

SECTION 23 09 23 - DIRECT DIGITAL CONTROLS

PART 1 – GENERAL

1.1 RELATED DOCUMENTS

- A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.

1.2 PRODUCTS FURNISHED BUT NOT INSTALLED UNDER THIS SECTION

- A. Heating and cooling piping:
 - 1. Control valves
 - 2. Flow meters
 - 3. Flow switches
 - 4. Press and temp sensor wells & sockets
 - 5. Temp sensor wells and sockets
- B. Duct accessories:
 - 1. Airflow stations
 - 2. BAS control dampers
 - 3. Terminal unit controls

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

- A. Communications with Third Party Equipment:
 - 1. Any additional integral control systems included with the products integrated with the work of this section shall be furnished with a BACnet interface for integration into the Direct Digital Control System described in this section (reference sequence of operations and points list for specifics). Those systems include:
 - a. Chillers
 - b. Switchgear
 - c. Variable Speed Drives
 - d. Rooftop Units

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. Division 01- General
 - 2. Division 23 – Mechanical
 - 3. Division 26 – Electrical

1.5 DESCRIPTION

- A. General: The control system shall consist of a complete BAS system with a high-speed, peer-to-peer network of DDC controllers and a web-based operator interface. Depict each mechanical system and building floor plan by a point-and-click graphics. A web server with a network interface card shall gather data from this system and generate web pages accessible through a conventional web browser on each PC connected to the network. Operators shall be able to perform all normal operator functions through the web browser interface. If individual software seat licenses or keys are required provide a minimum of 4 additional licenses to accommodate multiple owner operators.
- B. If manufacture offers a web-based BAS platform, the installing contractor shall provide the new web-based software and software updates required for this project. Additionally the installing contractor shall provide all computer related components (BAS web server – reference specifications for hardware requirements) for the new software platform to function in a peer-to-peer environment.
- C. The system shall directly control HVAC equipment as specified in Sequences of Operation. Each zone controller shall provide occupied and unoccupied modes of operation by individual zone. Furnish energy conservation features such as optimal start and stop, night setback, request-based logic, and demand level adjustment of setpoints.
- D. System shall use the BACnet protocol for communication to the operator workstation or web server and for communication between control modules. Schedules, setpoints, trends, and alarms specified shall be BACnet objects.

1.6 APPROVED CONTROL SYSTEMS

- 1. Automated Logic, ALC

1.7 QUALITY ASSURANCE

- A. Installer and Manufacturer Qualifications
 - 1. Installer shall have an established working relationship with Control System Manufacturer for a period of 10 years or greater. If the distributorship has not had duration of more than 10 years, the contractor will not be approved without the written approval prior to bid date (no exceptions).
 - 2. Installer shall have successfully completed Control System Manufacturer's control system training. Upon request, Installer shall present record of completed training including course outlines.
 - 3. BAS Graphics shall be Three Dimensional Thermographic.
 - 4. BAS provider shall warranty controllers for 10 years.
 - 5. BAS Provider shall provide lifetime training for the lifecycle of the facility to the owner at no additional cost.

1.8 CODES AND STANDARDS

- A. Work, materials, and equipment shall comply with the most restrictive of local, state, and federal authority's codes and ordinances for these plans and specifications. At 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 Energy Conservation Code (IECC)
 3. International Building Code (IBC)
 4. Uniform Mechanical Code (UMC)
 5. ASHRAE Standard 135-2016: BACnet - A Data Communication Protocol for Building Automation and Control Networks

1.9 SYSTEM PERFORMANCE

- A. Performance Standards. System shall conform to the following minimum standards over network connections. Systems shall be tested using manufacturer's recommended hardware and software for operator workstation (server and browser for web-based systems).
1. Graphic Display. A graphic with 20 dynamic points shall display with current data within 10 seconds.
 2. Graphic Refresh. A graphic with 20 dynamic points shall update with current data within 8 seconds and shall automatically refresh every 15 seconds.
 3. Configuration and Tuning Screens. Screens used for configuring, calibrating, or tuning points, PID loops, and similar control logic shall automatically refresh within 6 seconds.
 4. Object Command. Devices shall react to command of a binary object within 2 seconds. Devices shall begin reacting to command of an analog object within 2 seconds.
 5. Alarm Response Time. An object that goes into alarm shall be annunciated at the workstation within 15 seconds.
 6. Program Execution Frequency. Custom and standard applications shall be capable of running as often as once every 5 seconds. Select execution times consistent with the mechanical process under control.
 7. Performance. Programmable controllers shall be able to completely execute DDC 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 seconds of other workstations.
 9. Reporting Accuracy. System shall report values with minimum end-to-end accuracy listed in Table 1.

Control Stability and Accuracy. Control loops shall maintain measured variable at set point within tolerances listed in Table 2.

Table1
Reporting Accuracy

Measured Variable	Reported Accuracy
Space Temperature	±2°F
Ducted Air	±2°F
Outside Air	±2°F
Dew Point	±3°F
Water Temperature	±2°F
Delta-T	±0.25°F
Relative Humidity	±5% RH
Water Flow	±2% of full scale
Airflow (terminal)	±10% of full scale (see Note 1)
Airflow (measuring stations)	±5% of full scale
Airflow (pressurized spaces)	±3% of full scale
Air Pressure (ducts)	±0.1 in. w.g.
Air Pressure (space)	±0.01 in. w.g.
Water Pressure	±2% of full scale (see Note 2)
Electrical (A, V, W, Power Factor)	±1% of reading (see Note 3)
Carbon Monoxide (CO)	±5% of reading
Carbon Dioxide (CO ₂)	±50 ppm

Note 1: 10% - 100% of scale

Note 2: For both absolute and differential pressure

Note 3: Not including utility-supplied meters

Table 2
Control Stability and Accuracy

Controlled Variable	Control Accuracy	Range of Medium
Air Pressure	±0.2 in. w.g. ±0.01 in. w.g.	0-6 in. w.g. -0.1 to 0.1 in. w.g.
Airflow	±10% of full scale	
Space Temperature	±2.0°F	
Duct Temperature	±3°F	
Humidity	±5% RH	
Fluid Pressure	±1.5 psi ±1.0 in. w.g.	1-150 psi 0-50 in. w.g. differential

1.10 SUBMITTALS

- A. Product Requirements: Provide one electronic copy and 4 hard copies of shop drawings and other submittals on hardware, software, and equipment to be installed or furnished. Begin no work until submittals have been approved for conformity with design intent. If requested, provide drawings as AutoCAD 2017 and 4 prints of each drawing on 8.5 x 11 paper and 1 electronic copy of each drawing. When manufacturer's cut sheets apply to a product series rather than a specific product, **clearly indicate applicable data by highlighting** or by other means. Clearly reference covered specification and drawing on each submittal. General catalogs shall not be accepted as cut sheets to fulfill submittal

requirements. Select and show submittal quantities appropriate to scope of work. Submittal approval does not relieve Contractor of responsibility to supply sufficient quantities to complete work. Provide submittals on the following:

1. Direct Digital Control System Hardware
 - a. Complete bill of materials indicating quantity, manufacturer, model number, and relevant technical data of equipment to be used.
 - b. Manufacturer's description and technical data such as performance curves, product specifications, and installation and maintenance instructions for items listed below and for relevant items not listed below:
 1. Direct digital controllers (controller panels)
 2. Transducers and transmitters
 3. Sensors (include accuracy data)
 4. Actuators
 5. Valves
 6. Dampers
 7. Relays and switches
 8. Control panels
 9. Power supplies
 10. Batteries
 11. Operator interface equipment
 12. Wiring
 - c. Wiring diagrams and layouts for each control panel. Show termination numbers.
 - d. Floor plan schematic diagrams indicating field sensor and controller locations.
 - e. Riser diagrams showing control network layout, communication protocol, and wire types.
 - f. Schematic diagrams of control, communication, and power wiring for central system installation. Show interface wiring to control system.
 - g. Network riser diagrams of wiring between central control unit and control panels.

2. Controlled Systems
 - a. Schematic diagram of each controlled system. Label control points with point names. Graphically show locations of control elements.
 - b. Schematic wiring diagram of each controlled system. Label control elements and terminals. Where a control element is also shown on control system schematic, use the same name.
 - c. Instrumentation list (Bill of Materials) for each controlled system. List each control system element in a table. Show element name, type of device, manufacturer, model number, and product data sheet number.
 - d. Complete description of control system operation including sequences of operation. Include and reference schematic diagram of controlled system. List I/O points and software points specified. Indicate alarmed and trended points.
 3. Description of process, report formats, and checklists to be used in Section 23 09 23 Article 3.15 (Control System Demonstration and Acceptance).
- B. Schedules
1. Within two months of contract award, provide schedule of work indicating:
 - a. Intended sequence of work items
 - b. Start date of each work item
 - c. Duration of each work item
 - d. Planned delivery dates for ordered material and equipment and expected lead times
 - e. Milestones indicating possible restraints on work by other trades or situations
 2. Monthly written status reports indicating work completed and revisions to expected delivery dates. Include updated schedule of work.
- C. Project Record Documents. Submit 8 copies of record (as-built) documents upon completion of installation for approval prior to final completion. Submittal shall consist of:
1. Project Record Drawings. As-built versions of submittal shop drawings provided as AutoCAD 2017 and 6 prints of each drawing on 8 ½" x 11" paper.
 2. Testing and Commissioning Reports and Checklists. Completed versions of reports, checklists, and trend logs used to meet requirements of (Control System Demonstration and Acceptance).

3. Operation and Maintenance (O&M) Manual. Printed, electronic, or online help documentation of the following:
 - a. As-built versions of submittal product data.
 - b. Names, addresses, and telephone numbers of installing contractors and service representatives for equipment and control systems.
 - c. 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.
 - d. 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.
 - e. 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.
 - f. Documentation of programs created using custom programming language including setpoints, tuning parameters, and object database. Electronic copies of programs shall meet this requirement if control logic, setpoints, tuning parameters, and objects can be viewed using furnished programming tools.
 - g. Graphic files, programs, and database on magnetic or optical media.
 - h. List of recommended spare parts with part numbers and suppliers.
 - i. Complete original-issue documentation, installation, and maintenance information for furnished third-party hardware including computer equipment and sensors.
 - j. Complete original-issue copies of furnished software, including operating systems, custom programming language, operator workstation or web server software, and graphics software.
 - k. Licenses, guarantees, and warranty documents for equipment and systems.
 - l. 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: The contractor shall provide training to owner personnel in a laboratory classroom environment. Each student shall be provided with a dedicated computer workstation utilizing a simulated BAS software platform that is installed for this project. The instructor's shall have CEU accreditation for all training courses offered. Provide documentation for this requirement in the initial BAS submittal. If contractor does not have CEU instructor or offer these courses locally include cost for tuition, travel and boarding to send students to manufacturer training facility. The owner shall receive free training for the life of the system.
1. Operator Overview – Consists of general system navigation, scheduling functions, setpoint modifications and parameter adjustments.
 2. Advanced Topics Overview – Detailed analysis of trend setup/configuration, trend historian, alarm setup, alarm actions (email, printing, etc.), point renaming, and detailed analysis of equipment parameters.
 3. Program/Logic Manipulation – Modify system programs as needed for additions and modifications.
 4. Graphic Manipulation – Modify system graphics as needed for additions and modifications.
 5. Hardware Troubleshooting – Classroom setup shall have HVAC mock-up systems. Operators shall be able to interact with this live system through the BAS utilized for this project. Class will provide students the ability to identify and repair common problems regularly encountered.
 6. Software Troubleshooting - Classroom setup shall have HVAC mock-up systems. Operators shall be able to interact with this live system through the BAS utilized for this project. Class will provide students the ability to identify and repair common issues that can be utilized via software modifications.
 7. Central Plant Operation – At a minimum the instructor shall thoroughly explain different types of central plant equipment and proper system modifications that can be made to enhance system performance and energy savings.
 8. HVAC System Training – Objective of this class is to provide basic HVAC system knowledge of various types of systems including types of air side distribution and water side distribution. Topics such as thermodynamics, psychometrics, de-humidification, and demand control ventilation shall be thoroughly explained.

1.11 WARRANTY

- A. Warrant work as follows:
1. Warrant materials for specified control system and peripheral control devices free from defects for a period of **3 years** after certificate of substantial completion. Warrant all labor for a period of **1 year** after final acceptance. Control system failures during warranty period shall be adjusted, repaired, or replaced at no additional cost or reduction in service to Owner. Respond during normal business hours within 24 hours of Owner's warranty service request. Additionally contractor shall offer 24/7 after-hours support to include alarm monitoring and associated dispatch service.

2. Provide graphic modifications for a period of 3 years from date of substantial completion. This shall include room number and equipment modifications as requested by the owner.
3. Provide telephone support free to the owner for a period of 3 years after substantial completion. This service includes technical support for all BAS equipment and shall include troubleshooting and problem resolution via the telephone or web services. Service shall be available during the hours of 7am to 5pm Monday – Friday.
4. Work shall have a single warranty date, even if Owner receives beneficial use due to early system start-up. If specified work is split into multiple contracts or a multi-phase contract, each contract or phase shall have a separate warranty start date and period.
5. Provide updates to operator workstation or web server software, project-specific software, graphic software, database software, and firmware that resolve Contractor or Owner identified software deficiencies at no charge during warranty period. If available, 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 Owner's written authorization.
6. Exception: Contractor shall not be required to warranty existing devices except those that have been rebuilt or repaired during installation.

1.12 OWNERSHIP OF PROPRIETARY MATERIAL

- A. Project-specific software and documentation shall become Owner's property. This includes, but is not limited to:
 1. Graphics
 2. Record drawings
 3. Database
 4. Application programming code
 5. Documentation

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Provide new products the manufacturer is currently manufacturing and selling for use in new installations. Do not use this installation as a product test site unless explicitly approved in writing by Owner. Spare parts shall be available for at least five years after completion of this contract.

2.2 COMMUNICATION

- A. Control products, communication media, connectors, repeaters, hubs, and routers shall comprise a BACnet internetwork. Controller and operator interface communication shall conform to ASHRAE/ANSI Standard 135-2016, BACnet.

- B. Use existing Ethernet backbone for network segments marked "existing" on project drawings.
- C. Each controller shall have a communication port for temporary connection to a laptop computer or other operator interface. Connection shall support memory downloads and other commissioning and troubleshooting operations.
- D. Internetwork operator interface and value passing shall be transparent to internetwork architecture.
 - 1. An operator interface connected to a controller shall allow the operator to interface with each internetwork controller as if directly connected. Controller information such as data, status, and control algorithms shall be viewable and editable from each internetwork controller.
 - 2. Inputs, outputs, and control variables used to integrate control strategies across multiple controllers shall be readable by each controller on the internetwork. Program and test all cross-controller links required to execute control strategies specified in Sequence of Operations. An authorized operator shall be able to edit cross-controller links by typing a standard object address or by using a point-and-click interface.
- E. Controllers with real-time clocks shall use the BACnet Time Synchronization service. System shall automatically synchronize system clocks daily from an operator-designated controller via the internetwork. If applicable, system shall automatically adjust for daylight saving and standard time.
- F. System shall be expandable to at least twice the required input and output objects with additional controllers, associated devices, and wiring.
- G. System shall support Web services data exchange with any other system that complies with XML (extensible markup language) and SOAP (simple object access protocol) standards specified by the Web Services Interoperability Organization (WS-I) Basic Profile 1.0 or higher. Web services support shall as a minimum be provided at the workstation or web server level and shall enable the system to both read and write data.
 - 1. System shall support Web services read data requests by retrieving requested trend data or point values (I/O hardware points, analog value software points, or binary value software points) from any system controller or from the trend history database.
 - 2. System shall support Web services write data request to each analog and binary object that can be edited through the system operator interface by downloading a numeric value to the specified object.
 - 3. For read or write requests, the system shall require user name and password authentication and shall support SSL (Secure Socket Layer) or equivalent data encryption.

2.3 OPERATOR INTERFACE

- A. Operator Interface. Web server shall reside on high-speed network with building controllers. Each standard browser connected to server shall be able to access all system information. Existing manufacturer's BAS web server and workstation can be utilized. In addition to the primary operator interface, the system shall include a secondary interface compatible with a locally available commercial wireless network and viewable on a commercially available wireless device such as a Wireless Access Protocol (WAP) enabled cellular telephone or personal digital assistant (PDA). This secondary interface may be text-based and shall provide a summary of the most important data. As a minimum, the following capabilities shall be provided through this interface:
1. An operator authentication system that requires an operator to log in before viewing or editing any data, and which can be configured to limit the privileges of an individual operator.
 2. The ability to view and acknowledge any alarm in the system. Alarms or links to alarms shall be provided on a contiguous list so the operator can quickly view all alarms.
 3. A summary page or pages for each piece of equipment in the system. This page shall include the current values of all critical I/O points and shall allow the operator to lock binary points on or off and to lock analog points to any value within their range.
 4. Navigation links that allow the operator to quickly navigate from the home screen to any piece of equipment in the system, and then return to the home screen. These links may be arranged in a hierarchical fashion, such as navigating from the home screen to a particular building, then to a specific floor in the building, and then to a specific room or piece of equipment.
- B. Communication. Web server or workstation and controllers shall communicate using BACnet protocol. Web server or workstation and control network backbone shall communicate using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol and BACnet/IP addressing as specified in ASHRAE/ANSI 135-2016, BACnet Annex J.
- C. Hardware. If providing a new server, each workstation or web server shall consist of the following:
1. Hardware Base. Industry-standard hardware shall meet or exceed DDC system manufacturer's recommended specifications and shall meet response times specified in Section 23 09 23 Paragraph 1.8. Hard disk shall have sufficient memory to store system software, one year of data for trended points specified in Sequences of Operation, and a system database at least twice the size of the existing database at system acceptance. Configure computers and network connections if multiple computers are required to meet specified memory and performance. Web server shall be Compaq Rack Mounted Server (or equal) with a minimum of:
 - a. Dual Processor Intel Pentium 3.66 GHz processor
 - b. 1 GB RAM
 - c. 80 GB hard disk providing data at 100 MB/sec

- d. RAID 5 Configuration
 - e. 128x CD-ROM drive
 - f. Most Current Windows Server Operating System
 - g. Serial, parallel, and network communication ports and cables required for proper system operation.
2. If providing a server the server shall support one or more the following database types:
 - a. SQL Server 2012 R2
 - b. PostgreSQL
 - c. MySQL
 - d. MS Access
- D. Operator Functions. Operator interface shall allow each authorized operator to execute the following functions as a minimum:
1. Log In and Log Out. System shall require user name and password to log in to operator interface.
 2. Point-and-click Navigation. Operator interface shall be graphically based and shall allow operators to access graphics for equipment and geographic areas using point-and-click navigation.
 3. View and Adjust Equipment Properties. Operators shall be able to view controlled equipment status and to adjust operating parameters such as setpoints, PID gains, on and off controls, and sensor calibration.
 4. View and Adjust Operating Schedules. Operators shall be able to view scheduled operating hours of each schedulable piece of equipment on a weekly or monthly calendar-based graphical schedule display, to select and adjust each schedule and time period, and to simultaneously schedule related equipment. System shall clearly show exception schedules and holidays on the schedule display.
 5. View and Respond to Alarms. Operators shall be able to view a list of currently active system alarms, to acknowledge each alarm, and to clear (delete) unneeded alarms.
 6. View and Configure Trends. Operators shall be able to view a trend graph of each trended point and to edit graph configuration to display a specific time period or data range. Operator shall be able to create custom trend graphs to display on the same page data from multiple trended points.
 7. View and Configure Reports. Operators shall be able to run preconfigured reports, to view report results, and to customize report configuration to show data of interest.
 8. Manage Control System Hardware. Operators shall be able to view controller status, to restart (reboot) each controller, and to download new control software to each controller.

9. Manage Operator Access. Typically, only a few operators are authorized to manage operator access. Authorized operators shall be able to view a list of operators with system access and of functions they can perform while logged in. Operators shall be able to add operators, to delete operators, and to edit operator function authorization. Operator shall be able to authorize each operator function separately.
- E. System Software.
1. Operating System: Web server or workstation shall have an industry-standard professional-grade operating system. Acceptable systems include Microsoft Windows XP Pro, Red Hat Linux, or Sun Solaris.
 2. System Graphics: Operator interface shall be graphically based and shall include at least one graphic per piece of equipment or occupied zone, graphics for each chilled water and hot water system, and graphics that summarize conditions on each floor of each building included in this contract. Indicate thermal comfort on floor plan summary graphics using dynamic colors to represent zone temperature relative to zone setpoint. Graphics shall
 - a. Functionality: Graphics shall allow operator to monitor system status, to view a summary of the most important data for each controlled zone or piece of equipment, to use point-and-click navigation between zones or equipment, and to edit setpoints and other specified parameters.
 - b. Animation: Graphics shall be able to animate by displaying different image files for changed object status.
 - c. Alarm Indication: Indicate areas or equipment in an alarm condition using color or other visual indicator.
 - d. Format. Graphics shall be saved in an industry-standard format such as BMP, JPEG, or GIF. Web-based system graphics shall be viewable on browsers compatible with World Wide Web Consortium browser standards. Web graphic format shall require no plug-in (such as HTML and JavaScript) or shall require widely available no-cost plug-ins (such as Active-X and Macromedia Flash).
- F. System Tools. System shall provide the following functionality to authorized operators as an integral part of the operator interface or as stand-alone software programs. If furnished as part of the interface, the tool shall be available from each workstation or web browser interface. If furnished as a stand-alone program, software shall be installable on standard IBM-compatible PCs with no limit on the number of copies that can be installed under the system license.
1. Automatic System Database Configuration. Each workstation or web server shall store on its hard disk a copy of the current system database, including controller firmware and software. Stored database shall be automatically updated with each system configuration or controller firmware or software change.
 2. Controller Memory Download. Operators shall be able to download memory from the system database to each controller.
 3. System Configuration. Operators shall be able to configure the system.

4. Online Help. Context-sensitive online help for each tool shall assist operators in operating and editing the system.
5. Security. System shall require a user name and password to view, edit, add, or delete data.
 - a. Operator Access. Each user name and password combination shall define accessible viewing, editing, adding, and deleting functions in each system application, editor, and object. Authorized operators shall be able to vary and deny each operator's accessible functions based on equipment or geographic location.
 - b. Automatic Log Out. Automatically log out each operator if no keyboard or mouse activity is detected. Operators shall be able to adjust automatic log out delay.
 - c. Encrypted Security Data. Store system security data including operator passwords in an encrypted format. System shall not display operator passwords.
6. System Diagnostics. System shall automatically monitor controller and I/O point operation. System shall annunciate controller failure and I/O point locking (manual overriding to a fixed value).
7. Alarm Processing. System input and status objects shall be configurable to alarm on departing from and on returning to normal state. Operator shall be able to enable or disable each alarm and to configure alarm limits, alarm limit differentials, alarm states, and alarm reactions for each system object. Configure and enable alarm points as specified in Section 23 09 93. Alarms shall be BACnet alarm objects and shall use BACnet alarm services.
8. Alarm Messages. Alarm messages shall use an English language descriptor without acronyms or mnemonics to describe alarm source, location, and nature.
9. Alarm Reactions. Operator shall be able to configure (by object) actions workstation or web server shall initiate on receipt of each alarm. As a minimum, workstation or web server shall be able to log, print, start programs, display messages, send e-mail, send page, and audibly annunciate.
10. Alarm Maintenance. Operators shall be able to view system alarms and changes of state chronologically, to acknowledge and delete alarms, and to archive closed alarms to the workstation or web server hard disk from each workstation or web browser interface.
11. Trend Configuration. Operator shall be able to configure trend sample or change of value (COV) interval, start time, and stop time for each system data object and shall be able to retrieve data for use in spreadsheets and standard database programs. Controller shall sample and store trend data and shall be able to archive data to the hard disk. The contractor shall configure all physical control points and software control points to accumulate trend data. Analog values shall be configured utilizing time-based intervals and digital values shall be configured for COV. Provide at a minimum of 250 samples per control point. If data can be stored locally at the controller level this information shall be archived at the central server or all BAS workstations.

12. Object and Property Status and Control. Operator shall be able to view, and to edit if applicable, the status of each system object and property by menu, on graphics, or through custom programs.
13. Reports and Logs. Operator shall be able to select, to modify, to create, and to print reports and logs. Operator shall be able to store report data in a format accessible by standard spreadsheet and word processing programs.
14. Standard Reports. Furnish the following standard system reports:
 - a. Objects. System objects and current values filtered by object type, by status (in alarm, locked, normal), by equipment, by geographic location, or by combination of filter criteria.
 - b. Alarm Summary. Current alarms and closed alarms. System shall retain closed alarms for an adjustable period.
 - c. Logs. System shall log the following to a database or text file and shall retain data for an adjustable period:
 1. Alarm History.
 2. Trend Data. Operator shall be able to select trends to be logged.
 3. Operator Activity. At a minimum, system shall log operator log in and log out, control parameter changes, schedule changes, and alarm acknowledgment and deletion. System shall date and time stamp logged activity.
15. Custom Reports. Operator shall be able to create custom reports that retrieve data, including archived trend data, from the system, that analyze data using common algebraic calculations, and that present results in tabular or graphical format. Reports shall be launched from the operator interface.
16. Graphics Generation. Graphically based tools and documentation shall allow Operator to edit system graphics, to create graphics, and to integrate graphics into the system. Operator shall be able to add analog and binary values, dynamic text, static text, and animation files to a background graphic using a mouse.
17. Graphics Library. Complete library of standard HVAC equipment graphics shall include equipment such as chillers, boilers, air handlers, terminals, fan coils, and unit ventilators. Library shall include standard symbols for other equipment including fans, pumps, coils, valves, piping, dampers, and ductwork. Library graphic file format shall be compatible with graphics generation tools.
18. Custom Application Programming. Operator shall be able to create, edit, debug, and download custom programs. System shall be fully operable while custom programs are edited, compiled, and downloaded. Programming language shall have the following features:
 - a. Language. Language shall be graphically based or English language oriented. If graphically based, language shall use function blocks arranged in a logic diagram that clearly shows control logic flow. Function blocks shall directly provide functions listed below, and operators shall be able to create custom or compound function blocks. If English language oriented, language shall be based on the syntax of

BASIC, FORTRAN, C, or PASCAL, and shall allow for free-form programming that is not column-oriented or "fill-in-the-blanks."

- b. Programming Environment. Tool shall provide a full-screen, cursor-and-mouse-driven programming environment that incorporates word processing features such as cut and paste. Operators shall be able to insert, add, modify, and delete custom programming code, and to copy blocks of code to a file library for reuse in other control programs.
 - c. Independent Program Modules. Operator shall be able to develop independently executing program modules that can disable, enable and exchange data with other program modules.
 - d. Debugging and Simulation. Operator shall be able to step through the program observing intermediate values and results. Operator shall be able to adjust input variables to simulate actual operating conditions. Operator shall be able to adjust each step's time increment to observe operation of delays, integrators, and other time-sensitive control logic. Debugger shall provide error messages for syntax and for execution errors.
 - e. Conditional Statements. Operator shall be able to program conditional logic using compound Boolean (AND, OR, and NOT) and relational (EQUAL, LESS THAN, GREATER THAN, NOT EQUAL) comparisons.
 - f. Mathematical Functions. Language shall support floating-point addition, subtraction, multiplication, division, and square root operations, as well as absolute value calculation and programmatic selection of minimum and maximum values from a list of values.
 - g. Variables: Operator shall be able to use variable values in program conditional statements and mathematical functions.
 - 1. Time Variables. Operator shall be able to use predefined variables to represent time of day, day of the week, month of the year, and date. Other predefined variables or simple control logic shall provide elapsed time in seconds, minutes, hours, and days. Operator shall be able to start, stop, and reset elapsed time variables using the program language.
 - 2. System Variables. Operator shall be able to use predefined variables to represent status and results of Controller Software and shall be able to enable, disable, and change setpoints of Controller Software as described in Controller Software section.
19. BACnet. Web server or workstation shall have demonstrated interoperability during at least one BMA Interoperability Workshop and shall substantially conform to BACnet Operator Workstation (B-OWS) device profile as specified in ASHRAE/ANSI 135-2016, BACnet Annex L.

2.4 CONTROLLER SOFTWARE

- A. Building and energy management application software shall reside and operate in system controllers. Applications shall be editable through operator workstation, web browser interface, or engineering workstation.
- B. System Security. See Paragraph 2.3.F.5 (Security) and Paragraph 2.3.F.14.c.3 (Operator Activity).
- C. Scheduling. See Paragraph 2.3.D.4 (View and Adjust Operating Schedules). System shall provide the following schedule options as a minimum:
 - 1. Weekly. Provide separate schedules for each day of the week. Each schedule shall be able to include up to 5 occupied periods (5 start-stop pairs or 10 events).
 - 2. Exception. Operator shall be able to designate an exception schedule for each of the next 365 days. After an exception schedule has executed, system shall discard and replace exception schedule with standard schedule for that day of the week.
 - 3. Holiday. Operator shall be able to define 24 special or holiday schedules of varying length on a scheduling calendar that repeats each year.
- D. System Coordination. Operator shall be able to group related equipment based on function and location and to use these groups for scheduling and other applications.
- E. Binary and Analog Alarms. See Paragraph 2.3.F.7 (Alarm Processing).
- F. Alarm Reporting. See Paragraph 2.3.F.9 (Alarm Reactions).
- G. Remote Communication. System shall automatically contact operator workstation or server on receipt of critical alarms. If no network connection is available, system shall use a modem connection.
- H. Maintenance Management. System shall generate maintenance alarms when equipment exceeds adjustable runtime, equipment starts, or performance limits. Configure and enable maintenance alarms as specified in Section 23 09 93.
- I. Sequencing. Application software shall sequence chillers, boilers, and pumps as specified in Section 23 09 93.
- J. PID Control. System shall provide direct- and reverse-acting PID (proportional-integral-derivative) algorithms. Each algorithm shall have anti-windup and selectable controlled variable, setpoint, and PID gains. Each algorithm shall calculate a time-varying analog value that can be used to position an output or to stage a series of outputs.
- K. Staggered Start. System shall stagger controlled equipment restart after power outage. Operator shall be able to adjust equipment restart order and time delay between equipment restarts.

- L. Energy Calculations.
 - 1. System shall accumulate and convert instantaneous power (kW) or flow rates (gpm) to energy usage data.
 - 2. System shall calculate a sliding-window average (rolling average). Operator shall be able to adjust window interval to 15 minutes, 30 minutes, or 60 minutes.
 - 3. System shall calculate a fixed-window average. Window interval start shall be defined by utility meter digital input signal to synchronize system's and utility's fixed-window averages.
- M. Anti-Short Cycling. Binary output objects shall be protected from short cycling by means of adjustable minimum on-time and off-time settings.
- N. On and Off Control with Differential. System shall provide direct- and reverse-acting on and off algorithms with adjustable differential to cycle a binary output based on a controlled variable and setpoint.
- O. Runtime Totalization. System shall provide an algorithm that can totalize runtime for each binary input and output. Operator shall be able to enable runtime alarm based on exceeded adjustable runtime limit. Configure and enable runtime totalization and alarms as specified.

2.5 CONTROLLERS

- A. General. Provide Building Controllers (BC), Advanced Application Controllers (AAC), Application Specific Controllers (ASC), and Smart Actuators (SA) as required to achieve performance specified in Section 23 09 23 Article 1.8 (System Performance).
- B. BACnet.
 - 1. Building Controllers (BCs). Each BC shall have demonstrated interoperability during at least one BMA Interoperability Workshop and shall substantially conform to BACnet Building Controller (B-BC) device profile as specified in ASHRAE/ANSI 135-2016, BACnet Annex L.
 - 2. Advanced Application Controllers (AACs). Each AAC shall conform to BACnet Advanced Application Controller (B-AAC) device profile as specified in ASHRAE/ANSI 135-2016, BACnet Annex L and shall be listed as a certified B-AAC in the BACnet Testing Laboratories (BTL) Product Listing.
 - 3. Application Specific Controllers (ASCs). Each ASC shall conform to BACnet Application Specific Controller (B-ASC) device profile as specified in ASHRAE/ANSI 135-2016, BACnet Annex L and shall be listed as a certified B-ASC in the BACnet Testing Laboratories (BTL) Product Listing.
 - 4. Smart Actuators (SAs). Each SA shall conform to BACnet Smart Actuator (B-SA) device profile as specified in ASHRAE/ANSI 135-2016, BACnet Annex L and shall be listed as a certified B-SA in the BACnet Testing Laboratories (BTL) Product Listing.

5. BACnet Communication.
 - a. Each BC shall reside on or be connected to a BACnet network using ISO 8802-3 (Ethernet) Data Link/Physical layer protocol and BACnet/IP addressing.
 - b. BACnet routing shall be performed by BCs or other BACnet device routers as necessary to connect BCs to networks of AACs and ASCs.
 - c. Each AAC and ASC shall reside on a BACnet network using the ARCNET or MS/TP Data Link/Physical layer protocol.
 - d. Each SA shall reside on a BACnet network using the ARCNET or MS/TP Data Link/Physical layer protocol.
- C. Communication.
 1. Service Port. Each controller shall provide a service communication port for connection to a Portable Operator's Terminal. Connection shall be extended to space temperature sensor ports where shown on drawings.
 2. Signal Management. BC and ASC operating systems shall manage input and output communication signals to allow distributed controllers to share real and virtual object information and to allow for central monitoring and alarms.
 3. Data Sharing. Each BC and AAC shall share data as required with each networked BC and AAC.
 4. Stand-Alone Operation. Each piece of equipment specified in Sequences of Operation shall be controlled by a single controller to provide stand-alone control in the event of communication failure. All I/O points specified for a piece of equipment shall be integral to its controller. Provide stable and reliable stand-alone control using default values or other method for values normally read over the network.
- D. Environment. Controller hardware shall be suitable for anticipated ambient conditions.
 1. Controllers used outdoors or in wet ambient conditions shall be mounted in waterproof enclosures and shall be rated for operation at -20°F to 140°F.
 2. Controllers used in conditioned space shall be mounted in dust-protective enclosures and shall be rated for operation at 32°F to 120°F.
- E. Real-Time Clock. Controllers that perform scheduling shall have a real-time clock.
- F. Serviceability.
 1. Controllers shall have diagnostic LEDs for power, communication, and processor.
 2. Wires shall be connected to a field-removable modular terminal strip or to a termination card connected by a ribbon cable.

3. Each BC and AAC shall continually check its processor and memory circuit status and shall generate an alarm on abnormal operation. System shall continuously check controller network and generate alarm for each controller that fails to respond.
- G. Memory.
1. Controller memory shall support operating system, database, and programming requirements.
 2. Each BC and AAC shall retain BIOS and application programming for at least 72 hours in the event of power loss.
 3. Each ASC and SA shall use nonvolatile memory and shall retain BIOS and application programming in the event of power loss. System shall automatically download dynamic control parameters following power loss.
- H. 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% 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.).
- I. Transformer. ASC power supply shall be fused or current limiting and shall be rated at a minimum of 125% of ASC power consumption.

2.6 INPUT AND OUTPUT INTERFACE

- A. General. Hard-wire input and output points to BCs, AACs, ASCs, or SAs.
- B. Protection. Shorting an input or output point to itself, to another point, or to ground shall cause no controller damage. Input or output point contact with up to 24 V for any duration shall cause no controller damage.
- C. Binary Inputs. Binary inputs shall monitor the on and off signal from a remote device. Binary inputs shall provide a wetting current of at least 12 mA and shall be protected against contact bounce and noise. Binary inputs shall sense dry contact closure without application of power external to the controller.
- D. Pulse Accumulation Inputs. Pulse accumulation inputs shall conform to binary input requirements and shall accumulate up to 10 pulses per second.
- E. Analog Inputs. Analog inputs shall monitor low-voltage (0-10 Vdc), current (4-20 mA), or resistance (thermistor or RTD) signals. Analog inputs shall be compatible with and field configurable to commonly available sensing devices.
- F. Binary Outputs. Binary outputs shall send a pulsed low-voltage signal for pulse width modulation control or an on-or-off signal for on and off control. Building Controller binary outputs shall have three-position (on-off-auto) override switches and status lights. Outputs shall be selectable for normally open or normally closed operation.
- G. Analog Outputs. Analog outputs shall send a modulating 0-10 Vdc or 4-20 mA signal as required to properly control output devices. Each Building Controller analog output shall have a two-position (auto-manual) switch, a manually adjustable potentiometer, and status lights. Analog outputs shall not drift more than 0.4% of range annually.

- H. Tri-State Outputs. Control three-point floating electronic actuators without feedback with tri-state outputs (two coordinated binary outputs). Tri-State outputs may be used to provide analog output control in zone control and terminal unit control applications such as VAV terminal units, duct-mounted heating coils, and zone dampers.
- I. Pulse-Width Modulation. Control actuators designed for pulse-width modulation with a single binary output that cycle with variable on and off times as determined by the application software. Pulse-width modulation may be used to provide analog output control in zone control and terminal unit control applications such as VAV terminal units, duct-mounted heating coils, and zone dampers.
- J. Universal Inputs and Outputs. Inputs and outputs that can be designated as either binary or analog in software shall conform to the provisions of this section that are appropriate for their designated use.

2.7 POWER SUPPLIES AND LINE FILTERING

- A. Power Supplies. Control transformers shall be UL listed. Furnish Class 2 current-limiting type or furnish over-current protection in 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 over-voltage and over-current protection and shall be able to withstand 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 MILSTD 810C for shock and vibration.
 - b. Line voltage units shall be UL recognized and CSA listed.
- B. Power Line Filtering.
 - 1. Provide internal or external transient voltage and surge suppression for workstations and controllers. Surge protection shall have:
 - 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 greater at 40-100 Hz

2.8 AUXILIARY CONTROL DEVICES

- A. Motorized Control Dampers.
 - 1. Type. Control dampers shall have linear flow characteristics and shall be parallel-or opposed-blade type as specified below or as scheduled on drawings.
 - a. Outdoor and return air mixing dampers and face-and-bypass dampers shall be parallel-blade and shall direct airstreams toward each other.

- b. Other modulating dampers shall be opposed-blade.
 - c. Two-position shutoff dampers shall be parallel or opposed-blade with blade and side seals.
 2. Frame. Damper frames shall 13 gauge galvanized steel channel or 1/8 in. extruded aluminum with reinforced corner bracing.
 3. Blades. Damper blades shall not exceed 8 inches in width or 48 inches in length. Blades shall be suitable for medium velocity (2000 fpm) performance. Blades shall be not less than 16 gauge.
 4. Shaft Bearings. Damper shaft bearings shall be as recommended by manufacturer for application, oil impregnated sintered bronze, or better.
 5. Seals. Blade edges and frame top and bottom shall have replaceable seals of butyl rubber or neoprene. Side seals shall be spring-loaded stainless steel. Blade seals shall leak no more than (10 cfm per ft²) at (4 in. w.g.) differential pressure. Blades shall be airfoil type suitable for wide-open face velocity of (1500 fpm).
 6. Sections. Damper sections shall not exceed 48 in. - 60 in.. Each section shall have at least one damper actuator.
 7. Linkages. Dampers shall have exposed linkages.
- B. Electric Damper and Valve Actuators.
 1. Stall Protection. Mechanical or electronic stall protection shall prevent actuator damage throughout the actuator's rotation.
 2. Spring-return Mechanism. Actuators used for power-failure and safety applications shall have an internal mechanical spring-return mechanism or an uninterruptible power supply (UPS).
 3. Signal and Range. Proportional actuators shall accept a 0-10 Vdc or a 0-20 mA control signal and shall have a 2-10 Vdc or 4-20 mA operating range.
 4. Wiring. 24 Vac and 24 Vdc actuators shall operate on Class 2 wiring.
 5. Manual Positioning. Operators shall be able to manually position each actuator when the actuator is not powered. Non-spring-return actuators shall have an external manual gear release. Spring-return actuators with more than 60 inch -lb torque capacity shall have a manual crank.
 6. Acceptable Manufacturers:
 - a. Belimo
- C. Control Valves.
 1. General. Select body and trim materials in accordance with manufacturer's recommendations for design conditions and service shown.
 2. Type. Provide two or three-way control valves for two-position or modulating service as shown.

3. Water Valves.
 - a. Valves providing two-position service shall be quick opening. Two-way valves shall have replaceable disc or ball.
 - b. Close-off (Differential) Pressure Rating. Valve actuator and trim shall provide the following minimum close-off pressure ratings.
 1. Two-way: 100% 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.
 - c. Ports. Valves providing modulating service shall have equal percentage ports.
 - d. Sizing.
 1. Two-position service: line size.
 2. Two-way modulating service: select pressure drop equal to the greatest of twice the pressure drop through heat exchanger (load), 50% of the pressure difference between supply and return mains, or 35 kPa (5 psi).
 3. Three-way modulating service: select pressure drop equal to the smaller of twice the pressure drop through the coil exchanger (load) or 35 kPa (5 psi).
 - e. Fail Position. Water valves shall fail normally open or closed as follows unless otherwise specified.
 1. Water zone valves: normally closed.
 2. Heating coils in air handlers: normally closed.
 3. Chilled water control valves: normally open.
 4. Other applications: as scheduled or as required by sequences of operation.
 - f. Acceptable Valve and Actuator Manufacturers:
 1. Belimo
4. Steam Valves.
 - a. Close-off (Differential) Pressure Rating. Valve actuator and trim shall provide minimum close-off pressure rating equal to 150% of operating (inlet) pressure.
 - b. Ports. Valves providing modulating service shall have linear ports.
 - c. Sizing.
 1. Two-position service: select pressure drop equal to 10%-20% of inlet psig.

2. Modulating service at 100 kPa (15 psig) or less: select pressure drop equal to 80% of inlet psig.
3. Modulating service at 101-350 kPa (16-50 psig): select pressure drop equal to 50% of inlet psig.
4. Modulating service at over 350 kPa (50 psig): select pressure drop as scheduled on drawings.

D. Binary Temperature Devices.

1. Low-Voltage Space Thermostats. Low-voltage space thermostats shall be 24 V, bimetal-operated, mercury-switch type, with adjustable or fixed anticipation heater, concealed setpoint adjustment, 55°F-85°F setpoint range, 2°F maximum differential, and vented ABS plastic cover.
2. Line-Voltage Space Thermostats. Line-voltage space thermostats shall be bimetal-actuated, open-contact type or bellows-actuated, enclosed, snap-switch type or equivalent solid-state type, with heat anticipator, UL listing for electrical rating, concealed setpoint adjustment, 55°F-85°F setpoint range, 2°F maximum differential, and vented ABS plastic cover.
3. Low-Limit Thermostats. Low-limit airstream thermostats shall be UL listed, vapor pressure type. Element shall be at least 20 ft long. Element shall sense temperature in each 1 ft section and shall respond to lowest sensed temperature. Low-limit thermostat shall be manual reset only.

E. Temperature Sensors.

1. Type. Temperature sensors shall be Resistance Temperature Device (RTD) or thermistor.
2. Duct Sensors. Duct sensors shall be single point or averaging as shown. Averaging sensors shall be a minimum of 5 ft in length per 10 ft² of duct cross-section.
3. Immersion Sensors. Provide immersion sensors with a separable stainless steel well. Well pressure rating shall be consistent with system pressure it will be immersed in. Well shall withstand pipe design flow velocities.
4. Space Sensors: Space sensors shall be stainless steel flush plate mounted type.
5. Differential Sensors. Provide matched sensors for differential temperature measurement.

F. Humidity Sensors.

1. Duct and room sensors shall have a sensing range of 20%-80%.
2. Duct sensors shall have a sampling chamber.
3. Outdoor air humidity sensors shall have a sensing range of 20%-95% RH and shall be suitable for ambient conditions of 40°F-170°F.
4. Humidity sensors shall not drift more than 1% of full scale annually.

- G. Flow Switches. Flow-proving switches shall be thermal dispersion type (IFM U 40100 or approved equal) or differential pressure type (air or water service). Switches shall be UL listed, SPDT snap-acting, and pilot duty rated (125 VA minimum).
1. Thermal dispersion type switches shall have relay output, wire break output and temperature output.
 2. Differential pressure switches shall have scale range and differential suitable for intended application and NEMA 4 enclosure unless otherwise specified.
- H. Relays.
1. Control Relays. Control relays shall be plug-in type, UL listed, and shall have dust cover and LED "energized" indicator. Contact rating, configuration, and coil voltage shall be suitable for application.
 2. Time Delay Relays. Time delay relays shall be solid-state plug-in type, UL listed, and shall have adjustable time delay. Delay shall be adjustable $\pm 100\%$ from setpoint shown. Contact rating, configuration, and coil voltage shall be suitable for application. Provide NEMA 1 enclosure for relays not installed in local control panel.
- I. Override Timers.
1. Unless implemented in control software, override timers shall be spring-wound line voltage, UL Listed, with contact rating and configuration required by application. Provide 0-6 hour calibrated dial unless otherwise specified. Flush mount timer on local control panel face or where shown.
- J. Current Transmitters.
1. AC current transmitters shall be self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4-20 mA two-wire output. Full-scale unit ranges shall be 10 A, 20 A, 50 A, 100 A, 150 A, and 200 A, with internal zero and span adjustment. Unit accuracy shall be $\pm 1\%$ full-scale 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.
- K. Current Transformers.
1. AC current transformers shall be UL/CSA recognized and shall be completely encased (except for terminals) in approved plastic material.
 2. Transformers shall be available in various current ratios and shall be selected for $\pm 1\%$ accuracy at 5 A full-scale output.
 3. Use fixed-core transformers for new wiring installation and split-core transformers for existing wiring installation.

L. Voltage Transmitters.

1. AC voltage transmitters shall be self-powered single-loop (two-wire) type, 4-20 mA output with zero and span adjustment.
2. Adjustable full-scale unit ranges shall be 100-130 Vac, 200-250 Vac, 250-330 Vac, and 400-600 Vac. Unit accuracy shall be $\pm 1\%$ full-scale at 500 ohm maximum burden.
3. Transmitters shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA recognized at 600 Vac rating.

M. Voltage Transformers.

1. AC voltage transformers shall be UL/CSA recognized, 600 Vac rated, and shall have built-in fuse protection.
2. Transformers shall be suitable for ambient temperatures of 4°C-55°C (40°F-130°F) and shall provide $\pm 0.5\%$ accuracy at 24 Vac and 5 VA load.
3. Windings (except for terminals) shall be completely enclosed with metal or plastic.

N. Power Monitors.

1. Power monitors shall be three-phase type and shall have three-phase disconnect and shorting switch assembly, UL listed voltage transformers, and UL listed split-core current transformers.
2. Power monitors shall provide selectable output: rate pulse for kWh reading or 4-20 mA for kW reading. Power monitors shall operate with 5 A current inputs and maximum error of $\pm 2\%$ at 1.0 power factor or $\pm 2.5\%$ at 0.5 power factor.

O. Current Switches.

1. Current-operated switches shall be self-powered, solid-state with adjustable trip current. Select switches to match application current and DDC system output requirements.

P. Pressure Transducers.

1. Transducers shall have linear output signal and field-adjustable zero and span.
2. Continuous operating conditions of positive or negative pressure 50% greater than calibrated span shall not damage transducer sensing elements.
3. Water pressure transducer diaphragm shall be stainless steel with minimum proof pressure of 1000 kPa (150 psi). Transducer shall have 4-20 mA output, suitable mounting provisions, and block and bleed valves.
4. Water differential pressure transducer diaphragm shall be stainless steel with minimum proof pressure of 1000 kPa (150 psi). Over-range limit (differential pressure) and maximum static pressure shall be 2000 kPa (300 psi.) Transducer shall have 4-20 mA output, suitable mounting provisions, and 5-valve manifold.

- Q. Differential Pressure Switches. Differential pressure switches (air or water service) shall be UL listed, SPDT snap-acting, pilot duty rated (125 VA minimum) and shall have scale range and differential suitable for intended application and NEMA 1 enclosure unless otherwise specified.
- R. Pressure-Electric (PE) Switches. PE switches shall be UL listed, pilot duty rated (125 VA minimum) or motor control rated, metal or neoprene diaphragm actuated, operating pressure rated for 0-175 kPa (0-25 psig), with calibrated scale minimum setpoint range of 14-125 kPa (2-18 psig).
1. Provide one- or two-stage switch action (SPDT, DPST, or DPDT) as required by application.
 2. Switches shall be open type (panel-mounted). Exception: Switches shall be enclosed type for remote installation. Enclosed type shall be NEMA 1 unless otherwise specified.
 3. Each pneumatic signal line to PE switches shall have permanent indicating gauge.
- S. Carbon Monoxide Detector / Controller / Transducer requirements:
1. Approved Manufactures:
 - a. U.S. Draft Co.; Model CGM-505
 2. Shall comply with Texas State Boiler code 65.603-2015.
 3. ETL Listed to UL61010-1, CAN/CSA C22.2 No 61010-1, and LADBS Approved.
 4. Boilers shall be individually hard wired.
 5. Shall carry a (2) two year warranty.
 6. Shall be calibrated every (18) eighteen months and a record of calibration shall be posted in a conspicuous place.
 7. Shall be capable of displaying from 0-200 ppm of CO.
 8. NEMA 1 enclosure.
 9. Provide expansion board for additional equipment interlocks.
 10. Provide pre-programmed dry contacts to shut down equipment during unsafe operation.
 11. Fan relay actuation selectable with output for fan relay, alarm relay and 4-20ma signal.
 12. Provide digital display, buzzer, fan delay.
 13. Fan runtime shall have minimum.
 14. Fan relays shall be pilot duty, SPDT, latching or non-latching at 5A, 240 VAC.
 15. 0-10 VDC control signal out, visual alarm and audible alarm.

16. Alarm relay rating for 0.5A, 120V, 60VA.

17. Operating Environment from 0°F to 125°F at 10 to 90% RH.

T. Local Control Panels.

1. Indoor control panels shall be fully enclosed NEMA 1 construction with hinged door key-lock latch and removable sub-panels. A common key shall open each control panel and sub-panel.
2. Prewire internal and face-mounted device connections with color-coded stranded conductors tie-wrapped or neatly installed in plastic troughs. Field connection terminals shall be UL listed for 600 V service, individually identified per control and interlock drawings, with adequate clearance for field wiring.
3. Each local panel shall have a control power source power switch (on-off) with overcurrent protection.

2.9 WIRING AND RACEWAYS

- A. General. Provide copper wiring, plenum cable, and raceways as specified in applicable sections of Division 26.
- B. Insulated wire shall use copper conductors and shall be UL listed for 90°C (200°F) minimum service.

PART 3 - EXECUTION

3.1 EXAMINATION

- A. Thoroughly examine project plans for control device and equipment locations. Report discrepancies, conflicts, or omissions to Architect or Engineer for resolution before starting rough-in work.
- B. Inspect site to verify that equipment can be installed as shown. Report discrepancies, conflicts, or omissions to Engineer for resolution before starting rough-in work.
- C. Examine drawings and specifications for work of others. Report inadequate headroom or space conditions or other discrepancies to Engineer and obtain written instructions for changes necessary to accommodate Section 23 09 23 work with work of others. Controls Contractor shall perform at his expense necessary changes in specified work caused by failure or neglect to report discrepancies.

3.2 PROTECTION

- A. Controls Contractor shall protect against and be liable for damage to work and to material caused by Contractor's work or employees.
- B. Controls Contractor shall be responsible for work and equipment until inspected, tested, and accepted. Protect material not immediately installed. Close open ends of work with temporary covers or plugs during storage and construction to prevent entry of foreign objects.

3.3 COORDINATION

- A. Site.
 - 1. Assist in coordinating space conditions to accommodate the work of each trade where work will be installed near or will interfere with work of other trades. If installation without coordination causes interference with work of other trades, Contractor shall correct conditions without extra charge.
 - 2. Coordinate and schedule work with other work in the same area and with work dependent upon other work to facilitate mutual progress.
- B. Submittals. See Section 23 09 23 Article 1.9 (Submittals).
- C. Test and Balance.
 - 1. Provide Test and Balance Contractor a single set of necessary tools to interface to control system for testing and balancing.
 - 2. Train Test and Balance Contractor to use control system interface tools.
 - 3. Provide a qualified technician to assist with testing and balancing the first 20 terminal units.
 - 4. Test and Balance Contractor shall return tools undamaged and in working condition at completion of testing and balancing.
- D. Life Safety.
 - 1. Duct smoke detectors required for air handler shutdown are provided and wired under Division 26.
 - 2. Smoke dampers and actuators required for duct smoke isolation are provided under Division 23 and wired by Division 26.
 - 3. Fire and smoke dampers and actuators required for fire-rated walls are provided under Division 23. Fire and smoke damper control is provided under Division 26.
- E. Coordination with Other Controls. Integrate with and coordinate controls and control devices furnished or installed by others as follows.
 - 1. Communication media and equipment shall be provided as specified in Section 23 09 23 Article 2.2 (Communication).
 - 2. Each supplier of a controls product shall configure, program, start up, and test that product to meet the sequences of operation described regardless of where within the contract documents those products are described.
 - 3. Coordinate and resolve incompatibility issues that arise between control products provided under this section and those provided under other sections or divisions of this specification.
 - 4. Controls Contractor shall be responsible for integration of control products provided by multiple suppliers regardless of where integration is described within the contract documents.

3.4 GENERAL WORKMANSHIP

- A. Install equipment, piping, and wiring or raceway horizontally, vertically, and parallel to walls wherever possible.
- B. Provide sufficient slack and flexible connections to allow for piping and equipment vibration isolation.
- C. Install equipment in readily accessible locations as defined by National Electrical Code (NEC) Chapter 1 Article 100 Part A.
- D. Verify wiring integrity to ensure continuity and freedom from shorts and ground faults.
- E. Equipment, installation, and wiring shall comply with industry specifications and standards and local codes for performance, reliability, and compatibility.

3.5 FIELD QUALITY CONTROL

- A. Commissioning and start-up of the BAS system shall be performed factory certified employees of the BAS contractor or manufacturer. Under no instances shall electrical subcontractors perform this work.
- B. Work, materials, and equipment shall comply with rules and regulations of applicable local, state, and federal codes and ordinances as identified in Section 23 09 23 Article 1.7 (Codes and Standards).
- C. Continually monitor field installation for code compliance and workmanship quality.
- D. Contractor shall arrange for work inspection by local or state authorities having jurisdiction over the work.

3.6 WIRING

- A. To differentiate BAS wiring from that of other trades, all cable except for underground will have a yellow outer jacket. Green, blue or orange jacket may be provided as an alternative to the yellow jacket.
- B. Division 26 contractor shall supply a dedicated 120vac power to a junction box in each mechanical room for use by the BMCS.
- C. A Conduit fill based on plenum 18 gauge 2 conductor:
 - 1. 1/2 inch - No more than 4 conductors.
 - 2. 3/4 inch - No more than 8 conductors.
 - 3. 1 inch - No more than 12 conductors.
- D. Control and interlock wiring and installation shall comply with national and local electrical codes, Division 26, and manufacturer's recommendations. Where the requirements of Section 23 09 23 differ from Division 26, Section 23 09 23 shall take precedence.
- E. All wires whether control network or device wire shall be marked with Brady-type markers.

- F. NEC Class 1 (line voltage) wiring shall be UL listed in approved raceway as specified by NEC and Division 26.
- G. Low-voltage wiring shall meet NEC Class 2 requirements. Sub-fuse low-voltage power circuits as required to meet Class 2 current limit.
- H. NEC Class 2 (current-limited) wires not in raceway but in concealed and accessible locations such as return air plenums shall be UL listed for the intended application.
- I. Install wiring in raceway where subject to mechanical damage and at levels below 10ft. in mechanical, electrical, or service rooms.
- J. 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).
- K. Install Class 1 and Class 2 wiring in separate raceways. Boxes and panels containing high-voltage wiring and equipment shall not be used for low-voltage wiring except for the purpose of interfacing the two through relays and transformers.
- L. Do not install wiring in raceway containing tubing.
- M. Run exposed Class 2 wiring parallel to a surface or perpendicular to it and tie neatly at (5 ft) intervals.
- N. Contractor shall install all low voltage communication wiring as per all TIA/EIA communication cabling standards. All cabling shall be installed in dedicated cabling support such as j-hook, d-rings, or saddles. All supports shall be supported directly from building structure. Do not support cabling or supports from ceiling grid wire, conduit, ductwork, piping, or other system cabling. All cabling must be installed in independent support for that given system and may not share supports or run in same conduit or support. All cabling shall be supported every 5'-0" from approved cabling support method. Contractor shall bundle all system cabling and label all wiring for system they serve. All cabling passing thru walls shall require dedicated conduit sleeves with bushing to protect cabling during installation. Contractor shall provide 1 meter service loops at all device termination locations and 3 meter service loops at all head end termination locations. All low voltage HVAC control cabling shall be yellow in color unless specified otherwise. Do not use ductwork, electrical raceways, piping, or ceiling suspension systems to support or anchor cables.
- O. Secure raceways with raceway clamps fastened to structure and spaced according to code requirements. Raceways and pull boxes shall not be hung on or attached to ductwork, electrical raceways, piping, or ceiling suspension systems.
- P. Size raceway and select wire size and type in accordance with manufacturer's recommendations and NEC requirements.
- Q. Include one pull string in each raceway 2.5 cm (1 in.) or larger.
- R. Use color-coded conductors throughout.
- S. Locate control and status relays in designated enclosures only. Do not install control and status relays in packaged equipment control panel enclosures containing Class 1 starters.

- T. Conceal raceways except within mechanical, electrical, or service rooms. Maintain minimum clearance of 15 cm (6 in.) between raceway and high-temperature equipment such as steam pipes or flues.
- U. Adhere to requirements in Division 26 where raceway crosses building expansion joints.
- V. Install insulated bushings on raceway ends and enclosure openings. Seal top ends of vertical raceways.
- W. Terminate control and interlock wiring related to the work of this section. Maintain at the job site updated (as-built) wiring diagrams that identify terminations.
- 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. Do not use flexible metal raceway less than ½ in. electrical trade size.
- Y. Install raceway rigidly, support adequately, ream at both ends, and leave clean and free of obstructions. Join raceway sections with couplings and according to code. Make terminations in boxes with fittings. Make terminations not in boxes with bushings.

3.7 COMMUNICATION WIRING

- A. Communication wiring shall be low-voltage Class 2 wiring and shall comply with Article 3.7 (Wiring).
- B. Install communication wiring in separate raceways and enclosures from other Class 2 wiring.
- C. During installation do not exceed maximum cable pulling, tension, or bend radius specified by the cable manufacturer.
- D. Verify entire network's integrity following cable installation using appropriate tests for each cable.
- E. Install lightning arrestor according to manufacturer's recommendations between cable and ground where a cable enters or exits a building.
- F. Each run of communication wiring shall be a continuous length without splices when that length is commercially available. Runs longer than commercially available lengths shall have as few splices as possible using commercially available lengths.
- G. Label communication wiring to indicate origination and destination.
- H. Ground coaxial cable according to NEC regulations article on "Communications Circuits, Cable, and Protector Grounding."

3.8 FIBER OPTIC CABLE

- A. During installation do not exceed maximum pulling tensions specified by cable manufacturer. Post-installation residual cable tension shall be within cable manufacturer's specifications.
- B. Install cabling and associated components according to manufacturers' instructions. Do not exceed minimum cable and unjacketed fiber bend radii specified by cable manufacturer.

3.9 INSTALLATION OF SENSORS

- A. Install sensors according to manufacturer's recommendations.
- B. Mount sensors rigidly and adequately for operating environment.
- C. Install room temperature sensors on concealed junction boxes properly supported by wall framing.
- D. Air seal wires attached to sensors in their raceways or in the wall to prevent sensor readings from being affected by air transmitted from other areas.
- E. Use averaging sensors in mixing plenums and hot and cold decks. Install averaging sensors in a serpentine manner vertically across duct. Support each bend with a capillary clip.
- F. Install mixing plenum low-limit sensors in a serpentine manner horizontally across duct. Support each bend with a capillary clip. Provide 1 ft. of sensing element for each 1 ft. ² of coil area.
- G. Install pipe-mounted temperature sensors in wells. Install liquid temperature sensors with heat-conducting fluid in thermal wells.
- H. Install outdoor air temperature sensors on north wall at designated location with sun shield.
- I. Differential Air Static Pressure.
 - 1. Supply Duct Static Pressure. Pipe high-pressure tap to duct using a pitot tube. Make pressure tap connections according to manufacturer's recommendations.
 - 2. Return Duct Static Pressure. Pipe high-pressure tap to duct using a pitot tube. Make pressure tap connections according to manufacturer's recommendations.
 - 3. Building Static Pressure. Pipe pressure sensor's low-pressure port to the static pressure port located on the outside of the building through a high-volume accumulator. Pipe high-pressure port to a location behind a thermostat cover.
 - 4. Piping to pressure transducer pressure ports shall contain a capped test port adjacent to transducer.
 - 5. Pressure transducers, except those controlling VAV boxes, shall be located in control panels, not on monitored equipment or on ductwork. Mount transducers in a vibration-free location accessible for service without use of ladders or special equipment.
 - 6. Mount gauge tees adjacent to air and water differential pressure taps. Install shut-off valves before tee for water gauges.
- J. Smoke detectors, freezestats, high-pressure cut-offs, and other safety switches shall be hard-wired to de-energize equipment as described in the sequence of operation. Switches shall require manual reset. Provide contacts that allow DDC software to monitor safety switch status.

3.10 FLOW SWITCH INSTALLATION

- A. Adjust flow switch according to manufacturer's instructions.

3.11 ACTUATORS

- A. General. Mount actuators and adapters according to manufacturer's recommendations.
- B. Electric and Electronic Damper Actuators. Mount actuators directly on damper shaft or jackshaft unless shown as a linkage installation. Link actuators according to manufacturer's recommendations.
 - 1. For low-leakage dampers with seals, mount actuator with a minimum 5° travel available for damper seal tightening.
 - 2. To compress seals when spring-return actuators are used on normally closed dampers, power actuator to approximately 5° open position, manually close the damper, and then tighten linkage.
 - 3. Check operation of damper-actuator combination to confirm that actuator modulates damper smoothly throughout stroke to both open and closed positions.
 - 4. Provide necessary mounting hardware and linkages for actuator installation.

3.12 IDENTIFICATION OF HARDWARE AND WIRING

- A. Label wiring and cabling, including that within factory-fabricated panels, with control system address or termination number at each end within 5 cm (2 in.) of termination.
- B. Label pneumatic tubing 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 instrument or item served.
- D. Label control panels with minimum 1 cm (½ in.) letters on laminated plastic nameplates.
- E. Label each control component with a permanent label. Label plug-in components such that label remains stationary during component replacement.
- F. Label valves with nameplates.
- G. Manufacturers' nameplates and UL or CSA labels shall be visible and legible after equipment is installed.
- H. Label identifiers shall match record documents.

3.13 PROGRAMMING

- A. Point Naming. Name points as shown on the equipment points list provided with each Sequence of Operation. Where multiple points with the same name reside in the same controller, each point name may be customized with its associated Program Object number. For example, "Zone Temp 1" for Zone 1, "Zone Temp 2" for Zone 2.
- B. All DDC programming shall be accomplished through graphical programming, line code is unacceptable

- C. Software Programming. Programming shall provide actions for each possible situation. Graphic- or parameter-based programs shall be documented.
 - 1. Application Programming. Provide application programming that adheres to sequences of operation specified in Section 23 09 93. Program documentation or comment statements shall reflect language used in sequences of operation.
 - 2. System Programming. Provide system programming necessary for system operation.
- D. Operator Interface.
 - 1. Standard Graphics. Provide graphics as specified in Section 23 09 23 Article 2.3 Paragraph E.2 (System Graphics). Show on each equipment graphic input and output points and relevant calculated points such as indicated on the applicable Points List located in the Sequence of Operation. Point information on graphics shall dynamically update.
 - 2. Install, initialize, start up, and troubleshoot operator interface software and functions (including operating system software, operator interface database, and third-party software installation and integration required for successful operator interface operation) as described in Section 23 09 23.
 - 3. DDC screen graphic room numbers shall be based on final room graphics package. Obtain Architect/Owner approval of final room numbers prior to programming.

3.14 CONTROL SYSTEM CHECKOUT AND TESTING

- A. Startup Testing. Complete startup testing to verify operational control system before notifying Owner of system demonstration. Provide Owner with schedule for startup testing. Owner may have representative present during any or all startup testing.
 - 1. Calibrate and prepare for service each instrument, control, and accessory equipment furnished under Section 23 09 23.
 - 2. Verify that control wiring is properly connected and free of shorts and ground faults. Verify that terminations are tight.
 - 3. Enable control systems and verify each input device's calibration. Calibrate each device according to manufacturer's recommendations.
 - 4. Verify that binary output devices such as relays, solenoid valves, two-position actuators and control valves, and magnetic starters, operate properly and that normal positions are correct.
 - 5. Verify that analog output devices such as I/Ps and actuators are functional, that start and span are correct, and that direction and normal positions are correct. Check control valves and automatic dampers to ensure proper action and closure. Make necessary adjustments to valve stem and damper blade travel.
 - 6. Prepare a log documenting startup testing of each input and output device, with technician's initials certifying each device has been tested and calibrated.
 - 7. Verify that system operates according to sequences of operation. Simulate and observe each operational mode by overriding and varying inputs and schedules. Tune PID loops and each control routine that requires tuning.

8. Alarms and Interlocks.
 - a. Check each alarm with an appropriate signal at a value that will trip the alarm.
 - b. Trip interlocks using field contacts to check logic and to ensure that actuators fail in the proper direction.
 - c. Test interlock actions by simulating alarm conditions to check initiating value of variable and interlock action.

3.15 CONTROL SYSTEM DEMONSTRATION AND ACCEPTANCE

- A. Demonstration. Prior to acceptance, perform the following performance tests to demonstrate system operation and compliance with specification after and in addition to tests specified in Article 3.15 (Control System Checkout and Testing). Provide Engineer with log documenting completion of startup tests.
 1. Preliminary Review: At least 7 days prior to on-site demonstration, provide read-only username and password to Engineer for preliminary system review to be performed remotely. Engineer will review to verify all systems are connected and communicating and all points are reading properly and graphics are complete. The Engineer will provide a report of any deficiencies. The contractor shall correct all deficiencies prior to on-site demonstration.
 2. On-site Demonstration: Engineer, Owner, contractor(s) and any/all factory authorized equipment representatives shall be present to perform, observe and review system demonstration. Notify Engineer/Architect at least 10 days before system demonstration is scheduled.
 - a. Demonstration shall follow process submitted and approved under Section 23 09 23 Article 1.9 (Submittals). Complete approved checklists and forms for each system as part of system demonstration.
 - b. Demonstrate actual field operation of each sequence of operation as specified in Section 23 09 93. Provide at least two persons equipped with two-way communication. Demonstrate calibration and response of any input and output points requested by Engineer. Provide and operate test equipment required to prove proper system operation.
 - c. Demonstrate compliance with sequences of operation through each operational mode.
 - d. Demonstrate complete operation of operator interface.
 - e. Demonstrate each of the following.
 - f. DDC loop response. Supply graphical trend data output showing each DDC loop's response to a setpoint change representing an actuator position change of at least 25% of full range. Trend sampling rate shall be from 10 seconds to 3 minutes, depending on loop speed. Each sample's trend data shall show setpoint, actuator position, and controlled variable values. Engineer will require further tuning of each loop that displays unreasonably under- or over-damped control.

