security
k. Server security requirements
l. Server backup and maintenance requirements
m. System gateway requirements
n. System protocol requirements, including the following:
    1. TCP/IP
    2. FTP
    3. HTTP/HTTPS
    4. REST
    5. UDP
    6. SOAP/XML
    7. Other

12.8.2 BAS Equipment Panel. BAS equipment panels contain various hardware devices, including the following:

a. Controllers
b. Routers
c. Web servers
d. Relays
e. Contactors
f. Terminal blocks
g. Power supplies
h. Displays
i. Sensors
j. Lamps
k. Switches
l. Uninterruptible power supply (UPS)— internal or external depending on requirements

12.8.2.1 BAS equipment panels shall be "fit-for-purpose" such that local and project codes and requirements are met. Panels shall be designed to meet the minimum requirements for the project and not overdesigned to ensure cost effectiveness.

12.8.2.2 All panels shall be provided with full as-build drawings showing components, make/model information, spacing information, labeling, and other panel requirements according to the project requirements.

12.8.2.3 The BAS designer shall provide the specific panel requirements as part of the specification.

12.8.3 Routers and Switches

12.8.3.1 The BAS contractor shall provide any routers, protocol translators, or network switches required for the BAS devices at the building IP tier. The BAS contractor shall install and commission all necessary routers, switches, protocol translators, repeaters, or other such devices required to ensure a reliable, stable network.

12.8.3.2 The BAS contractor shall ensure that all network architecture elements adhere to the requirements for network wiring length, number of devices per segment, wire type, and other physical networking requirements for the protocol selected. Provide at least 10% growth headroom for all network channels such that 10% future growth will not require new wiring. See Clause 12.9 for additional details.

12.8.3.3 Routers, switches, and other IP-level equipment location designation shall be defined by the project engineer and coordinated with the site project manager. All design drawings shall include references to location of network infrastructure equipment location requirements.

12.8.4 Gateways

12.8.4.1 Use of gateways shall be restricted to the BAS controller tier. The output side of the gateway shall be configured to translate the proprietary protocol devices to the approved protocols allowed for use in the work. Gateways shall be approved via the submittal process.

12.8.5 Power Requirements

12.8.5.1 Design criteria shall identify all necessary power requirements of all connectivity devices. Typical power requirements are 120 VAC power. Identify power requirements at location of hardware. Coordinate with the electrical subject matter expert (SME) for power requirements for each panel. Each panel shall have a 120 VAC 15 amp dual receptacle for local laptop and other service tool power connection.

12.8.6 Uninterruptible Power Supply (UPS). The use of UPS backup power supplies is often required in situations when a general power failure would potentially cause an unsafe situation, damage equipment, or cause an undesirable disruption. This section addresses UPS design and usage.

There are 45 types of UPSs available on the market today. Here is a brief description of the features as they relate to the need for protecting the BAS device infrastructure if provided.

a. *Standby or Switching UPS:* The standby UPS is the most common type used for desktop computers and related devices. Also called a "switching UPS," it has a built-in transfer switch to switch to the battery and inverter inside the UPS should the commercial power source fail. A standby UPS is usually the lowest-cost unit available on the market. A problem with this kind of UPS is that the electronics in some BASs may still be damaged due to momentary surges, because the UPS cannot switch from commercial to UPS power fast enough.

b. *Line Interactive UPS:* In this design, the battery-to-AC power converter (inverter) is always connected to the output of the UPS. When the input power fails, the transfer switch opens and the power flows from the battery to the UPS output. With the inverter always on and connected to the output, this design provides additional filtering and yields reduced switching transients when compared with standby UPS operation. High efficiency, small size, low cost, and high reliability coupled with the ability to correct low or high line voltage conditions make this the dominant type of UPS in the 0.5 to 5 kVA power range.
c. *Standby-ferro UPS:* This design depends on a special saturating transformer that has three windings (power connections). The primary power path is from AC input, through a transfer switch, through the transformer, and to the output. In the case of a power failure, the transfer switch is opened, and the inverter picks up the output load. In the standby-ferro design, the inverter is in the standby mode. The inverter is energized when the input power fails and the transfer switch is opened. Standby-ferro UPS systems are frequently represented as on-line or non-switching units, even though they have a transfer switch. The inverter operates in the standby mode and it exhibits a transfer characteristic during an AC power failure. The principal reason why standby-ferro UPS systems are no longer commonly used is that they can be unstable when operating a modern computer power supply load.
d. Double conversion on-line UPS: This is the most common type of UPS above 10 kVA. In the double conversion on-line design, failure of the input AC does not cause activation of the transfer switch because the input AC is charging the backup battery source that provides power to the output inverter. During a commercial power failure, the continuous, on-line operation results in no transfer time. Both the battery charger and the inverter convert the entire load power flow in this design. This UPS provides nearly ideal electrical output performance. The constant wear on the power components reduces reliability over other designs. The input power drawn by the large battery charger may be non-linear which can interfere with building power wiring or cause problems with standby generators.
e. Delta conversion on-line UPS: This UPS design was introduced to eliminate the drawbacks of the double conversion on-line design and is available in sizes ranging from 5 kVA to 1.6 MW. Similar to the double-conversion on-line design, the delta-conversion on-line UPS always has the inverter supplying the load voltage. The additional delta converter also contributes power to the inverter output. Under conditions of commercial power failure or disturbances, this design exhibits behavior identical to the double-conversion online UPS.

Most UPSs will provide power to the BAS device network for 15 to 60 minutes depending on the load. This is normally long enough to permit an orderly power down of the controlled equipment by the BAS. If only the BAS is backed by a UPS and the air-handler controlled by the BAS is not, then the air-handler will abruptly shut down even though the BAS is going through its orderly shutdown.

Smaller BAS devices that control variable-air-volume (VAV) boxes now come with lithium batteries that backpower the electronics for days. Even if commercial power is lost, the flash memory used in modern BAS devices will retain custom programming, setpoints, and the internal clock.

The real value of a non-switching-type UPS is to provide continuous conditioned power to the sensitive electronics found in the BAS devices. If a commercial power voltage surge damages the UPS but the BAS devices are protected, then the cost to repair or replace the damaged UPS is usually small compared to that of protecting the expensive BAS device infrastructure.

12.8.7 When selecting the need for a UPS, the BAS designer must evaluate the following:

a. The quality of the commercial power available to the project. Are there numerous power outages? Are there voltage fluctuations from both the external commercial power, internal building sources, or both?
b. The critical nature of the equipment being controlled. Is the BAS controlling equipment in a lab, hospital, military command or data center where downtime is usually not tolerated? Is there a safety issue if the equipment or system shuts down without warning?
c. The sensitivity of the BAS device electronics when exposed to transients or surges. Does the BAS equipment have sufficient onboard protection against voltage surges? If not, is the BAS equipment warranty voided if the device is damaged by voltage surges or spikes?

12.8.8 The following subclauses provide options for UPS requirements: either a dedicated equipment UPS or a building circuit UPS.

12.8.8.1 All equipment panels housing controllers, router, or any networked equipment shall have installed a UPS of sufficient size to ensure continuous operation of the controls and infrastructure hardware for a minimum of one hour.

12.8.8.2 Alternatively, if the building provides a UPS circuit, the infrastructure panel shall be serviced by a dedicated UPS circuit.

12.8.8.3 UPS equipment shall be located with BAS controllers in a conditioned, secure location appropriate for computer and electronic equipment (see additional sections for equipment locations).

12.8.9 Communication Requirements

12.8.9.1 All network devices shall provide the required communication between systems and have the network capacity to handle the traffic load. IP routers shall be at least 100BaseT (no 10BaseT-only routers will be allowed). Auto-switching routers between 10 and 100BaseT are acceptable. The FMSI shall be responsible for ensuring that the communications requirements are met and that the hardware device selection meets or exceeds the design criteria.

12.8.10 Programmable Building System Equipment Panel Requirements

12.8.10.1 The programmable BAS equipment panel consists of a fully configured, built-up panel. It shall include all required controllers, routers, displays, wiring, termination, power, and receptacles. The maximum voltage for each BAS control panel shall be limited to 120 VAC.

12.8.10.2 As a minimum, all equipment shall be housed in a NEMA 4 HVAC standard commercial-grade panel.

12.8.10.3 Optional. For classified buildings, NEMA 4X panels shall be used as required by electrical code.

12.8.10.4 If there is a requirement for outdoor panels, specify the appropriate NEMA enclosure for the usage.

12.8.10.5 Design criteria for all panel components, placement, spacing, wiring, and connectors shall follow the samples provided in separate panel drawings.

12.9 Network Reliability and Performance Requirements

12.9.1 The system shall be designed such that all communications are within acceptable documented limits for bandwidth utilization, error rates, loading, and scalability.

12.9.2 The system shall be designed such that there is at least 10% dynamic headroom for future growth. This applies to both physical and logical requirements. The system shall maintain the following expansion requirements:

a. At least 10% growth capacity on all switches and hubs
b. At least 10% growth capacity on all control network infrastructure device control network
c. At least 10% additional capacity on cable runs to add additional segments

12.9.3 All network segments shall be tested for errors using a standard protocol analyzer. Each network channel shall be tested under normal operating conditions (active network) for a period of 24 hours. A report shall be generated and presented to the FMSI indicating that all parameters are within documented acceptable limits and that there are no network wiring issues, communications issues, bandwidth issues, address conflicts, and that the required 10% growth capacity is available. A printed report for each channel shall be included in the signoff documents for the project.

12.10 Contractor Roles and Responsibilities

12.10.1 The FMSI and BAS contractor shall conform and follow project execution responsibilities as defined in Clauses 12.10.3 through 12.10.7 and in the protocol-specific requirements (see Informative Annexes B, C, and F). Scope of work to be performed by the electrical contractor includes termination and connections of BAS sensors, actuators, and wiring as defined in Clause 12.10.6.

12.10.2 Commissioning

12.10.2.1 Project commissioning (Cx) shall follow the accepted best practices for ensuring the following requirements are met:

a. The system(s) are fully operational.
b. The system(s) are in compliance with the specification.
c. All sequences of operation are met and documented per the project specification.
d. Equipment requirements are adhered to and conform to code and specification requirements.
e. All systems are tested for correct operation.
f. All systems are balanced and ready for occupancy.
g. Networks shall be tested using appropriate testing tools (network analyzers) to ensure all systems are operating correctly and within acceptable error and bandwidth limits. See Clause 12.9 for details.

12.10.2.2 If a commissioning authority (CxA) is engaged, the specification requirements for must be provided and should include the roles, responsibilities, and deliverables of the CxA. Details of the CxA are outside the scope of this document.

12.10.2.3 Final system acceptance shall include operations and maintenance (O&M) manuals complete with verification and sign-off documentation.

12.10.3 Facility Master System Integrator (FMSI) Responsibilities. The FMSI is responsible for the integration of the BAS into the graphical workstation server connected to the facility IP network. In this case, BAS can refer not only to the HVAC system but to the lighting, fire alarm, gas detection, security, and other systems. The FMSI is responsible for ensuring each BAS contractor has provided all of the necessary equipment, controls hardware, infrastructure, connectivity, and documentation for their area of responsibility. The FMSI has direct responsibility as the owner's agent for the final integration of all elements of the control system as defined in this guideline. The FMSI is responsible for the following:

a. Review all IP related integration requirements.
b. Coordinate IP network integration with site IT department.
c. Coordinate IP addressing, security, firewall, and user interface requirements.
d. Coordinate all networking integration requirements for subsystems to the building management system (BMS).
e. Review system integrator/controls contractor submittals.
f. Review sequence of operation.
g. Review/approve HVAC unit submittals.
h. Review fire alarm interface to BAS control panel.
i. Review gas detection interface to BAS control panel.
j. Review sensor and actuator device submittals.
k. Review mechanical control strategies.
l. Review network integration structure and databases for accuracy.
m. Review/approve BMS integration.
n. Review preinstallation submittals.
o. Coordinate vendor device and subsystem data and protocol.
p. Review conformance to protocol requirements, certifications, and listings for devices.
q. Review point list.
r. Review data point sets.
s. Review naming conventions.
t. Provide network database for integration into BMS.

u. Integrate all BAS equipment into the BMS front end.
v. Deliver complete working BAS front-end system according to the specification.
w. Ensure equipment has been supplied with necessary controls and control functionality.

12.10.4 BAS Contractor

12.10.4.1 The BAS contractor is primarily responsible for selecting, delivering, installing, and commissioning the necessary building equipment, controls, and related hardware for the project. The BAS contractor is responsible for implementing the sequence of operation of all subsystems. The FMSI shall oversee the BAS contractor's work. The following is a list of BAS contractor responsibilities:

a. Provide BAS point list as delivered.
b. Commission BAS.
c. Integrate all mechanical and electrical equipment into BAS.
d. Provide BAS communication network infrastructure.
e. Provide data type and source list.
f. Provide device certification compliance validation for all controllers and networked devices.
g. Provide system drawings of all subsystems, equipment interactions, network architecture, sequence of operations, and related drawings.

12.10.5 Mechanical Contractor (Optional in the Event that the Mechanical Contractor is Also Acting as the BAS Contractor)

12.10.5.1 The mechanical contractor is typically responsible for delivering, installing, startup, and commissioning of the mechanical equipment, related ductwork, wiring, termination, and the like. The mechanical contractor shall coordinate all work with the BAS contractor such that the correct equipment, controls, and documentation are provided. The FMSI shall oversee the mechanical contractor's work.

a. Provide equipment installation.
b. Verify equipment installed meets project requirements.
c. Confirm proper equipment is delivered.
d. Provide all necessary equipment documentation, including operating manuals, service manuals, troubleshooting manuals, etc.
e. Document equipment installation and commissioning.
f. Provide as-built drawings of all mechanical systems and subsystems.

12.10.6 Electrical Contractor (Optional in the Event that an Electrical Contractor is Required for Specific Installation and Commissioning of Sensors, Actuators, and Non-Networked Field Devices)

12.10.6.1 The electrical contractor is typically responsible for installing, terminating, startup, and commissioning of any nonnetworked field devices, including sensor; actuators; relays; breakers; power panels; voice, data, and video (VDV) systems; etc. The project specification and local codes shall determine the specific electrical contractor requirements. In certain cases, mechanical systems require some electrical installation expertise.

a. Installation of non-equipment-mounted sensors, contactors, and actuators as defined in hardwired connectivity requirements
b. Installation of field hardwired sensor/actuator wiring connected to BAS controllers
c. Termination of sensor/actuator wiring
d. Documentation and labelling of all wiring, color coding, and related usage identification

12.10.7 Project Management

a. The FMSI contractor of record for the project shall be responsible for coordinating noncompliance issues of system integrators, controls contractors, and equipment suppliers.
b. The FMSI shall be responsible for identifying and alerting the project manager of any noncompliance or technical deviations from the specification.
c. The project manager shall be responsible for overseeing the FMSI standards compliance process.
d. The project manager shall have final determination of any technical deviation requirements.

12.11 Contractor Qualifications

12.11.1 FMSI

12.11.1.1 The FMSI contractor shall provide their contractor qualifications.

12.11.1.2 Provide a summary of professional training and experience. Include copies of training certificates for all personnel assigned to this project. Training must include both building controls and IP training to qualify as an FMSI.

12.11.1.3 The FMSI shall employ at least two trained personnel. Provide current certification of each qualified personnel member assigned to this project.

12.11.2 BAS Controls Contractor

12.11.2.1 The controls contractor shall employ at least two factory-trained or equivalent personnel. Provide copies of certificates for personnel assigned to this project. Provide details regarding the certifying body.

12.11.2.2 The contractor shall be in the regular business of system integration and controls contracting and have experience with prior work projects. Provide at least two references for prior like projects.

12.11.3 Contractor Licensing and Training

12.11.3.1 All mechanical and electrical contractors shall be licensed. Provide copies of the license certificates.

12.11.3.2 All contractors shall employ personnel that have attended relevant product and industry training classes. Submit personnel qualifications, including a list of classes project team employees have taken along with their certificates of completion.

12.11.4 Supply Chain Requirements

12.11.4.1 All contractors and vendors shall be authorized distributors, representatives, contractors, or installers of factory equipment to be used on the project. See additional contractor and vendor qualifications in Clauses 12.11.1 through 12.11.3.

12.12 Data Sourcing and Formatting

12.12.1 BASs typically produce and consume vast amounts of data. This data is transported across the BAS control network. Typically, data is segmented into real-time and historical data sets. Real-time data is normally referred to as data that requires prompt attention that emanates from or is directed to the control system. Typical real-time data rates for BASs are in the hundreds of milliseconds to many seconds. As an example, alarms from a control system typically need to be delivered and received within a few seconds. An HVAC controller that provides temperature data may report its status or change of state every 5 to 10 minutes. Each sensor or output variable update typically has a configuration property associated with it that defines the update interval and is adjustable by the installer. Understanding the impact of real-time updates on network bandwidth and performance are critical elements of system engineering and design.

12.12.2 Historical data typically refers to data sets emanating from sources where real-time information is not required. Data sources such as power meters and water meters can have the ability to store data points for a period of time and then forward a large amount of data to a server for analysis and reporting. Since this data is stored locally and then forwarded, the need for frequent updates is unnecessary, and the bandwidth utilization of the network can be optimized.

12.12.3 Understanding which data should be reported in real-time and which should be reported historically is a responsibility of the BAS designer and is typically annotated on a point list or object list schedule as part of the system specification.

12.12.4 Real-Time Data Interface. Design criteria shall accommodate data sourced from real-time metering, sensors, and controllers such as electric meters; water meters; and temperature, occupancy, and other sensors. Real-time data that is stored within a meter, sensor, or controller shall transfer that data periodically to the central server as designated in the specific design criteria for that subsystem.

12.12.5 Historical Data Import. Design criteria shall accommodate data sourced from historical logs, utility bills, and database export files such as comma-separated values (CSV) files. The central management system shall accommodate multiple data capture and import capabilities. Criteria for each subsystem data capture shall be provided by the BAS contractor, and the integration into the BAS front end shall be implemented by the FMSI.

12.13 Documentation and Closeout Submittals

12.13.1 System Architecture Single Line Drawings

12.13.1.1 The BAS contractor shall deliver a system architecture single-line drawing showing Tier 2 building network (IP/control connectivity) and Tier 3 BAS (equipment level/control network) elements, connectivity between networks, and communications media and protocols at each level.

12.13.1.2 The FMSI shall provide Tier 1 IP/enterprise connectivity drawings and update the site of drawings (for multiple building projects).

12.13.2 System IT and Security Drawing

12.13.2.1 The FMSI shall deliver an IT system security architecture drawing identifying system connectivity, location of switches, routers, firewalls and any other IT-related hardware and software.

12.13.3 System Databases

12.13.3.1 The BAS contractor shall deliver a set of complete, accurate system databases on optical media for each subsystem, and for the central server. This shall include the control network database for each BAS. It shall also include the central server database (SQL format), graphics library database, and any other relevant system databases.

12.13.4 Point/Object List

12.13.4.1 The BAS contractor shall document and deliver a point/object list for each subsystem interface, including logical description and naming convention and point type for GUI display requirements.

12.13.4.2 The FMSI shall review the point/object list for consistency and work with the BAS contractor to ensure all points/objects are network available. FMSI shall ensure required points/object are available and that BAS-supplied equipment has implemented the required optional points/object per the specification.

12.14 Building System Integration Requirements

12.14.1 Frequency of Data Updates. Real-time data sources shall update their readings and store and forward their data sets according to the specific subsystem update interval requirements as defined by the equipment vendor. Following is a list of potential systems that require real-time data; this is not an exhaustive list:

a. HVAC
b. Lighting occupancy
c. Energy
d. Hazardous gas sensors
e. Gas submetering (natural gas, propane)
f. Domestic water submetering
g. Fire (for HVAC event)

Historical data sources provide data from electronic sources such as online billing, paper sources, or database export files such as CSV files. Design criteria shall include the ability for the central server to accommodate the input of monthly historical data either manually or through automated scripting. Historical data sources include the following:

a. Utility electric bills
b. Utility water bills
c. Utility gas bills
d. Others (propane, diesel, steam, etc)

12.14.2 General Tier 1 to Tier 2 Integration Requirements

12.14.2.1 All devices on the control network shall be certified and incorporate the required profile interfaces according to the relevant HVAC standard. All required functionality shall be documented such that the FMSI will easily be able to integrate each device and subsystem. Optional variables shall be identified and documented, and the FMSI shall be informed of any anomalies for the provided equipment. Vendors that choose to implement manufacturer-specific variables may only do so to provide configuration and communication to their programming tools. Under normal operation, all devices shall follow the common profile model to reduce integration, installation, and commissioning time, costs, and confusion. The FMSI has the responsibility to address any vendor product that does not meet the standards. FMSI shall inform the relevant site SME in all such cases. Every effort to ensure vendor compliance to the standards shall be taken. In the event a vendor cannot meet the standards required, alternate vendors will be engaged.

12.14.2.2 The FMSI is responsible for integration of all required subsystems into the central server. Design criteria shall provide enough detail for the FMSI to carry out the necessary integration. The integration design of non-open-networked systems shall include technical and financial detail sufficient for the FMSI to provide integration and additional hardware and software costs necessary to successfully integrate the subsystem.

12.14.2.3 The FMSI is responsible for installation, configuration, and testing of the central server software, graphics, and dashboards. Design criteria shall provide the FMSI with sufficient detailed technical information to successfully install and configure the central server.

12.14.2.4 The FMSI is responsible for general setup, configuration, and customization of the various GUIs. The FMSI shall have the responsibility to work with each subsystem's SME to provide the necessary GUI requirements for subsystem operation personnel.

12.14.2.5 The FMSI shall train and oversee the usage of the central server user interfaces by the subsystem operators. See Clause 12.16 for specific training requirements.

12.14.2.6 Subsystem integration design criteria shall be coordinated with the SME for specific data monitoring and control integration.

12.14.3 General Tier 3 Requirements

12.14.3.1 Design criteria shall specify usage of Common Open Functional Profiles for all packaged equipment.

12.14.3.2 Reference the relevant HVAC standard for specific equipment requirements.

12.14.3.3 Functional Profile (Examples)

a. Packaged air handler (AHU)
b. Roof -top unit (RTU)
c. Unit heater
d. Thermostat
e. Chiller
f. Space comfort controller

12.14.3.4 Design criteria shall require all Tier 3 equipment to be certified and adhere to common profiles appropriate for that equipment.

12.14.3.5 The FMSI shall review Tier 3 equipment submittals.

12.14.4 Integration to Tier 2 HVAC Systems

12.14.4.1 Integration of the HVAC system into the enterprise shall include design criteria for monitoring the status of the HVAC systems, including system status, current zone temperature, and status of specific equipment. In certain cases, remote ability to control the HVAC via the central management workstation may be required in emergency or override situations. System design shall work with the mechanical designer of record to establish the necessary requirements of the HVAC system interface.

12.14.4.2 Fire Tier 2 Subsystem Integration. The HVAC system shall have the ability to monitor the fire/life safety system via dry contact relay connection to a programmable networked controller. The controller shall report the status of its ability to monitor the fire system. On fire event, the fire controller, via a network variable, shall send an output message to the BAS that an event has occurred.

12.14.4.3 Gas Detection Tier 2 Subsystem Integration. The HVAC system shall have the ability to monitor the status of the gas -detection system via a dry contact relay connection to a programmable networked controller. The controller shall report the status of its ability to monitor the gas detection system. On an event, the gas detection controller, via a network variable, sends an output message that an event has occurred.

12.14.4.4 HVAC Equipment with Gas Detection. HVAC equipment with internal gas detection shall have the ability to send output variables on the status of the gas sensors. The networked controller shall report the status of the gas sensors as an output network variable.

12.14.4.5 Logic. Table 12.14.4.5 defines the logical control/monitoring points associated with a typical HVAC system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

12.14.5 Integration of HVAC System into BAS. Figure 12.14.5 illustrates the integration of an HVAC system into a BAS.

12.14.6 Integration to Tier 2 Lighting Systems

12.14.6.1 Integration of the lighting system into the enterprise shall include design criteria for monitoring the status of smart lighting systems, including system status and room occupancy. In certain cases, remote ability to control the lighting via the central management workstation may be required in emergency or override situations.

12.14.6.2 User Interface. Design criteria for the operation and integration of the lighting control system may be provided via a Web-browser style interface accessible from the central server workstation. Web interface systems require approval from the SME.

12.14.6.3 Logic. Table 12.14.6.3 defines the logical control/monitoring points associated with a typical energy metering/sub-metering system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

12.14.7 Integration of Lighting System into BAS Drawing

12.14.7.1 Figure 12.4.7 provides design options for integration of the lighting system with the BAS.

12.14.8 Integration to Tier 2 Gas Detection Systems

12.14.8.1 Integration of the toxic/combustible gas system into the enterprise shall include design criteria for monitoring the status of the gas monitoring systems, including system status, alarm, and individual sensor current values. In certain cases, remote ability to reset alarms via the central management workstation may be required in emergency, override, or system test situations.

12.14.8.2 Reference Standards. System design shall establish the necessary interface requirements for the gas monitoring system interface, alarming, and reset capability.

Informative Note: If required, reference the relevant gas detection standard in separate documents.

12.14.8.3 Logic. Table 12.14.8.3 defines the logical control/monitoring points associated with a typical gas detection/monitoring system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

Figure 12.14.8 provides design options for integration of the gas detection system with the BAS.

12.14.9 Integration to Tier 2 Security System

12.14.9.1 Integration of the site security system into the enterprise shall include design criteria for monitoring the status of the security alarming system, including system status, alarm, and remote reset. In certain cases, remote ability to reset alarms via the central management workstation may be required in emergency, override, or system test situations.

12.14.9.2 Logic. Table 12.14.9.2 defines the logical control/monitoring points associated with a typical security system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

Figure 12.14.9 provides design options for integration of the security monitoring system with the BAS.

12.14.10 Integration to Tier 2 Fire/Life Safety Systems

12.14.10.1 Integration of the site fire/life safety system into the enterprise shall include design criteria for monitoring the status of the fire/life safety alarming system, including system status and alarm.

12.14.10.2 Reference Standards. System design shall reference the fire and life safety Standards. Design shall establish the necessary interface requirements of the security monitoring system interface and alarming.

12.14.10.3 Integration. Typical fire/life safety system interface consists of a hardwired, relay dry contact, monitored by a Tier 2 programmable controller. This controller shall provide an output variable that can be polled or bound to the BAS of any other network controller.

12.14.10.4 Status Monitoring. Design criteria shall include the ability of the BAS front end to monitor the networked programmable controller status of the fire alarm system. The controller, which is monitoring the dry contact from the fire system, shall report its operational status as an output variable.

12.14.10.5 Logic. Table 12.14.10.5 defines the logical control/monitoring points associated with a typical fire/life safety system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

12.14.11 Integration of Fire System into BAS Drawing

12.14.11.1 Figure 12.14.11 provides the design options for integration of the fire system with the BAS.

12.14.12 Integration to Tier 2 Energy Metering Systems

12.14.12.1 Integration of the site energy metering system into the enterprise shall include design criteria for monitoring the status of the metering system, including system status. Design criteria shall include the ability to access utility electrical power metering data and any system submeters as determined in energy metering standard and shall have the ability to collect real-time energy-use data.

12.14.12.2 Reference Standards and SME Support. System design shall establish the necessary interface requirements for the metering monitoring system capability. At a minimum, the central server shall have the ability to col1lect, store, analyze, and report on site energy usage.

12.14.12.3 Logic. Table 12.14.12.3 defines the logical control/monitoring points associated with a typical energy metering/submetering system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

12.14.13 Integration of Energy Metering System into BAS Drawing

12.14.13.1 Figure 12.14.13 provides the design options for integration of the energy metering system with the BAS.

12.14.14 Integration to Tier 2 Water Metering Systems

12.14.14.1 Integration of the site water metering system into the enterprise shall include design criteria for monitoring the status of the metering system, including system status. Design criteria shall include the ability to access utility water metering data, any system sub-meters as determined in the water metering standard, and shall have the ability to collect real-time water usage data and leak detection.

12.14.14.2 Reference Standards and SME Support. System design shall establish the necessary interface requirements for the metering monitoring system capability. At a minimum, the central server shall have the ability to collect, store, analyze, and report on site water usage.

12.14.14.3 Logic. Table 12.14.14.3 defines the logical control/monitoring points associated with a typical water metering/submetering system and associated design requirements. Design shall account for specific project functionality and retain a consistent naming and point identification methodology as defined.

12.14.15 Integration of Water Metering System into BAS Drawing

12.14.15.1 Figure 12.14.15 provides the design options for integration of the water metering system with the BAS.

12.15 Enterprise Energy Management Requirements

12.15.1 The central enterprise energy management system (EEMS) system shall have the capabilities listed in the following subclauses.

12.15.1.1 Energy Metrics. Building-to-building, site-to-site energy comparison visualization and reporting.

12.15.1.2 Analytics. Detailed energy use analytical ability to provide operational adjustments and reduce energy waste, improve conservation, and highlight possible areas for efficiency improvements.

12.15.1.3 Rule Engine and Configuration. Allow user-based rules engine configuration or specific data analysis, alarming, alerting, and reporting criteria.

12.15.1.4 Optimization. Provide system and site optimization reports.

12.15.1.5 Trending. Capture, store, and trend specific data points. Specification criteria shall define the storage duration, range, and resolution of each data point trended. This is typically project specific. Trend log data shall be stored on a server and backed up according to the backup procedures defined elsewhere. Trend log visualizations shall be defined and created by the FMSI and approved by the owner.

12.15.1.6 Reporting. Standard and customizable system and site reports.

12.15.1.7 Data Exports. Ability to export data sets from internal database to external applications and servers as required.

12.15.1.8 Data Imports. Ability to import data from external sources such as utility bills, trend logs, CSV files, etc.

12.15.1.9 Monitoring. Provide graphical interface for real-time system monitoring as defined for each subsystem.

12.15.1.10 Web Browser. Provide standard Web-browser interface for multiple users.

12.15.1.11 Tablet and Smart Phone Interface. Provide a standard Web-browser and/or custom application for monitoring specific systems via a smartphone, tablet, or remote client device.

12.15.1.12 Alarming. The capture, display, and logging of all relevant system alarms. Alarm management shall be delivered by the FMSI and coordinated with the BAS contractor. Alarm reporting, acknowledgements, overrides, and history shall be delivered according to the system design. Design criteria shall establish minimum alarming requirements.

12.15.1.13 Alarming and Alerting Interface. Provide full alarming and alerting capability and a user-defined criteria set. Provide alarms/alerts as required via the following:

a. E-mail
b. Text messaging
c. Graphics interface

12.15.2 Graphical User Interface (GUI) Standards

12.15.2.1 Graphics. Design criteria shall include a full graphical user interface (GUI) providing visualizations for each subsystem and critical monitored data points and summarizations of operations and efficiency. The GUI shall be hosted by the central server as defined in Clause 12.7. A set of sample graphics pages shall be included in the design criteria and coordinated with the EEMS SME. See documentation and submittal requirements in Clauses 5.6 and 7.10.

12.15.2.2 Responsibilities. The site FMSI shall be responsible for the generation, customization, and maintenance of the GUI.

12.15.2.3 Customization. The user interface shall have full customization capability by the user, including size, shape, location, and labeling of graphical and text elements on the user interface. All software solutions shall provide native customization and configuration capability. Under no circumstances shall customization and configuration require proprietary vendor tools or technicians.

12.15.2.4 Tools. All software, databases, configuration tools, and analysis tools shall be delivered as part of the project. All software shall be properly licensed and conveyed at contract sign off. In no circumstances shall any software keys, licenses, or tools be licensed to a contractor or subcontractor on the owner's behalf. Deliver all software licenses, keys, dongles, or other software security mechanisms. The site FMSI shall coordinate the compliance and conveyance of licenses.

12.15.3 Dashboard and Kiosk Application Requirements

12.15.3.1 Design criteria shall include requirements for a user interface dashboard display. Dashboards shall be accessible from multiple workstations or displays using simple browser-based services (HTML, HTML5, Java, or equivalent). Multiple dashboards shall be available and configurable by the user.

12.15.3.2 Provide Sample Dashboard Pages. Design criteria shall establish baseline requirements for required dashboard visual representations. Contractor shall submit example graphic visualizations and sample screenshots. At a minimum, submit examples for energy monitoring, system status, sustainability status, alarm status, and one page for each subsystem (gas, water, fire, life safety, etc.). See Clauses 5.6 and 7.10 for details on submittal requirements.

12.15.3.3 Customization. The system shall have the ability to customize various dashboards per specific use requirements, subsystem monitoring requirements, and analysis requirements. The system shall have the ability to customize and configure any dashboard display.

12.15.3.4 Information Kiosks. The design criteria shall include an information kiosk display for use in public spaces. Green Kiosks or Information Kiosks are typically provided for sharing information on facility greening efforts, energy conservation efforts, usage data, carbon offsets, and other information relevant for the purposes of ensuring public awareness of the importance of the facilities' conservation and efficiency initiatives. The design of the kiosk display screens is the responsibility of the FMSI and shall be coordinated with the facility manager such that the key objectives and information are displayed in a timely manner.

12.15.3.5 Responsibilities. The site FMSI is responsible for setting up, configuring, maintaining, and managing the dashboard and kiosk information and displays.

12.15.4 Data Collection, Storage, and Retention

12.15.4.1 Design criteria shall include details on the scope, size, number of simultaneous user interfaces (seats/licenses), and other requirements for the interface to the system.

12.15.4.2 The central server shall have the capability to collect and store data from every connected site for a minimum of five years. Data beyond five years shall be backed up on nonvolatile media and archived.

12.16 System Training

12.16.1 Design criteria shall include complete training requirements for owner's personnel or designated contractors. Training shall include operations as well as configuration, programming, commissioning, and customization of Tier 1, Tier 2, and Tier 3 responsibilities including the following:

a. Enterprise server training, including configuration, customization, and maintenance
b. General system operation and system maintenance training
c. Network management tool training
d. Protocol analysis tool training
e. GUI, dashboard, tool customization training
f. BAS Tier 2 system and equipment operational and maintenance training
g. Other, as determined by the project

12.17 System Maintenance and Service

12.17.1 System software maintenance and service shall be performed by the FMSI and shall include the regular system software updates, patches, and necessary upgrades, including security, virus protection, spyware protection, etc. Annual licenses shall be renewed and kept current. Additional system maintenance requirements shall follow relevant IT standards.

12.17.2 All BAS points/objects and devices shall be calibrated, tested, and recertified at least once a year through the annual support contract (see separate requirements for warranty and support).

12.18 System Documentation

12.18.1 Complete system documentation files (electronic) and binders (hard copy) shall be updated and kept current by the FMSI. All software manuals, documentation files, and binders shall be clearly labeled and backups stored in a secure place identified by the FMSI.

12.18.2 Original software installation discs shall be delivered and clearly labeled and stored in a secure place identified by the FMSI. No software copies shall be accepted. The owner shall receive the original installation discs for all loaded software.

12.18.3 Downloaded Software. If downloaded files are implemented, the FMSI shall copy installation files onto an optical media disc and clearly label and identify any license keys on the disc. Discs are to be stored in a secure location.

12.18.4 System Databases. All databases shall be delivered on optical media by a Tier 2 BAS contractor to the FMSI.

TABLE 12.14.4.5 HVAC System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
HVAC	HVAC equipment and space control system					Enterprise system to monitor and control HVAC in designated buildings.
		System status and alarm		Bound	Polled by central server for current status on 5 to 15 min intervals. (Note 1)	Note 2
	Current zone temp.	Zone temp.		Polled	Note 5	Note 3
	Monitor current zone temp. setpoint	Temp. setpoint		Polled	Note 5	Design criteria shall allow for the monitoring of each zone temp. setpoint.
	Control zone temp. setpoint		Zone temp. setpoint	Bound	On send	Design criteria shall allow for the central server to control certain zone temp. setpoints. Coordinate with HVAC SME to establish specific zone control capabilities.
	Zone humidity	Humidity		Polled	Note 5	Monitor zone humidity to ensure that it is in acceptable range. Central server to flag alarms if humidity is out of range. See HVAC Standard for required humidity ranges for specific buildings.
	Zone Pressure	Pressure		Polled	Note 5	Monitor zone pressure relative to outdoors to ensure within acceptable range. Central server to monitor pressure and flag on alarm. See HVAC Standard for required pressure ranges for specific buildings.
	HVAC equipment status	Equipment status		Polled	Note 5	Note 4
	HVAC equipment override		Override	Bound	On send	Note 6
	Fire-system monitoring	Fire relay		Bound	On positive event state	HVAC system shall monitor the status of the fire life safety system via a dry contact.
	Gas detection system monitoring	Gas detected—either via dry contact (external) or via active equipment sensor (internal)		Bound	On positive event state	HVAC system shall monitor the status of the gas detection system and internal equipment sensors and provide an output logical variable to the BAS Tier 1 system.

Note 1: If alarm condition occurs, output variable initiates immediate output alarm.

Note 2: Current operational status of the HVAC system is monitored by the enterprise server via a system status logical output variable as defined. System design shall allow each HVAC-specific equipment or system to be monitored for its status from the central server. This logical output shall be considered an alarm output should the system status indicate the HVAC system is malfunctioning. Providing a positive status output allows the central server to actively ping/poll the subsystem to ensure it is communicating and it is not in alarm. Alarm output is to send on status change to the central server to indicate alarm state and must be acknowledged.

Note 3: Defined the space temperature status and utilized a specific logical output variable definition of the current temperature from thermostat sensor. The enterprise system has the ability to monitor space temperature from any sensor exposed to the HVAC system. Design criteria should include designated HVAC zones that will provide monitoring of temperature. Freeze conditions are to be monitored and alarmed from the central server. See the relevant HVAC standard for required temperature ranges for specific buildings.

Note 4: System design shall have the ability to monitor the status of specific HVAC equipment. Equipment such as air handlers, variable-frequency drives and fans that have the ability to monitor their operational status shall be incorporated into the central management monitoring system.

Note 5: Polled by central server at frequency determined by the FMSI—typically 1 to 5 minutes, including bandwidth limitations.

Note 6: Design criteria shall allow for specific equipment to be controlled from the central server in the event of an emergency, system test, or other necessary condition.

TABLE 12.14.6.3 Lighting System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Lighting	Lighting space or zone control					Enterprise system to monitor and control lighting in designated areas.
		System status and alarm		Bound	Note 1, Note 3	Note 2
	Absence, presence detection	Occupancy		Polled	Note 3	Note 4
	Lighting circuit control— on/off		Override	Bound	Network variable input action on immediate receipt	Note 5

Note 1: If alarm condition occurs, output variable initiates immediate output alarm.

Note 2: Current operational status of the lighting system is monitored by the enterprise server via a system status logical output variable as defined. System design shall allow each lighting panel or system to be monitored for its status from the central server. This logical output shall be considered an alarm output should the system status indicate the lighting system/panel is malfunctioning. Providing a positive status output allows the central server to actively ping/poll the subsystem to ensure it is communicating and it is not in alarm. Alarm output is to send on status change to the central server to indicate alarm state and must be acknowledged.

Note 3: Polled by central server at frequency determined by FMSI—typically 1 to 5 minutes. Bandwidth limitations shall be determined by the FMSI.

Note 4: Defined the space occupancy status and utilized a specific logical output variable definition defining presence/absence from the sensor. The enterprise system has the ability to monitor space occupancy from any sensor exposed to the lighting system. Design criteria should include designated lighting zones that will provide monitoring of occupancy.

Note 5: System design shall have the ability to override lighting controls from the central server interface. Used in the event of an emergency, special situation, or for system testing. Design criteria shall define specific lighting panels/zones that can be overridden from the central server.

TABLE 12.14.8.3 Gas Detection System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Gas	Hazardous gas detection monitoring					Note 1
		System status		Polled point from the central server, or other life safety interface.	Note 2	Current operational status for the gas monitoring system shall be polled from the central management system. Polled value shall confirm communication and current operational status.
	Low explosion limit	LEL		Polled	5 min or less	Monitoring of the LEL status
	Sulfur dioxide gas	SO_2		Polled	5 min or less	Monitoring of the SO_2 level
	Hydrogen sulfide gas	H_2S		Polled	5 min or less	Monitoring of the H_2S level
	Carbon monoxide	CO		Polled		Monitoring of CO levels
	Nitrogen dioxide (diesel exhaust)	NO_2		Polled		Monitoring of NO_2 levels
		Alarm		Bound output (Note 3)	Immediate on alarm event. Point may be polled as well at 5 min or better intervals.	Note 4
			Reset, alarm acknowledge	Bound	On send	Note 5

Note 1: Enterprise system shall monitor the status of the site gas monitoring system in order to affect action based on conditional criteria. Design criteria shall be coordinated on a per-project basis to determine any interactions necessary.

Note 2: Data polling rate shall be defined by the FMSI and system bandwidth limitations. In no case shall the poll frequency be greater than 5 minute intervals.

Note 3: Additional hardwired-alarms design criteria shall be followed per referenced standards.

Note 4: The gas-monitoring alarm logical output shall be connected to the central server and shall indicate the gas detection system is in alarm and an event has occurred. Individual sensor data shall also be sent and shall trigger an alarm. See relevant gas limit levels in the relevant HVAC standards.

Note 5: Design criteria shall enable an output command variable from the central server to reset a local alarm condition. In no event shall a remote reset command override a local reset requirement. Design criteria shall account for specific reset requirements and procedures.

TABLE 12.14.9.2 Security Monitoring System Integration Criteria Integration

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Security	Security monitoring system					Enterprise system shall monitor the status of the site security monitoring system in order to affect action based upon conditional criteria. Design criteria shall be coordinated on a per-project basis to determine any interactions necessary. Coordinate with site security SME to provide specific sequences.
		System Status		Polled from central server	5 min minimum updates. SME to provide guidance on polling frequency.	Security monitoring system status output provides operational and communication functional status to central server.
		Alarm		Bound	Immediate on alarm event. Point may be polled as well at 5 min or better intervals.	Security system alarm output shall notify the central server of an alarm as a logical output point.
			Reset alarm	Bound	On send	Design criteria shall enable an output command variable from the central server to reset a local alarm condition. SME for the security alarming system shall establish the criteria for remote alarm reset conditions. In no event shall a remote reset command override a local reset requirement. Design criteria shall account for specific reset requirements and procedures.

TABLE 12.14.10.5 Fire/Life Safety Monitoring System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Fire	Fire monitoring system					Enterprise system shall monitor the status of the site fire detection system. Control shall be implemented via a networked programmable controller using a relay dry contact out of the main fire system.
		System status		Polled	5 min minimum updates. SME to provide guidance on more frequent polling.	Fire monitoring system status output provides operational and communication functional status to central server.
		Alarm		Bound	On send	Fire system alarm output shall notify the central server of an alarm as a logical output point.

TABLE 12.14.12.3 Energy Metering System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Power	Electrical power metering system					Enterprise system shall monitor the energy metering system. Utility meters and submeters shall be integrated into the central management system interface. Coordinate with site energy manager for specific site facilities to meter or submeter.
	Kilowatt-hours providing energy usage over time	Energy sum		Polled	15 min or better	Data to be stored and forwarded to central server for analysis and comparative purposes.
	Peak demand power consumption	Peak demand		Polled	15 min or better	Peak demand to be polled by central server. Central server to set alarms based on peak demand limits to help identify power surge issues.
	Others TBD			Polled		Add additional power quality, phase loading, voltage, and current monitoring as site energy management SME requires.
	Status	System status		Polled	5 minute minimum updates.	Energy monitoring system status output provides operational and communication functional status to central server.

TABLE 12.14.14.3 Water Metering System Integration Criteria

Subsystem Name	Functionality Description	Monitoring Points	Control Points	Polled or Bound	Data Frequency	Design Criteria and Notes
Power	Electrical power metering system					Enterprise system shall monitor the energy metering system. Utility meters and submeters shall be integrated into the central management system interface. Coordinate with site energy manager for specific site facilities to meter or submeter. Refer to referenced standards for energy metering requirements.
	Kilowatt-hours providing energy usage over time	Energy sum		Polled	15 min or better	Data to be stored and forwarded to central server for analysis and comparative purposes.
	Peak demand power consumption	Peak demand		Polled	15 min or better	Peak demand to be polled by central server. Central server to set alarms based on peak demand limits to help identify power surge issues.
	Other TBD			Polled		Add additional power quality, phase loading, voltage, and current monitoring as site energy management SME requires.
	Status	System status		Polled	5 min minimum updates	Energy monitoring system status output provides operational and communication functional status to central server.

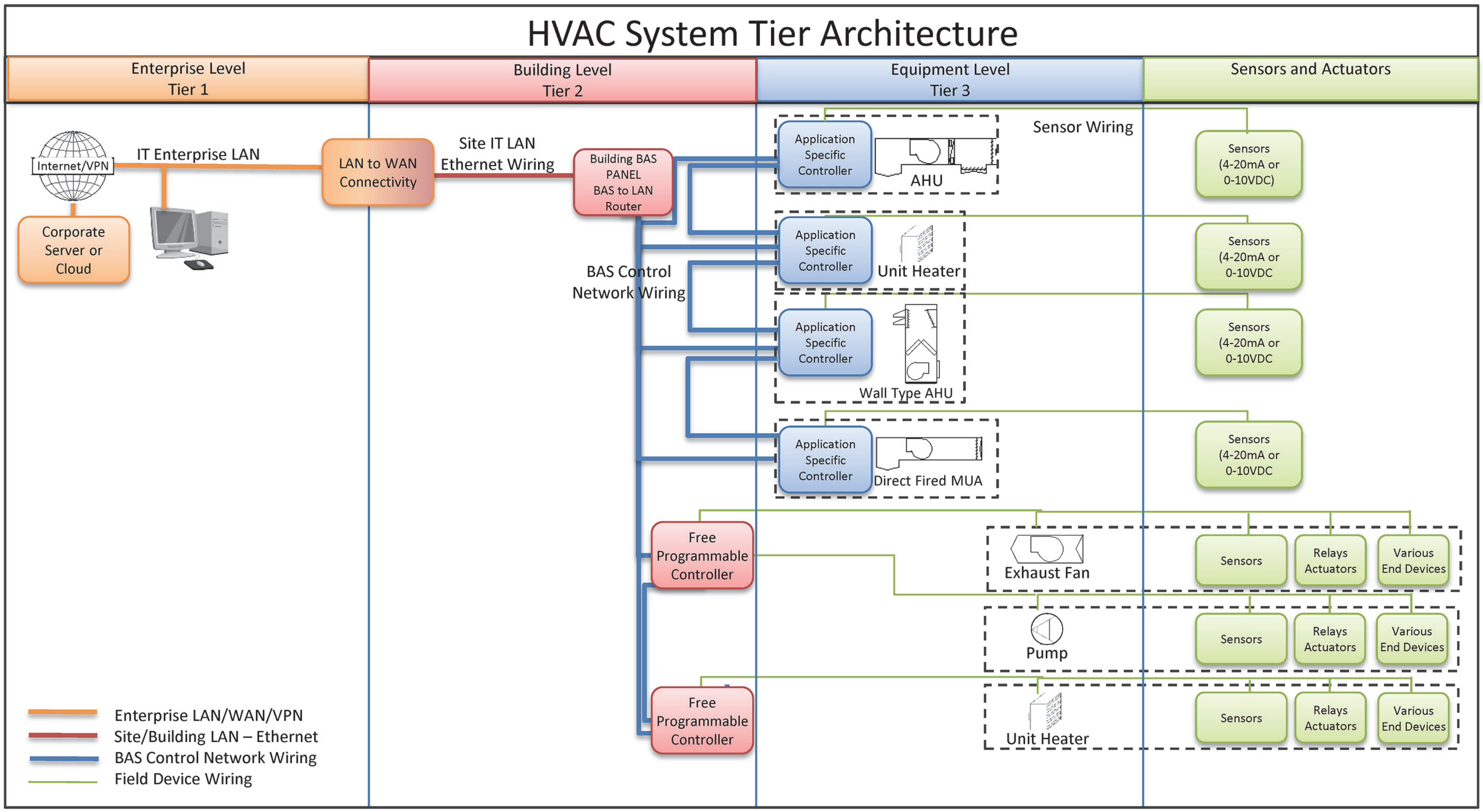

FIGURE 12.14.5 Example multitier HVAC integration overview drawing.

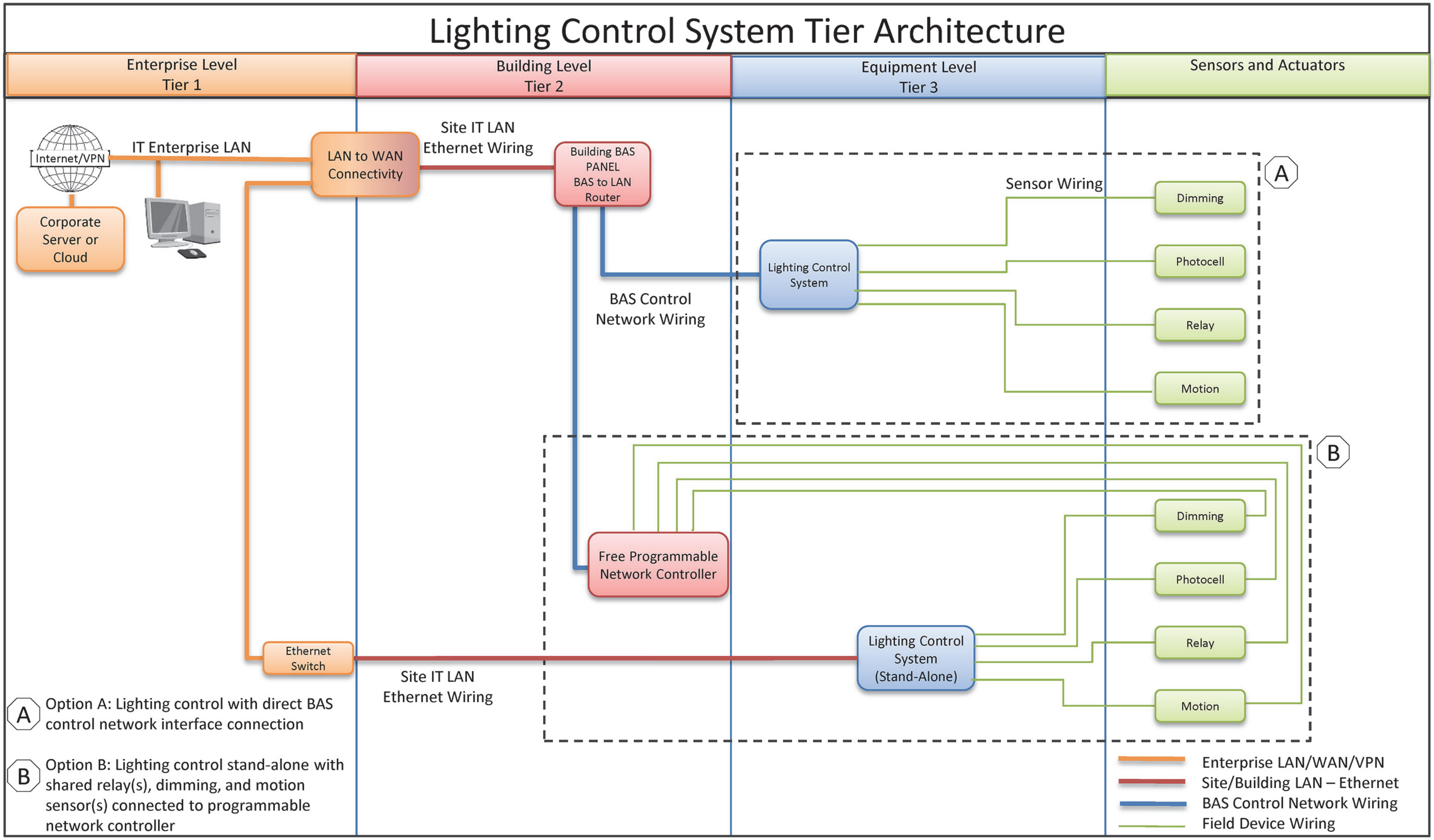

FIGURE 12.14.7 Example multitier lighting system integration overview drawing.

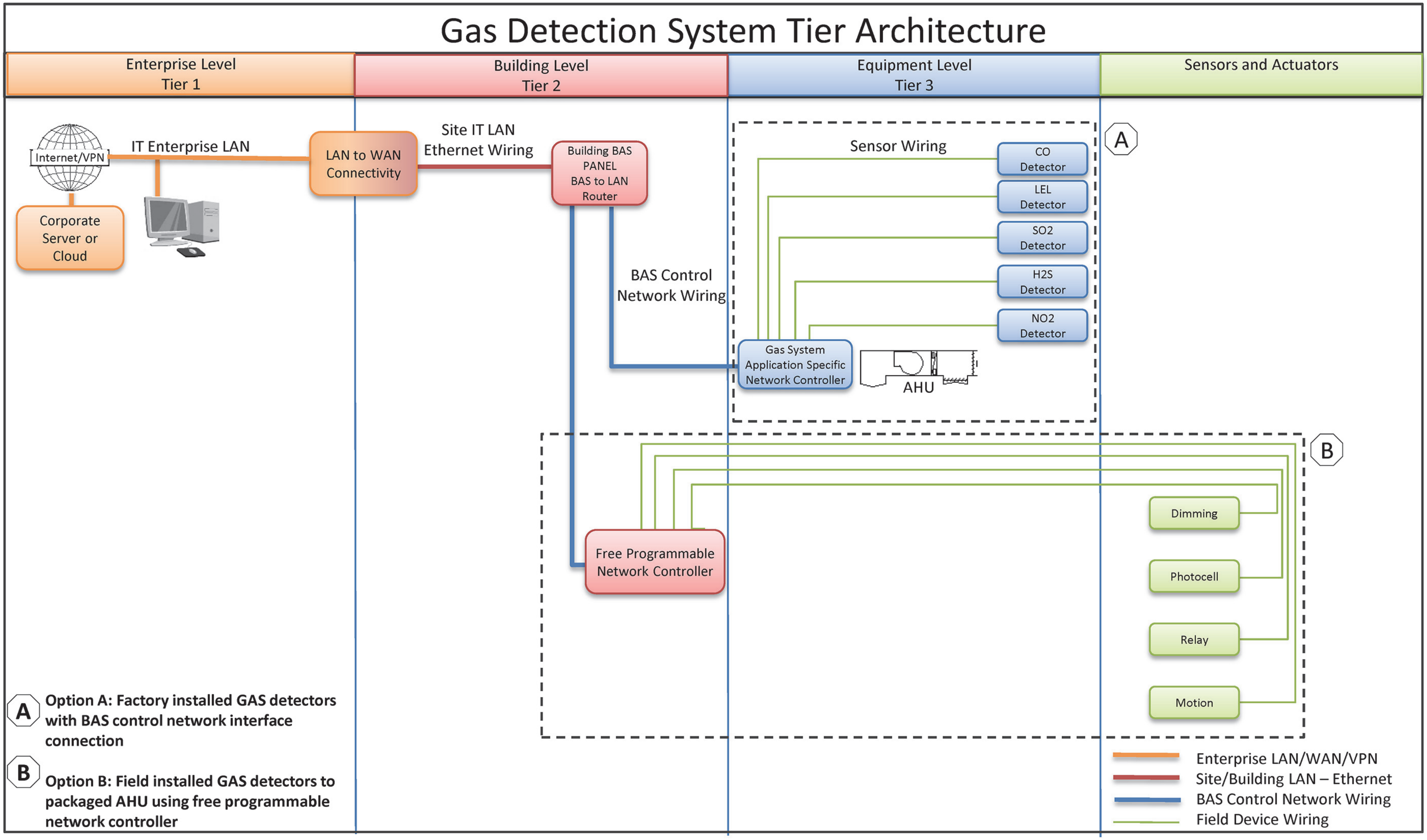

FIGURE 12.14.8 Example multitier gas detection system integration overview drawing.

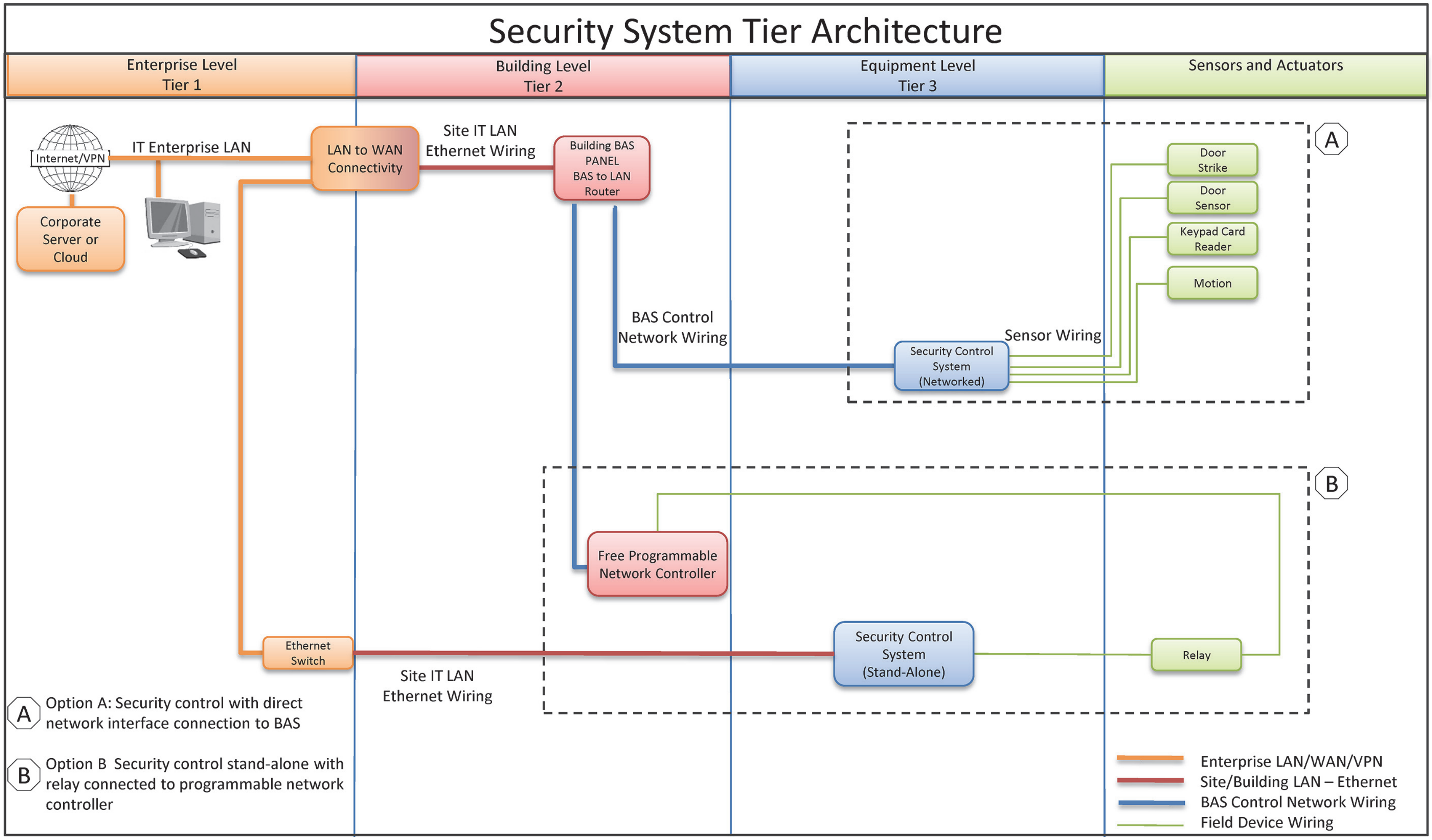

FIGURE 12.14.9 Example multitier security system integration overview drawing.

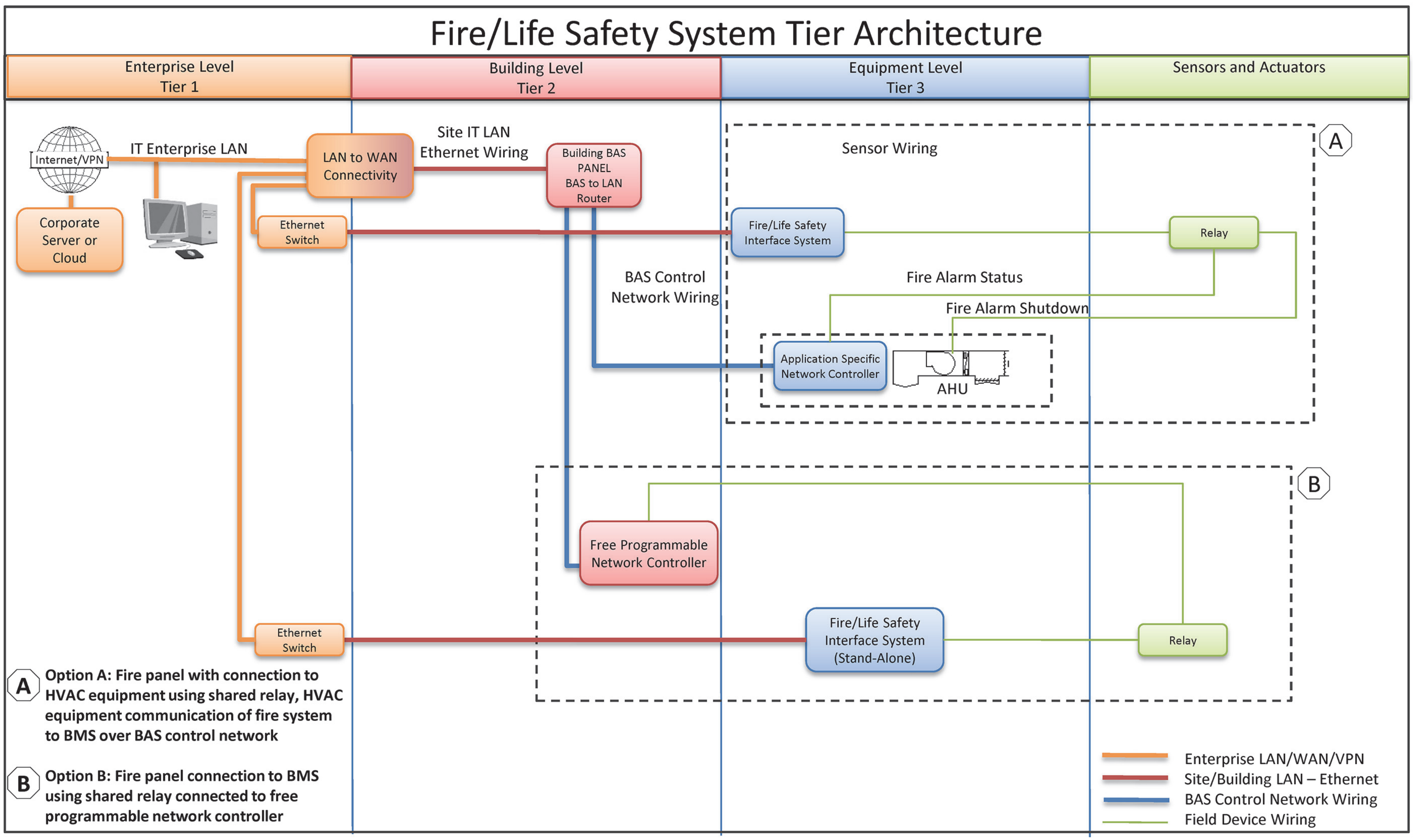

FIGURE 12.14.11 Example multitier fire/life safety system integration overview drawing.

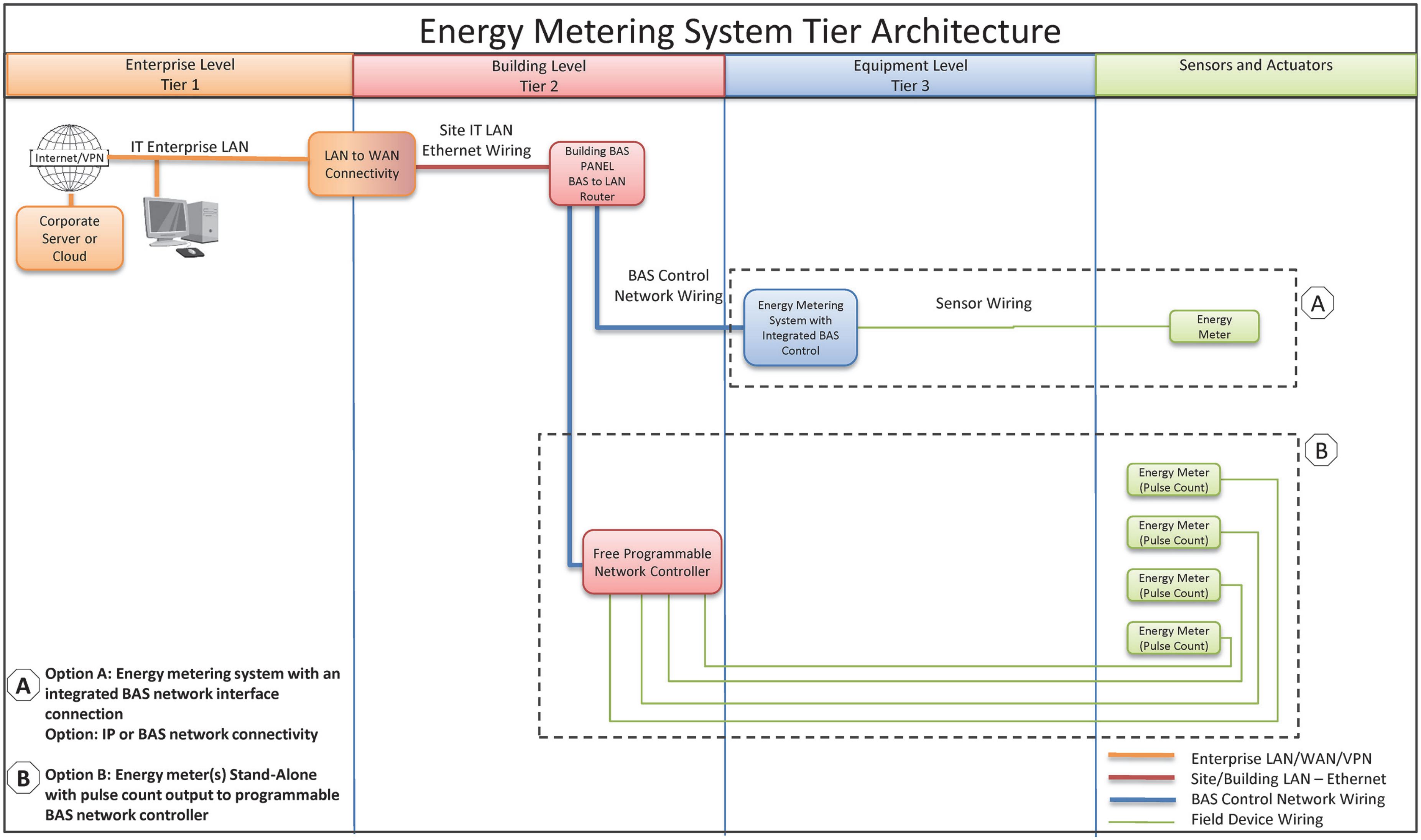

FIGURE 12.14.13 Example multitier energy metering system integration overview drawing.

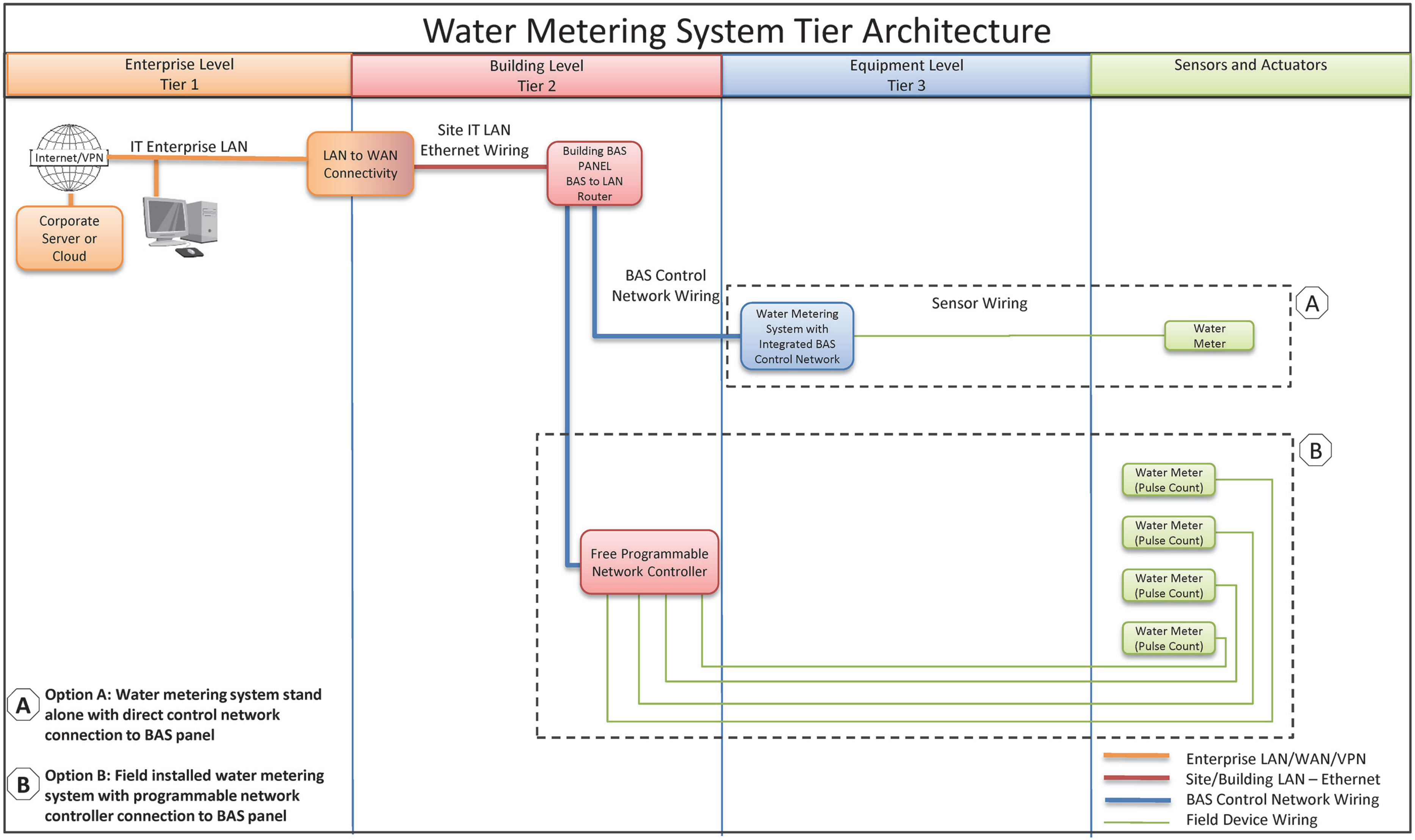

FIGURE 12.14.15 Example multitier water metering system integration overview drawing.

13. LEGACY CONTROL SYSTEMS

The following text, along with information provided at the beginning of Clause 12, addresses the section of the guideline specification that deals with legacy systems and the criteria for determining whether to abandon continued investment or find ways to prolong the life of current assets. This information is provide for guidance only; specific project criteria should be established as defined by project management and project funding.

13.1 Terms. The term "legacy systems" refers to older installed control systems that may or may not be compatible, integrateable, serviceable, or reliable or have parts available according to more current standards. Evaluation of the state of the currently installed system will help the BAS designer determine what direction to take regarding whether to continue support or replace the system.

13.2 Usability

13.2.1 The potential usability of a legacy system can be divided into three primary categories.

13.2.1.1 Upgradeable. An older system that currently does not meet the standards but can be upgraded by the system manufacturer to make it compliant to an acceptable degree. Often this might mean installing new software, new drivers, or even new hardware such as gateways or interfaces.

13.2.1.2 Integrateable. An older system that is not upgradeable by the existing manufacturer but for which third-party tools, such as gateways, drivers, or interfaces, may enable integration to an acceptable degree into the new standard.

13.2.1.3 Replaceable. An older system that does not meet the current standards and has no cost-effective upgrade path and no reasonable gateway solution is considered a replaceable system.

13.3 Evaluation. Evaluating the viability and value of a legacy system is an important step in assessing the best path for ensuring that the end solution is economically and operationally viable. The baseline criteria and specification details listed in Clause 13.4 are key performance indicators for helping to evaluate the usefulness and life-cycle stage of a legacy system. These criteria are for general guidance and must be evaluated on a case-by-case basis. In general, an assessment of current and future needs should provide a clear understanding of which options are needed. Project criteria should identify metrics for specific project decision factors based on the criteria. Consider the purpose of the system as well as economic, reliability, security, and overall performance criteria in the evaluation of a legacy systems and whether it is appropriate to abandon continued investment.

13.4 Tier 1 BAS Specification Criteria

13.4.1 Upgrade BAS Front End

13.4.1.1 Software/Tools (Tier 1 BAS Level). The Tier 1 system software and servers shall be upgraded to meet current requirements only if all of the following criteria are true:

a. The current software is less than 10 years old.
b. The software and tools are performing satisfactorily.
c. There are no reliability issues with the current software.
d. The software can run on a currently supported operating system and current commercially available computer hardware (for example, running on Windows 7 or 8 rather than Windows 95/98/2000/Vista).
e. The software and computer platform supports an open-control networking system infrastructure without proprietary requirements such that multiple vendor products can be integrated.
f. The current software is performing according to current and future needs.
g. Software is supported by the vendor.
h. Software upgrades are available to bring the system up to current performance requirements.
i. Software upgrade costs are competitive with new system standards.
j. Software documentation and training is generally available at a competitive cost.
k. Software is capable of running on a current-model computer and operating system.

13.4.1.2 Hardware BAS Server. The Tier 1 computer server is one of the primary areas of concern with legacy systems. The following criteria should be used to evaluate the server's viability for ongoing usage:

a. The server is less than 5 years old.
b. The server is performing satisfactorily.
c. The server operating system is currently supported by the vendor.
d. The server has the required RAM and hard drive space.
e. The CPU of the server is current enough to support additional applications and demands.
f. The server hardware is currently supported by the vendor.
g. There are currently no issues with the operating system that would prevent the server from performing correctly.

If all of these criteria are satisfactory, upgrading the software only is viable.

13.4.2 Integrate to the BAS Front End

13.4.2.1 Integration options for the BAS front end and servers are primarily limited to the following:

a. Installing new applications either from the current vendor or from additional vendors.
b. Integrating into a common open database such as SQL.
c. Building common Web-page graphical interfaces using a common application form such as HTML or HTML5.

13.4.2.2 Careful consideration should be given to whether it is economically viable to try to integrate new software applications into a current legacy system software package.

13.4.2.3 Use the criteria listed under Clause 13.4.1.2 to evaluate whether the current software can be extended by adding new, compatible software applications. Software applications from multiple vendors must coexist and not interfere with one other's operations, especially if they share a common database. Thorough testing for compatibility should be performed.

13.4.2.4 Use the criteria in Clause 13.4.1.2 to determine whether the legacy server is up to date and robust enough to consider integrating new software.

13.4.3 Replace the BAS Front End

13.4.3.1 The BAS front end software should be replaced if the criteria outlined for integration and for upgrade are not met.

13.4.3.2 The BAS server should be replaced if all of the criteria identified in the upgrade and integration are not met.

13.4.3.3 Selection of a new BAS server should take into account the following criteria:

a. Server hardware is currently powerful enough to support applications for a minimum of 5 years.
b. Server memory (RAM) meets current application requirements as specified by the software vendor. Consider additional memory if multiple applications are to run on the same server concurrently.
c. Server hard-drive space is great enough to accommodate the required trend logging and storage for at least 5 years. Refer to the software vendor recommendations on disk size requirements.
d. Server can run a currently supported operating system that supports the intended new software. Care should be given to the choice between 32 vs. 640bit CPUs and software compatibility. Additionally, care should be given to the choice in operating system and note should be made of the duration of support offered by the vendor. Ensure at least 5 years of support at a minimum.
e. Server security requirements should, at minimum, meet IT standards for firewalls, virus protection, antispam, and other security-related concerns. Refer to IT best practices to ensure that the new server has all of the relevant security software applications required.

13.5 Tier 2 Controls Infrastructure Specification Criteria

13.5.1 Upgrade Controls Infrastructure

13.5.1.1 Controls Infrastructure (Tier 2 Building Level). The Tier 2 BAS infrastructure shall be upgraded to new firmware, routers, interfaces, or necessary hardware/firmware changes only if all of the following criteria are true:

a. The controls infrastructure is less than 10 years old.
b. The current controls infrastructure performs satisfactorily.
c. There are no infrastructure reliability issues (wiring, connection, termination, bandwidth, or power-related issues).
d. The current infrastructure uses an open-control system protocol and infrastructure model and can be upgraded with new routers and interfaces.
e. The current system is not based on a proprietary closed protocol or vendor-specific infrastructure.
f. Routers, repeaters, and interfaces are currently available and supported at a reasonable price.
g. The infrastructure does not implement a vendor proprietary solution.
h. Training for new service personnel is available on the infrastructure architecture at a reasonable cost.
i. The controls infrastructure uses currently supported technology and is not obsolete.
j. The current infrastructure wiring performs satisfactorily and no rewiring is needed.
k. Performance of the infrastructure meets current and future needs with no latency, bandwidth, or bottleneck issues.

If all of the criteria outlined in Clause 13.5.1.1 are true, consider upgrading the current software to the latest version and ensure the computer hardware, operating system, security software, and memory are up to the latest industry standards for performance and reliability.

If any of the identified criteria of the current legacy system are not upgradeable, consider not investing in an upgrade and explore either an integration or replacement option.

The infrastructure shall be upgraded or expanded to meet the current and future needs as defined if all of the listed criteria are true and an economically and technically viable upgrade path can be implemented.

13.5.2 Integrate Controls Infrastructure

13.5.2.1 Integrate (Tier 2 BAS to Tier 1 BAS Integration). Following the model in Clause 13.5.1, if an upgrade path of the existing system is fundamentally a bad investment, but the current system is performing well enough, consider implementing an integration process until such time as the existing system can be retired and replaced. Funding an integration method can prolong a legacy system with minimal cost as compared to a full replacement. Integration to legacy systems typically requires the use of a third-party gateway.

A gateway traditionally converts information from one system to another. In the case of a proprietary system protocol and data set, a gateway can take key information, reformat it, and provide connectivity to a newer, more open platform.

Key considerations for integrating a legacy system focus on the ability of collecting data and providing some level of control to the entire system and do not typically require hardware or infrastructure changes.

13.5.2.2 Specification Criteria—Integrate. The Tier 2 BAS infrastructure shall be integrated using a gateway interface only if all of the following criteria are true:

a. A commercially viable gateway is available that can translate the legacy system information into the needs of the current open standard.
b. Programming of a gateway does not require proprietary tools or information from the legacy system vendor.
c. Gateway mapping programming is available and will meet the needs of the new standard.
d. No significant modifications to the legacy system are needed in order to obtain a functioning interface to the new infrastructure and BAS front end.
e. The gateway can provided needed one-way or two-way monitoring and control functionality as required.

Addition of a gateway to integrate the legacy or proprietary system shall be implemented if all of these are true and represent an economically and technically viable option.

13.5.3 Replace Controls Infrastructure

13.5.3.1 The infrastructure shall be replaced to meet the current standard if any of the upgrade or integration criteria are not true.

13.5.3.2 When considering the replacement of the Tier 2 control networking infrastructure, follow the design criteria established in Clause 12 at a minimum. New control network wiring and new infrastructure devices such as routers, repeaters, and LAN interfaces will be required. Follow the requirements of the specific control networking protocol option selected. See Informative Annexes B, C, and F for references and resources.

13.6 Tier 3 BAS Equipment Controllers and Networked Devices

13.6.1 Upgrade Controls Infrastructure

13.6.1.1 Control Hardware (Tier 3 Devices). The Tier 3 BAS equipment controls shall be upgraded to new firmware, software, or hardware only if all of the following criteria are true:

a. The controls hardware is less than 10 years old.
b. A majority of the current controller hardware is performing satisfactorily, meets the sequence and operation needs, and does not need to be replaced.
c. The current controllers are reliable and stable.
d. The current controllers meets security requirements.
e. The controllers use an open-communication protocol and can interoperate with the new system.
f. The current hardware is available from one or more sources at a market-competitive price.
g. The controller performance meets the minimum currently acceptable needs of the current system.
h. The controllers are supported by the manufacturer for spare parts and upgradeable firmware.
i. The existing operations and maintenance can service and maintain the controls; no additional extensive training is needed.
j. Training for new operations personnel is available at a reasonable cost.
k. Current documentation for the hardware is available and accessible.
l. Programming tools, management tools, configuration tools, and the like are available for purchase by the user and are not vendor or vendor-channel proprietary.
m. For programmable controllers to update internal algorithms, programming tools are available at a competitive price and are able to run on a current-model computer and operating system.

If all of the above criteria are true, then the controls shall be upgraded if there is an economically and technically viable upgrade path to ensure the legacy system meets the minimum requirements for use and integration into the new standard, including integration into a common infrastructure and BAS front end software system.

13.6.2 Integrate Controls Infrastructure

13.6.2.1 Integration of new controls into an existing control system is primarily a Tier 2 task. Two options exist for integrating new controls into a legacy system:

a. *Option 1:* Ensure the new control solution is of the same protocol type and is fully interoperable with the existing system. This includes wiring, network speed, and other related interoperability concerns. Refer to the specific protocol documentation for interoperability requirements. When selecting new controls hardware where the protocol has various implementation options, ensure that the choice is fully compatible with the installed legacy system such that devices can coexist and interoperate on the current control network. Be sure new network infrastructure is not required.
b. *Option 2:* Use an effective gateway product to allow the legacy system to interoperate with the control system. Gateways can allow legacy system hardware to share data with a newly added system; however, the potential exists for significant costs associated with the new infrastructure. New infrastructure should only be considered if technical and economic reasons prevent justification for replacement.

13.6.3 Replace Controls Infrastructure

13.6.3.1 If all other options are impractical, not cost justifiable, or are not in line with objectives, a full retrofit may be the best option. The entire control system, including controller hardware, wiring, infrastructure tools, servers, and software are removed (recycled or sold for spare parts) and replaced with a new system. This typically means that only the controllers attached to HVAC or other equipment (chillers, air handlers, boilers, etc.) are replaced and not the equipment itself.

13.6.3.2

The legacy system shall be replaced if any of the following criteria are true:

a. The legacy system is underperforming.
b. No economical path exists for upgrading.
c. The legacy system is not reliable.
d. The current operations and maintenance staff do not know how to service and maintain the system.
e. No training is available.
f. No spare parts are available.
g. The manufacturer no longer supports the system.
h. A competitive service contract is unavailable.
i. The system does not meet the current open-systems requirements.
j. The system is based on obsolete technology.
k. There is no expansion path for the existing system.
l. The current system has security issues that cannot be resolved.
m. The system is older than 10 years.
n. The manufacturer of the system is no longer in business.
o. The cost of maintaining the existing system is unreasonable.
p. The existing system is not energy efficient.
q. The existing system does not meet the operational needs or sequence and control requirements.
r. The system is difficult to manage and requires extensive expertise.
s. There is a lack of availability of qualified service personnel.
t. The current system has maximized its ability and no new elements can be added.

A full system replacement shall be implemented if any of these criteria are true and an upgrade or integration path is not viable for any reason.

At such time as integration, reliability, serviceability, security, or other issues, makes further investing in a legacy system economically impractical or technically inviable, a full retrofit shall be implemented.

14. REFERENCES

ASHRAE **1791 Tullie Circle NE** **Atlanta, GA 30329** **404-636-8400**	
ANSI/ASHRAE 62.1-2013	Ventilation for Acceptable Indoor Air Quality
ANSI/ASHRAE Standard 135-2012	BACnet—A Data Communication Protocol for Building Automation and Control Networks
ANSI/ASHRAE Standard 135.1-2013	Method of Test for Conformance to BACnet
ANSI/ASHRAE Standard 147-2013	Reducing the Release of Halogenated Refrigerants from Refrigerating and Air-Conditioning Equipment and Systems
2012 ASHRAE Handbook	HVAC Systems and Equipment
2013 ASHRAE Handbook	Fundamentals
	2005 Sequences of Operation for Common HVAC Systems (ASHRAE CD)
Canadian Standards Association **5060 Spectrum Way** **Mississauga, ON L4W 5N6** **800-463-6727**	
CAN/CSA-ISO/IEC 8802-3-95	Information Technology—Local and Metropolitan Area Networks—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications (Adopted ISO/IEC 99-2-3:1993)
	2012 Canadian Electrical Code Part 1
Electronic Industries Association **2500 Wilson Boulevard** **Arlington, VA 22201-3834** **703-907-7500**	
EIA-232-E -1991	Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange
EIA-485-1983	Standard for Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems
International Code Council **5360 Workman Mill Road** **Whittier, CA 90601-2298** **562-699-0541**	
	International Building Code
	International Mechanical Code
	International Energy Conservation Code
International Electrotechnical Commission **3, rue de Varembé** **PO Box 131** **CH—1211 Geneva 20—Switzerland** **+41 22 919 02 11**	
ISO/IEC 8802-3-2014	Information Processing Systems—Local Area Networks—Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications
LonMark International **550 Meridian Avenue** **San Jose, CA 95126** **408-938-5266**	
ISO/IEC 14908-1	Information Technology—Control Network Protocol— Part 1: Protocol Stack
ISO/IEC 14908-2	Information Technology—Control Network Protocol—Part 2: Twisted Pair Communication
ISO/IEC 14908-3	Information Technology—Control Network Protocol—Part 3: Power Line Channel Specification

ISO/IEC 14908-4	Information Technology—Control Network Protocol—Part 4: IP Communication
ANSI/CEA-709.1	Control Network Protocol Specification
EN 14908-5	Open Data Communication in Building Automation—Controls and Building Management Implementation Guideline. Control Network Protocol. Implementation.
EN 14908-6	Open Data Communication in Building Automation—Controls and Building Management—Control Network Protocol. Application Elements.
	LonMark Certification Version 3.2, 3.3, 3.4 (LonMark International is the certifying body of ISO/ANSI/EN)
National Fire Protection Association **1 Batterymarch Park** **Quincy, MA 02269-9101** **617-770-3000**	
2014 National Electrical Code	
2014 National Electrical Code Handbook	
National Research Council Canada **1200 Montreal Road** **Building M-58** **Ottawa, Ontario K1A 0R6**	
2010	National Building Code of Canada
NEMA **1300 North 17th Street** **Suite 1847** **Rosslyn, Virginia 22209**	
NEMA 250-2008	Enclosures for Electrical Equipment (1000 V Maximum)

(This annex is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE ANNEX A
SAMPLE SPECIFICATION OUTLINE

PART 1: GENERAL

1.0 Section includes:
1.1 Products Furnished but not Installed Under this Section
1.2 Products Installed but not Furnished Under this Section
1.3 Products not Furnished or Installed but Integrated with the Work of this Section
1.4 Related Sections
1.5 Description
1.6 Approved BAS Contractors and Manufacturers
1.7 Quality Assurance
1.8 Codes and Standards
1.9 BAS Performance
1.10 Submittals
1.11 Warranty
1.12 Ownership of Proprietary Material
1.13 Definitions

PART 2: PRODUCTS

2.0 Section includes:
2.1 Materials
2.2 Communication
2.3 Operator Interface
2.4 Controller Software
2.5 Building Controllers
2.6 Custom Application Controllers
2.7 Application-Specific Controllers
2.8 Input/ Output Interface
2.9 Power Supplies and Line Filtering
2.10 Auxiliary Control Devices
2.11 Wiring and Raceways
2.12 Fiber Optic Cable System
2.13 Compressed Air Supply—Pneumatic

PART 3: EXECUTION

3.0 Section includes:
3.1 Examination
3.2 Protection
3.3 Coordination
3.4 General Workmanship
3.5 Field Quality Control
3.6 Existing Equipment
3.7 Wiring
3.8 Communication Wiring
3.9 Fiber Optic Cable
3.10 Control Air Tubing
3.11 Installation of Sensors
3.12 Flow Switch Installation
3.13 Actuators
3.14 Warning Labels
3.15 Identification of Hardware and Wiring
3.16 Controllers
3.17 Programming
3.18 BAS Checkout and Testing
3.19 BAS Demonstration and Acceptance
3.20 Cleaning
3.21 Training
3.22 Sequences of Operation

INSTRUCTIONS TO OTHER CONTRACTORS

3.23 Control Valve Installation
3.24 Control Damper Installation
3.25 Smoke Damper Installation
3.26 Duct Smoke Detection
3.27 Controls Communication Protocol
3.28 Start-Up and Checkout Procedures

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INFORMATIVE ANNEX B BACNET

B1. WHAT IS BACNET?

The building automation and control network (BACnet) protocol is a standardized set of rules that governs how building automation systems (BASs) exchange information. This standardization enables the integration of DDC products made by different manufacturers into a single, cohesive system. The objective is the transparent movement of information across the BAS network so that the user does not have to be concerned with which vendor's system is providing the data. While it is initially being used in HVAC applications, the BACnet standard is designed to support other building control functions such as life safety, security, lighting, energy metering, and power analysis.

Readers should be aware that BACnet is not a plug-and-play system. For example, you cannot simply remove a VAV box controller and replace it with one from another supplier without performing additional setup and programming. The use of BACnet (or any open protocol) may result in a loss of system performance and functionality. This is because BACnet is designed to provide the tasks that the daily operator needs to accomplish. It does not address system programming, configuration, or setup. These are all functions that will continue to be achieved in unique manners by each supplier. This means that when BACnet is applied correctly, it can deliver an interoperable system. However, the owner will still need unique software packages in order to edit or reconfigure the system.

B2. HOW DOES BACNET WORK?

While BACnet can be used at many different locations within an overall building automation architecture, the same basic data communication elements are always involved. These are the following:

a. *What is Communicated?* BACnet represents common building automation and control functions as collections of information called objects. Presently BACnet defines 25 standard objects, including analog inputs and outputs, binary inputs and outputs, and schedules. These objects are the building blocks for defining the degree of information that will be passed between products in the system and throughout the BAS architecture. Manufacturers are allowed to design and provide their own proprietary objects if the need arises.
b. *How to Communicate?* BACnet defines methods for exchanging data. These methods are referred to as *services* and are used by system suppliers to exchange (read, write) information between systems.
c. *How are the Messages Transported on the Network?* Whether dealing with local area networks (LANs) or wide area networks (WANs), BACnet can work over a variety of commonly available network technologies used in the DDC industry, including Ethernet, ARCNET, PTP, EIA-232, MS/TP (EIA-485), LON TP/FT-10, and Zigbee data link layers.

B3. SPECIFYING BACNET SOLUTIONS

In order to specify an interoperable system, the BAS developer must first decide what interoperable functions should be provided. These functions can be grouped into several categories.

B3.1 Data Exchange. The most basic level of interoperability is support for data exchange. This allows one device (either a controller or workstation) to view (read) or change (write) data that exist on another device. While this function is fairly basic, it can be used to achieve a number of tasks. It can be used to connect equipment from multiple suppliers into a single system, to display information on a workstation graphic, or to collect data for reports and logs.

In addition to data exchange, there is a series of advanced interoperable tasks that allow for expanded functionality. While all of these tasks can be accomplished using proprietary functions along with data exchange, they are performed more efficiently using these functions. These advanced functions are particularly valuable for large systems or where a central workstation is being used for monitoring and controlling a number of remote buildings.

B3.2 Alarms and Events. This function provides the ability to have a controller recognize when a problem exists and to communicate this to another device (typically a workstation). This is most commonly used to annunciate an alarm from a BACnet controller to a workstation, but it also can be used to provide control interlocks.

B3.3 Scheduling. This function allows for a schedule to be defined or modified at a BACnet workstation and executed in a controller. Scheduling may include daily and weekly schedules. These schedules may be overridden by exception schedules that change the building operation on holidays or during special events.

B3.4 Trends. This function defines how data is to be stored in a controller so that it can be retrieved by a BACnet workstation. Trends may be single-point or multipoint.

B3.5 Network Management. This function covers the tasks associated with a network of controllers. For example, it allows for the time to be coordinated in all controllers; the addition, removal, and replacing of network devices; and the configuration of devices on the network.

The success of the project will depend on the preplanning and levels of checkout and testing that will be used throughout the project. While BACnet was originally designed for use by the HVAC industry, it is now also used by the lighting, fire, and security industries. The BAS designer may require that all systems be BACnet compliant to avoid the need for gateways to translate data between BACnet and non-BACnet systems.

Due to the flexibility and openness of the BACnet standard, all parties involved in the planning process will need to focus on the desired performance and functionality of the system. BAS vendors have the ability to create proprietary objects and services to the standard. These are normally used for configuration and device management and do not affect the ability of the BAS designer to specify a system. The BAS designer can include language in the contract documents to say that all sequences shall be provided using standard BACnet objects and services. Given the extensive worldwide use of BACnet, this requirement will be easily implemented by all prospective BAS bidders.

See Informative Annex F for a reference to the BACnet guideline specification document.

B4. USE OF BACNET FOR LEGACY SYSTEMS

Specifying BACnet to connect to existing (or legacy) systems is a challenge because the existing BAS in a building may not have the ability to pass information on a BACnet network. The designer will need to work closely with the existing equipment's supplier to determine what degree of BACnet capability (if any) is possible with the existing system. These legacy systems will require a gateway to connect the BACnet network and the legacy system. In specifying the gateway, the BAS designer needs to list the alarms, trends, schedules, variables, and point data that must be transferred. Simply stating in the specification that the existing system has to be made BACnet compatible is not a suitable way of specifying compliance to the BACnet standard.

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INFORMATIVE ANNEX C
LOCAL OPERATING NETWORK (LON)

C1. WHAT IS LONWORKS OR LON?

Often referred to simply as LON (Local Operating Network), the LonWorks control networking platform defines the set of rules and standards for full system interoperability. Devices that comply with ISO/ANSI/CEA standards and are tested are ensured to be fully plug-and-play interoperable with like devices from a control networking perspective. Devices complying with the ISO/ANSI/CEA standards provide a common equipment or system profile such that other network devices or front ends are able to communicate and interact with them in a common way without the need for recommissioning if a device is replaced with one by a competing manufacturer. It's the foundation for an open, interoperable system in which products and solutions from companies are brought together in a simple, straightforward implementation that integrates many system components into one complete solution.

C2. HOW DOES LONWORKS WORK?

The basic premise is to facilitate the need to integrate multiple system components using a common system architecture and infrastructure—in essence, one set of wires through which all components are attached and can share common information. Data can travel from any device on the network to any other device with no single point of failure, embedding high-level security and allowing full component interoperability in a peer-to-peer fashion. Each device adheres to an agreed upon set of rules for interoperability. LonMark International (a nonprofit standards development association) ensures that each tested device conforms to the LonMark interoperability guidelines and provides and provides the assurance that devices work together.

C3. LONWORKS STANDARDS

Among other national, regional, and industry-specific standards around the world—including ISO, ANSI/CEA, EN, IEEE, AAR, SEMI, SAC, and others—the LonWorks platform is a set of regional and international standards for commercial building automation, controls, and building management. These standards continue to be enhanced to include new and useful functionality while remaining compatible with current installations. LonWorks is under the authority of ISO/IEC for international usage and ANSI/CEA for U.S. usage. These standards bodies work with members and with LonMark International to periodically update the standards with new equipment profiles, network management, security, and other technical implementations. All developments follow standards development organization (SDO) rules via task groups and committee work to ensure full industry support and compliance.

C4. TECHNICAL OVERVIEW

LonWorks control networking follows the 3 Tier model:

a. *Tier 1—Network Management, User Interfaces, Databases:* LonWorks defines a common set of data types called "variables" or "Standard Network Variable Types" (SNVTs) and configuration properties called "Standard Configuration Property Types" (SCPTs) which outline the interoperability data transfer requirements for devices. The network management tool platform defines the required structure for the collection and storage of these data objects using a common database referred to as LonWorks Network Services, a set of APIs and database structure used by the Tier 1 tools. Building management system (BMS) front ends access data to and from the control networking using these common data types and then populate an internal database such as SQL. User interfaces then use this database to render information to the user, provide reporting and visualization, and perform analysis tasks such as trending and fault detection and diagnostics (FDD). Key is that data typing and structure stay consistent from the source device to the destination graphical user interface (GUI).
b. *Tier 2—Network Infrastructure:* This includes the set of connectivity, wiring, and related components of an interoperable system, such as routers, repeaters, media converters, etc. ISO and ANSI standards identify the necessary requirements for building fully interoperable infrastructure components such that multiple vendors for all elements are available. Standards are in place to ensure proper physical wiring, termination, bandwidth use, and network connectivity for LON to LAN networking (IP-852), and other relevant technical details are defined to ensure interoperability at all levels.
c. *Tier 3—Network Devices and Equipment:* This includes the network media, protocol stack, and application layer guidelines that ensure interoperability at the physical layer, network layer, and application layer. Multiple media are available for LonWorks, including twisted-pair wire, power line, radio frequency (RF), Ethernet, and others. Routers enable devices from multiple media types to interoperate on the same network. Microprocessors and microcontrollers are available from a variety of sources that have implemented the LON protocol stack and can be implemented on simple to very complex control networking devices. The primary rule governed by ISO and ANSI is that to use LonWorks, you must implement the entire protocol stack—no substacks are permitted, as this would interfere with the basic premise of full interoperability. Devices which implement the LON protocol stack are tested and must define core functionality such as media type, speed (only one option defined for each type), and the core profile or profiles the device implements. With this information, any system integrator can poll the device, extract its self-documentation information and integrate the device into the network.

C5. HOW WAS IT DONE?

LonMark task groups were formed to allow experts to focus on the vertical markets for which they could contribute the most—building automation, lighting, security, home, transportation, down to specific applications such as sunblind control.

It was the goal of the groups to achieve interoperability by profiling the interfaces to a device's functions at the exchange level, leaving the definition of algorithms and processes to each manufacturer. The result was "functional profiles" that allow for modular implementation with the assurance of being able to connect data points in a logical, meaningful way regardless of manufacturer.

Defining the "dictionary and encyclopedia of control networking" was undertaken by industry supporting the LON standards in a governed SDO model. Over 100 device/equipment profiles have been developed for building and other related industries. The technical components of LonMark communications can be compared to human language, where without context a person may have difficulty conveying their meaning to another person:

English	
Letters/sounds	a, b, c
Words	dog, cat, bonnet
Dictionary	bonnet: engine hood of automobile
Sentences	"Lift the bonnet."
Context	"…to put oil in the engine"—manual for car repairs

LonMark	
Bits/bytes	0xFF, 1111 1111, 256
Basic types	char, unsigned long
SNVTs/SCPTs	SNVT_temp_p: temperature by 1/100° Celsius
NVs/CPs	"nvoTemp"
Profiles	"…present temperature of the room"—thermostat functional profile

Just as "bonnet" is the term for an automobile hood, it can also be a metal cover for a fireplace, a hat for a baby, or a cap for a man. Without a common, singularly defined dictionary, there is no common definition. Likewise temperature data must be defined in a common resolution and units, such as Celsius to 100th of a degree, for commercial and residential heating systems. LonMark, working with ISO and ANSI has defined this "language" and the criteria necessary for complete understanding in an interoperable controls environment.

C6. DESIGN CRITERIA

When designing a LonWorks-based control networking building automation system (BAS)/BMS solution, care should be taken to ensure that all devices conform to the protocol standards. The best way to accomplish this is by ensuring they have been fully tested for interoperability compliance. Additionally, integrators should be conversant and proficient with the technology and carry a professional certification. As part of any robust and proven solution, the design criteria should allow for implementation flexibility while preserving the core open interoperability requirements of the project. Define the criteria required for each of the 3 tiers identified, and ensure that vendors can validate and comply with the requirements. A good solution can go awry by allowing noncompliant solutions to attach to an open network. LonWorks in no different than any other protocol in this regard. Strong compliance and specification language is required. Following Clauses 12 and 13 of this guideline will help ensure positive results. Given the several decades of successful installations, LonWorks is a proven, known entity in the marketplace with hundreds of certified products and professionally certified system integrators available to support most any project.

C7. USE OF LONWORKS FOR LEGACY SYSTEMS

With regard to legacy system integration, LonWorks, like BACnet, are the same. Care must be taken to ensure that legacy equipment can share information with the LonWorks network. Many commercially available gateway, interface, and driver technologies and products are available that allow legacy systems to directly share information across a LonWorks network. It is important to specify the required infrastructure to ensure success. Due to the strong data typing, profile definitions, and management rule, gateways have a relatively easy time of interfacing with LonWorks. Care should be taken to ensure, once a legacy system is connected to a LonWorks system, that if changes are made to the legacy system they are correctly transferred to the new system. Gateways often need to recommissioned for this to occur, which can sometimes be a costly, time consuming process.

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INFORMATIVE ANNEX D
INTEROPERABILITY CASE STUDIES

D1. CASE STUDY #1

The State University's Chemistry Building is a new construction project, replacing an existing classroom and laboratory building. The Chemistry Building is to be built in several phases.

a. The first phase will include two three-story classroom and laboratory wings (east and west wings) and a central lobby/atrium space that connects the two wings. The third floor of the east wing will be shelled out in the first phase, meaning that only the building envelope will be built, with no interior construction other than roughing in some utilities, such as plumbing stacks from the floors below.
b. The second phase, planned for the year following the opening of the first phase, will build out the shelled space of the east-wing third floor.
c. The third phase, planned for the third year following the opening of the first phase, is a third three-story wing (north wing) that will connect to the central lobby and is planned to house mostly research labs and offices for graduate students.

The interior architecture of the classroom and laboratory wings is very flexible, allowing professors and graduate research teams to set up new laboratory configurations at will, including adding new fume hoods and offices.

The State University uses a campus-wide energy management system supplied by Existing Control Company to monitor and control the environmental systems in most of its buildings. A recent directive from the state attorney general requires that the energy management systems in all new construction and renovation projects at the State University to be competitively bid. The State University wants to retain single-seat monitoring and control of its energy management systems and is interested in doing some automated demand management campus-wide to take advantage of real-time pricing structures.

Regarding the issue of single-seat monitoring and control, the State University and its consultant investigate two options:

a. Continue to use the Existing Control Company's operator workstation and alarm printers with a gateway that communicates and translates between the Existing Control Company's network and the new Chemistry Building's open-protocol energy management system. State University personnel will continue to use the familiar Existing Control Company's operator workstation. The configuration of the new Chemistry Building database and graphic displays in that workstation and the gateway must be a part of the new project. In the future, as other buildings are built and renovated using the open-protocol communication, the workstation database and gateway will need to be expanded and upgraded concurrently. The gateway will increasingly become a very sophisticated device as new open systems are connected to Existing Control Company's side of the network.
b. Start using a new open-protocol operator workstation, provided as a part of the Chemistry Building project. A gateway will still be required to translate between the Existing Control Company's systems and the new workstation and open-protocol network, but the configuration of its database will be a one-time expense.

If Existing Control Company did not have a gateway to an open protocol in its product offerings, the State University would be forced to maintain two separate networks (an open network and Existing Control Company's network). This would continue while Existing Control Company systems are replaced as existing campus facilities are renovated and upgraded.

The State University elects the second option and directs the consultant to design for a new operator workstation using an open protocol. Existing Control Company has available the following open-protocol gateways:

a. An Ethernet gateway to the open protocol, Protocol A
b. An Ethernet gateway to the open protocol, Protocol B
c. An EIA-485 gateway to the open protocol, Protocol B

The gateway must be capable of communicating a great deal of information at relatively high speed, so the decision is made to use one of the Ethernet protocol gateways. Both Protocol A and Protocol B open protocols are also compatible with the campus-wide information system backbone. A consultation with the university's information technology staff reveals that enough bandwidth remains in the backbone that the new information can be carried without degrading the overall information flow.

The consultant works with the State University to determine what information should come from Existing Control Company systems through the gateway to the new open-protocol network and vice versa. The consultant uses Existing Control Company's workstation database as a starting point. Since most of the configuration data are relatively static, the consultant suggests that the following information be exchanged through the gateway:

a. Monitoring and control of virtually every analog and binary point's present value in the Existing Control Company's systems
b. The ability to annunciate and acknowledge the BAS's alarms in the Existing Control Company's systems
c. The ability to modify the schedules contained in the Existing Control Company's controllers
d. The ability to trend certain vital points, such as outdoor air temperature and power demand
e. The ability to reset the controllers remotely, that is, return them to a preset data condition in the event of an upset

This also sets the parameters for the information exchange on the open-protocol side of the internetwork.

The phased nature of the project helps define how far down into the network the open protocol will reach. Since the building will be built in phases under separate construction contracts, the subsequent phases' controls will need to use the open protocol selected in the first-phase contract. The subsequent phases could use gateways to connect proprietary systems inside the boundaries of the new contracts to the first contract's open system or could use the open protocol as their native communication protocol, eliminating the need for gateways.

The flexibility and desire to frequently reconfigure the Chemistry Building's interior spaces and their functions move the decision to use an open protocol fairly deep down in the system architecture, probably down to unitary controllers, if not to smart sensors and actuators.

The designer also faces a choice between different open protocols as the open-protocol choice moves down into the architecture. Since communication between device-level controllers and the building controller in phase one is relatively low-bandwidth, there may not be a need for a high-speed open protocol at this level. If one of the protocols (Protocol B, for instance) supports lower bandwidth network technology, such as EIA-485, then the consultant will specify a router between the high-speed and lower-speed Protocol B network segments. If another low-bandwidth open protocol satisfies the requirements, say Protocol C, the consultant must specify a gateway (if one exists) between Protocol C and Protocol A or Protocol B.

Since gateways are relatively more complex than routers, the consultant chooses Protocol B for both high-speed controller/workstation communication and the lower-bandwidth device-level protocol and specifies that the building controllers act as routers between the Ethernet and EIA-485 segments.

In every case, the consultant must specify which open protocol is to be used in each network segment, especially since he/she is integrating equipment controllers (such as chiller and boiler controls and lighting controls) that are specified elsewhere and supplied by manufacturers other than the building controls manufacturer. Otherwise, the goal of integrating with these other applications will be severely hampered, if not lost entirely.

D2. CASE STUDY #2

Associates Inc., a property manager, is planning on constructing a new 50-story office building. Building space will be leased to a number of different tenants. Competition for premium office space is intense. Associates wants the office space to attract high-quality tenants. Mechanically, the building will be designed state of the art. Associates will provide the major base building infrastructure components, including electrical, mechanical, HVAC, fire/life safety, and access/security. A decision was made by Associates that each tenant would be responsible for the build-out of their space. The project will be bid as follows:

a. Building structure and major infrastructure (base building)
b. Each tenant build-out will be competitively bid in an effort to control costs

Control of the major HVAC equipment and systems will be part of the base building infrastructure. Individual floor control will be the responsibility of each tenant. However, Associates requires that all controls, including tenant spaces, operate as a single integrated system. Therefore, the tenant space controls must be capable of connecting into the base building controls. If one controls vendor is awarded the entire job, this won't be an issue. However, there is no way of knowing if this will happen. Therefore, as part of the base building, the designer will require that the system be based on an open protocol. The workstation provided as part of the base building will be the main operating workstation for the entire office building. A high-speed data communication backbone (Ethernet) will be provided as part of the base building. This can also be used for controls communication. The information technology consultant has determined there is sufficient bandwidth for this.

Associates is planning to have a lean facility engineering staff. However, they cannot afford building system failures that sacrifice tenant satisfaction. Therefore, they want all critical building subsystems to be monitored. This includes chillers, air handlers, fire/life safety system, elevators, and emergency generators.

Associates would like the building to be safe and secure for their tenants. The desire is to allow admittance using a card access system. HVAC and lighting will be supplied to all tenants during normal operating hours. However, the building will go into an unoccupied mode during off-hours. Admittance will be allowed through the access system during unoccupied hours. HVAC and lighting will be provided during this period based on occupancy. Tenants will be billed for usage during this period. This will require interaction between the building BAS, security, and lighting systems.

The first decision that needs to be made is how far should an open-protocol strategy go? The designer has already decided that the base building and tenant space controls will be bid as separate projects. Therefore, they may end up being supplied by different vendors. The open-protocol strategy should apply to the base building controls and the tenant space controls. This will include the mechanical system, air-handling unit, and terminal box controls. The base building workstation will communicate on the Ethernet network. This will provide a highway for workstation-to-workstation communication, as well as to other building controllers for global control functions. This network will use an XYZ open protocol. It seems best suited for this type of communication. In addition, there is sufficient coverage by vendors so that there is sufficient competition.

Workstation and building controllers must support the following:

a. Monitoring and commanding of analog and binary information
b. Scheduling
c. Historical data collection
d. Ethernet LAN

It is impracticable to think that the floor level controls will directly communicate on the Ethernet LAN. In this case, a router will be necessary to go from one data link layer to another.

D2.1 Project Considerations. Is it acceptable for a vendor to bid floor-level controls that do not support the XYZ protocol? Yes, as long as the vendor supplies a gateway and makes the necessary information available to meet the desired functionality. In this case, floor-level controls are treated as an independent island.

Floor-level controls (XYZ or other protocols acceptable if a gateway is supplied):

a. Supply analog and binary information.
b. Base building system must be able to control occupied/unoccupied functions.

So far, workstations, building controllers, and floor-level controls have been covered. Now, how will the mechanical equipment be connected into the system? Does the XYZ protocol have sufficient coverage by mechanical system vendors to be used as the common protocol? In this case, the air-handling units are large built-up units controlled by building controllers via hardwire controls. These building controls will be connecting to the Ethernet LAN directly. But what about the chillers and other equipment?

D2.2 Project Considerations. Many controls suppliers have drivers available to directly connect to the controls of several major equipment suppliers. This solution is acceptable as long as the appropriate information is available via the open-protocol network. In addition, the equipment supplier may be able to connect directly or via a router to the open-protocol LAN. If the equipment supplier has both options available, they should be able to bid either option. One option may be more economical than the other. Again, the equipment controls can be directly connected into the open-protocol network or treated as an independent island. The designer should request pricing on these options as well as a list of vendors to which they can provide connection.

The designer now has to make a decision concerning the connection between the lighting controls and the access system. Do vendors in these industries use the XYZ protocol? Is there another open protocol that will allow connections to these systems? If the designer takes a look at the universe of products available in these industries, one finds that some lighting systems use a PDQ or ABC protocol, but there is no clear leader. The story is even worse in the access control area. There is no common, open or standard protocol supported. The designer will have to rely on direct connections from these systems to the base building controls or get these vendors to provide a gateway to the XYZ protocol. A hardwired solution is always available, but this will sacrifice both flexibility and the amount of information available. The designer could leave this choice up to the lighting and access control vendors, who will either provide a gateway to connect into the existing backbone or will allow direct-connect integration by the base building control vendor.

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INFORMATIVE ANNEX E
PERFORMANCE MONITORING

E1. WHAT IS PERFORMANCE MONITORING?

Performance monitoring is the capability to provide facility managers and operators with the means to easily assess the current and historical performance of the building/facility as a whole and its significant energy consuming systems and components. Performance monitoring requires not only the needed instrumentation and architecture but also the means to calculate, timestamp, display, and archive resultant parameters. The monitoring capability can be included within a building automation system (BAS) or implemented as a separate energy information system (EIS) or a combination of the two. Performance monitoring can be implemented as part of a new construction project or as part of a BAS installation or upgrade project in an existing building. This annex provides three levels of performance monitoring. Level 1 supports trending of data. Level 2 supports the collection of the data in the form of time-value trendlogs and provides data analysis. Level 3 uses the data collected by the Level 1 functionality and analyzed by the Level 2 functionality to predict equipment faults, energy consumption, and demand patterns.

E2. BENEFITS OF PERFORMANCE MONITORING

Monitoring main electricity and natural gas meter data enables building staff to track building electricity and natural gas use by time of day, facilitating management of peak loads and identification of unnecessary equipment operation during unoccupied periods. It also enables monitoring of power quality supplied to the building and the power factor of the building load if advance metering instrumentation is utilized. Monitoring of water use can provide information to help detect and diagnose unnecessary consumption.

Building monitoring can direct a building owner to additional energy savings potential at the plant or equipment level. For example, monitoring chilled-water plant equipment power meter data enables building staff to track and manage chilled-water plant contributions to peak load and monitor chiller health. Monitoring building chilled-water flowmeter and chilled-water supply and return temperature data enables the monitoring system to calculate the actual cooling delivered by plant chillers, allowing growth in chiller capacity requirements to be tracked and managed and aiding the detection of anomalous loads that increase operating costs. Monitoring of both plant power and thermal loads enables the tracking of chiller/boiler plant efficiencies, which allows the identification of more efficient operating strategies. It also enables the detection of degradations in performance that indicate the need for maintenance in order to minimize operating costs and maximize equipment life.

Use of a high-quality weather station provides reliable measurement of outdoor air dry-bulb and wet-bulb temperatures, which help in identifying more operating hours for air-side and water-side economizers, facilitating the most effective use of free heating and cooling resources, and minimizing central plant energy use. Reliable measurement of outdoor wet-bulb temperature enables proper cooling tower operation, maximizing chilled-water plant efficiency.

Advanced data calculations and automatically updated data displays provide operators with effective, standardized ways of viewing the performance of the building and the HVAC system, including comfort conditions. Careful grouping of plots puts all the information required to monitor and, if necessary, troubleshoot each different part of the HVAC system on a single screen. This makes it easier to spot and diagnose a fault before it becomes a problem, reducing hot and cold calls and operation and maintenance (O&M) costs and making it easier to operate the building, freeing up stationary engineers to meet other needs.

As utilities implement demand response plans and as the Smart Grid becomes a reality, owners will see the benefits of the Level 3 performance monitoring option. BAS designers are referred to the National Institute of Standards and Technology (NIST) website (www.nist.gov) for information on the Smart Grid. The local energy service provider serving the facility can provide information on current and future demand response programs.

Example calculations to determine end-to-end accuracy of a measurement can be found in ASHRAE Guideline 22, *Instrumentation for Monitoring Central Chilled-Water Plant Efficiency*, Annex C4.[D1]

This annex aligns with *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide*[D2] in the following manner. There is limited alignment with the Basic Evaluation Level (Indicative) of *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide*, as this level is largely a manual exercise to determine roughly how a building under review compares to another building or a group of buildings. Data needed for the Basic Evaluation Level, such as whole-building utility consumption and demand, are available from the BAS at Performance Monitoring Level 1 as outlined in this annex. The Diagnostic Measurement Level (Diagnostic) as outlined in *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide* aligns with Performance Monitoring Annex Levels 2 and 3, as the Diagnostic Measurement Level uses more detailed energy data at hourly or shorter intervals than is available in electronic form from the BAS. The Advanced Analysis Level (Investigative) in *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide* also aligns with Performance Monitoring Annex Levels 2 and 3. The main difference between the two levels described in *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide* is that under the Advanced Analysis Level there may be a requirement for longer-term historical trends or detailed fault detection and diagnosis (FDD) information that is available at Performance Monitoring Annex Level 3. Readers wishing to make a more detailed comparison are referred to *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide*.

E3. BAS REQUIREMENTS TO IMPLEMENT PERFORMANCE MONITORING

Table E3 shows the requirements and architecture for specific BAS elements that are needed to implement performance monitoring.

E4. LEVELS OF PERFORMANCE MONITORING

This annex provides guidance on three possible levels of performance monitoring that can be implemented in a BAS. The specifying BAS designer, in concert with the owner or owner's representative, should include in the specification those requirements needed to meet specific owner's project requirements.

E4.1 Level 1: Data Collection and Trending. Level 1 is a building block for the higher levels. This level assumes that the specified BAS manufacturer can meet the Level 1 performance monitoring requirements within the company's current product offering. The BAS must support trending, but the extent of the trending is based on the project requirements as defined by the BAS designer. Depending on the scope of the project, the BAS designer may specify the long-term trending software module that BAS suppliers sell as part of their front-end software suite.

For purposes of this annex, a *trend* or *trendlog* is a collection of time-value pairs (e.g., the outdoor air temperature was 20°C [68°F] at 15:00 [3:00 p.m.]). The time interval, whether the value is a minimum, maximum, average, or instantaneous value, and the amount of the data to be collected are based on the project requirements. Most BASs do not support the creation of X-Y plots (e.g., outdoor air temperature versus chiller kW/ton), so this requirement is not included in Level 1. This level allows for the collection of the data for performance monitoring and the graphing of one or more trendlog values against time, but it does not require the support for any analysis of the trendlog time-value pairs.

Level 1 also applies to a BAS that is either controlling directly or monitoring other systems such as lighting and fire alarm systems. The principles outlined in the next two levels apply to such control implementations.

E4.2 Level 2: Trendlog Data Analysis. Level 2 includes the trendlog data of Level 1 and assumes that the data collected in the form of time-value trendlogs will be analyzed in some manner to meet the BAS designer's design intent for the project. BASs must either support the creation of X-Y plots natively or be able to export these data to a third-party graphing and analysis tool such as Microsoft Excel®. The BAS designer must ensure that the plot requirements are clearly laid out in the specification so the BAS supplier has guidance on what work is expected for the project. There may also be a requirement for structured queries of energy and operational BAS data to assist in certification under the Leadership in Energy and Environmental Design (LEED) Green Building Rating System[D3] or other sustainable rating systems.

E4.3 Level 3: Equipment Fault Diagnosis and Event Response. Level 3 includes the functions of Level 1 and Level 2 and assumes that the data that are collected under Level 1 and analyzed under Level 2 can then be used to identify and predict mechanical, electrical, or other equipment faults or can provide analysis of data relating to operational issues, power quality, or other applications. One could use these data to predict energy consumption and demand patterns to prepare a demand response strategy based on a change to a real-time energy pricing request from the local energy service provider. A BAS at this level is not just a server responding to requests from a user but may also have the ability to act as a client, taking action to respond automatically to a real-time pricing signal. This demand response may implement fuel switching by starting building generators or shedding equipment loads, or it may make changes in local zone space conditions. The BAS would return the building equipment under its control to a normal operating condition once the demand response event ends. The BAS would then provide automated reports on the impact on building health (e.g., changes to temperature or carbon dioxide levels) once the demand event ends. Projects at this level may be eligible for LEED certification and such smart shedding strategies may give the BAS designer the opportunity to apply for the LEED Measurement and Verification or Innovation credits.

E5. IMPACT OF THE PERFORMANCE MONITORING LEVEL ON BAS DESIGN

The level of sophistication of the BAS design varies from Level 1 to Level 3. The various levels require differing considerations in the implementation of hardware, software, and system functionality, discussed as follows.

a. *Selection of Controlled Equipment:* Equipment with packaged controls on a BAS project at Level 1 may allow for enable/disable, setpoint changes, and a common alarm contact. This same equipment at Level 2 or Level 3 may require a network connection with interoperable communications that allow data access. For a chiller, these data might include bearing temperature, head pressures, revolutions per minute, faults, equipment metering data, etc.
b. *Server Requirements:* Projects at Level 1 may not require a server to collect data. It may be sufficient to trend the data in the BAS panels. Level 2 or 3 projects may require a server that supports Web services or can act as a client to respond to Simple Object Access Protocol (SOAP) remote procedure calls that may be invoked, for example, as part of a real-time pricing request from an energy service provider.
c. *Software License Levels and Costs:* The data volumes increase as one goes from specifying a Level 1 to a Level 3 BAS. Most BAS vendors have front-end software licenses that are based on the object count. There is normally an increase in the software cost to handle greater volumes of data either from within the HVAC BAS or by bringing in (mapping) data from other building systems such as lighting, fire, or other systems.
d. *Interoperability Considerations:* BAS projects at Level 1 may only require one vendor's equipment on the project. Level 2 or 3 projects may require chillers, boilers, meters, or other equipment with networking capabilities, implying that these building devices communicate using one or more common protocols so they can respond collectively, for example, to a building-level strategy such as demand response.
e. *BAS Equipment Sophistication:* Performance monitoring is not restricted to measuring utility consumption and demand. The BAS may act as a server device to pass run-

TABLE E3 BAS Requirements for Performance Monitoring

Requirements related to:	Related Specification Sections	BAS Elements: Network	BAS Elements: Sensor(s)	BAS Elements: Building Controller or Custom Application Controller	BAS Elements: Central Operator Workstation (OWS) or Enterprise Server	BAS Elements: Historical Data Server
Sensor—certification and O&M requirements	1.5		NIST certified, with calibration data supplied as required.			
Reporting accuracy	1.9	Network should be selected to maximize system throughput. Ethernet is recommended for high speed and high performance.	Sensor accuracy selected to meet end-to-end accuracy requirements. See Table E5 for detailed accuracy requirements.	analog to digital converter(s) in controller support end-to-end accuracy requirements for sensor readings. Minimum 12-bit A/D conversion is required.	The OWS or server may require additional database and structured query language (SQL) software in order to provide custom reports.	
Accurate records	There are no related specification sections for this item. The BAS designer must provide information on the objects to be trended. The BAS designer must also specify the amount of trending in the BAS controller controls as well as which trendlogs need to be long-term trends, as the data needs to be uploaded to the server when the BAS controller controls trendlog buffer is full.	Time sync by server to a standard time sync service. Access to the server clock is restricted by physical and software security measures. Time functions in BAS are synchronized to the system server.		Synchronized (interval) and event-driven trending. Adjustable trend buffer high threshold limit will notify workstation when to upload trend data records from field BAS controls.	Upload trend data from BAS controllers when trend buffer limit reaches high threshold limit.	View data records stored on server. Create reports using historical data server report manager.
Protection of records	The BAS designer must provide language on who is supposed to be backing up the records (i.e., is this a BAS responsibility or will this be done by the facility IT department?).			Battery backup of field controller application programs. Firmware program stored in Electrically Erasable Programmable Read-Only Memory (EEPROM).	Incremental backup of OWS software to designated server hard drive partition. Offload backup of server database to external media. Archiving records is normally done with a separate application provided by the BAS contractor.	Disable data purging. Incremental backup of each hourly transaction log file. Offload backup of server database to external media.
System security	The BAS designer must provide a security plan that specifies user access rights by categories such as guests, technicians, administrators, etc.	Access rights to system records and client applications are all controlled using Windows integrated security.		User account required to access building controller from BAS front end.	Integrated security. Group policy permissions for files and directories are assigned to user groups. OWS user account required to access BAS.	Integrated security or equivalent. Group policy permissions for files and directories are assigned to user groups. Secured access to historical data.

TABLE E3 BAS Requirements for Performance Monitoring *(Continued)*

Requirements related to:	Related Specification Sections	BAS Elements: Network	Sensor(s)	Building Controller or Custom Application Controller	Central Operator Workstation (OWS) or Enterprise Server	Historical Data Server
Records—length of retention	Modern BASs with servers have virtually unlimited trending capability. Many BAS vendors have additional applications for archiving data. The BAS designer needs to specify which trendlogs are to be archived and for what length of time.					Historical data retention software locks down records in a secure database and retains them for a user-definable and/or indefinite time.
Written procedures	The BAS designer must either specify these procedures or arrange for these procedures to be provided by others.	The BAS designer should recommend that the following Standard Operating Procedures (SOPs) be developed: backup procedures, calibration procedures, system security procedures, electronic records/data management procedures, incident management procedures, and disaster recovery procedures.				
Control documents	The BAS designer must either specify these procedures or arrange for these procedures to be provided by others.	The customer needs to have the required documentation available and protected. Revision and change control procedures should be in place for all the required documentation. The list of required documentation includes, but is not limited to, operations and maintenance manuals, training records, calibration records, system acceptance and sign-off, and maintenance records.				
Training	The BAS designer must specify the training needed.	The customer will require additional training that is appropriate to the level of performance monitoring specified.				
Ongoing support	The BAS designer must either specify these procedures or arrange for these procedures to be provided by others.	The BAS designer needs to determine if the owner requires ongoing support to maintain the infrastructure or to analyze the data generated by the performance monitoring system. The owner may decide to contract out these services instead of creating additional internal capacity in the facility management organization.				

time or other information to other applications in the Enterprise, such as the preventive maintenance (PM) program. The reporting capabilities may extend to generating runtime reports, alarm reports, tenant energy usage reports, etc., that provide management with timely information on the performance of the facility.

f. *Client/Server Capabilities:* BASs are normally designed so that the field controls respond to a request from the front end for information on the status of a point or to receive an update to a schedule. The field controller is called the "server" because it responds to a request for information. The front-end software is called the "client" because it generates the information request. Field controllers installed as part of Level 1 or Level 2 monitoring can be strictly server devices. Field controllers installed to meet Level 3 performance monitoring need client functionality as they need to generate a response to an event. An event in this case might be to report an alarm, a change of status, or excessive energy consumption.
g. *Event Response:* The client functionality required for Level 3 includes taking action in response to a trigger, such as initiating a demand response to deal with a real-time pricing signal from an energy service provider. These smart devices may shed a load or start an alternative and less expensive source of energy so the owner of the facility does not have to pay the high price during a demand peak on the electric grid.
h. The electric grid delivers electricity from points of generation to consumers, and the electricity delivery network functions via two primary systems: the transmission system and the distribution system. The transmission system delivers electricity from power plants to distribution substations, while the distribution system delivers electricity from distribution substations to consumers. The grid also encompasses myriad local area networks that use distributed energy resources to serve local loads and/or to meet specific application requirements for remote power, village or district power, premium power, and critical loads protection.
i. Historically, the energy service provider would only know that service was out if a customer called to report an outage. The Smart Grid is an initiative that uses the Internet and BASs in the facility to permit two-way communications to allow the energy service provider to report changes in price or the availability of electric power. The facility can report internal power quality problems or can tell the grid that alternative power sources in the facility are being brought online. The idea of two-way communications from the energy service provider to the facility to control residential appliances such as clothes dryers or air conditioners during peak demand periods is not new. Improvements in data communications and more sophisticated BASs will permit the facility to implement load shedding or to start alternative power sources automatically without human intervention.
j. *The BAS as an Ongoing Commissioning as well as a Performance Monitoring Tool:* BASs used for Level 3 performance monitoring may have the capability to undertake commissioning on a regular basis. Under this process, the BAS would report sensor faults or sensors out of calibration or would report when equipment is not performing to the original design intent. The BAS would use this information to generate an event notification. The BAS may also relay this information as a client to the Enterprise PM system server to raise a work order to have maintenance order a part or fix the problem. This will require support for data interaction from the BAS to other applications.
k. *The BAS as an Integral Component for Fault Detection and Diagnosis (FDD):* Building designs are becoming more complex to meet "green," or sustainability, requirements such as those of LEED[D3], Go Green™[D4], or Green Globes™[D3]. BASs can help operators to optimize maintenance and equipment performance by using FDD techniques to identify causes of degraded equipment performance and impending equipment failures such as miscalibrated temperature sensors, excess outdoor air during heating mode, inadequate unit airflow, or refrigerant problems in chillers.

FDD is a natural enhancement to monitoring the performance of an HVAC system. The rating systems referred to above require that the system can monitor indoor air quality, energy consumption, and thermal comfort. In order to sustain the air quality and energy targets over time, the HVAC systems must be properly maintained. Simple alarms will not catch subtle problems such as miscalibrated temperature sensors or refrigerant problems in chillers.

FDD techniques have been refined based on research funded by ASHRAE and other organizations such as NIST. FDD is based on a set of rules for how a chiller, boiler, or air-handling unit is supposed to operate. BAS designers using FDD tools should specify the data requirements the BAS needs to provide in order to satisfy the needs of the FDD software tool. This tool would likely be provided by a third party that would take trendlog data from the BAS and then apply the rules for detecting the fault. The BAS designer should lay out the performance monitoring requirements and specify the FDD tool or tools to be used to meet the requirements.

Table E5 lists the BAS characteristics required to meet the three levels of performance monitoring.

E6. REFERENCES

D1. ASHRAE. 2012. ASHRAE Guideline 22-2012, *Instrumentation for Monitoring Central Chilled-Water Plant Efficiency*. Atlanta: ASHRAE.

D2. ASHRAE. 2012. *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide.* Atlanta: ASHRAE.

D3. USGBC. 2013. Leadership in Energy and Environmental Design (LEED) Green Building Rating System. Washington, DC: U.S. Green Building Council. www.usgbc.org/leed

D4. Redleaf Press. 2013. Go Green Rating Scale for Early Childhood Settings. St. Paul, MN: Redleaf Press. www.gogreenratingscale.org

D5. GBI. 2013. Green Globes. Portland, OR: The Green Building Initiative. www.greenglobes.com

D6. ASHRAE. 2006. *Sequences of Operation for Common HVAC Systems*. Atlanta: ASHRAE.

TABLE E5 BAS Requirements for Performance Monitoring Levels 1, 2, and 3

Requirement	Level 1: Data Collection and Trending	Level 2: Level 1 plus Trendlog Data Analysis	Level 3: Levels 1 and 2 plus Equipment Fault Diagnosis and Event Response
Data Displays			
Software Requirements The BAS designer needs to determine if the BAS supplier can provide the software or if it has to come from another supplier.	Level 1 is specifically designed so that a BAS designer does not have to add additional software. The standard BAS front-end software package will be able to meet Level 1 data display requirements.	The BAS may permit the analysis of the trendlog data from the equipment graphic directly. Otherwise the user may have to launch a separate application and then import the trendlog data as time-value pairs into this application.	It is likely that to meet the Level 3 requirements the BAS designer will have to specify software from third parties that specialize in automated commissioning, FDD, sophisticated metering, and event responses.
Equipment/System Graphic Most BASs can present data on a floor plan or equipment graphic.	Floor plan with zone temperatures; system graphic with performance data from trendlogs only that may be accessed from a link on the equipment graphic.	Add performance data to the equipment graphic.	Level 2 graphics would meet the requirements for Level 3. Additional graphics to meet Level 3 would be provided by the third-party software tools required for the project.
Data Tables Most BASs can present real-time data in tabular form.	Building air handler summary table as described in Figure 5.3.2.	Expand building air handler summary table, add floor zone table, expand metrics results table to include additional metrics such as energy targets.	Expand metric results table to include additional metrics such as the performance of specific pieces of equipment or the demand response sequence (e.g., starting a generator or increases in space temperature setpoints).
Trendlogs System performance trendlogs over a time series that is specified by the BAS designer.	Collect the following trendlogs (instantaneous, average over the interval, maximum during the interval, minimum during the interval) with a common time interval (e.g., from 1 to 30 min): • Chilled-water-plant delta-T • Chilled-water-plant tons • Outdoor air temperature (dry-bulb temperature) • Outdoor air wet-bulb temperature • Outdoor-air-temperature fraction • Outdoor-air-damper fraction • Meter data (gas, water, electricity, steam, chilled-water flow, etc.)	Add equipment performance plots and third-party software to create these plots	Add system and equipment diagnostic plots as well as software to permit interoperable responses to these events.
X-Y Group Trend Plots This functionality is normally not part of a standard BAS software package. The BAS designer may require BAS trendlog data to be exported in a format that can be consumed by software to be provided by the BAS supplier via a subcontract or from a third party. Alternatively, the BAS designer can require X-Y plots to be built using a spreadsheet tool such as Microsoft Excel.	Not available at this level.	Add X-Y plots (X-Y plots plot data from one trendlog against another trendlog collected at Level 1): • Chilled-water-plant delta-T and chilled-water-plant tons vs. outdoor air temperature • Chilled-water-plant power vs. chilled-water-plant tons • Chilled-water-plant kilowatts per ton vs. outdoor air temperature, outdoor air wet-bulb temperature, and chilled-water-plant tons • HVAC power vs. outdoor air temperature, outdoor air wet-bulb temperature, and chilled-water-plant tons • Total gas flow vs. outdoor air temperature • Outdoor-air-temperature fraction vs. outdoor-air-damper fraction • Whole-building electric energy-use intensity, whole-building HVAC electric energy-use intensity, whole-building natural-gas energy-use intensity, and whole-building water-use intensity vs. average daily outdoor air temperature	Add X-Y plot diagnostics: • Average daily chilled-water supply temperature, daily chilled-water-plant efficiency, and daily total chilled-water-plant electricity use vs. average daily outdoor air temperature, when at least one chilled-water pump is running • Average daily boiler efficiency, daily total boiler-heating-system thermal output, daily total HVAC gas use, and daily total HVAC gas energy vs. average daily outdoor air temperature, when at least one hot-water pump is running • Daily total air-handler volume, average daily air-handler efficiency, and daily total air-handler electricity use vs. average daily outdoor air temperature, when at least one air handler is running Average daily building power vs. average daily outdoor air temperature • Daily HVAC energy-use intensity vs. average daily outdoor air temperature

TABLE E5 BAS Requirements for Performance Monitoring Levels 1, 2, and 3 *(Continued)*

Requirement	Level 1: Data Collection and Trending	Level 2: Level 1 plus Trendlog Data Analysis	Level 3: Levels 1 and 2 plus Equipment Fault Diagnosis and Event Response
X-Y Group Trend Plots (Continued) This functionality is normally not part of a standard BAS software package. The BAS designer may require BAS trendlog data to be exported in a format that can be consumed by software to be provided by the BAS supplier via a subcontract or from a third party. Alternatively, the BAS designer can require X-Y plots to be built using a spreadsheet tool such as Microsoft Excel.	Not available at this level. (Continued)	Add X-Y plots (X-Y plots plot data from one trendlog against another trendlog collected at Level 1) (Continued): • Whole-building electric energy-use intensity, whole-building HVAC electric energy-use intensity, whole-building natural-gas energy-use intensity, and whole-building water-use intensity vs. average daily outdoor air temperature • Chiller kilowatts per ton vs. condenser entering-water temperature and chiller tons • Chiller power vs. chiller tons • Whole-building HVAC electric energy-use intensity, total boiler gas energy-use intensity, whole-building lighting energy-use intensity, and whole-building plug energy-use intensity vs. average daily outdoor air temperature	Add X-Y plot diagnostics (Continued): • Average building air-handler variable-frequency-drive frequency and average building duct static pressure vs. outdoor air temperature
Points (Objects)			

Measured
The BAS designer needs to include these points (objects) in the project Point List Schedule.
	• Outdoor air temperature
	• Outdoor air wet-bulb temperature
	• Main power
	• Main natural-gas flow
	• Main water flow
	• Chiller power
	• Other chilled-water-plant equipment power
	• Plant chilled-water supply temperature
	• Plant chilled-water return temperature
	• Plant chilled-water flow rate
	• Air-handler mixed air temperature, return air temperature, and supply air temperature
	• Air-handler supply-fan and return-fan power
	• Air-handler flow rate
	• Zone temperatures; air-handler duct static pressure; supply air hot duct static pressure, if dual duct
	• Terminal unit supply-air flow, supply air temperature; if dual duct, supply air heating-duct flow and supply air heating-duct temperature
	• Lighting-circuit power
	• Plug-circuit power
	• Rooftop-unit power
	• Other HVAC-equipment power
	• Chiller chilled-water supply temperature
	• Chiller chilled-water return temperature
	• Chiller chilled-water flow rate
	• Boiler gas flow
	• Boiler hot-water supply temperature
	• Boiler hot-water return temperature
	• Boiler hot-water flow rate
	• Air-handler supply-fan variable-frequency-drive frequency
	• Plant condenser-water supply temperature
		Add:
		• Information from devices such as chillers that can only be obtained by making a network connection to the chiller control panel:
		  • Chiller bearing temperature
		  • Chiller effective setpoint (this is the value that the chiller is using based on a setpoint signal from the BAS)
		  • Boiler carbon monoxide (CO) percentage
		  • Boiler stack gas temperature
		  • Internal equipment faults
			It is assumed that all data needed for diagnostic or event triggers is available at Level 1 or Level 2.

TABLE E5 BAS Requirements for Performance Monitoring Levels 1, 2, and 3 *(Continued)*

Requirement	Level 1: Data Collection and Trending	Level 2: Level 1 plus Trendlog Data Analysis	Level 3: Levels 1 and 2 plus Equipment Fault Diagnosis and Event Response
Measured (Continued) The BAS designer needs to include these points (objects) in the project Point List Schedule.	(Continued) • Plant condenser-water return temperature • Plant condenser-water flow rate • Rooftop-unit gas flow rate • HVAC-heater gas flow rate	(See previous page.)	(See previous page.)
Virtual These are software points (objects) that are listed in the Point List Schedule or are determined by the BAS contractor from the sequence of operations.	• Air-handler outdoor-air-damper percentage • Return-damper percentage • Supply-fan mode (per *Sequences of Operation for Common HVAC Systems*[X6]) • Supply-fan status • Chilled-water-valve percentage • Supply air temperature setpoint • Supply air hot deck temperature, supply air hot deck temperature setpoint, hot-water valve position, if dual duct	• Chiller chilled-water supply temperature setpoint • Air-handler duct static pressure setpoint, variable-frequency-drive speed setpoint, and supply air hot duct static pressure setpoint, if dual duct • Terminal unit cooling temperature setpoint, heating temperature setpoint, cooling control signal, and heating control signal	—
Calculated—Whole Building	• Average daily outdoor air temperature • Whole-building peak power • Whole-building electric energy-use intensity • Whole-building natural gas energy-use intensity • Whole-building water-use intensity	Add: • Average building static pressure • Total HVAC electric power • Whole-building lighting power • Whole-building plug power • Whole-building HVAC electric energy-use intensity • Whole-building lighting energy-use intensity • Whole-building plug energy-use intensity	Add: • Average daily outdoor air temperature, when at least one chilled-water pump is running • Average daily outdoor air temperature, when at least one hot-water pump is running • Average daily outdoor air temperature, when at least one air handler is running • Average daily building power; total HVAC electric demand; whole-building HVAC energy-use intensity
Calculated—Chilled Water	• Chilled-water-plant delta-T • Chilled-water-plant power • Chilled-water-loop tons • Total chilled-water-plant tons • Chilled-water-plant efficiency	Add: • Chiller tons • Chiller efficiency • Total chiller power • Total chilled-water-plant heat rejection • Chilled-water-plant heat balance	Add: • Average daily chilled-water supply temperature • Daily total chilled-water-plant electricity use • Daily chilled-water-plant energy • Maximum daily chilled-water-plant energy • Average daily chilled-water-plant efficiency
Calculated—Natural Gas Equipment	—	Add: • Total boiler gas flow • Total boiler gas energy-use intensity • Boiler output • Boiler efficiency • Total boiler output • Total boiler efficiency	Add: • Total roof top unit gas flow rate • Total HVAC gas flow rate • Daily total HVAC natural gas use • Daily total HVAC natural gas energy • Maximum daily HVAC natural gas energy • Total HVAC natural gas energy-use intensity • Average daily boiler efficiency
Calculated —Supply Air	• Air-handler outdoor-air-temperature fraction • Air-handler outdoor-air-damper fraction • Total air-handler power • Total air-handler volume • Air-handler specific power	Add: • Instantaneous average building air-handler supply fan variable-frequency-drive frequency	Add: • Daily total air-handler electricity use • Daily total air-handler volume • Maximum daily air-handler volume • Average daily air-handler specific power
Event Response Initiation	None	None	Initiate a runtime report or a demand response request based on a real-time pricing signal.

(This annex is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE ANNEX F SOURCES OF PROTOCOL-SPECIFIC SPECIFICATION LANGUAGE

F1. SOURCES OF PROTOCOL-SPECIFIC SPECIFICATION LANGUAGE

ASHRAE Guideline 13 is written to be communications protocol neutral. Users of this guideline are encouraged to employ open, nonproprietary communications protocols wherever possible. To this end, the following sources are known to have guideline specification language based on their respective, specific open protocols. This language can be used by BAS designers and others interested in incorporating such language into their specifications.

The communications protocols and the organizations responsible for their maintenance are listed in alphabetical order. Readers will need to navigate the site to find the most up-to-date links to the guideline specification language. Each organization has specific requirements for the use of their material. Copyrights to the guideline specifications listed on the following sites are the property of their respective organizations. Other open-protocol resources will be added to this annex as they become available.

BACnet

BACnet is a communications protocol developed and maintained by ASHRAE. (www.bacnetinternational.org)

Konnex

Konnex is a communications protocol developed and maintained by the Konnex Association. (www.weinzierl.de)

LonMark

LonMark is a communications protocol developed and maintained by LonMark International. (www.lonmark.org)

Modbus

Modbus is a communications protocol developed and maintained by the Modbus Organization. (www.modbus.org)

Profibus

Profibus is a communications protocol developed and maintained by PROFIBUS and PROFINET International. (www.profibus.org)

Zigbee

Zigbee is a communications protocol developed and maintained by the ZigBee Alliance. (www.zigbee.org

(This annex is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE ANNEX G
ADDENDA DESCRIPTION INFORMATION

ASHRAE Guideline 13-2015 incorporates ASHRAE Guideline 13-2014 and Addendum a to ASHRAE Guideline 13-2014. Table G-1 provides a brief summary of how the guideline is affected by the changes. It also lists the ASHRAE approval date for addendum a.

TABLE G-1 Addenda to ASHRAE Guideline 13-2014

Addendum	Section(s) Affected	Description of Changes*	ASHRAE Approval
a	All	Addendum a to Guideline 13-2014 added and enhanced the guideline in a variety of ways that touch almost every section of the document. The following list provides a brief summary of those changes. a. The term "DDC" is replaced by "BAS" (building automation system) in many instances. b. The term "engineer" is largely replaced by "BAS designer," recognizing that often the designer is not a registered professional engineer. c. New content on building automation system (BAS) network design is added. d. New content on radio-frequency (RF) media types is added. e. New content on design and construction is added. f. New content on network security is added. g. New information on contractor roles and responsibilities is added. h. New Clause 12, "BAS Device Network Design," is added, which includes the following: 1. New system architecture content, drawings, and point list examples 2. New multitier architecture model 3. New information on profiles for HVAC and other system equipment 4. New system integration information i. New Clause 13, "Legacy Control Systems," is added. j. Content throughout the document is revised to bring it in line with current technical standards. k. New Informative Annex C, "Local Operating Network (LON)," and Informative Annex F, "Sources of Protocol-Specific Specification Language," are added, both of which address protocols and resources.	

* These descriptions may not be complete and are provided for information only.

NOTE

When addenda, interpretations, or errata to this guideline have been approved, they can be downloaded free of charge from the ASHRAE Web site at http://www.ashrae.org.

NOTICE

INSTRUCTIONS FOR SUBMITTING A PROPOSED CHANGE TO THIS GUIDELINE UNDER CONTINUOUS MAINTENANCE

This guideline is maintained under continuous maintenance procedures by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the guideline. SGPC consideration will be given to proposed changes within 13 months of receipt by the Senior Manager of Standards (SMOS).

Proposed changes must be submitted to the SMOS in the latest published format available from the SMOS. However, the SMOS may accept proposed changes in an earlier published format if the SMOS concludes that the differences are immaterial to the proposed change submittal. If the SMOS concludes that a current form must be utilized, the proposer may be given up to 20 additional days to resubmit the proposed changes in the current format.

ELECTRONIC PREPARATION/SUBMISSION OF FORM FOR PROPOSING CHANGES

An electronic version of each change, which must comply with the instructions in the Notice and the Form, is the preferred form of submittal to ASHRAE Headquarters at the address shown below. The electronic format facilitates both paper-based and computer-based processing. Submittal in paper form is acceptable. The following instructions apply to change proposals submitted in electronic form.

Use the appropriate file format for your word processor and save the file in either a recent version of Microsoft Word (preferred) or another commonly used word-processing program. Please save each change proposal file with a different name (for example, "prop01.doc," "prop02.doc," etc.). If supplemental background documents to support changes submitted are included, it is preferred that they also be in electronic form as word-processed or scanned documents.

For files submitted attached to an e-mail, ASHRAE will accept an electronic signature (as a picture; *.tif, or *.wpg) on the change submittal form as equivalent to the signature required on the change submittal form to convey non-exclusive copyright.

Submit an e-mail containing the change proposal files to:
change.proposal@ashrae.org

Alternatively, mail paper versions to:
ASHRAE
Senior Manager of Standards
1791 Tullie Circle, NE
Atlanta, GA 30329-2305

Or fax them to:
Attn: Senior Manager of Standards
404-321-5478

The form and instructions for electronic submittal may be obtained from the Standards section of ASHRAE's Home Page, www.ashrae.org, or by contacting a Standards Secretary via phone (404-636-8400), fax (404-321-5478), e-mail (standards.section@ashrae.org), or mail (1791 Tullie Circle, NE, Atlanta, GA 30329-2305).

FORM FOR SUBMITTAL OF PROPOSED CHANGE TO AN ASHRAE GUIDELINE UNDER CONTINUOUS MAINTENANCE

NOTE: Use a separate form for each comment. Submittals (Microsoft Word preferred) may be attached to e-mail (preferred) or submitted in paper by mail or fax to ASHRAE, Senior Manager of Standards, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: change.proposal@ashrae.org. Fax: +1-404-321-5478.

1. Submitter:

Affiliation:

Address: City: State: Zip: Country:

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I hereby grant ASHRAE the non-exclusive royalty rights, including non-exclusive rights in copyright, in my proposals. I understand that I acquire no rights in publication of the guideline in which my proposals in this or other analogous form is used. I hereby attest that I have the authority and am empowered to grant this copyright release.

Submitter's signature: ____ Date: ____________________________

All electronic submittals must have the following statement completed:

I *(insert name)* ____, through this electronic signature, hereby grant ASHRAE the non-exclusive royalty rights, including non-exclusive rights in copyright, in my proposals. I understand that I acquire no rights in publication of the guideline in which my proposals in this or other analogous form is used. I hereby attest that I have the authority and am empowered to grant this copyright release.

2. Number and year of guideline:

3. Page number and clause (section), subclause, or paragraph number:

4. I propose to: [ ] Change to read as follows [ ] Delete and substitute as follows
(check one) [ ] Add new text as follows [ ] Delete without substitution

Use underscores to show material to be added (<u>added</u>) and strike through material to be deleted (~~deleted~~). Use additional pages if needed.

5. Proposed change:

6. Reason and substantiation:

7. Will the proposed change increase the cost of engineering or construction? If yes, provide a brief explanation as to why the increase is justified.

[ ] Check if additional pages are attached. Number of additional pages: ________

[ ] Check if attachments or referenced materials cited in this proposal accompany this proposed change. Please verify that all attachments and references are relevant, current, and clearly labeled to avoid processing and review delays. *Please list your attachments here:*

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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For more information or to become a member of ASHRAE, visit www.ashrae.org.

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To ensure that you have all of the approved addenda, errata, and interpretations for this guideline, visit www.ashrae.org/standards to download them free of charge.

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