An Introduction to Energy Efficient HVAC Controls

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CONTENTS

1. GENERAL. This discussion covers automatic temperature and humidity controls, space pressurization controls, safety controls, and energy monitoring and central supervisory control systems. A complete automatic control system shall be designed by an HVAC controls design engineer with experience in designing systems of this type and complexity. A commissioning plan shall be submitted to and approved by EPA prior to the commissioning of the control system. The final product shall be a complete, reliable, fully functional, maintainable, fully integrated, addressable, control system that has been properly designed, installed, and commissioned. In existing facilities, the design shall be integrated and interfaced into the existing control system so that the new equipment and conditions can be controlled and monitored similar to the existing controlled equipment. Compliance is recommended with Section 104 of the Energy Policy Act of 2005 which requires that Energy Star-designated products.

1.1 TECHNICAL REQUIREMENTS. The control system shall be a direct digital control (DDC) system reflecting the latest technology that has been widely accepted by the control industry. DDC systems shall be electric/electronic only. Pneumatics shall not be allowed except in instances when the existing controls absolutely require that the new controls be pneumatic. The system shall be complete and suitable for the HVAC systems to be installed. The DDC system shall be compatible with any existing systems in the facility or shall be able to completely and seamlessly interface with the existing central control and monitoring system (CCMS) network. All control points, including the VAV controllers, shall be fully compatible with the CCMS, allowing complete monitoring, control, and setpoint adjustment of all points and VAV terminal unit controllers from the CCMS host. Outside air quantity to each air handling unit shall be automatically controlled at a volume to meet the requirements of ASHRAE Standard 62-2001. Typical points to be monitored and controlled include:

Air Handling Units

- Leaving air temperature
- Entering air temperature
- Entering chilled water temperature
- Leaving chilled water temperature
- Entering hot water temperature
- Leaving hot water temperature
- Temperature and humidity in each zone
- Fan speed indication
- Filter differential pressure
- Supply air quantity
- Outside air quantity

Central Plant

- Chiller on-off (each chiller)
- Chilled water temperature in and out
- Chiller status
- Boiler on-off (each boiler)

- Hot water temperature in and out
- Boiler status
- Steam-HW heat exchanger, water temperature in and out
- Pump on-off indication, each pump
- Cooling Tower fan speed
- Condenser water temperature in and out
- Steam pressure and temperature

<u>Variable Air Volume Zones (through VAV unit controller)</u>

- Zone temperature
- Zone primary air flowrate (supply and exhaust volumes, CFM)
- Zone temperature setpoint
- <u>Alarm Print Outs:</u>
- Chiller failure to start
- Air handling unit fan failure
- Zone space temperature rise to 5 degrees (F) above set point
- Chilled water rise 5 degrees above set point
- Hot water fall 5 degrees below set point

- Zone RH 5% above set point
- Pump failure.
- Water on Floor of Mechanical Room
- Laboratory fume hood sash position and hood alarm condition

<u>Points to be Controlled:</u>

- Start/stop chillers/chilled water pumps
- Reset chilled water temperature
- Start/stop boilers/hot water pumps
- Reset hot water temperature
- Start/stop air handling units
- Start/stop exhaust and supply fans
- Setpoint adjust - all controllers with setpoints
- Enable/disable economizer cycles
- Setpoint adjust - all VAV zone

1.2 CODES AND STANDARDS. The following codes and standards shall be referenced as applicable:

- ASHRAE 135-1995: BACnet - A Data Communication Protocol for Building Automation and Control Networks. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1995 including Addendums A through E
- UL 916, Energy Management Systems
- NEMA 250, Enclosure for Electrical Equipment
- NEMA ICS 1: General Standards for Industrial Controls
- NFPA 45, Fire Protection for Laboratories Using Chemicals
- NFPA 90A, Standard for the Installation of Air-Conditioning and Ventilating Systems (where applicable to controls and control sequences)
- NFPA 70, National Electrical Code (NEC).

1.3 CONTROL SYSTEM SUBMISSION. The design submission shall include complete control system drawings, complete technical specifications, and commissioning procedures for each control system. As a minimum, the following documentation shall be required for review by the owner:

<u>HVAC Control System Drawings</u>: Each control system element on a drawing shall have a unique identifier. The HVAC control system drawings shall be delivered together as a complete submittal. HVAC control system drawings shall include the following:

- Drawing index, HVAC control system legend, valve schedule, damper schedule, control system schematic and equipment schedule, sequence of operation and data terminal strip layout, control loop wiring diagrams, motor starter and relay wiring diagram, communication network and block diagram, DDC panel installation and block diagram.

- The HVAC control system drawing index shall show the name and number of the building, state or other similar designation, and country. The HVAC control system legend shall show generic symbols and the name of devices shown on the HVAC control system drawings.

- The valve schedule shall include each valve's unique identifier, size, flow coefficient Cv, pressure drop at specified flow rate, spring range, actuator size, close-off pressure data, dimensions, and access and clearance requirements data.

- The damper schedule shall contain each damper's and each actuator's identifier, nominal and actual sizes, orientation of axis and frame, direction of blade rotation, locations of actuators and damper end switches, arrangement of sections in multi-section dampers, and methods of connecting dampers, actuators, and linkages. The damper schedule shall include the maximum leakage rate at the operating static-pressure differential. The damper schedule shall contain actuator selection data supported by calculations of the torque required to move and seal the dampers, access and clearance requirements.

- The HVAC control system schematics shall show all control and mechanical devices associated with the HVAC system. A system schematic drawing shall be submitted for each HVAC system.

- The HVAC control system equipment schedule shall be in the form shown. All devices shown on the drawings having unique identifiers shall be referenced in the equipment schedule. An equipment schedule shall be submitted for each HVAC system.

- Sequences of operation shall be submitted for each HVAC control system including each type of terminal unit control system. A complete sequence of operation shall be included on the drawings along with a schematic control diagram for each typical system. The sequence of operation and schematic control diagrams shall specifically cover the following items and others as the project requires.

- Refrigeration compressor control
- Refrigeration system protective devices
- Chilled, DX and hot water control
- Water coil or evaporator control, temperature and/or humidity as required
- Cooling tor or air-cooled condenser control
- Air handling unit control with protective devices
- Individual unit control
- Motor interlocks with system, starting and stopping instruction
- All thermostat, humidistat, and protective device control settings

The HVAC control system wiring diagrams shall be functional wiring diagrams which show the interconnection of conductors and cables to HVAC control panel terminal blocks and to the identified terminals of devices, starters and package equipment. The wiring diagrams shall show necessary jumpers and ground connections. The wiring diagrams shall show the labels of all conductors. Sources of power required for HVAC control systems and for packaged equipment control systems shall be identified back to the panel board circuit breaker number, HVAC system control panel, magnetic starter, or packaged equipment control circuit. Wiring diagrams shall be submitted for each HVAC control system.

• Service Organizations: A list of service organizations qualified to service the HVAC control system shall be provided. The list shall include the service organization name, address, technical point of contact and telephone number, and contractual point of contact and telephone number.

- Equipment Compliance Booklet: The HVAC Control System Equipment Compliance Booklet (ECB) shall be provided. It shall consist of, but not be limited to, data sheets and catalog cuts which document compliance of all devices and components with the specifications. The ECB shall include a Bill of Materials for each HVAC control system. The Bill of Materials shall function as the table of contents for the ECB and shall include the device's unique identifier, device function, manufacturer, and model/part/catalog number used for ordering.

- Performance Verification Test Procedures: The performance verification test procedures shall refer to the devices by their unique identifiers, and shall explain, step-by-step, the actions and expected results that will demonstrate that the HVAC control and LFH exhaust systems performs in accordance with the sequences of operation, and other contract documents.

- Training: An outline for the HVAC control system training course with a proposed time schedule. Approval of the planned training schedule shall be obtained from the Government at least 60 days prior to the start of the training. Three copies of HVAC control system training course material 30 days prior to the scheduled start of the training course. The training course material shall include the operation manual, maintenance and repair manual, and paper copies of overheads used in the course.

- Operation Manual, Maintenance and Repair Manual: The HVAC Control System Operation Manual and the HVAC Control System Maintenance and Repair Manual shall be provided for each HVAC control system.

2. HUMIDITY CONTROL. Summer and winter space or zone humidity control shall be provided only on a space-by-space or zone-by-zone basis and not for the entire central ventilation system unless required for project-specific humidity requirements as stated in the project criteria. No controls shall be provided for dehumidifying spaces to below 50 percent relative space humidity or for humidifying spaces to greater than 30 percent relative space humidity unless required by project-specific criteria.

3. SIMULTANEOUS HEATING AND COOLING. Simultaneous heating and cooling, which controls comfort conditions within a space by reheating or recooling supply air or by concurrently operating independent heating and cooling systems to serve a common zone, shall not be used except under the following conditions:

- Renewable energy sources are used to control temperature or humidity.
- Project-specific temperature, humidity, or ventilation conditions require simultaneous heating and cooling to prevent space relative humidity from rising above special-space relative humidity requirements.
- Project-specific building construction constraints, as established in the project criteria, prohibit installation of other types of HVAC systems.

4. MECHANICAL VENTILATION CONTROL All supply, return, and exhaust ventilation systems shall be equipped with automatic and manual control of fan operation to shut off the fan when ventilation is not required. To prevent introduction of outside air when ventilation is not required, these systems shall also be provided with manual gravity-operated or automatic control of dampers for outside air intake and exhaust or relief. Systems that circulate air shall be provided with minimum outdoor air damper position control to ensure that the minimum amount of outdoor air is being introduced into the system. Unless otherwise required by life safety or the specific project criteria, automatic dampers should fail open for return air and fail to a minimum setting for outside air.

5. ENERGY CONSERVATION CONTROL SCHEMES. HVAC systems will be provided with automatic controls which will allow systems to be operated to conserve energy. The following energy saving controls will be considered, if applicable to the system:

- Enthalpy controlled economizer cycle
- Controls to close outside air supply when the facility is unoccupied (for non-laboratory areas only)
- Night setback controls where appropriate
- Master outdoor temperature sensing unit that resets the supply hot water temperature in accordance with outdoor ambient temperature. This sensing unit shall automatically shut off the heating system and the circulating pumps when the outdoor temperature reaches 65 degrees F (unless needed for research)
- Controls to shut off exhaust fans, where appropriate
- Reset controls for hot and cold decks on air conditioning systems having hot and cold decks.

6. AUTOMATIC CONTROL DAMPERS. Automatic air control dampers must be of the low-leakage type with a maximum leakage of 6 cfm per square foot at a maximum system velocity of 1,500 feet per minute (fpm) and a 1-inch pressure differential, as stipulated in Air Movement and Control Association (AMCA) standard 500. The dampers shall be opposed-blade type for modulating control, but may be parallel-blade type for two-position control. Pilot positioners and operators shall be out of the airstream.

7. VARIABLE-AIR-VOLUME SYSTEM FAN CONTROL. Variable-air-volume (VAV) systems shall be designed with control devices that sense ductwork static air pressure and velocity air pressure, and control supply-fan airflow and static pressure output through modulation of variable inlet vanes, inlet/discharge dampers, scroll dampers, bypass dampers, variable pitch blades, or variable frequency electric drive controls, as described in ASHRAE *HVAC Applications Handbook*, Chapter 41, and ASHRAE *Handbook of HVAC Systems and Equipment*, Chapter 18. These control systems shall have a minimum of one static pressure sensor mounted in ductwork downstream of the fan and one static pressure controller to vary fan output through either the inlet vane, the damper, the belt modulator, or the speed control. Exhaust fans, supply fans, and return or relief fans shall have devices that control the operation of the fans to monitor air volumes and maintain fixed minimum outdoor air ventilation requirements.

8. FIRE AND SMOKE DETECTION AND PROTECTION CONTROLS. All air-handling systems shall be provided with the smoke and fire protection controls required by NFPA 72. All supply, return, relief, and exhaust air ventilation systems shall have interlock controls that interface with the fire and smoke detection system controls. In the event of fire, these interlock controls shall either turn off or selectively operate fans and dampers to prevent the spread of smoke and fire through the building. These controls shall comply with NFPA 90A. Special exhaust systems shall be designed to include fire and smoke safety controls as required by NFPA 91. Kitchen exhaust ductwork systems shall be designed to include all fire and smoke safety controls as required by NFPA 96. Engineered smoke pressurization and evacuation systems shall comply with the following:

- NFPA 72
- NFPA 90A
- NFPA 92A
- ASHRAE manual, Design of Smoke Control Systems for Buildings
- ASHRAE Handbook of HVAC Systems and Equipment.

9. GAS-FIRED AIR-HANDLING UNIT CONTROL. Gas-fired air-handling units shall be equipped with operating limit, safety control, and combustion control systems. Gas burner and combustion controls shall comply with Factory Mutual (FM) loss prevention data sheets and be listed in the FM Approval Guide. Gas-fired air-handling units shall have controls that lock out the gas supply in the following conditions:

- Main or pilot flame failure
- Unsafe discharge temperature (high limit)
- High or low gas pressure
- No proof of airflow over heat exchanger
- Combustion air loss
- Loss of control system actuating energy.

10. COOLING TOWER AND WATER-COOLED CONDENSER SYSTEM CONTROLS. Controls for cooling towers shall conform to NFPA 214, Standard on Water-Cooling Towers. Design of cooling tower fans shall consider use of variable-speed drives (if feasible) or two-speed motors (if feasible) and on/off controls to reduce power consumption and maintain condenser water temperature. Bypass valve control shall be provided, if required, to mix cooling tower water with condenser water in order to maintain the temperature of entering condenser water at the low limit. To decrease compressor energy use, condenser water temperature shall be allowed to float, as long as the temperature remains above the lower limit required by the chiller. The design shall provide basin temperature-sensing devices and, if the cooling tower is operated under freezing conditions, shall provide additional heat and control system components to maintain cooling tower sump water temperatures above freezing. When appropriate, additional controls and sensors may be added to the condenser water system to provide condenser water to laboratory equipment that may require it. In addition, provisions for supplying emergency condenser water to laboratory equipment may be required.

11. CENTRAL CONTROL AND MONITORING SYSTEMS. The entire control system shall be connected to the central control and monitoring system (CCMS) network. The VAV controllers shall be fully compatible with the CCMS allowing complete monitoring, control, and setpoint adjustment of all VAV terminal unit controllers from the CCMS host. One personal computer must be provided for monitoring, controlling and resetting of any control device in the complex. This computer shall also serve as the connection through a modem to a CCMS. A minimum of one laptop computer shall also be provided for use as a field interface device to monitor, control, and reset any applicable point for any control device. The supplier of the control system shall provide three (3) copies of the operating software (one copy on the central control computer and 2 sets on CDs) and three (3) sets of technical manuals for the control system to the EPA. This system must be expandable to include the future phases.

12. ENERGY METERING. All utilities including electric, gas, oil, and potable water utilities to be monitored shall be metered and tracked by the central control and monitoring system (CCMS). All meters shall be compatible with the installed control system, shall be provided with signaling devices and shall fully interface with building HVAC control panel. Submetering of utilities to various buildings or equipment shall be based on project criteria or, in the absence of these, on sound engineering judgment. Sub-metering of lighting systems should also be considered.

13. DDC HARDWARE REQUIREMENTS. Units of the same type of equipment shall be products of a single manufacturer. Each major component of equipment shall have the manufacturer's name and address, and the model and serial number in a conspicuous place. Materials and equipment shall be standard products of a manufacturer regularly engaged in the manufacturing of such products, which are of a similar material, design and workmanship. The standard products shall have been in a satisfactory commercial or industrial use for two years prior to use on a project. The two years' use shall include applications of equipment and materials under similar circumstances and of similar size. The two years' experience shall be satisfactorily completed by a product which has been sold or is offered for sale on the commercial market through advertisements, manufacturers' catalogs, or brochures. Products having less than a two-year field service record will be acceptable if a certified record of satisfactory, field operation, for not less than 6,000 hours exclusive of the manufacturer's factory tests, can be shown. The equipment items shall be supported by a service organization. Items of the same type and purpose shall be identical, including equipment, assemblies, parts and components.

Portable Workstation/Tester: A portable workstation/tester shall be a Dell Inspiron 2600 or equivalent. It shall include carrying case, extra battery, charger and a compatible network adapter. The workstation/tester shall:

- Run DDC diagnostics.
- Load all DDC memory resident programs and information, including parameters and constraints.
- Display any point in engineering units for analog points or status for digital points.
- Control any analog output (AO) or digital output (DO).

- Provide an operator interface, contingent on password level, allowing the operator to use full English language words and acronyms, or an object oriented graphical user interface.

- Display database parameters.

- Modify database parameters.

- Accept DDC software and information for subsequent loading into a specific DDC. Provide all necessary software and hardware required to support this function, including an EIA ANSI/EIA/TIA 232-F port.

- Disable/enable each DDC.

- Perform all workstation functions as specified.

<u>Central Workstation/Tester</u>: A central workstation/tester shall be tester shall be a Dell Dimension 4500 or equivalent. The central workstation/tester shall:

- Run DDC diagnostics.

- Load all DDC memory resident programs and information, including parameters and constraints.

- Display any point in engineering units for analog points or status for digital points.

- Control any AO or DO.

- Provide an operator interface, contingent on password level, allowing the operator to use full English language words and acronyms, or an object oriented graphical user interface.

- Display database parameters.

- Modify database parameters.

- Accept DDC software and information for subsequent loading into a specific DDC. Provide all necessary software and hardware required to support this function, including an EIA ANSI/EIA/TIA 232-F port.

- Disable/enable each DDC.

- Perform all workstation functions as specified.

13.1 INCORPORATION OF WIRELESS SENSOR TECHNOLOGY. Installation of wireless sensor technology should be considered for control, metering, and monitoring devices. The primary components of a wireless sensor data acquisition system include: sensors; signal conditioners; transmitters; repeaters (optional); at least one receiver; a computer (if data processing is planned); and connections for external communications to users (e.g., building operators). Depending on the specific application of wireless sensors, the following table may be referred to:

Application	Power Source	Frequency band (MHz)	Communications and topology	Maximum range	Typical cost (2006)
Monitoring of electric power use and other parameters	Battery or line powered	Cellular network bands	Point-to-point and point-to-internet	No practical limit in areas with service	$400 and up
Temperature, humidity, occupancy and other building parameters	Battery or line powered	900 and 2400	Mesh network	100 to 300 feet	Varies with vendor.
Temperature, humidity and other parameters monitoring	10-30 V DC from power supply connected to line power	2400	Point-to-point: serial	150 feet line-of-sight	Transmitter and receiver: $800 each
Remote monitoring with long distance communication. Building-to-building communication. Remote facility monitoring.	11-25 V DC from power supply connected to line power	900	Point-to-point and point-to-multipoint: serial	15 to 35 miles line-of-sight	Transmitter: $1400 to $1800. Point-to-point bridge: $1000 to $2000. Point-to-multipoint: $2000.
Building temperature sensing. Electric power metering. Building security.	Temperature sensors: battery powered. Receiver: line powered with 24 V AC power supply. Repeaters: line powered with battery backup.	900	Point-to-multipoint: serial FHSS	2500 feet open field. Several hundred feet indoors.	Transmitter with air temperature sensor: $70. Repeater: $250. Receiver: $300.
Rarely used for building sensing.	Transmitter: 24 V AC. Receiver: DC power supply connected to 120 V AC.	433	Point-to-point: proprietary protocols	Approximately 200 feet.	Transmitter: $300. Receiver: $600.

TYPICAL CHARACTERISTICS OF COMMERCIAL WIRELESS TECHNOLOGIES

For each project, the implementation of wireless sensor technology will depend on the determination of economic cost-effectiveness of the wireless data acquisition system.

14. DDC SOFTWARE REQUIREMENTS. All DDC software described in this specification shall be furnished as part of the complete DDC system. Updates to the software shall be provided for system, operating and application software, and operation in the system shall be verified. Updates shall be incorporated into operations and maintenance manuals, and software documentation. There shall be at least one scheduled update near the end of the first years' warranty period, at which time the latest released version of the Contractor's software shall be installed and validated.