

SECTION 15950
DIRECT DIGITAL CONTROL SYSTEM

PART 1 - GENERAL

1.1 RELATED DOCUMENTS

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

1.2 SUMMARY

- A. This Section includes new DDC (Direct Digital Control) systems including associated equipment and accessories. Provide each control system complete, and operating as specified. Manufacturer's products, including design, materials, fabrication, assembly, erection, examination, inspection and testing shall be in accordance with ASME B31.9 and NFPA 70, except as modified herein or indicated otherwise. The DDC system shall maintain stable temperature control and all other conditions as indicated. The end-to-end accuracy of the system, including temperature sensor error, wiring error, A/D conversion, and display, shall be 2 degree F or less.
1. Requirements for direct digital control (DDC) of heating, ventilating, and air conditioning (HVAC) systems. The intent of this specification is to provide a multiloop, stand-alone, and distributed digital control system as manufactured by companies in the HVAC control field. This control system shall provide for all HVAC control functions. Analog and digital (binary, on/off, open/close) control signals are input to microprocessor based digital controllers. The digital controllers perform the control logic and output analog and digital signals to the HVAC equipment.
 - a. Interface ports are to allow connection to a terminal, portable computer, and a central building computer. The interface equipment will not provide day to day control of the HVAC system, but it will allow the operator to enable and disable equipment, change setpoints, change operating schedules, receive trends and alarms, and allow downloading of control programs.
- B. Related Sections include the following:
1. Division 15, Section 15960, "Laboratory Airflow Control System."
 2. Division 16, Section 16484, "Variable Frequency Drives."
 3. Division 16, Section 16730, "Fire Alarm Specification, Local Building Devices."
 4. Division 16, Section 16735, "Site Fire Detection and Alarm System."

1.3 REFERENCES

- A. The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.
- B. Air Movement and Control Association, Inc. (AMCA):
1. AMCA 500 (1991) Louvers, Dampers and Shutters.
- C. American National Standards Institute (NFPA):
1. ANSI C12.10 (1987) Electromechanical Watthour Meters.
 2. ANSI C57.13 (1978; R 1987) Instrument Transformers.
- D. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE):
1. ASHRAE 3 (1990; Addendum 1992).

Reducing Emission of Fully Halogenated Chlorofluorocarbon
(CFC) Refrigerants in Refrigeration and Air-Conditioning
Equipment and Applications.

- E. American Society of Mechanical Engineers (ASME):
1. ASME/ANSI B16.5 (1996) Pipe Flanges and Flanged Fittings NPS ½ through NPS 24.
 2. ASME/ANSI B16.18 (1984; R 1994) Cast Copper and Alloy Solder Joint Pressure Fittings.
 3. ASME/ANSI B16.22 (1995) Wrought Copper and Copper Alloy Solder Joint Pressure Fittings.
 4. ANSM/ANSI B16.26 (1988) Cast Copper Alloy Fittings for Flared Copper Tubes.
 5. ASME/ANSI B16.34 (1996) Valves – Flanged, Threaded, and Welding End.
 6. ANSI/ASME B40.1 (1991) Special Notice 1992) Gauges – Pressure Indicating Dial Type – Elastic Element.
 7. ASME BPVC SEC VIII (1995) Addenda 1995) Boiler and Pressure Vessel Codes: Section VIII Pressure Vessels.
- F. American Society for Testing and Materials (ASTM):
1. ASTM A 126 (1995) Gray Iron Castings.
 2. ASTM B 32 (1996) Solder Metal.
 3. ASTM B 75 (1995) Rev. A) Seamless Copper Tube.
 4. ASTM B 88M (1996) Seamless Copper Water Tube (Metric).
 5. ASTM B 88 (1996) Seamless Copper Water Tube.
 6. ASTM D 638 (1995) Tensile Properties of Plastics.
 7. ASTM D 792 (1991) Density and Specific Gravity (Relative Density) of Plastics by Displacement.
 8. ASTM D 1238 (1995) Thermoplastics by Extrusion Plastometer Flow Rates.
 9. ASTM D 1693 (1995) Environmental Stress-Cracking of Ethylene Plastics.
- G. National Fire Protection Association (NFPA):
1. NFPA 70 (1996) National Electrical Code.
 2. NFPA 90A (1993) Installation of Air Conditioning and Ventilating Systems.
- H. Sheet Metal & Air Conditioning Contractors' National Association, Inc. (SMACNA):
1. SMACNA DCS (1995; Addendum 1997) HVAC Duct Construction Standards, Metal and Flexible.
 2. SMACNA HVACTAB (1993) HVAC Systems Testing, Adjusting and Balancing.
- I. Underwriters Laboratories, Inc. (UL):
1. UL 506 (1994; R 1994, Bul. 1995 and 1996) Specialty Transformers.
 2. UL 916 (1994; Bul. 1994 and 1996, R 1996) Energy Management Equipment.
 3. UL 1449 (1985; Errata 1986, Bul. 1993, 1994, and 1995) Transient Voltage Surge Suppressors.

1.4 DEFINITIONS

- A. Digital Controller. A control module which is microprocessor based, programmable by the user, has integral input/output within the module or on network connected modules, and performs stand-alone operations.
- B. Direct Digital Control (DDC). Digital controls, as defined in this specification, perform control logic. The controller directly senses building environment and makes control decisions based on user defined, controller resident programs. The controller outputs control signals that di-

rectly operate valves, dampers, and motor controllers. No conventional control devices, pneumatic or electronic, such as receiver-controllers, thermostats, and logic units are present within or interface with a direct digital control loop. Actuators are electric or pneumatic, and the controller output is converted to the appropriate type of signal.

- C. DDC System. A system made up of one or more digital controllers that communicates on a network.
- D. Distributed Control. The intent of distributed control is to install the controllers near their respective controlled equipment. The control system consists of stand-alone controllers, with the total number of input and output points limited to 48 or less per controller. Failure of any single controller will not cause the loss of more than 48 control points.
- E. Dynamic Control. A process that optimizes operation of HVAC systems (air handling units, boilers, etc.) by increasing and decreasing setpoints or starting and stopping equipment in response to heating and cooling needs of downstream equipment. A requirement of dynamic control is to know the heating/cooling demand status of the downstream equipment, therefore dynamic control requires controllers connected in a communications network.
- F. Firmware. Firmware is software programmed into Read Only Memory (ROM) and Erasable Programmable Read Only Memory (EPROM) chips. Software may not be changed without physically altering the chip.
- G. Hand-Held Terminal. A hand-held terminal is a manufacturer specific device connected directly to a communications port on a controller, through which the controller is accessed and, in some cases, programmed.
- H. Input/Output (I/O) Points I/O points refer to analog inputs (AI), digital inputs (DI), analog outputs (AO), and digital outputs (DO) in a digital controller. Another term for digital inputs and outputs is binary inputs and outputs. Inputs are from analog sensors (temperature, pressure, humidity, flow) and digital sensors (motor status, flow switches, switch position, and pulse output devices). Outputs operate modulating and on/off control devices.
- I. I/O Expansion Unit An I/O expansion unit provides additional point capacity to a digital controller and communicates with the stand-alone digital controller on a LAN. An I/O unit is not stand-alone because the control program does not reside in the I/O unit. An I/O expander which connects directly to a stand alone controller through a multi-line microprocessor bus is restricted to reside within 3 feet of the stand alone controller and is considered part of the stand alone controller.
- J. Local Area Network (LAN):
 - 1. A communications bus that interconnects digital controllers for peer-to-peer (see "peer-to-peer" below) communications. Different levels of LANs are possible within a single DDC system. In this case, a digital controller on a higher level LAN acts as a network controller to the controllers on the lower level LAN. The network controller, then, has at least two LAN communications ports. One port supports peer-to-peer communications with other digital controllers on the higher level LAN. The other port supports communications with the digital controllers on the lower level LAN.
 - 2. LANs permit sharing global information. This allows building control strategies such as energy monitoring, peak demand limiting, dynamic control strategies, coordinated response to alarm conditions, and remote monitoring and programming of digital controllers.
- K. Microprocessor. A microprocessor refers to the Central Processing Unit (CPU) that contains all registers and logic circuitry that allow digital controllers to function.

- L. Output Signal Conversion. Output signal conversion refers to changing one kind of control output into a proportionally related signal appropriate for direct actuation of the controlled device. An example is converting a 4 to 20 mA or 0 to 10 VDC signal to a proportional 3 to 15 psig signal to operate a pneumatic actuator.
- M. Optimum Start. Optimum start is a method of starting HVAC equipment prior to scheduled occupancy in order to have the building at setpoint when occupied. Optimum start is based on the zone temperatures, zone setpoints, and outdoor temperature.
- N. Peer-to-Peer. Peer-to-peer refers to controllers connected on a communications LAN that act independently, as equals, and communicate with each other to pass information.
- O. Proportional-Integral-Derivative (PID). The three types of control action that are used in controlling modulating HVAC equipment.
- P. Resolution. Refers to the number of possible states an input value or output value can take and is a function of the digital controller I/O circuitry; the A/D converter for input and the D/A converter for output. Ten bit resolution has 1024 possible states.
- Q. Stand-Alone Control. Refers to the digital controller performing required climate control, and energy management functions without connection to another digital controller or computer. Requirements for stand-alone control are a time clock, a microprocessor, resident control programs, PID control, and I/O. All stand-alone controllers have a communication port and firmware for direct connection and interrogation with a laptop computer or similar hand-held device. This interrogation includes parameter changes and program downloads.
- R. Terminal Control Unit (TCU). An off-the-shelf, stand-alone digital controller equipped for communication on a lower level LAN. TCUs may deviate from stand-alone only in receiving energy management and time information from a stand alone digital controller. A TCU is commonly application specific and is used for distributed control of specific HVAC subsystems. A TCU communicates with other digital controllers. Typically, a TCU communicates on a lower level LAN. Examples where TCUs are used include, variable air volume (VAV) boxes and fan coil units.

1.5 SUBMITTALS.

- A. Submit manufacturers' specification sheets for each type of equipment to show compliance with the project specification. For each type of equipment highlight each compliance item and reference each item to the relevant specification paragraph number. Submit sufficient manufacturers' information to allow verification of compliance by the reviewing authority. Equipment and software for which specification compliance data shall be submitted includes but is not limited to the following:
 - 1. Preconstruction Materials:
 - a. List of Drawings.
 - b. List of Symbols and Abbreviations Used on Drawings.
 - c. List of I/O Points.
 - d. Equipment Components List.
 - e. AC Power Table.
 - 2. Shop Drawings:
 - a. Control system schematic.
 - b. Ladder diagrams.
 - c. Component wiring diagrams.
 - d. Terminal strip diagrams.
 - e. Communication architecture schematic.
 - 3. Product Data:
 - a. DDC hardware.

- b. DDC capabilities.
 - c. Workstation software.
 - d. Input devices.
 - e. Output devices.
 - f. Surge and transient protection.
 - g. Notebook computer.
 - h. Hand-held terminal.
 - i. Smoke detectors.
 - j. Pneumatic tubing.
4. Test Reports:
- a. Field tests.
 - b. Performance verification tests.
5. Certificates:
- a. Contractors' Qualifications.
 - b. Training.
 - c. Pressure Tank Certification.
6. Operation and Maintenance Data:
- a. Controls and HVAC System Operators Manual.
 - b. DDC Manufacturer's Hardware and Software Manuals.
7. Closeout Submittals:
- a. Provide administrative and closeout submittals:
 - 1) Training course documentation.
 - 2) Service organizations.
 - 3) Contractor organization.

1.6 QUALITY ASSURANCE

- A. Standard Products. Material and equipment shall be standard products of manufacturer regularly engaged in the manufacturing of such product, using similar materials, design and workmanship. The standard products shall have been in commercial or industrial use for 2 years prior to bid opening. The 2year use shall include applications of similarly sized equipment and materials used under similar circumstances and sold on the commercial market through advertisements, manufacturers' catalogs, or brochures. Products shall be supported by a local service organization.
- 1. DDC Hardware:
 - a. I/O type and characteristics.
 - b. Resident programs.
 - c. Communications ports.
 - d. Protected memory.
 - e. Operating temperature limits.
 - 2. DDC Capabilities:
 - a. Communications; baud rates, communication ports, hierarchy.
 - b. Trending capabilities.
 - c. Alarming capabilities; capable of alarm generation.
 - d. Messaging capabilities.
 - e. PID control capabilities.
 - f. Energy Monitoring.
 - 3. Workstation Software:
 - a. Mouse and keyboard operation.
 - b. Communications.
 - c. DDC Program download capability.
 - d. Dynamic point update.
 - e. Program modification.
 - f. Database modification.
 - g. Graphics and graphics modification.
 - h. Penetration of graphics.

4. Input Devices:
 - a. Transmitters.
 - b. Temperature sensors.
 - c. Humidity sensors.
 - d. Pressure sensors.
 - e. Flow switches and sensors.
 - f. Sensor wells.
 - g. Energy monitoring modules.
 5. Output Devices:
 - a. Dampers.
 - b. Valves.
 - c. Actuators.
 - d. Control relays.
 - e. Solenoid air valves.
 - f. Electronic to pneumatic transducer.
 6. Surge and Transient Protection:
 - a. Power line.
 - b. Communications lines.
 - c. Controller I/O.
- B. Nameplates and Tags:
1. Nameplates and tags bearing device unique identifiers shall be engraved or stamped. Permanently attach nameplates to HVAC control panel doors and back plates.
 2. For each field mounted piece of equipment attach a plastic or metal tag with equipment name and point identifier.
- C. Verification of Dimensions. The contractor shall verify all dimensions in the field, and shall advise the Construction Manager of any discrepancy before performing work.
- D. Drawings. Because of the small scale of the drawings, it is not possible to indicate all offsets, fittings, and accessories that may be required. The Contractor shall carefully investigate the mechanical, electrical, and finish conditions that could affect the work, and shall furnish all work necessary to meet such conditions.
1. List of Drawings. Provide a list of drawings.
 2. List of Symbols and Abbreviations Used on Drawings. Provide an index of symbols and abbreviations used on the drawings.
 3. List of I/O Points. For each input and output physically connected to a digital controller provide, on a controller by controller basis, the following:
 - a. Point description (for ex): mixed air temperature, supply fan start/stop, energy monitoring, etc.
 - b. Point type: AO, AI, DO, or DI.
 - c. Point range.
 - d. Sensor range associated with point range.
 - e. Software name(s) associated with point, if any.
 - f. Point connection terminal number.
 4. Equipment Components List. Submit a listing of controllers and connected devices shown on control system schematic. List the following:
 - a. Control system schematic name.
 - b. Description.
 - c. Manufacturer of controller.
 - d. Controller's name.
 - e. Equipment part numbers.
 - f. Cv for valves.
 - g. For actuators:
 - 1) Motive force (such as pneumatic, or electric).
 - 2) Normal position.

- 3) Nominal operating range (such as 3 to 7 psi, 4 to 8 mA).
 5. AC Power Table. Submit a table listing each controller and the circuit breaker number, panel box number, and physical location of each controller's source of AC power.
- E. Contractor's Qualifications:
1. The Contractor or subcontractor performing the work shall have completed at least three DDC systems installations of a similar design and have successfully operated a similar sequence of operation for at least three years.
- F. Training Course Documentation. Training course documentation shall include a manual for each trainee plus two additional copies and two copies of audiovisual training aids, if used. Documentation shall include an agenda, defined objectives for each lesson and detailed description of the subject matter of each lesson.
- G. Service Organizations. Qualified service organization list that shall include the names and telephone numbers of organizations qualified to service the HVAC control systems.
- H. Contractor's Completion Certification. Provide certification that the installation of the control system is complete and meets the technical requirements of this section.
- I. Controls and HVAC System Operators Manual. Provide six copies of a Control and HVAC Systems Operators Manual. Provide in a 3 ring binder with a minimum of the following 7 Sections. Use tabs to divide each section.
1. Description of HVAC Systems: Provide a description of the HVAC system components and control system. Include sequence of operation and a complete points list.
 2. Controls Drawings: Provide drawings as specified in submittal paragraph.
 3. Control Program Listings: Provide listing of all control programs, including terminal equipment controller setup pages if used.
 4. Current Operating Parameters: Provide printouts of input and output setup information, (database setups). This section provides information such as point addresses, slopes and offsets for all points, database of points, etc.
 5. Design Information: Provide tab, but leave this section blank.
 6. Control Equipment Technical Data Sheets: Provide technical data sheets for all controller hardware and accessories.
 7. Backup of Control Program: Provide backup copies of the control program and ACAD control drawings on a CD-ROM Disk.
- J. DDC Manufacturer's Hardware and Software Manuals. Provide the following manuals:
1. Installation and Technical Manuals for all digital controller hardware.
 2. Installation and Technical Manuals for workstation.
 3. Operator Manuals for all digital controllers.
 4. Operator Manuals for all workstation software.
 5. Programming Manuals for all digital controllers.
 6. Programming Manuals for workstation software.
- K. Modification of References. The advisory provision in ASME B31.1 and NFPA 70 are mandatory. Substitute the word "shall" for "should" wherever it appears and interpret all references to the "authority having jurisdiction" and "owner" to mean the Construction Manager.

1.7 DDC SYSTEM DESCRIPTION REQUIREMENTS

- A. Provide control system schematic that includes the following:
1. Location of each input and output device.
 2. Flow diagram of each HVAC component, for airflow through coils, fans and dampers.

3. Name or symbol for each component such as V-1, DM-2, and T-1 for a valve, damper motor, and temperature sensor, respectively.
 4. Setpoints.
 5. Sensor range.
 6. Actuator range.
 7. Valve and damper schedules and normal position.
 8. Switch points on input switches.
 9. Written sequence of operation for each schematic.
 10. Schedule identifying each sensor and controlled device with the following information:
 - a. LAN and Software point name with send and receive address if applicable.
 - b. Point type (AO, AI, DO, DI).
 - c. Point range.
 - d. Digital controller number for each point.
- B. Electrical Equipment Ladder Diagrams. Submit diagrams showing electrical equipment interlocks, including voltages and currents.
- C. Component Wiring Diagrams. Submit a wiring diagram for each type of input device and each type of output device. Diagram shall show how the device is wired and powered; showing typical connections at the digital controller and each power supply, as well as at the device itself. Show for all field connected devices, including, but not limited to, control relays, motor starters, electric or electronic actuators, and temperature, pressure, flow, proof, and humidity sensors and transmitters.
- D. Terminal Strip Diagrams. Submit a diagram of each terminal strip, including digital controller terminal strips, terminal strip location, termination numbers and the associated point names.
- E. Communication Architecture Schematic. Submit a schematic showing communication networks used for all DDC system controllers, workstations, and field interface devices.

PART 2 - PRODUCTS

2.1 DDC SYSTEM

- A. Provide a DDC system as a distributed control system. The system shall have stand-alone digital controllers, a communications Network, and a separate workstation computer with workstation software. Provide an operator programmable system to perform closed-loop, modulating control of building equipment. Connect all digital controllers through the communication network to share common data and report to workstation computers. Provide workstation DDC software capable of programming and monitoring the digital controllers. The control system shall be capable of downloading programs between the workstation and digital controllers. Provide the quantity of digital controllers indicated on the drawings to perform required climate control, energy management, and alarm functions. The quantity of controllers shall be no less than the number shown on drawings. All material used shall be currently in production.
1. Direct Digital Controllers. DDC Hardware shall be UL 916 rated.
 - a. Distributed Control. Apply digital controllers in a distributed control manner.
 - b. I/O Point Limitation. Total number of I/O hardware points, including those communicated over a LAN, used by a single stand-alone digital controller, including I/O expansion units shall not exceed 48.
 - c. Environmental Operating Limits. Provide digital controllers that operate in environmental conditions between 32 and 120 degrees F.
 - d. Stand-Alone Control. Provide stand-alone digital controllers.
 - e. Internal Clock. Provide a clock with each stand-alone controller. Each controller shall have its clock backed up by a battery or capacitor with sufficient capacity to maintain clock operation for a minimum of 72 hours during power outage.

- f. Memory:
 - 1) Provide sufficient memory for each controller to support required control, communication, trends, alarms, and messages.
 - 2) Memory Protection: Programs residing in memory shall be protected either by using EEPROM, flash memory, or by an uninterruptible power source (battery or uninterruptible power supply (UPS)). The backup power source shall have sufficient capacity to maintain volatile memory during an AC power failure. Where the uninterruptible power source is rechargeable (a rechargeable battery), provide sufficient back-up capacity for a minimum of seventy-two hours. The rechargeable power source shall be constantly charged while the controller is operating under normal line power. Where a non-rechargeable power source is used, provide sufficient capacity for a minimum of two years accumulated power failure. Batteries shall be replaceable without soldering.
- g. Inputs. Provide input function integral to the direct digital controller. Provide input type(s) as required by the DDC design. For each input type used on high-level controllers, provide at least one similar spare input point per controller.
 - 1) Analog Inputs: Allowable input types are 100 ohm (or higher) platinum RTDs, thermistors, 4 to 20 mA, and 0-10 VDC. Thermistor and direct RTD inputs must have appropriate conversion curves stored in controller software or firmware. Analog to digital (A/D) conversion shall have 10-bit minimum resolution.
 - 2) Digital Inputs: Digital inputs shall sense open/close, on/off, or other two state indications.
- h. Outputs. Provide output function integral to the direct digital controller. Provide output type(s) as required by the DDC design. For each output type used on high-level controllers, provide at least one similar spare point per controller.
 - 1) Analog Outputs: Provide controllers with a minimum output resolution of 10 bits. Output shall be 4 to 20 mA, 0 to 10 VDC, or 0 to 20 psig. Each pneumatic output shall have feedback for monitoring of the actual pneumatic signal.
 - 2) Digital Outputs: Provide contact closure with contacts rated at a minimum of 1 ampere at 24 volts.
- i. PID Control. Provide controllers with proportional integral, and derivative control capability. Terminal controllers are not required to have the derivative component.
- j. Digital Controller Networking Capabilities. The upper level digital controllers shall be capable of networking with other similar upper level controllers. Upper level controllers shall also be capable of communicating over a network between buildings.
- k. Communications Ports :
 - 1) Controller-to-Controller LAN Communications Ports: Controllers in the building DDC system shall be connected in a communications network. Controllers shall have controller to controller communication ports to both peer controller (upper level controllers) and terminal controllers (lower level controllers). Network may consist of more than one level of local area network and one level may have multiple drops. Communications network shall permit sharing information between controllers, allowing execution of dynamic control strategies, and coordinated response to alarm conditions. Minimum baud rate for the lowest level LAN shall be 9,600 Baud. Minimum baud rate for the highest level LAN shall be 9,600 Baud. Minimum baud rate for a DDC system consisting of a single LAN shall be 9,600 Baud.
 - 2) On-Site Interface Ports: Provide a RS-232, RS-485, or RJ-11 communications port for each digital controller that allows direct connection of a computer or hand held terminal and through which the controller may be

- fully accessed. Controller access shall not be limited to access through another controller. On-site interface communication ports shall be in addition to the communications-port supporting controller to controller communications. Communication rate shall be 9,600-Baud minimum. Every controller on the highest level LAN shall have a communications port supporting direct connection of a computer; a hand held terminal port is not sufficient. By connecting a computer to this port, every controller in the direct digital control system shall be able to be fully accessed and programmed. The following operations shall be available: downloading and uploading control programs, modifying programs and program database, and retrieving or accepting trend reports, status reports, messages, and alarms.
- 3) Remote Work Station Interface Port: Provide one additional direct connect computer port in each DDC system for permanent connection of a remote operator's work station, unless the workstation is a node on the LAN. All operations possible by directly connecting a computer to a controller at the highest level LAN shall be available through this port.
 - 4) Telecommunications Interface Port: Provide one additional telecommunications port in each DDC system permitting remote communications via telephone. All operations possible by directly connecting a computer to a controller at the highest level LAN shall be available through the telecommunications port. A telecommunications port provided on a digital controller shall be in addition to the port required for directly connecting a computer to the controller. Telecommunication baud rate shall be 28,000 minimum.
- l. Modem. Provide two modems per DDC system to communicate between the digital control system and the computer workstation. Minimum modem baud rate is 56 Kbaud with v.90 communication standard.
 - m. Digital Controller Cabinet. Each indoor digital controller cabinet shall protect the controller from dust and shall be rated NEMA 1, unless specified otherwise. Each outdoor digital controller cabinet shall protect the controller from all outside conditions and shall be rated NEMA 4. Cabinets for high level controllers shall be hinged door, lockable, and have offset removable metal back plate.
 - n. Main Power Switch. Each controller on the highest level LAN or each control cabinet shall have a main external power switch for isolation of the controller from AC power. The switch shall be located in the DDC cabinet.
2. Terminal Control Units. The same company as the digital controllers shall manufacture TCUs. TCUs shall automatically start-up on return of power after a failure, and previous operating parameters shall exist or shall be automatically downloaded from a digital controller on a higher level LAN. TCUs do not require an internal clock, if they get time information from a higher level digital controller.
 3. DDC Software:
 - a. Sequence of Control. Provide, in the digital controllers, software to execute the sequence of control. Provide one registered copy of all software used to program control sequences in direct digital controllers, LAN controllers and field configurable smart controllers on the stationary (notebook) workstation. Provide access-keys that restrict programming language software functions or the ability to compile or prepare programming for download to controllers. Provide final copy of each program used in the system in both compiled and editable formats. Where specially programmed factory configured smart controllers are used in the system, provide the minimum factory programming tools and specialized controller programs ready for download to replacement controllers. At minimum, controllers must be capable of performing programming functions outlined in the following "Parameter Modification" section.
 - b. Parameter Modification. Provide software to modify control parameters. Parameter modification shall be accomplished for all controllers (high level and

low level application specific) through the main workstation computer and with laptop computer or keypad terminal directly at each controller. Modifications shall be accomplished without having to make changes directly in line-by-line programming. When the control program is of the line-by-line type, database parameters in the following list that take real number values shall require assignment of variable names so parameters can be changed without modifying programming. Alternatively, block-programming languages shall provide for modification of these database parameters in fill-in-the-blank screens. Parameters of like type, including those in different high level and low level controllers, may be grouped together for a single, global change. For example, an operator may group all second floor space temperature setpoints into a group and raise the setpoint by two degrees with a single command. The following parameters shall be modifiable in this way:

- 1) Setpoints.
 - 2) Dead band limits and spans.
 - 3) Reset schedules.
 - 4) Switchover points.
 - 5) PID gains and time between control output changes.
 - 6) Time.
 - 7) Timed local override time.
 - 8) Occupancy schedules.
 - 9) Holidays.
 - 10) Alarm points, alarm limits, and alarm messages.
 - 11) Point definition database.
 - 12) Point enable, disable, and override.
 - 13) Trend points, trend intervals, trend reports.
 - 14) Analog input default values.
 - 15) Passwords.
 - 16) Communications parameters, including network and telephone communication setups.
- c. Differential. Where setpoint is in response to some analog input such as temperature, pressure, or humidity, include a setpoint differential for the control loop to prevent short cycling of control devices.
- d. Flow Status Delay. Provide an adjustable delay between when a motor is commanded on or off and when the control program looks to the flow status input for confirmation of successful command execution.
- e. Runtime Accumulation. Provide resettable run time accumulation for each controlled digital output.
- f. Timed Local Override. Provide user definable adjustable run time for each push of a momentary contact timed local override. Pushes shall be cumulative with each push designating the same length of time. Provide a user definable limit on the number of contact closures summed, such as 6, before the contact closures are ignored. Timed local overrides are disabled during occupancy periods.
- g. Time Programs. Provide programs to automatically adjust for leap years, and make daylight savings time and standard time adjustments.
- h. Scheduling:
- 1) Individual controlled equipment shall be schedulable with schedule based on time of day, day of week, and day of year. Equipment may be associated into groups. Each group may be associated with a different schedule. Changing the schedule of a group shall change the schedule of all equipment in the group. Groups may be modified, created and deleted by the operator.
 - 2) Provide capability that will allow current schedules to be viewed and modified in a seven-day week format. When control program does not

- automatically compute holidays, provide capability to enter holiday schedules one full year at a time.
- i. Point Override. I/O and virtual points shall accept software overrides to any possible value.
 - j. Alarming. I/O points and software points shall be alarmable. Alarms may be enabled and disabled for every point. Alarm limits shall be adjustable on analog points. Controllers connected to an external communications device such as a printer, terminal, or computer, shall download alarm and alarm message when alarm occurs. When a computer workstation is connected to a DDC system with a modem, operator selected alarm conditions will initiate a call and report to the computer. Otherwise alarms will be stored and automatically downloaded when a communications link occurs. The following conditions shall generate alarms:
 - 1) Motor is commanded on or off but the motor status input indicates no change.
 - 2) Temperature, humidity, or pressure strays outside selectable limits.
 - 3) An analog input takes a value indicating sensor failure.
 - 4) A module is not communicating on the LAN.
 - 5) A power outage occurs.
 - 6) Alarms as shown on the drawings.
 - k. Messages. Messages shall be operator defined and assigned to alarm or status conditions. Messages shall be displayed on the workstation or printer when these conditions occur.
 - l. Trending. DDC system shall have the capability to trend all I/O and virtual points. Points may be associated into groups. A trend report may be set up for each group. The period between logging consecutive trend values shall range from one minute to 60 minutes at a minimum. The minimum number of consecutive trend values stored at one time shall be 30 per variable. When trend memory is full, the most recent data shall overwrite the oldest data. Trend data shall be capable of being uploaded to computer. Trend data shall be available on a real time basis; trend data shall appear numerically and graphically on a connected computer's screen as the data is processed from the DDC system. Trend reports shall be capable of uploading to computer for storage.
 - m. Status Display. Current status of I/O and virtual points shall be displayed on command. Points shall be associated into functional groups, such as all the I/O and virtual points associated with control of a single air handling unit, and displayed as a group, so the status of a single mechanical system can be readily checked. A group shall be selectable from a menu of groups having meaningful names; such as AHU-4, Second Floor, Chiller System, and other such names.
 - n. Diagnostics. Each controller shall perform self-diagnostic routines and provide messages to an operator when errors are detected. The DDC system shall be capable of recognizing a non-responsive module on a LAN. The remaining, responsive modules on a LAN shall not operate in a degraded mode.
 - o. Power Loss. During a power outage, each controller shall assume a disabled status and outputs shall go to a user definable state. Upon restoration of power, DDC system shall perform an orderly restart, with sequencing of outputs.
 - p. Program Transfer. Provide software for download of control programs and database from a computer to controllers and upload of same to computer from controllers. Every digital controller in the DDC system shall be capable of being downloaded and uploaded to through a single controller on the highest level LAN.
 - q. Password Protection. Provide at least three levels of password protection to the DDC system permitting different levels of access to the system. The lowest

- level allows monitoring only. The highest level allows full control of all functions, including setting new passwords.
4. Workstation. Provide a central workstation computer with installed software to provide an interface for monitoring, troubleshooting, and making adjustments to the program or operating parameters of all DDC controllers, including TCUs. The workstation shall also be capable of programming all controllers, including TCUs. DDC system shall routinely operate continuously without connection to the workstation. Information at the workstation is not required for day to day operations of the direct digital controllers.
 - a. Hardware. The DDC system manufacturer shall recommend all workstation computer equipment and peripherals. The workstation shall be configured to operate according to the DDC system manufacturer's specifications. Workstation hardware shall be configured to allow operation of software, uploading and downloading of programs, and creation of graphics. At a minimum the workstation hardware shall consist of:
 - 1) Computer; computer shall use the latest version of Microsoft Windows, and shall not have less than the current Intel processor, running at 350 megahertz speed, 12 giga-byte hard disc, 128 megabyte RAM, 2 serial and 1 parallel port, 17 inch monitor with 740 x 1024 and 0.28 dpi minimum resolution, 101 character keyboard, a 1.4 megabyte 3 1/2 inch floppy drive, 48X internal CD ROM drive, and internal 100MB Zip drive with 2 Zip disks.
 - 2) Mouse.
 - 3) Modem; 56 Kbaud, v.90 standard.
 - 4) Printer; printer resolution shall be inkjet laser quality.
 - 5) 120-volt terminal strip UL 1449 6-outlet with surge protection.
 - b. Software. Workstation software shall be recommended and supported by the DDC system manufacturer and configured to operate according to the DDC system manufacturer's specifications. Software shall be resident in the workstation computer and permit monitoring and troubleshooting of the DDC system. Workstation software permits modification of controller parameters and control for all controllers, both high level and low level application specific. Operations shall be menu selected. Menu selections shall be made with a mouse.
 - 1) Menu System: Menu system shall allow an operator to select a particular function or access a particular screen through successive menu penetration.
 - 2) Controller Parameter Modification: The workstation software shall be an interface for performance specified in paragraph entitled "Parameter Modification" and available through direct connection of a computer to a digital controller. Parameter modification shall require only that an operator "fill in the blank" for a parameter on a screen requesting the information in plain language. Parameter modifications shall download to the appropriate controllers at operator request.
 - 3) Program modification: For systems using a line-by-line programming language, provide an off-line text editor, similar to a BASIC program editor, permitting modification of controller resident control programs. For systems using a block programming language, provide a capability for linking blocks together to create new programs or modify to existing programs. Program modifications shall download to appropriate controllers at operator request.
 - c. Graphic-Based Software. The workstation shall use graphic-based software to provide a user-friendly interface to the DDC system. Graphic-based software shall provide graphical representation of the building, the buildings mechanical systems, and the DDC system. The current value and point name of every I/O point shall be shown on at least one graphic and in its appropriate physical location relative to building and mechanical systems.

- 1) Graphics shall closely follow the style of the control drawings in representing mechanical systems, sensors, controlled devices, and point names.
 - 2) Graphic Title: Graphics shall have an identifying title visible when the graphic is being viewed.
 - 3) Dynamic Update: When the workstation is on-line with the control system, point data shall update dynamically on the graphic images.
 - 4) Graphic Penetration: Provide graphic penetration when the capability exists. For systems without graphic penetration, provide menu penetration for selection of individual graphics to give the same hierarchical affect provided by graphic penetration.
 - 5) Graphic Types: Graphic-based software shall have graphics of the building exterior, building section, floor plans, and mechanical systems. Provide the following graphics:
 - a) Building Exterior Graphic: Show exterior architecture, major landmarks, and building number.
 - b) Building Section Graphic: Show floors in section graphic with appropriate floor names.
 - c) Floor Plan Graphics: Provide a single graphic for each floor, unless the graphic will contain more information than can reasonably be shown on a single graphic. Each heating or cooling zone within a floor plan shall have a zone name and its current temperature displayed within the zone outline. Show each controlled variable in the zone. Provide visual warning for each point in alarm.
 - d) Mechanical System Graphics: Provide two-dimensional drawings to symbolize mechanical equipment; do not use line drawings. Show controlled or sensed mechanical equipment. Each graphic shall consist of a single mechanical system; examples are a graphic for an air handling unit, a graphic for a VAV box, a graphic for a heating water system, and a graphic for a chilled water system. Place sensors and controlled devices associated with mechanical equipment in their appropriate locations. Place point name and point value adjacent to sensor or controlled device. Provide visual warning of each point in alarm. Condition, such as zone temperature, associated with the mechanical system shall be shown on the graphic. Point values shall update dynamically on the graphic.
 - 6) Graphic Editing: Full capacity as provided by a draw software package shall be included for operator editing of graphics. Graphics may be created, deleted, modified, and text added. Provide capability to store graphic symbols in a symbol directory and import these symbols into graphics. A minimum of 256 colors shall be available.
 - 7) Dynamic Point Editing: Provide full editing capability for deleting, adding, and modifying dynamic points on graphics.
 - 8) Trending: Trend data shall be displayed graphically, with control variable and process variable plotted as functions of time on the same chart. Graphic display of trend data shall be internal to the workstation software and not resulting from download of trend data into a third-party spreadsheet program, unless such transfer is automatic and transparent to the operator, and the third-party software is included with the workstation software package. At the operator's discretion, trend data shall be plotted real time.
- d. Maintenance Personnel Interface Tools. Provide a notebook computer for field communication with the digital controllers. In addition to changing setpoints,

and making operational changes, field personnel shall be able to download programs with the notebook computer.

- 1) Notebook Computer:
 - a) Provide notebook computer, necessary software, and direct connection cable to communicate with all digital controllers.
 - b) Provide a current notebook computer with the following features as a minimum:
 - 350 MHz processor or faster if available with an active matrix color screen.
 - Internal hard disk; minimum 6 Gigabytes.
 - Internal battery operation; for a minimum of 3 hours of operation.
 - RAM; minimum 64 Megabytes.
 - 24X CD ROM and 3.5 inch 1.44 MB floppy drive.
 - Serial interface port to communicate with the digital controller. Parallel port to communicate with a printer.
 - Software: Digital control manufacturer's graphic DDC software, and all other required programs installed. Windows 98 operating system installed. Include all documentation and original media.

2.2 SENSORS AND INPUT HARDWARE

A. Field Installed Temperature Sensors:

1. Thermistors. Precision thermistors may be used in temperature sensing applications below 200 degrees F. Sensor accuracy over the application range shall be 0.36 degree F or less between the range of 32 to 150 degrees F. Stability error of the thermistor over five years shall not exceed 0.25 degree F cumulative. Sensor element and leads shall be encapsulated. Bead thermistors are not allowed. A/D conversion resolution error shall be kept to 0.1 degree F. Total error for a thermistor circuit shall not exceed 0.5 degree F, which includes sensor error and digital controller A/D conversion resolution error. Provide 18 gage twisted and shielded cable for thermistors.
 - a. Resistance Temperature Detectors (RTDs). Provide RTD sensors with 1,000 ohm, or higher, platinum elements that are compatible with the digital controllers. Sensors shall be encapsulated in epoxy, series 300 stainless steel, anodized aluminum, or copper. Temperature sensor accuracy shall be 0.1 percent (1 ohm) of expected ohms (1,000 ohms) at 32 degrees F. Temperature sensor stability error over five years shall not exceed 0.25 degree F cumulative. Direct connection of RTDs to digital controllers, without transmitters, is preferred provided controller supports direct connection of RTDs. When RTDs are connected directly to the controller, keep lead resistance error to 0.25 degree F or less. Total error for a RTD circuit shall not exceed 0.5 degree F, which includes sensor error, lead resistance error or 4 to 20 mA or 0 to 10 VDC transmitter error, and A/D conversion resolution error.
 - b. Temperature Sensor Details:
 - 1) Room Type: Conceal element behind protective cover matched to the room interior. Room temperature sensors connected directly to application specific controllers shall have integral pushbutton, system override digital input button, and a setpoint adjustment lever.
 - 2) Duct Averaging Type: Continuous averaging RTDs for ductwork applications shall be one foot in length for each 4 square feet of ductwork cross-sectional area with a minimum length of 6 feet. Probe type duct sensors of one foot length minimum are acceptable in ducts 12 feet square and less.

- 3) Immersion Type: Three inches total immersion for use with sensor wells, unless otherwise indicated.
 - 4) Sensor Wells: Stainless steel material. Provide heat-sensitive transfer agent between exterior sensor surface and interior well surface.
 - 5) Outside Air Type: Provide element on the buildings north side with sunshade to minimize solar effects. Mount element at least 3 inches from building outside wall. Sunshade shall not inhibit the flow of ambient air across the sensing element. Shade shall protect sensing element from snow, ice, and rain.
- c. Transmitters: Transmitters shall have 4 to 20 mA or 0 to 10 VDC output linearly scaled to the temperature, pressure, humidity, or flow range sensed. Transmitter shall be matched to the sensor, factory calibrated, and sealed. Total error shall not exceed 0.1 percent at any point across the measured span. Supply voltage shall be 24 volts ac or dc. Transmitters shall have non-interactive offset and span adjustments. For temperature sensing, transmitter stability shall not exceed 0.05 degrees F a year.
- 1) Spans and Ranges: Transmitter spans or ranges shall meet the following requirements:
 - a) Temperature:
 - 50 degrees F span: Room, chilled water, cooling coil discharge air, return air sensors.
 - 100 degrees F span: Outside air, hot water, heating coil discharge air, mixed air sensors.
 - 200 degrees F span: Heating hot water, chilled/hot water system sensors.
 - b) Pressure:
 - -0.5 to 0.5 inches water differential range: static pressure control of rooms
 - 0 to 5 inches water differential range: Duct static pressure
 - 0 to 60 psig differential: Water differential pressure
 - c) Relative Humidity:
 - 10 to 90 percent minimum relative humidity range.
- d. Relative Humidity Transmitters. Provide integral humidity transducer and transmitter. Output of relative humidity instrument shall be a 4 to 20 mA or 0 to 10 VDC signal proportional to full range of relative humidity input. Accuracy shall be 2 percent of full scale, long-term stability shall be less than one percent drift per year. Sensing element shall be polymer or thin film polymer type.
- e. Pressure Transmitters. Provide integral pressure transducer and transmitter. Output of pressure instrument shall be a 4 to 20 mA signal proportional to the pressure span. Span shall be as specified. Accuracy shall be 1.0 percent. Linearity shall be 0.1 percent.
- f. Input Switches:
- 1) Timed Local Override. Provide momentary contact push button override with override time set in controller software. Provide to override DDC time of day program and activate occupancy program for assigned units. Upon expiration of override time, the control system shall return to time-of-day program. Time interval for the length of operation shall be software adjustable and shall expire unless reset.
 - 2) Insertion Freeze Protection Switch. Electric switch shall be capillary type. Provide special purpose insertion thermostats with flexible elements a minimum of 20 feet in length for coil face areas up to 40 square feet. Switch contacts shall be rated for motor starter circuit voltage being interrupted. Switch shall be equipped with auxiliary set of contacts for input of switch status to digital controller. Provide additional elements or longer elements for larger coils at the rate of 1-foot of element per 4

square feet of coil. Serpentine capillaries perpendicular to the air flow to uniformly sense the entire airflow. A freezing condition at 18-inch increments along the sensing element shall activate the thermostatic switch. Switch shall require manual reset after activation.

- g. Electronic Airflow Measurement Stations and Transmitters:
 - 1) Station: Each airflow measuring station shall contain an array of multi-point, symmetrically averaging "pitot tube" transverse station and straightening vanes inside of a flanged sheet metal casing. The sensing elements shall be distributed across the duct cross section in the quantity and pattern set forth for measurements and instruments of ASHRAE 3 and SMACNA HVACTAB for the traversing of ducted air flows. The resistance to airflow through the airflow measurement station shall not exceed 0.08 inches water gage at airflow of 2,000 fpm. Station construction shall be suitable for operation at airflow of up to 5,000 fpm over a temperature range of 40 to 120 degrees F, and accuracy shall be plus or minus 3 percent over a range of 125 to 2,500 fpm scaled to air volume.
 - 2) The air flow measuring station shall include a transmitter to send an electronic signal that is created proportional to the linear velocity (via square root extraction) to report "total" airflow. Each transmitter shall produce a linear, temperature compensated 4 to 20 mA or 0 to 10 VDC output corresponding to the actual air flow. The transmitter shall be a 2-wire, loop-powered device. The output error of the transmitter shall not exceed 0.5 percent of the calibrated measurement.
- h. Energy Monitoring:
 - 1) Integrate electric power monitor signals received from owner-furnished power monitor modules into DDC system. Verify that signal output is compatible with DDC input. DDC shall measure both instantaneous and accumulated electrical usage. Provide control wiring necessary to connect power monitoring modules to DDC.
 - 2) Energy meters: Provide energy meters (BTU/hr) for the CNMS branch connected to central site-services for chilled water and for heating hot water. Integrate electric meter signal into DDC system; meter signal output must be compatible with DDC input. DDC shall measure both instantaneous and accumulated energy usage.

2.3 OUTPUT HARDWARE

- A. Dampers: Damper shall conform to SMACNA DCS.
 - 1. A single damper section shall have blades no longer than 1,220 mm 48 inches and shall be no higher than 1,830 mm 72 inches. Maximum damper blade width shall be 203 mm 8 inches. Larger sized damper shall be made from a combination of sections.
 - 2. Dampers shall be steel, or other materials where shown. Flat blades shall be made rigid by folding the edges. Blades shall be provided with compressible seals at points of contact. The channel frames of the dampers shall be provided with jamb seals to minimize air leakage. Dampers shall not leak in excess of 20 cfm per square foot at 4 inches water gage static pressure when closed. Seals shall be suitable for an operating temperature range of 40 degrees F to 200 degrees Fahrenheit. Dampers shall be rated at not less than 2,000 fpm air velocity. All blade-operating linkages shall be within the frame so that blade-connecting devices within the same damper section will not be located directly in the air stream. Damper axles shall be 0.5 inch (minimum) plated steel rods supported in the damper frame by stainless steel or bronze bearings. Blades mounted vertically shall be supported by thrust bearings. Pressure drop through dampers shall not exceed 0.04 inches water gage at 1,000 fpm in the wide-open position. Frames shall not be less than 2 inches in width. Dampers shall be tested in accordance with AMCA 500.

- a. Operating links external to dampers (such as crankarms, connecting rods, and line shafting for transmitting motion from damper actuators to dampers) shall withstand a load equal to twice the maximum required damper-operating force. Rod lengths shall be adjustable. Links shall be brass, bronze, zinc-coated steel, or stainless steel. Moving parts in contact with one another shall be of different materials. Working parts of joints and clevises shall be brass, bronze, or stainless steel. Adjustments of crankarms shall control the open and closed position of dampers.
- B. Valves:
1. Valve Assembly: Valves shall have stainless steel stems. Valve bodies shall be designed for not less than 125 PSIG working pressure or 150 percent of the system operating pressure, whichever is greater. Valve leakage rating shall be 0.01 percent of rated Cv. Class 125 copper alloy valve bodies and Class 150 steel or stainless steel valves shall conform to ASME/ANSI B16.5 as a minimum. Cast iron valve components shall conform to ASTM A 126 Class B or C as a minimum.
 2. Butterfly Valve Assembly: Butterfly valves shall be threaded lug type suitable for dead-end service and for modulation to the fully closed position, with noncorrosive discs, stainless steel shafts supported by bearing, and EPDM seats suitable for temperatures from minus 20 degrees F to plus 250 degrees F. Valves shall have a manual means of operation independent of the actuator.
 3. Two-Way Valves. Two-way modulating valves shall have equal percentage characteristics.
 4. Three-Way Valves: Three-way valves shall have equal percentage characteristics.
 5. Duct Coil and Terminal Unit Coil Valves. Provide control valves with either flare-type or solder-type ends provided for duct or terminal-unit coils. Provide flare nuts for each flare-type end valve.
 6. Valves for Chilled Water, Condenser Water and Glycol Service:
 - a. Bodies for valves 40 mm 1 1/2 inches and smaller shall be brass or bronze, with threaded or union ends. Bodies for valves from 2 inches to 3 inches inclusive shall be of brass, bronze or iron. Bodies for 2 inches valves shall have threaded ends. Bodies for valves from 2 1/2 to 3 inches shall have flanged-end connections. Internal valve trim shall be brass or bronze except that valve stems may be Type 316 stainless steel. Water valves shall be sized for a 3 PSI differential through the valve at rated flow, except as indicated otherwise. Select valve flow coefficient (Cv) for an actual pressure drop not less than 75 percent or greater than 125 percent of the design pressure drop at design flow.
 7. Valves 6 inches and larger shall be butterfly valves.
 8. Valves for Hot Water Service: Valves for hot water service below 250 deg F:
 - a. Bodies for valves 1-1/2 inches and smaller shall be brass or bronze with threaded or union ends. Bodies for valves larger than 50 mm 2 inches shall have flanged-end connections. Water valves shall be sized for a 3 PSI differential through the valve at rated flow, except as indicated otherwise. Select valve flow coefficient (Cv) for an actual pressure drop not less than 75 percent or greater than 125 percent of the design pressure drop at design flow.
 - b. Internal trim, including seats, seat rings, modulation plugs, and springs, of valves controlling water hotter than 210 degrees F shall be Type 316 stainless steel.
 - c. Internal trim for valves controlling water 210 degrees F or less shall be brass or bronze.
 - d. Non-metallic parts of hot water control valves shall be suitable for a minimum continuous operating temperature of 250 degrees F or 50 degrees F above the system design temperature, whichever is higher.
 - e. Valves 4 inches and larger shall be butterfly valves.
 9. Actuator:

10. Pneumatic Actuators: Provide piston or diaphragm type actuator with full range or split range springs for temperature control valves to accomplish required sequence specified of operations indicated on drawings. Actuators for automatic dampers shall be supplied as part of package equipment when otherwise indicated.
 11. Electric Actuators: Provide direct drive electric actuators only as indicated on control drawings. When operated at rated voltage, each actuator shall be capable of delivering torque required for continuous uniform motion and shall have end switch to limit travel, or shall withstand continuous stalling without damage. Actuators shall function properly with range of 85 to 110 percent of line voltage. Provide gears of steel or copper alloy. Fiber or reinforced nylon gears may be used for torque less than 16 inch pounds. Provide hardened steel running shafts in sleeve bearing of copper alloy, hardened steel, nylon, or ball bearing. Provide two-position actuators of the single direction, spring return, or reversing type. Provide proportioning actuators capable of stopping at all points in the cycle and starting in either direction, from any point. Provide reversing and proportioning actuators with limit switches to limit travel in either direction unless operator is stall type. Actuators shall have a simple switch for reversing direction, and a button to disengage clutch for manual adjustments. Provide reversible shaded pole, split capacitor, synchronous, or stepper type electric motors.
- C. Output Signal Conversion
1. Electronic to Pneumatic Transducer: Electronic to pneumatic transducer shall convert 4 to 20 mA or 0 to 10 VDC digital controller output signal to a proportional 0 to 20 psig pressure signal (operator scaleable). Accuracy shall be 1.0 percent or better. Linearity shall be 0.1 percent. Transducer shall have feedback circuit that converts pneumatic signal to a proportional 4 to 20 mA or 0 to 10 VDC signal.
 2. Pneumatic to Electronic Pressure Transducer: Pneumatic to electronic transducer shall convert 0 to 20 PSIG signal to a proportional 4 to 20 mA or 0 to 10 VDC signal (operator scaleable). Supply voltage shall be 24 VDC. Accuracy shall be 1.0 percent or better. Linearity shall be 0.1 percent.
 3. Output Switches:
 - a. Control Relays: Shall be double pole, double throw (DPDT), UL listed, with contacts rated to the application, indicator light, and dust proof enclosure. Light indicator is lit when coil is energized and is off when coil is not energized. Relays shall be socket type, plug into a fixed base, and replaceable without need of tools or removing wiring. Encapsulated "PAM" type relays are permissible for terminal control applications.
 - b. Solenoid Air Valves: Each valve shall have three port operations: common, normally open, and normally closed. Internal parts shall be brass, bronze, or stainless steel. Valves shall be rated at 50 PSIG minimum when used in a control system operating at 25 PSIG or less, or 150 PSIG when used in a control system operating in the range 25 to 100 PSIG.

2.4 ELECTRICAL POWER AND DISTRIBUTION

- A. For control power provide a new, dedicated source 120 volts or less, 60 Hz, three wire (black, white, and green). Run green ground wire to panel ground; conduit grounds are not sufficient.
- B. Transformers. Transformers shall conform to UL 506. Power digital controllers and terminal control units (TCU's) from dedicated circuit breakers with surge protection specified. Transformers for digital controllers serving terminal equipment on lower level LANs may be grouped to have specified surge protection sized for the number of controllers on a single transformer. Provide a fuse on secondary side of transformer.
- C. Surge Protection. Surge and transient protection consist of devices installed externally to digital controllers.

- a. Power Line Surge Protection: Surge suppressors external to digital controller, shall be installed on all incoming AC power. Surge suppressor shall be rated by UL 1449, have a fault indicating light, and have clamping voltage ratings below the following levels:
 - b. Unit is a transient voltage surge suppressor 120 VAC/1 phase/2 wire plus ground, hard wire individual equipment protector.
 - c. Unit must react within 5 nanoseconds and automatically reset.
 - d. Voltage protection threshold, line to neutral, starts at no more than 211 volts peak on the 120 VAC line.
 - e. The transient voltage surge suppressor must have an independent secondary stage equal to or greater than the primary stage joule rating.
 - f. The primary suppression system components must be pure Silicon Avalanche Diodes.
 - g. Silicon Avalanche Diodes or Metal Oxide Varistors are acceptable in the independent secondary suppression system.
 - h. The Transient Suppression System shall incorporate an indication light which denotes whether the primary and/or secondary transient protection components is/are functioning.
 - i. All system functions of the Transient Suppression System must be individually fused and not short circuit the AC power line at any time.
 - j. The Transient Suppression System shall incorporate an EMI/RFI noise filter with a minimum attenuation of 13 dB at 10 kHz to 300 MHz.
 - k. The system must comply with IEEE C62.41, Class "B" requirements and be tested according to IEEE C62.45.
 - l. The system shall operate at -20 degrees C to +50 degrees C.
 2. Telephone and Communication Line Surge Protection. Provide transient surge protection to protect the DDC controllers and LAN related devices from surges that occur on the phone lines (modem or direct connect) and on inter-unit LAN communications. Devices shall be UL listed.
 - a. The surge protection shall be a rugged package with continuous, non-interrupting protection and not use crowbar technology. Instant automatic reset after safely eliminating transient surges, induced lightning, and other forms of transient over voltages.
 - b. Unit must react within 5 nanoseconds using only solid-state silicone avalanche technology.
 - c. Unit shall be installed at the proper distance as recommended by the manufacturer.
 3. Controller Input/Output Protection. Controller input/output points shall surge protection with optical isolation, metal oxide varistors (MOV), or silicon avalanche devices. Fuses are not permitted for surge protection.
- D. Wiring: Provide complete electric wiring for DDC System, including wiring to transformer primaries. Control circuit wiring shall not run in the same conduit as power wiring over 100 volts. Circuits operating at more than 100 Volts shall be in accordance with Division 16. Circuits operating at 100 Volts or less shall be defined as low voltage and shall be run in rigid or flexible conduit, metallic tubing, metal raceways or wire trays, armored cable, or multi-conductor cable. Provide circuit and wiring protection as required by NFPA 70. Aluminum-sheathed cable or aluminum conduit may be used but shall not be buried in concrete. Use conduit or plenum-rated cable in HVAC plenums. HVAC plenums include the space between a drop ceiling and the architectural ceiling, within walls, and within ductwork. Protect exposed wiring from abuse and damage.
1. AC Control Wiring:
 - a. Control wiring for 24 V circuits shall be insulated copper 18 AWG minimum and rated for 300 VAC service.
 - b. Wiring for 120 V shall be 14 AWG minimum and rated for 600 V service.
 2. Analog Signal Wiring:

- a. Analog signal wiring shall be 18 AWG single or multiple twisted pair.
- b. Each cable shall be 100 percent shielded, and have 20 AWG drain wire.
- c. Each wire shall have insulation rated to 300 V ac.
- d. Cables shall have an overall aluminum-polyester or tinned-copper (cable-shield tape). Install analog signal wiring in conduit separate from AC power circuits.

2.5 FIRE DETECTION DEVICES.

- A. Provide smoke detectors in return and supply air ducts on downstream side of filters in accordance with NFPA 90A, except as otherwise indicated. Provide UL listed or FM approved detectors for duct installation.
- B. Smoke Detectors:
 1. Provide in systems as shown in accordance with NFPA 90A. Furnish detectors under Division 16 and install under this section.
 2. Design for detection of abnormal smoke densities by the ionization or photoelectric principle, responsive to both invisible and visible particles of combustion, and not susceptible to operation by changes to relative humidity.
 3. Provide UL listed or FM approved detectors for duct installation.
 4. Provide duct detectors with an approved duct housing, mounted exterior to the duct, and with perforated sampling tubes extending across the width of the duct.
 5. Provide permanent descriptive zone labels indicating in which air handling units the detectors in alarm are located.
 6. Provide detectors with a test port test switch or remote keyed test device.
 7. Provide control and power modules required for operation of detectors in their own control unit.
 8. A ground fault or single break or open condition in the electrical circuitry to detector or its control or power units shall cause activation of the building fire alarm control panel trouble signals.
 9. Electrical supervision of wiring provided exclusively for air handling unit shutdown is not required provided a break in wiring will cause shutdown of the associated unit.
 10. Equipment and devices shall be compatible and operable in all respects with, and shall in no way impair reliability or operational functions of, existing building fire alarm system.
 11. Provide each detector with a visible indicator lamp that lights when detector is activated.
 12. Activation of duct detector shall cause shutdown of associated air handling unit and shall send a signal to the building fire alarm control panel.

2.6 INDICATORS

- A. Thermometers
- B. Pressure Gages
 1. Provide pressure gages for all pneumatic outputs. Select gage range so normal pressures are approximately equal to the midpoint readings on the scale, unless otherwise specified. Accuracy shall be plus or minus 2 percent of the range. Gages shall conform to ANSI/ASME B40.1.
 2. Gages indicating pneumatic outputs shall have 2 inches diameter faces. Scale shall be 0 to 30 psi, with one psi graduations.
 3. Gages for low differential pressure measurements shall be 4 1/2 inch (nominal) size with two sets of pressure taps, and shall have a diaphragm actuated pointer, white dial with black figures, and pointer zero adjustment. Gage shall have ranges and graduations as shown. Accuracy shall be plus or minus 2 percent of scale range.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Perform installation under supervision of competent technicians that are regularly employed in the installation of DDC systems.
- B. Wiring Criteria:
 - 1. Input/output identification: Permanently label each field wire, cable, or pneumatic tube at each end with unique descriptive identification.
 - 2. Rigid or flexible conduit shall be terminated at all sensors and output devices.
 - 3. Surge Protection: Install surge protection per manufacturer's specification.
 - 4. Grounding: Ground controllers and cabinets to a good earth ground. Ground controller to a ground in accordance with Section 16400, "Services and Distribution." Grounding of the green ac ground wire, at the breaker panel, alone is not adequate. Run metal conduit from controller panels to adequate building grounds. Ground sensor drain wire shields at controller end.
 - 5. Contractor is responsible for correcting all associated ground loop problems.
 - 6. Wiring in panel enclosures shall be run in covered wire track.
- C. Digital Controllers:
 - 1. Do not divide control of a single mechanical system such as an air handling unit, boiler, chiller, or terminal equipment between two or more controllers. A single controller shall manage control functions for a single mechanical system. It is permissible, however, to manage more than one mechanical system with a single controller.
 - 2. Provide digital control cabinets that protect digital controller electronics from dust, at locations shown on the drawings.
- D. Temperature Sensors: Provide temperature sensors in locations to sense the appropriate condition. Provide sensor where they are easy to access and service without special tools. Calibrate sensors to accuracy specified. In no case will sensors designed for one application be installed for another application.
 - 1. Room Temperature Sensors. Provide on interior walls to sense average room temperature conditions. Avoid locations near heat sources or which may be covered by office furniture. Temperature sensors should not be mounted on exterior walls when other locations are available. Mount sensor's center at 5 feet above finished floor.
 - 2. Duct Temperature Sensors:
 - a. Provide sensors in ductwork in general locations as indicated. Select specific sensor location within duct to accurately sense appropriate air temperatures. Do not locate sensors in dead air spaces or positions obstructed by ducts or equipment. Install gaskets between the sensor housing and duct wall. Seal duct and insulation penetrations.
 - b. Install duct-averaging sensors between two rigid supports in a serpentine position to sense average conditions. Insulate (temperature) sensing elements from supports. Provide hinged duct access doors to install averaging sensors.
 - c. Locate freeze protection sensors in appropriate locations to sense lowest temperatures, to avoid potential problems with air stratification.
 - 3. Immersion Temperature Sensors: Provide thermowells for sensors measuring temperatures in liquid applications or pressure vessels. Locate wells to sense continuous flow conditions. Do not install wells using extension couplings. Where piping diameters are smaller than the length of the wells, provide wells in piping at elbows to sense flow across entire area of well. Wells shall not restrict flow area to less than 70 percent of pipe area. Increase piping size as required to avoid a restriction. Provide thermowells with thermal transmission material within the well.
 - 4. Outside Air Temperature Sensors: Provide outside air temperature sensor in weatherproof enclosure on north side of the building, away from exhaust hoods, air intakes and other areas that may affect temperature readings. Provide sunshields to from direct sunlight.

- E. Damper Actuators: Actuators shall not be mounted in the air stream.
- F. Thermometers: Provide thermometers at locations indicated. Mount thermometers to allow reading when standing on the floor.
- G. Pressure Sensors:
 - 1. Differential Pressure:
 - a. Duct Static Pressure Sensing: Locate duct static pressure tip approximately two-thirds of distance from supply fan to end of duct with the greatest pressure drop.
 - b. Pumping Proof with Differential Pressure Switches: Install the high pressure side between pump discharge and check valve.
- H. Control Drawings:
 - 1. Post laminated copies of as-built control system drawings in each mechanical room.
 - 2. Provide 3 sets of as-built control drawings to the Construction Manager.

3.2 TEST AND BALANCE SUPPORT

- A. Controls contractor will coordinate with and provide full time on-site technical support to test and balance (TAB) personnel specified under Section 15990 or any other documents in the project specification. This support shall include:
 - 1. On-site operation of control systems for proper operating modes during all phases of balancing and testing.
 - 2. Control setpoint adjustments for proper balancing of all relevant mechanical systems, including VAV boxes.
 - 3. Setting all control loops with setpoints and adjustments determined by TAB personnel.

3.3 FIELD QUALITY CONTROL

- A. General:
 - 1. Demonstrate compliance of the heating, ventilating, and air conditioning control system with the contract documents. Furnish personnel, equipment, instrumentation, and supplies necessary to perform calibration and site testing. Ensure that test personnel are regularly employed in the testing and calibration of DDC systems.
 - 2. Testing will include the field tests and the performance verification tests. Field tests shall demonstrate proper calibration of input and output devices, and the operation of specific equipment. Performance verification test shall ensure proper execution of the sequence of operation and proper tuning of control loops.
 - 3. Obtain approval of the field test plan and performance verification test plan for each phase of testing before beginning that phase of testing. Give to the Construction Manager (CM) with written notification of planned testing at least 30 days prior to test. Notification shall be accompanied by the proposed test procedures. In no case will the Contractor be allowed to start testing without written Construction Manager's approval of field test plan and performance verification test plan.
 - 4. Before scheduling the performance verification test, furnish field test documentation and written Certified Statement of Field Test Completion to the CM for approval. The statement, certified by the DDC system provider, states that the installed system has been calibrated, tested, and is ready for the performance verification test. Do not start the performance verification test prior to receiving written permission from the CM.
 - 5. Tests are subject to oversight and approval by the CM. Testing shall not be run during scheduled seasonal off-periods of heating and cooling systems.
- B. Test Reporting for Field Testing and Performance Verification Tests:

1. During and after completion of the Field Tests, and again after the Performance Verification Tests, identify, determine causes, replace, repair or calibrate equipment that fails to meet the specification, and submit a written report to the CM.
 2. Document all tests with detailed test results. Explain in detail the nature of each failure and corrective action taken. Provide a written report containing test documentation after the Field Tests and again after the Performance Verification Tests. Convene a test review meeting at the job site to present the results to the CM. As part of this test review meeting, demonstrate by performing all portions of the field tests or performance verification test that each failure has been corrected. Based on the report and test review meeting, the CM will determine either the restart point or successful completion of testing. Do not retest until after receipt of written notification by the CM. At the conclusion of retest, assessment will be repeated.
- C. Contractor's Field Tests. Field Tests shall include the following:
1. System Inspection: Observe the HVAC system in its shutdown condition. Check dampers and valves for proper normal positions. Document each position for the test report.
 2. Calibration Accuracy and Operation of Inputs Test: Verify correct calibration and operation of input instruments. For each sensor and transmitter, including those for temperature, pressure, humidity, and air quality, record the reading at the sensor or transmitter location using calibrated test equipment. On the same table, record the corresponding reading at the digital controller for the test report. The test equipment shall have been calibrated within one year of use. Test equipment calibration shall be traceable to the measurement standards of the National Institute of Standards and Technology.
 3. Actuator Range Adjustment Test: With the digital controller, apply a control signal to each actuator and verify that the actuator operates properly from its normal position to full range of stroke position. Record actual spring ranges and normal positions for all modulating control valves and dampers. Include documentation in the test report.
 4. Digital Controller Startup and Memory Test. Demonstrate that programming is not lost after a power failure, and digital controllers automatically resume proper control after a power failure.
 5. Surge Protection Test: Show that surge protection, meeting the requirements of this specification, has been installed on incoming power to the digital controllers and on communications lines.
 6. Application Software Operation Test: Test compliance of the application software for:
 - a. Ability to communicate with the digital controllers, uploading and downloading of control programs.
 - b. Text editing program: Demonstrate ability to edit the control program off line.
 - c. Reporting of alarm conditions: Force alarms conditions for each alarm, and ensure that workstation receives alarms.
 - d. Reporting trend and status reports: Demonstrate ability of software to receive and save trend and status reports.
- D. Performance Verification Tests: Conduct the performance verification tests to demonstrate control system maintains setpoints, control loops are tuned, and controllers are programmed for the correct sequence of operation. Conduct performance verification test during seven days of continuous HVAC and DDC systems operation and before final acceptance of work. Specifically the performance verification test shall demonstrate the following:
1. Execution of Sequence of Operation: Demonstrate the HVAC system operates properly through the complete sequence of operation, for example seasonal, occupied/unoccupied, and warm-up. Demonstrate proper control system response for abnormal conditions by simulating these conditions. Demonstrate hardware interlocks and safeties work. Demonstrate the control system performs the correct sequence of control after a loss of power.

2. Control Loop Stability and Accuracy: Furnish the CM graphed trends of control loops to demonstrate the control loop is stable and that setpoint is maintained. Control loop response shall respond to setpoint changes and stabilize in 3 minutes. Control loop trend data shall be real time and the time between data points shall not be greater than one minute. The contractor shall provide a printer, either the project printer or temporary, at the job site for printing graphed trends. The printer shall remain on the job site throughout Performance Verification Testing to allow printing trends.
- E. Training: Submit a training course schedule, syllabus, and training materials 14 days prior to the start of training. Furnish a qualified instructor to conduct training courses for designated personnel in the maintenance and operation of the HVAC and DDC system. Orient training to the specific system being installed under this contract. Use operation and maintenance manual as the primary instructional aid in contractor provided activity personnel training. Manuals shall be delivered for each trainee with two additional sets delivered for archiving at the project site. Training manuals shall include an agenda, defined objectives and a detailed description of the subject matter for each lesson. Furnish audio-visual equipment and all other training materials and supplies. A training day is defined as 8 hours of classroom or lab instruction, including two 15 minutes breaks and excluding lunchtime, Monday through Friday, during the daytime shift in effect at the training facility. The Contractor should assume the attendees will have a high school education and are familiar with HVAC systems.
1. DDC Training Phase: The first class shall be taught for a period of 2 consecutive training days at least 2 weeks prior to the scheduled Performance Verification Test. Training shall be classroom, but have hands-on operation of similar digital controllers. A maximum of 6 personnel will attend this course. Upon completion of this course, each student, using appropriate documentation, should be able to perform elementary operations, with guidance, and describe the general hardware architecture and functionality of the system. This course shall include but not be limited to:
 - a. Theory of operation.
 - b. Hardware architecture.
 - c. Operation of the system.
 - d. Operator commands.
 - e. Control sequence programming.
 - f. Data base entry.
 - g. Reports and logs.
 - h. Alarm reports.
 - i. Diagnostics
 2. DDC Training Phase II: The second course shall be taught in the field, using the operating equipment at the project site[s] for a total of 2 consecutive days. A maximum of 6 personnel will attend the course. The course shall consist of hands-on training under the constant monitoring of the instructor. Course content should duplicate DDC Training Phase I course as applied to the installed system. The instructor shall determine the level of the password to be issued to each student before each session. Upon completion of this course, students should be fully proficient in the operation of each system function.

END OF SECTION 15950