

SECTION 23 09 23

DDC CONTROLS

PART 1 - GENERAL SYSTEM DESCRIPTION

1.01 GENERAL REQUIREMENTS

- A. Drawings and general provisions of the Contract, including General and other Conditions and other Division 1 – General Requirements sections, apply to the work specified in this Section.

1.02 BASIC SYSTEM

- A. Alter existing Automated Logic Control System where HVAC systems are modified.
- B. Building Automation System (BAS) system shall utilize DDC to control valve and damper actuators for all mechanical equipment as specified in the sequence of operation and in the drawings for all systems.
- C. The control system shall be fully integrated and installed as a complete package of controls and instruments in a manner that provides maximum benefit to the end user.
- D. The system shall include all computer software and hardware, control unit hardware and software, operator input/output devices, sensors, control devices, and miscellaneous devices required for complete operation and future modifications. Documentation for all software and hardware devices shall be provided.
- E. Provide engineering, installation, calibration, commissioning, acceptance testing assistance, software programming, and checkout for complete and fully operational DDC.
- F. Complete Commissioning tasks as required by Commissioning Specification.

1.03 SCOPE OF SERVICES (OVERVIEW OF SECTION 23 09 23)

- A. Work under this section of the specification shall include, but not limited to, the following:
 - 1. Furnish and install a complete sensor, actuator, wiring and piping system for all air handling and related equipment as shown on the plans and specified in this section. Install all necessary sensors and actuators as required by the plans and specifications and equipment schedules.
 - 2. Label all sensors, control devices, and control units.
 - 3. Furnish and install conduit, wire, branch circuit protection, etc. as required to bring 120 VAC power to control panel locations and equipment (actuators, sensors, control devices, etc.) as shown on the drawings and described in the specifications.
 - 4. All line drivers, signal boosters, and signal conditioners etc. shall be provided as necessary for proper data communication.
 - 5. Coordination as required with other sections of the specification for the proper and complete installation of the wiring system, control devices, dampers, valve, actuators, etc.
 - 6. Furnish and install Direct Digital Control Equipment (DDC) as required by the point list, plans, and specifications including, control units, software, database development, check-out, and debugging. Provide points necessary for a complete and operable system.
 - 7. Install the sequence of operations specified in the drawings and in this section.

8. Software testing requirements shall include testing in the field of all logic sequences including actual simulation of different processes and events and observing program response to the process or event. All deviations from the requirements of the sequence as specified on the drawings or this specification shall be corrected immediately at no additional cost to the Owner.
9. Provide documentation of software system testing before acceptance testing.
10. Provide staff for acceptance testing procedures. Modify hardware and software errors/problems at no additional cost to the Owner.
11. Provide a series of training classes for Owner staff.
12. Setup trending data before and after system acceptance.
13. Attend a series of meetings with the Engineer and Owner to agree on system setup and operating parameters.
14. Provide detailed documentation of system configuration including control units and all control devices.
15. Provide all software (with hardware connections) and software license for district computer as required.
16. Read this section in its entirety for specific details.
17. If the Control Contractor can not comply with any of these specifications, then the Control Contractor must explain in writing the reasons for non-compliance and provide an alternative approach that satisfies these requirements.
18. Provide all equipment and personnel to complete system commission per previous section and as listed further in specification.

1.04 QUALITY ASSURANCE AND SYSTEM OVERVIEW

- A. The BAS system shall be designed, installed, commissioned, and serviced by qualified contractor.
- B. Acceptable control system contractors and manufacturers: Control systems shall be BTL listed across the line of product controllers (BACnet advanced application controller B-AAC, BACnet Building Controller (B-BC) controllers and BACnet application specific controllers) B-ASC as defined by BACnet International testing standards.
- C. System shall use BACnet/IP on the internet side of the controller and shall use BACnet MS/TP at the building control network side. System shall utilize web based control and access. BACnet /IP communication to third party control devices (BACnet controllers for chillers and boilers) shall be allowed.
- D. All products proposed for this contract shall have been in continuous and successful use for at least two (2) year (not including beta testing).
- E. All materials and equipment used shall be standard components, regularly manufactured for this and/or other systems and not custom designed specially for this project.
- F. The control system shall be forward compatible with future versions of the manufacturer's hardware, firmware, and software. Future versions of the manufacturer's hardware, firmware, and software shall be backward compatible with the installed control system. Forward and backward compatibility shall be guaranteed for at least five (5) years from the time of system acceptance. Any hardware, firmware, or software modifications or replacements required within that period because of incompatibility with new hardware, firmware, or software installed in the same facility shall be at no cost to the Owner.
Note: Equipment (controllers and software) should be provided by single manufacturer. All other products (e.g., sensors, valves, dampers, and actuators) need not be manufactured by the control manufacturer.

- G. System shall be web based.

1.05 CONTROL CONTRACTOR/MANUFACTURER QUALIFICATIONS

- A. The Control Contractor shall have WEB based programming tools required to program and modify the BAS controllers.
- B. Proprietary programming tools are not allowed
- C. All programming tools shall be supplied to the owner for future use.
- D. See basic system requirements (1.02) for additional requirements
- E. The Control Contractor's or Manufacturer's installer shall have successfully completed control manufacturer's classes on control systems and shall present for review the certification of training.
- F. Factory mounted controls are excluded from this section's requirements.
- G. Acceptable control system contractors and manufacturers:
 - 1. Automated Logic installed by Clima-Tech.

1.06 RELATED SECTIONS

- A. Drawings and general provisions of Contract, including General and Supplementary Conditions, Mechanical Special Conditions, Electrical Special Conditions and Division - 1 Specification.
- B. Coordination with Other Trades:
 - 1. This section specifies cooperation of the Control Contractor (the combination of installer and programmer hence forth) with other trades and including balancing firm to assure proper arrangement of control items. Control valves, dampers, wiring, thermostat wells, and other control devices that are to be built into the field assembled ductwork, piping, or wiring systems shall be furnished by the Control Contractor and installed under other sections of the specification as directed by the Control Contractor and indicated in other portions of the specifications and drawings.
 - 2. The Control contractor shall insure that the DDC system communicates successfully with other equipment (e.g., air handling units, packaged rooftop units, heat pumps, motors, actuators, etc.). Note: the equipment supplier is responsible for the proper performance of their equipment (assuming the proper signal are sent/received from the BAS). The control contractor is responsible for all system sensors, including those which are factory installed.
 - 3. Electrical Wiring: All wiring required for work under this section of the specification shall be provided under this section of the specification unless otherwise specified.
 - 4. Electrical wiring - power for control panels, control devices, and sensors
 - a. Power for control units, control devices and sensors shall be coordinated with the air handling manufacturer for the project and/or the Owner.
 - b. Contact locations in starter control circuits. All contacts controlling motor starters, including overload contacts, shall be located on the hot side of the coil (ungrounded control power leg). Coordinate this requirement with the air handling manufacturer for the project.
 - c. Extend power to damper actuators.
 - 1) Actuators will be powered at 24 VAC.
 - 2) At each auxiliary panel location, furnish and install a 24 VAC transformer with 20 VA of capacity for each actuator installed and served from the panel.
 - 3) Furnish and install a fused terminal in the +24 VAC lead and a disconnecting terminal in the neutral lead of the power cable to each actuator.

5. Testing, Adjusting and Balancing: If necessary, The Controls Contractor shall operate the BAS to assist the TAB Contractor.

1.07 QUALITY CONTROL – CODES AND STANDARDS

- A. All work, materials, and equipment shall comply with the rules and regulations of all codes and ordinances of the local, state, and federal authorities. Such codes, when more restrictive, shall take precedence over these plans and specifications, As a minimum, the installation shall comply with the current editions in effect 30 days prior to receipt of bids for the following codes:
 1. National Electric Code (NEC)
 2. Uniform Building Code (UBC), Oregon Structural Specialty Code
 3. Uniform Mechanical Code (UMC), Oregon Mechanical Specialty Code
 4. Underwriters Laboratories (UL)
 5. National Electric Manufacturers' Association (NEMA)
 6. National Fire Prevention Association (NFPA)
 7. American Society Of Heating, Refrigeration, And Air Conditioning Engineers (ASHRAE)
 8. Instrument Society Of America (ISA)
 9. National Institute of Standards and Technology (NIST).

1.08 SUBMITTALS

- A. Shop drawing submittals are required for the following, in accordance with Section 23 05 00. The Contractor shall not start the project until the Shop Drawings have been submitted and approved. Shop drawings shall include:
 1. All submittals should be provided on paper (with legible font type and size).
 2. Sheets shall be consecutively numbered.
 3. One drawing per air handler or system (e.g., boiler plant). Drawing should include point descriptors (DI, DO, AI, AO), addressing, and point names. Each point names should be unique (within a system and between systems). For example, the point named for the mixed air temperature for AH#1, AH #2, and AH #3 should not be MAT but could be named AH #1 MAT, AH #2 MAT, and AH #3 MAT. The point names could be logical and consistent between systems and AHs. The abbreviation or short hand notation (e.g., MAT) should be clearly defined in writing by the Control Contractor. Naming standard will be decided on during meeting between Engineer, Control Contractor, and Owner.
 4. Floor plans depicting all BAS control devices (control units, control devices, gateways, LAN interface devices, actuators, sensors, motor control centers, etc.) in relation to mechanical rooms, HVAC equipment, and building footprint.
 5. DDC System Engineer diagram indicating schematic location of all Control Units, workstations, LAN Interface devices, gateways, etc. Indicate address and type for each Control Unit. Indicate protocol, baud rate, and type of LAN (per Control Unit).
 6. For each drawing, include a schematic flow diagram of each air and water system showing fans, coils, dampers, valves, pumps, heat exchange equipment, control devices, etc. Label each control device with setting or adjustable range of control. Label each input and output with the appropriate range.
 7. Electrical wiring diagrams shall include both ladder logic type diagrams for motor start, control, and safety circuits and detailed digital interface panel control point termination diagrams with all wire numbers and terminal block numbers identified. Indicate all required electrical wiring. Provide panel termination drawings on separate drawings. Ladder diagrams shall appear on system schematic. Clearly differentiate between portions of wiring that are existing, factory-installed and portions to be field-installed.
 8. Show all electric connections of the controls system to equipment furnished by others complete to terminal points identified with manufacturer's terminal recommendations.
 9. Control Contractor shall provide one complete drawing that shows the equipment (fan unit, boiler, chiller, etc.) manufacturers wiring diagram with the control contractors wiring diagram superimposed on it. Supply hard copy.

10. Provide sequence of operation based on sequence in these documents, as discussed with Engineer and Owner and as modified based on site conditions and normal programming protocol. Provide details such as levels controlled to and point designations. Simply copying the sequence from these documents is not sufficient. For Integrated systems provide the BACnet instance the BAS is writing to or reading within the sequence.
 11. Provide complete panel drawings that are
 - a. Clearly labeled.
 - b. Drawn to scale
 - c. Show the internal and external component arrangement so that the operators can identify the components by their position if the labels come off
 - d. Wiring access routes should also be identified so that Class 1 wiring is separated from Class 2 and 3 and so high voltage wiring is segregated from low voltage wiring and tubing.
 12. Complete identification of all control devices (manufacturer's type, number, and function).
 13. Provide all necessary BACnet-compliant hardware and software to meet the system's functional specifications. Provide Protocol Implementation Conformance Statement (PICS) for Windows-based control software and every controller in system, including unitary controllers.
 14. Damper schedule should include:
 - a. Action (normally open or closed)
 - b. Direct or reverse actuation
 - c. Manufacturer make and model
 - d. Design pressure drop at full flow
 - e. Leakage rate
 - f. Operating range
 - g. Flow rate
 - h. Actuator requirements
 - i. Actuator spring range
 - j. Special construction features (U.L. listed smoke damper, etc.)
 15. A set of drawings showing the details of the valve and valve actuator installation for each valve, required for operation and maintenance manuals only. This should include:
 - a. Action (normally open or closed)
 - b. Manufacturer make and model
 - c. C_v
 - d. Close off rating
 - e. Flow rate
 - f. Actuator spring range
 - g. Cavitation coefficient (where applicable)
 - h. Special construction features
- B. Record Documents:
1. Incorporate existing controls from the 2007 to 2009 installation and all revisions for this contracts work into one O & M document. Drawing formats need not match. All Sherwood High School control system whether altered or not that are in current operation shall be shown.
 2. Provide a complete set of control drawings with as-installed equipment and operating sequences on paper and in electronic format (AutoCAD). "As-built" (i.e., as-installed and debugged and after system acceptance) documentation shall include the following as minimum:
 - a. All data specified in the shop drawings section in its final "as-built" form.
 - b. Schematic outline of the overall control system for quick reference
 - c. Adequate record of the work as installed, including exact location of control panels and the wiring route (using TC documents, section 1.08-A).
 - d. Blue prints shall include sequence of operation.

- e. System hardware specification data which provides a functional description of all hardware components.
 - f. System engineering information which provides all of the information for the system set-up, definition and application.
 - g. System database information that provides the point names and application data programmed into the system.
 - h. All of the information, data, procedures and drawings shall be supplied in the form of manuals.
3. Provide as-installed (after system acceptance) control logic diagrams showing all points (real and virtual).
 4. DDC systems that use line-based programming must reference line code number with control logic diagrams and/or with sequence of operation text. Control Contractor shall discuss final format with owner.
 5. Provide licensed electronic copies of all software for each workstation and laptop. This includes, but is not limited to: project graphic images, project database, trouble-shooting and debugging programs, project-specific application programming code and all other software required to operate and modify the programming code (including software at system level, primary control units, secondary control units, and all communication software). Any hardware devices (cables, protection devices) required to operate the software/hardware shall also be provided.
 6. The Control Contractor shall document deviations from the shop drawing submittals. Documentation should include what equipment was changed and the reason for the change.
 7. Provide copy of final test reports.
- C. Operating and Maintenance Materials:
1. Incorporate existing controls from the 2007 to 2009 installation and all revisions for this contracts work into one O & M document. Drawing formats need not match. All Sherwood High School control system whether altered or not that are in current operation shall be shown.
 2. Provide Operation and maintenance data on all equipment requiring service or adjustment (prior to and after final acceptance).
 3. Provide user guides and programming manuals for all hardware and software.
 - a. A reference manual shall be furnished and shall contain, as a minimum, an overview of the system, its organization, the concepts of networking and central site/field hardware relationships. It shall be a complete guide to operating all aspects of the software system, including activating the system, use of the mouse, description of all menus, establishing setpoints and schedules, downloading or uploading information to or from field hardware, generating or collecting trends, alarms and reports, backing up system software and data files and interface with third party software.
 - b. Manuals for advanced programming (for each controller type and for all workstations) shall be provided.
 4. Provide a Bill of Materials with each schematic drawing. List all devices/equipment and match to schematic and actual field labeling. Provide quantity, manufacturer, actual product ordering number, description, size, accuracy, operating ranges (voltage, temperature, pressure, etc.), input/output parameters, etc.
 5. Field copies of wiring for Primary and Secondary Control Units. (Laminated and permanently affixed in or above controller).
 6. For the equipment not manufactured by the Control Vendor, an alphabetical list of system components with the name, address and 24-hour telephone number of the company responsible for servicing each item during the first two years of operation shall be provided.
 7. Operating and maintenance instructions for each piece of equipment that includes:
 - a. Emergency procedures for fire or failure.
 - b. Start-up, operation, maintenance, disassembly and shutdown procedures.
 - c. Maintenance instructions for each piece of equipment.

- d. Proper lubricants and lubricating instructions.
 - e. Cleaning, replacement and/or adjustment schedule.
 - f. Product data on each piece of equipment, including damper and valve information noted earlier.
8. Points list shall include all physical input/output and virtual points. Points list shall be provided in hard copy and shall include:
- a. Name
 - b. Address
 - c. Scanning frequency
 - d. Engineering units
 - e. Offset calibration and scaling factor for engineering units
 - f. High and low alarm values and alarm differentials for return to normal condition
 - g. Default value to be used when the normal controlling value is not reporting.
 - h. Message and alarm reporting as specified.
 - i. Identification of all adjustable points
 - j. Description of all points
9. Control Logic documentation shall include:
- a. Drawings documenting control logic for all aspects of the BAS including control units, controlled devices, sensors, etc.
 - b. A detailed sequence of operation (see Part 6) should be submitted on separate sheets for each AH or HVAC system. The text description of the sequence of operation should include:
 - 1) Logic control statement (i.e., describe control loop process)
 - 2) Setpoints and throttling ranges, deadbands, and differentials for temperature and pressure variables, gains, reset schedules, etc.
 - 3) Limits/conditions and interlocks
 - 4) Measured variables (e.g., mixed air temperature)
 - 5) Variables to communicate to/from the network
 - c. Control diagrams should identify
 - 1) System being controlled (attach abbreviated control logic text)
 - 2) All DO, DI, AO, AI points
 - 3) Virtual points
 - 4) All functions (logic, math, and control) within control loop
 - 5) Legend for graphical icons or symbols
 - 6) Definition of variables or point names (e.g., OAT = outside air temperature)
 - 7) Define values (e.g., 1 = on, 0 = off)
 - 8) Voltage, amperage, or resistance input/output signal for all sensors and controlled devices
- D. Conformance Certificates: Upon substantial completion of the work, supply and turn over all required inspection certificates from governing authorities to certify that the work as installed conforms to the rules and regulations of the governing authorities.
- E. Warranty Certificates:
- 1. Warrant all work as follows:
 - a. Labor and materials for the control system specified shall be warranted free from defects for a period of 24 months after final completion and acceptance. Control system failures during the warranty period shall be adjusted, repaired, or replaced at no additional cost or reduction in service to the owner.
 - b. The Control Contractor shall respond to the owner's request for warranty service within 24 hours during normal business hours.
 - c. The Control Contractor shall respond to the owner's request for Emergency service during the warranty period within 4 hours.
 - 2. Emergency service rates for additional assistance shall be provided.

- a. The contractor shall provide unlimited phone technical support to the owner during the warranty period. If the technical support location of the contractor is outside of the toll free calling area for the customer, the contractor shall have a toll free number or accept collect calls for the purpose of providing technical support.
- b. The contractor shall provide technical support bulletin service (if available) for two years.
- c. During the warranty period and if required by the School District, parts for the DDC system shall arrive at the School District within 24 hours of placing an order.
- d. At the end of the final startup, testing, and commissioning phase, if equipment and systems are operating satisfactorily to the Engineer, the Engineer shall sign certificates certifying that the control system's operation has been tested and accepted in accordance with the terms of the specifications listed in Section 23 09 23 (see 6.2 thru 6.3). The date of acceptance shall be the start of the warranty period.
- e. All work shall have a single warranty date, even when the owner has received beneficial use due to an early system startup.
- f. Operator workstation software, project-specific software, graphic software, database software, and firmware updates which resolve known software deficiencies as identified by the Control Contractor shall be provided at no charge during the warranty period.
- g. Any hardware or software discovered to incorrectly process dates starting January 1, 2000 through the year 2040 shall be replaced by the Control Contractor at no cost to the owner.
- h. Control contractor shall be available for a final check and adjustment of the DDC system before the warranty period ends. The final check will include input from the maintenance staff as well as the Engineer.

1.09 DELIVERY AND STORAGE

- A. Provide factory-shipping cartons for each piece of equipment and control device not factory installed. Provide factory applied plastic end caps on each length of pipe and tube. Maintain cartons and end caps through shipping, storage, and handling as required to prevent equipment and pipe-end damage, and to eliminate dirt and moisture from equipment and inside of pipe and tubes. Store equipment and materials inside and protected from weather.

1.10 DISCREPANCIES

- A. Any items not included in the specification but referred to in the Appendix and/or Drawings in reference to this project and any other incidentals not referred to but required as a basic element to the overall performance and/or successful completion of the work shall be installed as part of this contract.

PART 2 - PRODUCTS

2.01 BASIC MATERIALS, CONTROL DEVICES, SENSORS

- A. Installation of some of the equipment in this section may be the responsibility of other contractors (see 1.5).
- B. All sensors and equipment related to or connected to the DDC system shall be installed according to manufacturer's recommendations.

2.02 WIRING, CONDUIT, AND HANGERS

- A. To supply, install and connect all conduits, boxes and wires between all the different components related in this section including all line voltage to the equipment.

- B. Provide all necessary field wiring and devices from the point of connection indicated on the drawings. Bring to the attention of the Engineer in writing, all conflicts, incompatibilities, and/or discrepancies prior to bid or as soon as discovered.
- C. Field Wiring: It is the intent of these specifications that all systems shall be complete and operable. Refer to all drawings and specifications to determine voltage, phase, circuit ampacity and number of connections provided.
- D. All wiring and fiber optic cable in the central plant, tunnels, and plenums to be supported by B-line Bridle rings or equal. All wiring and fiber optic cable in the hallways, rooms, and other public areas shall be in conduit unless noted otherwise in section H.
- E. All wires in Bridle Rings or conduit shall follow building lines (i.e., wires in plenum space shall run within several inches of the wall and shall NOT run in the middle of the space). Those areas of the building with RA plenum ceilings where wire is routed above that wire shall be plenum rated or routed in conduit.
- F. Wire:
 - 1. Wire and cable of the sizes and types shown on the plans and/or hereinafter specified shall be furnished and installed by the Control Contractor. All wire and cable shall be new soft drawn copper and shall conform to all the latest requirements of the National Electrical Code, IPCEA, and shall meet the specifications of the ASTM.
 - 2. All control wiring to be copper stranded TEW-105, with appropriate gauge in accordance with the Codes. The minimum gauge used to be 16 AWG.
 - 3. Input/Output Wiring: Wiring serving inputs and outputs from the BAS shall be cables consisting of single or multiple twisted individually shielded pairs. Each pair shall have an independent shield with drain wire. Cables installed without conduit shall be plenum rated and comply with NEC article 725. Where automation input/output wiring is run in cable tray furnish and install conductors or multiconductor cable rated for use in cable trays per NEC articles 340 and/or 725. Conductors shall be minimum #18 wire gauge.
 - 4. Power Conductors: All feeder and branch circuit wire shall be 600 V insulated of THHN type unless shown or specified to be otherwise. No wire less than No. 12 gauge shall be used except for control circuits or low voltage wiring. Wire sizes No. 14 to No. 10 shall be solid except where otherwise indicated. Wire sizes No. 8 and larger shall be stranded. All wire sizes shown are American Wire Gauge sizes. Where power conductors are run in cable tray, furnish and install conductors or multiconductor cable rated for use in cable trays per NEC articles 340 and/or 725.
 - 5. All the conductors used for signals from the Controllers and field sensors must be shielded two wire, 18 AWG. with a drain wire unless other sizes are recommended by the control manufacture. Shield must be purple.
 - 6. All power wiring to be copper stranded RW 90 type, with appropriate gauge in accordance with the Codes. The following color code must be applied: line voltage to be black and/or white, ground to be green.
 - 7. Acceptable Manufacturers: Cable and wire shall be a standard type as manufactured by General Electric Company, National Electric Company, U. S. Rubber Company, Simplex, General Cable Company, Carol, Anaconda, Rome, Southwire, Belden, Alpha, Houston Wire and Cable, or ITT Royal.
- G. Wiring Installation:
 - 1. All wires shall be continuous from outlet to outlet and there shall be no unnecessary slack in the conductors.
 - 2. All wire terminations will be identified using rail terminal strips (see 5.11)
 - 3. All drain wires must be grounded at the source end. The other end must be protected with a dielectric material (tape).

4. All control wiring (24 V and more) must be in a separate conduit from the shielded conductors.
5. Pull-Box and Junction Box:
 - a) Pull boxes and junction boxes shall be installed where indicated on the drawings or where required to facilitate wire installation. Locate in conjunction with other trades so as to install without conflict with other materials or equipment.
 - b) A pull-box will be located at every 50'.
 - c) All switch, pull, junction boxes, etc., shall be hot dipped galvanized or sherardized, concrete tight, with interlocking ring or multiple point locking devices. Connectors shall be three piece. Indentation fittings are not acceptable.
 - d) In suspended ceilings, all boxes must be installed on the structure.
 - e) Boxes shall be attached by fasteners designed for the purpose and shall provide adequate mechanical strength for future maintenance.
 - f) Junction and pull boxes not dimensioned shall be minimum 4 inch square.
6. Care shall be used to avoid proximity to heat ducts and/or steam lines. Where crossings are unavoidable, conduit shall clear covering of line by at least six inches.
7. Motor Interlock Wiring: Interlock circuit wiring shall be No. 14 solid or stranded wire. Stranded wire only shall be used where wiring is used for flexible wiring harnesses. Stranded control wire shall be provided with crimp type spade terminators. Interlock circuit wiring shall be color coded or numbered using an identical number on both ends of the conductor. Wire numbers shall be installed before conductors are pulled. Where motor interlock conductors are run in cable tray, furnish and install conductors or multiconductor cable rated for use in cable trays per NEC articles 340 and/or 725.
8. All splices, taps, and terminations shall be made at outlet, junction, or pull boxes. Wire to No.6 gauge shall be spliced using Scotchlok wire nuts. No Bakelite wirenuts shall be used. Wire No. 6 and larger shall be spliced using solderness connectors as manufactured by Penn Union Company. Splices No. 6 and larger shall be insulated by taping with plastic vinyl tape as manufactured by Minnesota Mining and Manufacturing Company. Splices shall not be permitted in automation input and output wiring without specific written authorization from the Engineer. If such a splice is approved, the location of the splice shall be clearly documented on the "As Built" drawings. Splices in automation wiring, if necessary, shall be made using Thomas&Betts STA-KON connectors installed per the manufacturer's directions to maintain NEMA specified voltage drops and wire retention forces.
9. Grounding:
 - a. The contractor shall extend existing equipment grounding systems. The Contractor shall use only approved grounding clamps and connectors as manufactured by Penn-Union, Burndy or O-Z Mfg. Company.
 - b. The conduit system of the 480/277 and 208Y/120 volt systems shall be continuous and shall be used as the static grounding conductor, except for circuits installed in flexible conduit. Install a green grounding conductor inside all flexible conduits and extend to the nearest outlet or junction box. Install a green grounding conductor inside all non-metallic conduits or raceways.
10. All safety circuits shall be hard wired circuits with independent manual reset type switches.

H. Conduit:

1. Conduit Material:
 - a. All wiring to be in E.M.T. type conduits unless in plenum or otherwise noted below.
 - 1) Above accessible ceilings open cable with bridle ring support is allowed.
 - 2) 12 ft. or more above the floor in mechanical rooms where supported per specifications.
 - b. All conduits to be a minimum of 1/2".
 - c. All flexible conduits will not exceed 24" in length and are to be used only in areas where vibrations and/or expansion joints are present.

- d. Jacketed flexible steel conduit (Sealtite) shall be used where flexible conduit connections are required outdoors and at connections to all motorized equipment and motors outdoors.
 - e. In damp areas, the conduit and related equipment must be suitable for the application.
 - f. Electrometallic tubing shall be installed for all exposed work and for all concealed work in applications where conduit is required.
 - g. Conduit shall be by Allied, Triangle, Republic, Youngstown, Carlon, Rob Roy, or approved equal.
 - h. For exposed installations where the conduit cannot be run in ceiling spaces, wall cavities or attics, surface-mounted raceway (wire mold) is acceptable. No EMT is allowed in these locations. Provide samples for size and color selection.
2. Conduit Installation:
- a. All wiring in mechanical rooms at heights below 12 feet must be run in conduit. Otherwise, wiring in all other open areas must have conduit (at all heights). Existing conduit runs where compliant with these specifications may be re-used.
 - b. All conduits to be installed in a concealed manner where possible and shall be installed parallel to the lines of the building.
 - c. All exposed conduits shall be installed parallel or at right angles to the building walls or floors.
 - d. Conduit bends shall be made with standard hickeyes of proper size; radius of bends to be at least 6 times the diameter of the conduit. Runs between outlets shall not contain more than the equivalent of three quarter bends. Conduit runs shall be continuous from outlet to outlet, outlet to cabinet, etc.
 - e. Conduits shall be installed with pitch toward outlet box wherever possible. All heavy wall conduits shall have two locknuts and a bushing at each termination outlet box, junction box, etc., except where terminated in a threaded hub. Fittings on electrometallic tubing shall be compression type.
 - f. A bushing shall be used where conduit enters a panel box. Bushing for No. 4 AWG or larger shall be insulated type with provisions for grounding as type "BL" made by O-Z Electric Company, or approved equal.
 - g. Expansion fittings shall be provided at all conduits across the building expansion joints. Fittings shall be Type "AX" or "TX" as made by O-Z Electric Company, or approved equal. Provide copper bonding jumper at each expansion fitting.
 - h. All 1/2" conduit to be supported every 6', the supports will be located at the connector end of the conduit.
 - i. Exposed conduit shall be securely fastened in place on maximum 5 ft. intervals for 3/4" through 2-1/2 inch nominal sizes. Supports may be one hole malleable straps or other approved devices. No perforated metal straps will be permitted.
- I. Wireway:
- 1. Furnish and install at all control panel locations a NEMA 1 lay-in wireway system to bring cable into and out of the panel as detailed on the drawings and specified in this section. Furnish 3-way wireways at each panel location: one for Class 1 wiring, 1 for Class 2 and Class 3 wiring. Panels at units to be NEMA 3R or better.
 - 2. Wireway systems at locations where cables are to be run without conduit or in a cable tray shall consist of a connection to the control panel with a vertical extension to 8'-0" or the pipe rack or cable tray level, whichever is higher. The vertical section shall terminate in a 90° fitting with a closure plate. The closure plate shall be provided with a conduit nipple with locknuts and bushings as a wire entry point into the square duct. The conduit nipple shall be one size smaller than the wireway it is associated with.
 - 3. Wireway systems at locations where cables are to be run in conduit shall consist of a horizontal section of wireway with a length equal to the control panel width and located above the control panel and connected to the control panel with three conduit nipples, locknuts, and bushings; one for tubing, one for Class 1 wiring and one for Class 2 and 3 wiring. Conduits for cable runs shall terminate on the wireway.

4. The intent of the wireway configurations outlined above is to provide a method for adding input and output wiring to the control panel without having to drill directly into the electronics enclosure after the system is on-line and running and to provide sufficient area to land field conduits while maintaining appropriate circuit segregation for wire entry into the controller enclosure. The installation of wireway shall be made with this consideration in mind.

J. Hangers and Anchors:

1. Where control system tubing is run on trapezes and/or hangers used by and or installed by other trades, supports for the trapezes shall be coordinated by all trades using the trapeze to assure that the anchor system is not overloaded and is sufficient for the load imposed including a margin of safety and seismic considerations. Under no circumstances shall a trapeze or hanger system installed by the electrical trades be used to support work by any other trade, nor shall the electrical trades use the trapezes installed by any of the other trades for the support of electrical equipment, all as required by the National Electric Code. Similarly, under no circumstances shall a trapeze or hanger system installed by the sprinkler trades be used to support work by any other trade, nor shall the sprinkler trades use the trapezes installed by any of the other trades for the support of sprinkler systems or equipment, all as required by NFPA 13, Standard For The Installation Of Sprinkler Systems.
2. Anchors to be loaded in tension for use in existing concrete structure and anchors loaded in tension and not cast in place shall be epoxy resin set anchors installed per the manufacturers recommendations for technique, size, loading, embedment, etc. Where anchors are loaded in shear at these locations, suitably sized and installed wedge type anchors may be used.
3. In all cases, anchor loading shall be based on hanger spacing, weight of the pipe to be supported when full and insulated, weight of any additional loads imposed upon the anchor, wind loading, seismic loading, quality of the material that the anchor is being installed in, etc. The Control Contractor shall verify in the field that the anchors used and the materials that they are being installed in are suitable for the load imposed and shall bring any problems to the attention of the Engineer in writing immediately and not proceed without direction from the Engineer.
4. Wedge type anchors shall be Hilti Kwik Bolt II. Adhesive anchors shall be Hilti HVA.

2.03 UNIT CONTROL PANELS (INSTALLATION AND FABRICATION)

- A. Enclosed cabinet type with hinged door for mounting all relays, switches, thermometers, and miscellaneous controls not requiring direct mounting on equipment such as sensing elements, valves and damper motors. Provide cabinet for each control unit adjacent to each system.
- B. Each panel shall have power conditioners on electrical supply, Crucial Power Product MI Series.
- C. Control panels shall be fabricated to match the approved shop drawings submitted by the control contractor. Fabrication shall be in a neat and workmanlike manner and shall facilitate repair, maintenance, and adjustment of the equipment contained therein.
- D. Control panels shall be fabricated and laid out to incorporate the following features:
 1. Identification of all internally and cover mounted devices. Cover mounted labels shall be engraved labels as specified in this section (5.10). Labels shall be mounted adjacent to the device they are associated with so that replacement of the device does not eliminate the label. Provide laminated control diagram at each panel.
 2. Electrical wiring shall enter the panel from the top, bottom, and/or side of the left side of the panel or as required by the panel supplier to meet NEC requirements.

3. All wires entering or leaving the panel shall pass through a rail terminal strip. Where the wires are part of a current loop transmission circuit, the terminals shall be the disconnecting link type. Terminals shall be identified with a number that corresponds to the terminal number on the job wiring diagram. Rail terminal strip specifications include:
 - a. General: Terminal rail assemblies shall be fabricated from components selected from the product line of one manufacturer. Sizes (heights, widths, and profiles) of each terminal shall be selected to be compatible with the other terminals on the rail. Terminal units located at the end of a rail or adjacent to terminals with a different profile (for example, where disconnecting terminals are located next to resistor terminals) shall be provided with end caps to completely close off the terminal unit interior components from the local environment. End stops shall be provided for on all rails to secure the terminals located on the rail in place.
 4. All internal wiring and tubing shall be run inside plastic wiring/tubing duct as manufactured by Tyton. Wire duct shall be sized to hold the required number of wires and tubes without crimping the tubes and with sufficient space to allow wiring and tubing to be traced during troubleshooting operation.
 5. Wires that pass from the panel interior to cover mounted devices shall be provided with a flex loop that is anchored on both sides of the hinge. Wiring running to cover mounted devices shall be bundled using cable ties.
 6. Provide strain relief type cord and cable connectors for all cables that leave the panel as individual cables not in conduit.
 7. All control panels shall be provided with removable sub panels to allow the panel enclosures to be installed at the job site during rough in while the panels are fabricated off-site for later installation.
 8. Provide one duplex outlet mounted inside the control panel and separately fused with a non-time delay fuse at 15 A at any panel location containing electronic or electrical control components. This receptacle may be served from the control panel 120 VAC power source.
 9. Each control panel shall be provided with a control power disconnect switch located and wired so as to disconnect all control power in the panel. The leaving side of this switch shall be wired to the panel and field components through a fuse or fuses sized and applied to protect both the components of the system as well as the wire and as required for code compliance.
 10. Power to the following equipment will be have a fuse rated for applicable current and voltage. Fuses will be on rail terminal strips. Equipment includes:
 - a. Each control unit
 - b. Control devices
 - c. Panel light
 - d. Receptacle loads (e.g., modems, laptops)
 11. All control panels containing electrical equipment shall be NEMA rated for the location in which they are installed. Cover mounted components, tubing penetration, and conduit penetrations shall be made in a manner consistent with the NEMA rating.
 12. All wiring leaving the panel shall be separated by classification; i.e., Class 1 circuits shall not be run with Class 2 circuits, etc. Segregation shall be maintained inside the panel to the fullest extent possible. Where low voltage wires carrying low level ac and dc signals cross wires containing power and high level ac signals, the wires shall cross at a 90° angle.
- E. Control panels shall be shop fabricated and tested prior to installation in the field. The panels shall be inspected and approved by the Engineer at the assembly location prior to installation in the field. The Engineer shall be given the opportunity to witness the testing of the panels.
- F. Panel Location:
1. Each control panel is to be located for convenient servicing.
 2. Mount panels adjacent to associated equipment on vibration isolation.

2.04 CONTROL DAMPER ACTUATORS

- A. All damper actuators shall be Belimo electric actuators.
- B. Torque rating shall be based on the damper manufacturers operating torque requirements at the design flows and pressure drops or shall be based on the manufacturers required shut-off torque to achieve the design leakage rate, whichever is greater. This higher torque rating shall be doubled. An actuator with this doubled torque rating shall be installed.
- C. All damper sections which operate in sequence with each other shall have identical actuators and identical linkage arrangements to assure similar performance between all sections.
- D. Modulated actuator operation shall be industry standard 0-10v.
- E. Two or three position operation is not acceptable for economizers, VAV dampers, multi-zone dampers, or any other application specifying modulated operation. OSA Dampers to be normally closed, mixed air dampers to be normally open.
- F. Actuator quantities for dampers shall be based on the following criteria.
 - 1. Actuators must be outside unit enclosure.
 - 2. Actuators shall be installed to maximize the linearity between actuator stroke and actuated device travel (25% actuator stroke produces approximately 25% of the desired angular rotation required; 50% stroke produces 50% angular rotation). In addition, actuators should be installed to maximize force available for useful work over the entire stroke.
- G. Actuators for VAV boxes to be provided to VAV manufacturer for installation at the factory.

2.05 CONTROL VALVES AND ACTUATORS:

- A. Provide adequate size and number of modulating or two-position action.
- B. Provide positive positioning devices where shown or where sequencing cannot be accomplished by using standard spring ranges.
- C. Modulating valve sizing shall be based on the following conditions.
 - 1. Water Valves:
 - a. Minimum pressure drop-2 psi or equal to the water side pressure drop of the coil it is associated with, whichever is greater.
 - b. Maximum pressure drop-3 psi
 - 2. Flow rates for valve sizing shall be based upon the flow rates indicated on the equipment schedules on the drawings.
 - 3. Valve sizing shall consider the valve cavitation coefficient. In no case shall a valve be sized so that the pressure drop through the valve causes cavitation with fluid temperatures and pressures encountered in the system during start up or normal operation.
 - 4. Valves on heating systems to be normally open.
- D. Valves:
 - 1. Equip with custom flow control modulating ball valve.
 - 2. Two position valves shall be the full size of the pipe that they are associated with unless otherwise specified.
 - 3. Two-way valve actuators shall be sized to close off tight against the full pump shut off head on the system upon which they are installed.
 - 4. Three-way valve actuators shall be sized to close off tight in both directions against 2.5 times the valve pressure drop at full flow.

5. Valves shall close against differential pressures. Water control valves, acting as pressure control or pressure relief valves, shall be capable of closing against a differential pressure equal to 150% of rated pump head of each application.
6. Screwed ends on valves 2-inches and smaller. Flanged ends on valves 2-21/2 inches and larger.
7. Three-way valves where indicated on drawings, otherwise two-way valves.

E. Valve Actuators:

1. Electronic actuators shall be manufactured by Belimo for all valves.
2. Torque shall be rated at twice the required load.

2.06 SENSORS

- A. All sensing inputs shall be provided industry standard signals.
- B. Immersion temperature sensors, humidity, differential pressure signals, and all other signal inputs shall be:
 1. 4-20 mA or 0-10v.
 2. Provide signal transmitters for temperature sensors as required. All other devices shall be direct 40-20 mA.
 3. Thermistors are allowed for duct or room sensors only.
- C. All signal inputs shall be compatible with the controllers used and with the requirement for readout of variables as specified.
- D. If sensors are not linear, then software will linearize sensor output.
- E. Controls and sensors for VAV boxes to be provided to VAV manufacturer for installation at the factory.
- F. Minimum sensor accuracy (as compared to a test standard) and range are listed in Table. Accuracy is not the same as resolution (the ability of the DDC to measure incremental change). Resolution is specified in "Part 3. DDC Hardware."
 1. All accuracy values should be combined effect numbers taking into account thermal drift, interchangeability, hysteresis, etc.

Sensor Type	Range	Min. Accuracy
Duct/Air Handling		
Unit Temperature	40 – 130°F	± 0.5 Degree F
Room Temperature	50 – 85°F	± 1 Degree F
Outside Air Temperature	- 20 to 120°F	± 0.5 Degree F
Chilled Water Temperature	32 – 80°F	± 0.1 to ± 0.5 Degree F
Hot Water Temperature	80 – 220°F	± 0.1 to ± 0.5 Degree F
Water flow	Sized for application	± 5% of reading
Humidity	0 to 100% RH	± 3% RH
Duct Static Pressure	0 to 3" w.c.	± 1% full scale per 50°F
Space Static Pressure	- 0.25" to 0.25" w.c.	± 1% full scale per 50°F
High Limit Static	0-5" w.c.	± 1% full scale per 50°F
Steam Pressure	Sized for application	± 1% full scale
Current Sensor	Sized for application	± 1% full scale
Power (kWh)	Sized for application	± 2.5% full scale (at 0.5 PF) ± 2% full scale (at 1.0 PF)

Air flow	700 to 4,000 fpm	± 2% full scale
CO ₂ sensors	0 to 2,000 PPM	± 3% full scale
Freeze Stat	34°F to 68°F	± 1°F

Sensors shall not drift more than 1% of full scale per year

2.07 TEMPERATURE SENSORS/THERMOSTATS

- A. All sensors shall be completely electronic.
- B. Duct/ Air Handling Unit type temperature sensor (mixed, discharge/supply, and return air):
1. The probe of the duct sensor shall be 12" in length, and be made of Stainless Steel. Applications where the smallest dimension of the duct is less than 24", the probe shall be sized to reach the center of the duct.
 2. Large systems above 9 square feet may require an averaging probe if sufficient mixing of the air stream is not possible.
 3. Mount the sensor far enough down stream to allow mixing of the air stream, this is most important on Hot and Cold Deck applications where the coil is placed after the fan.
 4. Sensors for mounting on insulated ducts or casings are to be equipped with brackets for mounting clear of the isolation.
 5. Do not locate sensors in dead air spaces or in positions with obstructed air flow.
 6. Provide separate duct flange for each sensing element.
 7. Temperature sensing elements shall be thermally isolated from brackets and supports.
 8. Securely seal ducts where elements or connections penetrate duct.
 9. Mount sensor enclosures to allow for easy removal and servicing without disturbance or removal of duct insulation.
- C. Immersion Type Temperature Sensor:
1. The probe of the sensor shall be constructed of stainless steel and pressure rating consistent with system pressure and velocity.
 2. The well shall be constructed of stainless steel and sized to reach into the center of the pipe. Pipes with small diameters shall have the well mounted at a 90 degree elbow to allow sufficient contact with the fluid.
 3. Locate wells to sense continuous flow conditions.
 4. Do not install wells using extension couplings.
 5. Wells shall not restrict flow area to less than 70 percent of line-size-pipe normal flow area. Increase piping size as required to avoid restriction.
 6. Provide thermal transmission material within the well.
 7. Provide wells with sealing nuts to contain the thermal transmission material and allow for easy removal.
- D. Room Type Temperature Sensor:
1. All thermostat locations shall be submitted for approval before installation.
 2. Provide all sensors with blank wall plate, vandal-proof covers that are flush with wall. Mamac TE-205-P series are equal.
 3. Coordinate sensor location with light switches, and mount 60" above the floor. Verify location before installation, so that no direct sunlight or influences from heat and cooling sources will be imposed on the sensor.
 4. Unless otherwise indicated or specified, provide one discharge and one space temperature sensor for each VAV Terminal Control Unit.
 5. Metal guards shall be provided as shown on Drawings.
 6. Insulation shall be installed between the temperature sensor and open conduit to eliminate false temperature readings due to cold drafts.

2.08 AIR PRESSURE SENSORS

- A. Static Pressure and Velocity Controllers:

1. Static pressure sensors shall be of either the diaphragm or rigid element bellows, electronic type, photo helic.
2. Each sensor shall be provided with connections, i.e., stop cock and tubing, for attaching a portable pressure gauge.
3. Sensors for mounting on insulated ducts or casings are to be equipped with brackets for mounting clear of the insulation.
4. The transmitter shall be a two-wire type and provide a 4-20 mA signal which is proportional and linear over the calibrated pressure range.
5. The transmitter shall be capable of operating from an unregulated 18-30 VDC power supply.
6. The device housing shall provide 1/4" barbed brass fitting for the connection of the pressure lines. Pressure ranges shall suit the application so that normal operation will occur at mid range of the sensor span.
7. The location of the indoor measurement shall be remote from doors and openings to the outside, away from elevator lobbies, and shielded from air velocity effects. See Drawings for location.

2.09 FREEZE PROTECTION THERMOSTAT

- A. Length: one linear foot of sensing element per square foot of coil or duct area.
- B. Low temperature cutout control, snap acting, normally closed contacts.
- C. Sensing element contacts will open when any 16-inch portion of the element sensing at or lower than setpoint.
- D. Auto reset with manual alarm reset.
- E. Temperature sensing elements shall be thermally isolated from brackets and supports.
- F. Reset temperature 5°F above setpoint.

2.10 TRANSFORMERS

- A. Transformers selected and sized for appropriate VA capacity and installed and fused according to applicable Codes. **Provide with reset button.**

2.11 WATER PRESSURE SENSORS

- A. The device shall be capable of withstanding an over pressure of two times its calibrated span without any damage to the sensing element.
- B. Typical ranges: 0-150 psig.
- C. The device enclosure shall be a NEMA 4 type and provide rugged mounting feet. All wetted parts shall be stainless steel so that a wide variety of fluids may be measured.
- D. The transmitter shall be capable of operating from an unregulated 18-30 VDC power supply.
- E. Pressure sensors for liquid or pressurized applications shall be installed with shut off valve to that the system must not be shut down or drain to install or service the sensor.

2.12 CO₂ SENSORS

- A. Sensor output shall be 0-10 VDC which is proportional over the 0-2000 ppm range.

- B. The transmitter shall be capable of operating from an unregulated 20-30 VDC or 24 vac power supply.
- C. Sensors shall be non-dispersive Infra-Red diffusion sampling with accuracy of +/- 30ppm +/- 2% of measured value at normal temperature and pressure.
- D. Self-calibrating Algorithm with 5 year service interval.
- E. Provide CO₂ calibration tool with system. Turn over to owner after calibration and provide instructions on use.
- F. Veris C series or approved.

2.13 CURRENT SWITCHES

- A. The status of all non-VFD fan and pump motors and all VFD fan and pump motors less than 20 HP shall ONLY be detected using current switches.
- B. The current switch shall be provided for electrical equipment status applications only.
- C. Switch should attach directly to the conductor and have a mounting bracket for installation flexibility.
- D. The current switch shall be 100% solid state electronics.
- E. The current switch shall be induce powered from the monitored load

2.14 CURRENT SENSORS/TRANSFORMERS

- A. The status and amperage of all VFD motors for fan and pumps greater than 20 HP shall be detected using current sensors ONLY.
- B. The Amp signal shall be provided on operator screen.
- C. The scale used must be selected in order to obtain normal operating readings at the mid-point of the scale.
- D. The scale used must be selected in order to detect changes in current flow resulting from motor belt or coupling loss, belt slippage, and other mechanical failures and should be able to distinguish low load conditions.

2.15 TIMER SWITCH

- A. Spring wound timer switch, 0-2HR, rated for control current. Use as a local override. Intermatic FF series or equal.

2.16 SURGE PROTECTION

- A. All equipment shall be protected from power surges and voltage transients. If failure occurs from surges and transients during the warranty period, then the contractor shall repair surge protection equipment and other equipment damaged by the failure at no cost to the owner.
- B. Isolation shall be provided at all peer-to-peer network terminations, as well as all field point terminations to suppress induced voltage transients, and shall be consistent with IEEE standards 587-1980.

2.17 FACTORY MOUNTED DEVICES

- A. Sensors as required shall be provided by Control contractor to the manufacturer for installation. All materials and labor beyond this is the responsibility of the Control contractor.

PART 3 - DIRECT DIGITAL CONTROLS – HARDWARE

3.01 SYSTEM ARCHITECTURE

- A. Retain existing architecture. Replace or provide expansion modules for systems where point count is increased. Where systems are modified or replaced and existing controller has sufficient capacity for the level of control now required the controller may be re-used.
- B. The Control Contractor shall provide set-up and software for the digital control system and web access on existing Owner's computer. Upgrade existing software as required. Coordinate with School District I.T. personnel for access, wiring and standards of installation if more restrictive than these specifications:

3.02 PRIMARY CONTROL UNITS

- A. Primary control units are stand-alone units able to control HVAC equipment per the specified sequence of operation.
 - 1. Each controller shall be capable of performing all specified control functions independently. The primary control unit shall directly control all units, fans, and control devices. All control software shall be implemented in the primary control unit. The sequence of operation precisely identifies all points of monitoring and control.
 - 2. Shall monitor specific analog and digital inputs, process the data received, and produce analog or digital outputs to control the systems specified.
 - 3. Systems utilizing controllers that operate in a default mode only as a stand-alone will not be acceptable.
 - 4. The controller platform shall provide options and advanced system functions that allow standard and customizable control solutions required in executing the "Sequence of Operation".
- B. Minimum specifications include:
 - 1. Microprocessor-based controllers, fully equipped with power supply, input and output terminals, internal (electronic) timeclock, and self-charging battery backup.
 - 2. Modular multi-tasking microprocessor based direct digital controller with minimum of 1MB of EEPROM and RAM memory.
 - 3. Minimum 10 bit Analog-to-Digital (A/D) converter.
 - 4. Minimum 12 bit Digital-to-Analog (D/A) converter.
 - 5. Sufficient memory for storing 288 trend values for every point (real and virtual).
 - 6. Controllers shall have unused physical points available for future add-ons. The number of spare points shall equal 20% of all physical points (20% AI, 20% AO, 20% BI, 20% BO) or at least two spare points of each type.
 - 7. Shall include all control strategies listed in "Part 4: DDC Software."
 - 8. Each control loop shall be fully definable in terms of inputs and outputs that are a part of the control strategy.
 - 9. Each control unit shall be equipped with a communication interface connection, minimum of 16 universal analog or digital inputs and outputs, and shall communicate via the LAN to the building level controller.
 - 10. On board power supply for all sensors.
 - 11. On board sockets for plug-in resistors.
 - 12. Each control units shall be capable of proper operation in an ambient environment of between 32°F and 110°F and from 10% to 90% RH.

13. Control units provided for outside installation shall be capable of proper operation in an ambient environment of 0°F to 120°F, and 5 to 95% RH. If such hardware is not available, locate hardware in an accessible indoor location or as approved by the Engineer.
 14. Power Failure Protection:
 - a. All control panels shall be provided with automatic protection from power failure for at least 168 hours.
 - b. This protection shall, at a minimum, include continuous real-time clock operation, automatic system restart upon power return, and integrity of all volatile point data.
 - c. Panel outputs shall, at a minimum, be configured to remain in the last commanded state and return to the required state upon restoration of power.
 15. Diagnostics: Controller shall continuously perform self-diagnostics, communication diagnosis, and diagnosis of all panel components. The network controller shall provide both local and remote annunciation of any detected component failures, low battery conditions, or repeated failures to establish communication.
 16. Power Failure: In the event of the loss of normal power, there shall be an orderly shutdown of all controllers to prevent the loss of database or operating system software. Nonvolatile memory shall be incorporated for all critical controller configuration data, and battery backup shall be provided to support the real-time clock and all volatile memory for a minimum of 72 hours.
 - a. During a loss of normal power, the control sequences shall go to the normal system shutdown conditions.
 - b. Upon restoration of normal power and after a minimum off-time delay, the controller shall automatically resume full operation without manual intervention through a normal soft-start sequence.
 - c. Should a controller memory be lost for any reason, the operator workstation shall automatically reload the program without any intervention by the system operators.
 17. Certification: All controllers shall be listed by Underwriters Laboratories (UL).
 - a. All controllers shall be listed by Underwriters Laboratories (UL).
 - b. NiCS (Compatibility Statement) shall show no restrictions to conductivity. Provide devices with station compatibility in and out and tool compatibility in and out. Having a value of "all" for each.
- C. Primary control units shall be installed on:
1. Air handling units greater than 2,000 CFM
 2. Air handling units with VFDs
 3. Any application not listed in secondary and application control units.

3.03 SECONDARY CONTROL UNITS

- A. Secondary control units are able to control HVAC equipment per specified by the sequence of operation.
 1. Each controller shall be capable of performing specified control functions. The secondary control unit shall directly control all units, fans, dampers and control devices. All control software shall be implemented in the secondary control unit. The sequence of operation precisely identifies all points of monitoring and control.
 2. Each controller shall monitor specific analog and digital inputs, process the data received, and produce analog or digital outputs to control the systems specified.
 3. The controller platform shall provide options and advanced system functions, programmable and configurable using Niagara AX Framework™, that allow standard and customizable control solutions required in executing the "Sequence of Operation".
- B. Minimum specifications include:
 1. Microprocessor-based controllers, fully equipped with power supply, input and output terminals.

2. Modular multi-tasking based direct digital controller with minimum of 2048 bytes of EEPROM and RAM memory.
 3. Minimum 8 bit Analog-to-Digital (A/D) converter.
 4. Minimum 10 bit Digital-to-Analog (D/A) converter.
 5. Controllers shall have unused physical points available for future add-ons. The number of spare points shall equal 20% (20% AI, 20% AO, 20% BI, 20% BO) of all physical points or two spare points whichever is greater.
 6. Shall include all control strategies listed in "Part 4: DDC Software."
 7. Each control loop shall be fully definable in terms of inputs and outputs that are a part of the control strategy.
 8. Each secondary control unit shall be equipped with a USB communication interface connection, minimum of 16 universal analog or digital inputs or outputs, and shall communicate via the LAN to the network front end. Each control units shall be capable of proper operation in an ambient environment of between 32°F and 110°F and from 10% to 90% RH.
 9. Control units provided for outside installation shall be capable of proper operation in an ambient environment of 0°F to 120°F, and 5 to 95% RH. If such hardware is not available, locate hardware in an accessible indoor location, in a ventilated control panel or as approved by the Engineer.
- C. Secondary control unit. Secondary control units are microprocessor-based devices that are less programmable and will be used on:
1. Small unitary equipment (flow rate less than 2,000 CFM)
 2. Fan coil units

3.04 APPLICATION SPECIFIC CONTROL UNITS

- A. Pressure Independent VAV Terminal Unit Controller
1. General
 - a. Controls shall be microprocessor based Pressure Independent Variable Air Volume Terminal Unit Controllers (VTC). The VTC shall be based on a minimum 8-bit microprocessor working from software program memory that is physically located in the VTC. The VTC controller "intelligence" shall be resident within the same enclosure that translates sensor signals into digital information.
 - b. The VTC shall consist of microprocessor, power supply, enclosure, pressure transducer, field terminations, field adjustments, and operating/application system software in a single integrated package. Device shall operate remote Belimo damper actuator and valve actuator.
 - c. All input/output signals shall be directly hardwired to the VTC. Troubleshooting of input/output signals shall be easily executed with a volt/ohm meter (VOM) or hand-held operator interface device or laptop.
 2. Non-Volatile Memory
 - a. All control sequences programmed in the VTC shall be stored in non-volatile memory which is not dependent upon the presence of a battery to be retained.
 - b. Power failures shall, therefore, not cause the VTC memory to be lost, nor shall there be any need for batteries to be recharged or replaced.
 3. Controller Location: To simplify controls, mechanical service and troubleshooting, all components of the VTC shall be mounted directly at the Variable Air Volume terminal box. This shall allow all controls maintenance and troubleshooting to be made while at the VTC zone location. Enclosure assembly shall be mounted and positioned so that it is easily accessible to operational personnel.
 - a. The VTC shall be powered by a 24 VAC power source and shall comply with Class 2 wiring requirements.

- b. For compatibility with the environment of a VAV terminal box, the VTC shall have wide ambient ratings for specified controls, sequences, and performance. VTC shall be rated for service from 40°F to 140°F.
 - c. Contractor shall submit description of location of VTC on VAV terminal box.
 - d. For compatibility of use in the supply or return air plenum, the VTC enclosure shall be constructed to comply with the requirements of UL-465.
4. Transducer
- a. Each VTC shall contain an integral flow transducer capable of measuring and controlling over a 0.05 to 2.00 WC range with an accuracy of +6% at full rated flow.
 - b. Flow transducer shall contain an automatic recalibration circuit that eliminates transducer error due to temperature variations and long-term sensor drift.
 - c. VAV box controllers not meeting this specification shall include their bid price the cost of sensor recalibration to factory tolerance on a quarterly basis for a minimum period of three years.
5. Actuator Operation
- a. Each VTC shall be capable of operating on VAV terminal boxes that require clockwise or counterclockwise primary damper operation.
 - b. All actuators shall provide a proportional signal over the entire control range.
 - c. Actuators shall stop automatically at end of travel and shall include a permanently lubricated gear train.
 - d. Interface to the VAV terminal box shall be directly to the damper shaft or through electrical connection to an existing 24 VAC bi-directional motor operator.
 - e. All actuators shall be Belimo. None others will be accepted.
6. Operational Features
- a. Each VTC shall have a discharge temperature sensor that provides data to the BAS.
 - b. Each VTC shall support the setup of the minimum and maximum flow setpoints, the cooling setpoint as well as the heating or parallel fan start point setpoints without the need for a separate hand-held communications device. In addition, the configuration modes described earlier in this specification must also be definable at the VTC without requiring an external hand-held communications device.
 - c. The set-up of the above parameters shall be permanent in the VTC, a power failure shall not require the reconfiguration of the VTC operating parameters.
7. BAS Communication/Control With VTC application control unit: BAS shall be in continual direct communication with the VTCs implemented in the facility. VTCs shall perform all control as specified in control functions for the respective VAV terminal box.

PART 4 - DIRECT DIGITAL CONTROLS – SOFTWARE

4.01 SYSTEM SOFTWARE

- A. Update existing software to current version. Revise existing graphics as required for new software. New graphics shall match existing. Alter programming for new sequences. Retain existing passwords and schedules. Alter alarms and trending for new systems. Revise system for current version of district wide Web access as required. New point designations to match existing format.

PART 5 - SYSTEM SETUP

5.01 OVERRIDES

- A. The DDC system should recognize the override and report to the screen.
- B. Overrides **shall be software driven with operation from graphic/front end.**
- C. Software shall have adjustable time limits for each override.

5.02 LABELING AND IDENTIFICATION

- A. All devices relating to the work or systems included herein, including controllers, valves, motors, relays, etc., shall be identified with a unique identification number or name on the submitted engineering drawings. This identification number or name, along with the service of the device (discharge air controller, mixed air controller, etc.), shall be permanently affixed to the respective device.
- B. All field devices will be supplied with a nameplate indicating its name, number, address, and all other pertinent information.
- C. If the field device is too small for the nameplate to be "adhered" to or on another piece of equipment near it (e.g., nameplate on air handling unit at wire penetration for mixed air temperature sensor), then attach the nameplate via nylon ties.
- D. Tagging shall be computer generated. For input/output wiring, cabling, or tubing, the panel side of the terminals shall be labeled with the automation panel circuit board and terminal numbers associated with the point. The field side shall be labeled with the point number. Cable, wiring and tubing not specifically associated with an input or output shall be labeled with a number and function.
- E. All wiring, tubing, and cabling both inside and outside of control panels shall be labeled at both ends using Thomas and Betts EDP printable wire and cable markers using style WSL self-laminating vinyl. Input and output cables and wiring shall be labeled with the point number and the point description, such as:

CPDPS005
Primary Heating Water
Pump #1 On/Off Status

- F. Cable and wiring not specifically associated with an input or output shall be labeled with a number and a function description such as:

120 VAC
Panel #

5.03 REPORTS

- A. At a minimum, the system shall allow the user to easily print the following types of reports.
 - 1. General listing of all points in the network
 - 2. List of user accounts and access levels
 - 3. List of all points currently in alarm
 - 4. List of all off-line points
 - 5. List of all points currently in override status
 - 6. List of all disabled points
 - 7. List of all points currently locked out
 - 8. List of all Weekly Schedules
 - 9. List of all Holiday Programming
 - 10. List of Limits and Deadbands, throttling ranges, gains, etc.
 - 11. List of all adjustable and virtual points

PART 6 - SYSTEM COMMISSIONING AND TRAINING

Air and water balancing shall be completed (and discrepancies resolved) before Control Contractor's final system check and before the acceptance test to be conducted in the presence of the Engineer.

6.01 CONTROL TECHNICIAN MEETING REQUIREMENTS

- A. During all pre-installation meetings with Owner/Engineers and separate meetings pertaining to the commissioning process, the control technician attending the meetings must be the same technicians that are/will install and program the DDC system. **The control technician shall also meet with manufactures representative for all systems being integrated. See specification for equipment for additional requirements.**
- B. The Control Contractor's installer and programmer must attend all the commissioning meetings. These meetings occur throughout the design and construction process.
- C. First Meeting - discuss point naming and sequence of operation with Engineer and Owner
 1. Prior to software and database installation and checkout but subsequent to software and database development, the Control Contractor shall meet with the Owner and the Engineer and review the database and program code in detail on a point by point, sequence by sequence basis. The Control Contractor (using blueprints and this specification) shall provide the project point list and sequence of operation to initiate discussion.
 2. Any necessary modifications required to make the database and sequence match the intent and requirements of the contract documents shall be identified at this meeting including point names, descriptors, alarm setpoint, numeric setpoint requirements, access requirements, sequence adjustments, etc.
 3. Successful completion of this review process will result in software and database approval for installation and start-up. Any software or database that is installed prior to this approval process shall be corrected to match the results of the approval process at no additional cost to the Owner.
 4. For integrated systems the equipment manufactures representative shall participate in sequence of operation review and coordinate with control contractor to identify the correct instance to view, read or write to accomplish the approved sequence.
 5. The results of this meeting shall be documented in meeting minutes taken and issued by the Control Contractor. Documentation can be in the form of marked up data base forms and sequences of operation.
- D. Second Meeting - graphic screen development shall be coordinated with the Owner through a series of meetings that will allow the functions described above (sequence of operation, alarms, etc.) and any other Owner's requirements to be incorporated into the graphic screens.

6.02 PRE-COMMISSIONING TESTING, ADJUSTING, AND CALIBRATION REQUIREMENTS

- A. Prior to acceptance, the following steps will be used by the Control Contractor to produce a testing and pre-commissioning report by system to be submitted for approval by the Engineer or Owner.
- B. Work and/or systems installed under this section shall be fully functioning prior to Demonstration, Acceptance Period and Contract Close Out. Control Contractor shall start, test, adjust, and calibrate all work and/or systems under this contract, as described below:
 1. Verify proper electrical voltages and amperages, and verify all circuits are free from grounds or faults.
 2. Verify integrity/safety of all electrical connections.
 3. Verify proper interface with fire alarm system.

4. Coordinate with TAB subcontractor to obtain control settings that are determined from balancing procedures. Record the following control settings as obtained from TAB contractor (and note any TAB deficiencies):
 - a. Minimum outside air damper settings for air handling units and CFM values.
 5. Test, calibrate, and set all digital and analog sensing, and actuating devices.
 - a. Calibrate each instrumentation device by making a comparison between the DDC display and the reading at the device, using a standard traceable to the National Bureau of Standards, which shall be at least twice as accurate as the device to be calibrated (e.g., if field device is +/-0.5% accurate, test equipment shall be +/-0.25% accurate over same range). Record the measured value and displayed value for each device in the Pre-Commissioning Report.
 - b. All analog input points are to be tested by comparing the reading obtained through the workstation and through an independent reading device (meter).
 - c. Check each analogue output by making a comparison between the control command at the DDC controller and the status of the controlled device. Check each output point by making a comparison of the state of the sensing device and the Host computer display. Record the results for each device in the Pre-Commissioning Report.
 - 1) All analog output points are to be tested using a command from the workstation modulating the output in 10% increments and recording the associated voltage/amps sent to the controlled device.
 6. Check each digital input/output point by making a comparison between the control command at the DDC controller and the status of the controlled device. Check each digital point by making a comparison of the state of the sensing/control device and the Host computer display. Record the results for each device in the Pre-Commissioning Report.
 - a. ON/OFF commands from the workstation should be performed in order to verify its true operation.
 7. Check and set zero and span adjustments for all actuating devices. Manually activate damper and valve operators to verify free travel and fail condition. Check valve or damper to insure that it shuts off tight when the appropriate signal is applied to the operator. Adjust the operator spring compression as required. If positioner or volume booster is installed on the operator, calibrate per manufacturer's procedure to achieve spring range indicated. Check split range positioner to verify proper operation. Record settings for each device in the Pre-Commissioning Report.
 8. Verify proper sequences of operation. Record results and submit with Pre-Commissioning Report. Verify proper sequence and operation of all specified functions by adjusting input variable to determine if sequence of operation is operating as specified.
 9. Tune all control loops to obtain the fastest stable response without hunting, offset or overshoot. Record tuning parameters and response test results for each control loop in the Pre-Commissioning Report. Except from a startup, maximum allowable variance from set point for controlled variables shall be as follows:
 - a. Air temperature: ± 0.5 degrees F
 - b. Water temperature: ± 1 degrees F
 - c. Duct pressure: ± 0.05 inches wc
- C. Pre-Commissioning Testing, Adjusting, and Calibration shall be completed prior to Substantial Completion.
- D. Provide Pre-Commissioning Test Report for approval by the Engineer and Owner before system demonstration.

6.03 DEMONSTRATION

- A. Prior to acceptance, the control system shall undergo a series of performance tests to verify operation and compliance with this specification. These tests shall occur after the Control Contractor has completed the installation, started up the system, and performed its own tests (outlined in 6.1 and to be submitted in writing).
- B. The tests described in this section are to be performed in addition to the tests that the Control Contractor performs as a necessary part of the installation, startup, and debugging process. The Engineer will be present to observe and review these tests. The Engineer shall be notified at least 10 days in advance of the start of the testing procedures.
- C. Demonstration shall not be scheduled until all hardware and software submittals, and the Pre-Commissioning Test Report are approved by the Engineer.
- D. Verifying compliance of equipment operation and sequence of operation with this specification through all modes of operation.
 - 1. If more than 10 percent of the demonstrated equipment operation and sequence of operation fails to operate per the submittals, the demonstration test will be rescheduled after the control contractor takes corrective action.
 - 2. If the Control Contractor fails to demonstrate proper equipment operation and sequence of operation in the second round of tests, the Engineer's costs for witnessing all further demonstration may be assigned to the Control Contractor by the Owner as a deduct to their contracted price. Note: The Control Contractor will not be responsible for costs related to poor design or to other factors beyond their control, though it is expected to call any design concerns and other factors beyond their control that might cause system failure to the attention of the Engineer and the Owner.
- E. Programming changes for correction of improperly programmed sequences will not be considered legitimate reasons for change orders.
- F. Demonstration/Commissioning Software:
 - 1. Provide fully licensed copy of the required BAS workstation graphic software to be used by the Engineer on a remote computer (not included in contract) for accessing the BAS network via modem. This software copy shall be used only for the purpose of commissioning this project. The Owner agrees that the commissioning BAS software license shall become null and void upon termination of the Contract Warranty Period. The software shall be returned to the Control Contractor within one year after system acceptance.
 - 2. Software shall be fully configured to view project specific database and shall include trend logs, specified graphic screens, alarms, and reports.
 - 3. Provide assistance by telephone upon request if required to assist Engineer in setting up software on Engineer's remote computer.
 - 4. Submit one complete set of programming and operating manuals for all graphics software packages concurrently with the commissioning software. This set will be returned to the Control Contractor within one year after system acceptance.
- G. The Control Contractor shall provide at least two persons equipped with two-way communication, and shall demonstrate actual field operation of each controlled 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 Control Contractor.

- H. As each control input and output is checked, a log shall be completed showing the date, technician's and Engineer's initials, and any corrective action taken or needed.
- I. The system shall be demonstrated following the same procedures used in Pre-Commissioning (Section 6.1)
- J. Demonstrate that all points specified and shown can be interrogated and/or commanded (as applicable) from all workstations.
- K. At a minimum, demonstrate correct calibration of input/output devices using the same methods specified for the pre-commissioning tests. A maximum of [10] percent of I/O points shall be selected at random by Engineer for demonstration. Upon failure of any device to meet the specified accuracy, an additional [10] percent of I/O points shall be selected at random by Engineer for demonstration. This process shall be repeated until 100 percent of randomly selected I/O points have been demonstrated to meet specified accuracy.
- L. The Contractor shall demonstrate that the panels' response to LAN communication failures meet the requirements of these Specifications.
- M. Demonstrate that required trend graphs and trend logs are set up per the requirements. Provide a sample of the data archive. Indicate the file names and locations.
- N. Demonstrate successful communication of point values between the BAS and other HVAC equipment (e.g., chiller).
- O. Demonstrate complete operation of Operator Interface such as graphic screens, trend logs, alarms, etc.
- P. Additionally, the following items shall be demonstrated:
 1. DDC Loop Response. The Control 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 set point that represents a change of actuator position of at least 25% of its full range. The sampling rate of the trend shall be from 1 second to 3 minutes, depending on the speed of the loop. The trend data shall show for each sample the set point, actuator position, and controlled variable values (e.g., VFD frequency or Amperage). Any loop that yields unreasonably under-damped or over-damped control shall require further tuning by the Control Contractor.
 2. Optimum Start/Stop. The Control Contractor shall supply a trend data output showing the capability of the algorithm. The 5 minute trends shall include the operating status of all optimally started and stopped equipment, as well as temperature sensor inputs of affected areas.
 3. Operational logs for each system that indicate all set points, operating points, valve positions, mode, and equipment status shall be submitted to the Engineer. 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.
 4. The DDC and HVAC systems will be shut down for 15 minutes and then re-started. Within 15 minutes, the DDC system shall start and obtain stable control of the HVAC systems without safety trips, alarms, or excessive deviations in temperature and pressure (as defined by the Engineer).
- Q. System acceptance shall occur within 120 days of substantial completion. Any delay beyond this period of time shall initiate liquidated damages unless waived by owner. Failure or delays on engineers / owners part shall not be included in 120 day count.

6.04 ACCEPTANCE

- A. All tests described in this specification shall have been performed to the satisfaction of both the Engineer and Owner prior to the acceptance of the control system as meeting the requirements of this document.
- B. The system shall not be accepted until all forms and checklists completed as part of the demonstration are submitted and approved.
- C. The warranty period starts when the engineering accepts the system and provides this acceptance in written from the Owner and the Control Contractor.
- D. Any tests that cannot be performed due to circumstances beyond the control of the Control Contractor may be exempt from the Completion requirements if stated as such in writing by the Engineer. The Owner shall then perform such tests no later than 3 months after the building is occupied. The costs for these additional tests will be incurred by the Control Contractor.

6.05 SPARE PARTS

- A. The Control Contractor shall provide two spare fuses of the correct size and capacity for each fuseholder located in all the installed control systems and the Control Contractor's related equipment.
- B. The Control Contractor shall provide two spare pilot lights for each control unit that contains one or more pilot lights.

6.06 TRAINING

- A. Provide a minimum of one 4-hour on-site training sessions after system acceptance and at the owner's request. The training session will occur after the as-built drawings and submittals have been provided and the Engineer has accepted the system.
- B. Training shall introduce users to the system changes.
- C. If during any training session, the trainer debugs more than two (2) items, the training session will be immediately terminated. The session will be rescheduled for another date. The re-scheduled training session will be carried out for the full four hours at no additional cost to the Owner.
- D. The trainer must be well grounded in both DDC system operation and in mechanical systems service and should be the programmer.
- E. The Owner may specify another school site for training if desired.

END OF SECTION 23 09 23