SECTION 230993 - SEQUENCE OF OPERATIONS FOR HVAC CONTROLS

PART 1 - GENERAL

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 1 Specification Sections, apply to this Section.

B. Alternate #6: Refer to Section 012300 – "Alternates".

C. Related Sections include the following:

1. Division 23 Section "Common Work Results for Mechanical"
2. Section 230900 – "Instrumentation And Control for HVAC" for control equipment and devices and submittal requirements.
3. Division 23 Section "Testing, Adjusting, and Balancing"
4. Division 26

1.2 SUMMARY

A. This Section includes control sequences for HVAC systems, subsystems, and equipment. Provide control devices, control software and control wiring as required for automatic operation of each sequence specified.

1. Provide automatic control for system operation as described herein, although word "automatic" or "automatically", is not used.
2. Manual operation is limited only where specifically described; however, provide manual override for each automatic operation.
3. Where manual start-up is called for, also provide scheduled automatic start-stop capabilities.

B. The system is BAS controlled using electric actuation. Provide proportional-integral-derivative (PID) algorithms for all control programs.

C. Functions called for in sequence of operations are minimum requirements and not to limit additional BAS system capabilities. Determine, through operation of the system, proportional bands, interval time, integral periods, adjustment rates, and any other input information required to provide stable operation of the control programs.

D. For each item of equipment, provide following functions which are not specifically mentioned in each Sequence of Operation:

1. Start-Stop, manual, and scheduled
2. On-Off status of each piece of equipment
3. Run-time
4. Alarm

E. All setpoints shall be monitored and adjustable. Setpoints listed herein are approximate. It is the responsibility of the BAS contractor to calibrate the system and all setpoints to actual working conditions once the system is on line.

F. Variable Frequency Drives: Current VFD status and operating conditions shall be monitored through its communications interface port. The interface shall monitor the following software points: Motor RPM, motor amps, motor runtime, VFD status, and "In fault condition".

G. Normal positions for controlled devices:

1. Unless noted, the following valves and dampers shall fail closed:

a. Outside air dampers
b. Relief air dampers
c. Exhaust air closure dampers
d. Smoke dampers
e. Steam converter valve.

2. Unless noted, the following valves and dampers shall fail open:

a. Heating coils.

PART 2 - BASE BID SEQUENCES OF OPERATION

2.1 STEAM TO HW CONVERTER

A. Heating

1. The pumping system and the steam/hot water converter operate continuously whenever the outside air temperature is low enough for the building to require heating. When this occurs, an outside air temperature controller starts the primary pump, enables the converter control.
2. The heating system will be enabled continuously. Provide a flow switch, at proof of flow, the converter steam valves modulates to maintain HWS temperature
3. The supply hot water set point is maintained by modulating the converter steam valve. The hot water supply set point is reset based on outdoor air temperature. When the outdoor air temperature is 0°F, the set point is 180°F and when the outdoor air temperature is 60°F, the set point is 120°F. When this loop is disabled, the valves shall be in their normal (failsafe) position.

B. System Pump:

1. Pump shall be enabled by the BAS.
2. Locate a differential pressure sensor at the most hydraulically remote location. Pump flow will modulate as terminal unit modulating valves open and close. The pump VFD shall modulate as required to maintain pressure setpoint.
3. Pump operates continuously thru VFD and differential pressure transmitter.

4. The BAS system shall use status wired to each VFD to confirm the pumps are in the desired state (i.e. on or off) and generates an alarm if status deviates from BAS start/stop control.

C. Operator Workstation: Display the following data:

1. Outside temperature.
2. Reset water temperature
3. Heating-water supply & return temperatures.
4. Heating-water supply temperature set point.
5. Converter steam-valve position.
6. Pumps status/failure
7. Flow switch
8. System pump VFD status
9. System pump VFD fault
10. System pump VFD Hz.

2.2 AIR HANDLER

A. Provide controls for the existing air handling unit.

1. Existing OA & RA direct coupled damper actuators may be utilized.
2. Fan motor and starter shall be replaced with a new motor and VFD (see Section 230500).
3. Existing AHU coil steam control valve may be re-used; provide a new actuator.

2.3

A. Provided an optimal start sequence: This sequence shall use the BAS to determine the length of time required to bring each zone from night setback temperature to the occupied setpoint temperature. The system shall wait as long as possible before starting, so that the temperature in each zone reaches occupied setpoint just in time for occupancy. This optimal starting time shall be determined using the difference between actual zone temperature and occupied setpoint. The BAS shall compare the difference with the historical performance of how quickly the zone has been able to warm up or cool down.

B. Provide an optimal stop sequence: At the end of the occupied period, the system is shut off and the temperature is allowed to drift away from occupied setpoint. Optimal stop shall use the BAS to determine how early heating and cooling can be shut off for each zone, so that the indoor temperature drifts 1°F from occupied setpoint for the last hour of the day.

C. Occupied mode:

1. Occupied mode shall be determined by: User defined occupancy schedule.
2. BAS shall start the supply fan to run continuously. A status signal shall be wired to the supply fan VFD. The BAS system uses the status to confirm the fan is in the desired state (i.e. on or off) and generates an alarm if status deviates from BAS start/stop control.
3. Morning warm up shall be based on "optimal start" control based on building temperature and lag time to reach each zone's setpoint. During warm up the OA and EA dampers are 100% closed, RA damper is 100% open, and AHU coil control valve is 100% open, and VAV boxes control to space setpoint. After each zone has reached setpoint, air system OA, RA and EA dampers go to set minimum positions, heating coil control valve modulates to maintain discharge air setpoint.
4. Discharge Air:

    a. Coordination of Air-Handling Unit Sequences: Ensure that coil controls have common inputs and do not overlap in function. Provide a 5°F deadband between heating and cooling stages.
    b. System resets supply-air temperature set point from higher, subject to warmest space temperature sensor reading. Reset by zone cooling demand during cool weather (<55ºF to 60ºF), then ramp down to design SAT in warm weather (>60ºF to 70ºF)
    c. Supply air temperature reset control: During occupied mode, the setpoint is reset from T-min (55°F) when the outdoor air temperature is 70°F and above, proportionally up to T-max when the outdoor air temperature is 65°F and below. T-max shall be reset using trim and respond logic within the range 55°F to 65°F. When fan is off, lock T-max at the maximum value (65ºF). While fan is proven on, every 2 minutes, increase the setpoint by 0.2ºF if there are no zone cooling requests. If there are more than two (adjustable) cooling requests, decrease the setpoint by 0.3ºF. A cooling request is generated when the cooling loop of any zone served by the system is >99%.
    d. Supply air temperature shall be maintained at +/-2.5°F minimum (to avoid cooling cycling).
    e. DA high temperature limit is 105°F (adj) and low temperature limit is 48°F (adj). Alarm high and low.
    f. Steam Heating: Modulate steam valve.
    g. DX Cooling Coil: System stages the DX system to maintain supply-air temperature.

        1) Provide at four stages of cooling (specified condensing unit has 4 stages). Stages shall be enabled in sequence with a time delay for each stage. The algorithm shall include separate time delays appropriate for turning stages off.
        2) A suction line temperature sensor on the evaporator near the TXV bulb location shall be used to determine if the coil is getting close to a freezing condition. Mechanical cooling capacity shall be shed as necessary to prevent icing. The supply fans shall not shut off and will de-ice the coil.
        3) To minimize compressor cycling, provide time delay logic.

            a) Minimum OFF time for a stage is five minutes
            b) Minimum ON time for a stage is five minutes (unless an alarm occurs).

4) When the outside air temperature is 50°F or cooler, the mechanical cooling shall be disabled.

5. Variable Air Volume Control

a. Supply air static pressure control shall be provided by a proportional integral derivative (PID) algorithm that modulates the supply fan VFD to maintain a duct static pressure set point. Locate pressure sensor in the 22x12 supply duct above Elementary Classroom A118.
b. Dump Box (BP-1): A pressure independent VAV terminal is provided to maintain a minimum airflow (See VAV box schedule) as needed by the AHU DX coil. This VAV terminal is located near the end of the run; "dumping" excess air (and pressure) to the return plenum.

1) See VAV box schedule for additional control strategy.

c. The dump box shall modulate to maintain a minimum AHU VFD Hz as determined during the balancing phase. As VAV zones modulate open and exceed this minimum flow, the dump box CFM shall modulate to zero CFM. When VAV zone terminals continue to open, the AHU VFD shall increase airflow in response to the duct pressure sensor.
d. If the controller does not receive a valid duct static-pressure value, it shall generates a diagnostic and shut down the unit.
e. Static-pressure controller located in fan discharge stops fan and signals alarm when static pressure rises above excessive-static-pressure set point.
f. Set variable-speed drive to minimum speed when fan is stopped.
g. The algorithm shall provide soft start of the fan by ensuring the VFD is at minimum speed before energizing the fan.

6. Minimum Outside Air Control for VAV Systems:

a. When in the occupied mode, the ERU shall energize and provide minimum outside air to the space.
b. As CO2 levels rise in the spaces, the AHU OA damper shall modulate open from zero to peak minimum OA flow (see VAV box schedule on plans). The peak minimum OA flow is a combination of ERU airflow (fixed amount confirmed during balancing) and OA duct flow, as measured by the airflow measuring station (AFMS).

1) All zones shall be polled and the highest CO2 sensor reading shall be sent to the AHU OA damper controller. This CO2 reading shall be compared to the CO2 setpoint at the AHU damper controller. If no zones are calling for max airflow from their VAV box and the reading is below the CO2 set point, the AHU OA damper shall be closed (ERU shall continue to run to provide a base minimum).
2) If any VAV box is at maximum airflow and requires more ventilation air and the CO2 reading is above the set-point for more than 5 minutes, the AHU OA damper controller shall modulate the OA dampers open (from zero to peak OA as scheduled) utilizing a PI loop to reduce the CO2 level in the space. Once the space CO2 level drops below the AHU CO2 set point, the OA dampers shall modulate toward set base ventilation rate.

7. Economizer cooling:

    a. Air economizer system shall be capable of modulating OA and RA to provide up to 100% of the design SA quantity as OA for cooling.
    b. During economizer mode the ERU supply fan shall be OFF (exhaust fan shall remain on) and the normally-closed 2-position relief damper shall be open to relieve building pressure.
    c. To save energy, economizer dampers shall be capable of being sequenced with the mechanical cooling equipment. To ensure proper sequencing, mixed air (MA) temperature shall not control the economizer. Instead, the dampers must be controlled by the same controller used to control the mechanical cooling (discharge air temperature)
    d. High Limit Shutoff: Economizer shall be capable of automatically reducing OA intake to the minimum OA quantity when OA intake will no longer reduce cooling energy usage. Provide a reference enthalpy High Limit Control. When OA enthalpy exceeds an adjustable reference enthalpy setting. An OA enthalpy sensor is provided to compare the total heat content of outdoor air to a locally adjustable setpoint. The setpoint is programmed at the human interface to determine if the outdoor enthalpy condition is suitable for economizer operation. The most common approach simply assumes an enthalpy state of the return air based on design conditions and then allows the economizer to function only if the measured outdoor air enthalpy is less than the assumed return air state.

D. Unoccupied mode:

1. OA, and EA dampers 100% closed, RA damper 100% open.
2. Associated exhaust fans and ERU do not operate.
3. Supply fan cycles and each zone terminal unit will modulate heating output to maintain night set back temperature at 62°F (adj). Note: due to the building's heavy construction the temperature will drop slowly at night ("thermal flywheel"). If is likely that minimal night setback heating will be required.
4. Systems shall have 2 hour (adj) unoccupied override ability. Associated exhaust fans shall also operate in override mode.

E. Safeties:

1. The supply fan and all BAS Hardware control loops shall be subject to Proofs and Safeties. Safeties shall be direct-hardwire interlocked to the fan starter circuit. BAS Hardware shall monitor all proofs and safeties and failure of any proof or activation of any safety shall result in all control loops being disabled and the AHU fan being commanded off until reset.
2. Shall stop the supply fan; cause the system valves and dampers to return to their normal positions.
3. BAS Hardware reset of all proofs and safeties shall be via a local binary push-button input to the BAS Hardware.
4. A capillary freezestat shall initiate a low temperature alarm if the temperature drops below the freezestat's setpoint.
5. Duct smoke detectors shall be installed in supply airstream and at smoke dampers as indicated on the plans. Installation in ductwork and connection to control system shall be under Division 23. Detector furnished and wired to the fire alarm system by Division 26.

Activated when products of combustion are detected in air stream. Wire to the fire alarm system, when smoke is detected, stop supply fan.

F. Display of input points thru BAS:

1. System graphic
2. System occupied/unoccupied mode.
3. Coldest and warmest zones (all zones sampled)
4. Fan status/failure Generate an Alarm)
5. Fan rpm and Hz. thru VFD
6. Outside, Return, & Relief damper commanded damper positions.
7. Outside, Return, Mixed, and Discharge temperature indications and setpoints
8. Coil low temperature thermostat (Generate Alarms).
9. High and Low DA limit (Generate an Alarm).
10. Supply-fan-discharge static-pressure indication and setpoint.
11. Supply-fan rpm and Hz. thru VFD.
12. Commanded heating-coil control-valve position.
13. Commanded cooling stage, 1, 2, 3, or 4.
14. Condensing unit fault/status
15. AFMS CFM
16. Total OA CFM

2.4 ENERGY RECOVERY UNIT

A. Occupied mode:

1. Normally closed outside air and exhaust dampers (furnished by ERU manufacturer) shall be open.

    a. Economizer mode, only exhaust damper shall be open.

2. ERU shall operate continuously during occupied hours, subject to damper end switches.
3. ERU supply fan shall be disabled during economizer mode.
4. Prove unit operation by current switch.
5. ERU VFD’s shall be used for soft start and balancing.

B. Unoccupied mode:

1. OA and EA dampers 100% closed.
2. Fans off.

2.5 AIR TERMINAL UNITS

A. Each pressure-independent VAV box shall have a discharge air sensor to monitor DA temperature.

B. Unoccupied Mode

1. When the central air handling unit is off, the BAS shall command the VAV supply air damper closed.
2. When the central air handling unit is off, the BAS shall command the hot water valve closed.
3. If the room temperature falls below 60°F (adjustable), the BAS shall generate an alarm.

C. Occupied Mode

1. The BAS shall schedule the VAV to occupied mode. The central air handling unit must be running before the VAV will operate in the occupied mode.
2. Provide “dual maximum” control for maximum efficiency.

    a. When the zone is in the cooling mode, the cooling loop output is mapped to the airflow setpoint from the cooling maximum to the minimum airflow setpoints. The hot water valve is closed.
    b. When the zone is in the deadband mode, the airflow setpoint shall be the minimum airflow setpoint. The hot water valve is closed.
    c. When the zone is in the heating mode, the heating loop shall maintain space temperature at the heating setpoint as follows:

        1) From 0%-50% loop signal, the heating loop output shall reset the discharge temperature from supply air temperature setpoint (e.g., 55°F) to 90°F. Note the upper temperature is limited to prevent stratification during heating.
        2) From 50%-100% loop signal, the heating loop output shall reset the zone airflow setpoint from the minimum airflow setpoint to the maximum heating airflow setpoint. The supply air discharge temperature remains at 90°F.
        3) The hot water valve shall be modulated using a PI control loop to maintain the discharge temperature at setpoint. Note that directly controlling the hot water valve from the zone temperature PI loop is not acceptable since it will not allow supply air temperature to be under control and limited in temperature to prevent stratification.
        4) The VAV damper shall be modulated to maintain the measured airflow at setpoint.

3. CO2 Demand Control Ventilation (provide as indicated in the VAV box schedule):

    a. When the zone CO2 sensor is below 900 ppm (adj.), the system will have the terminal damper at minimum position and modulate the damper based on its PID temperature control algorithm to maintain desired zone temperature set-points.
    b. If the CO2 level at the zone exceeds its set point the system will begin to modulate the damper using a PID control loop. When the CO2 level set point is reached the box will stop modulation and begin back toward minimum position.
    c. If while modulating-open the damper, the space temperature limit is reached the system will engage reheat, modulating the hot water (2-way or 3-way, see VAV box schedule) control valve to maintain setpoint.
    d. If the maximum damper position is reached and the CO2 set point is still not satisfied the AHU will modulate its OA damper using a PID loop to bring the zone CO2 level below set point.

4. The BAS shall limit the maximum cooling setpoint to 78°F (adj.) and the minimum cooling setpoint to 74°F (adj.).
5. The BAS shall limit the maximum heating setpoint to 72°F (adj.) and the minimum heating setpoint to 65°F (adj.).
6. Operator Workstation: Display the following data:

    a. Room/area served.
    b. Room temperature, alarm high and low (2°F out of range)
    c. Room temperature set point, occupied.
    d. Room temperature set point, unoccupied.
    e. VAV Supply box pressure
    f. VAV supply box CFM
    g. VAV box damper % open
    h. VAV box supply temperature (units with reheat coils)
    i. Heating coil control-valve position as percent open.
    j. CO2 Setpoint
    k. CO2 ppm

2.6 DUCT SMOKE DAMPERS

A. Installation in ductwork and connection to control system shall be under Division 23. Detector furnished and wired to the fire alarm system by Division 26.

B. Upon activation, the smoke detector shall close the damper and shut down the air system.

PART 3 - ALTERNATE #6 SEQUENCES OF OPERATION

3.1 AIR HANDLER

A. Provide controls for the existing air handling unit.

1. Existing OA & RA direct coupled damper actuators may be utilized.
2. Existing AHU coil steam control valve may be re-used.

B. Existing Honeywell start-stop controls to remain. Program per Owner’s occupancy schedule.

C. Occupied mode:

1. Occupied mode shall be determined by: User defined occupancy schedule.
2. BAS shall start the supply fan to run continuously.
3. Morning warm up shall be based on “optimal start” control based on building temperature and lag time to reach each zone’s setpoint. During warm up the OA and EA dampers are 100% closed, RA damper is 100% open, and AHU coil control valve is 100% open, and VAV boxes control to space setpoint. After each zone has reached setpoint, air system OA, RA and EA dampers go to set minimum positions, heating coil control valve modulates to maintain discharge air setpoint.

4. Discharge Air:

    a. Coordination of Air-Handling Unit Sequences: Ensure that coil controls have common inputs and do not overlap in function. Provide a 5°F deadband between heating and cooling stages.
    b. Supply air temperature reset control: During occupied mode, the setpoint is reset from T-min (55°F) when the outdoor air temperature is 70°F and above, proportionally up to T-max when the outdoor air temperature is 65°F and below. T-max shall be reset using trim and respond logic within the range 55°F to 65°F. When fan is off, lock T-max at the maximum value (65ºF). While fan is proven on, every 2 minutes, increase the setpoint by 0.2ºF if there are no zone cooling requests. If there are more than two (adjustable) cooling requests, decrease the setpoint by 0.3ºF. A cooling request is generated when the cooling loop of any zone served by the system is >99%.
    c. Supply air temperature shall be maintained at +/-2.5°F minimum (to avoid cooling cycling).
    d. DA high temperature limit is 105°F (adj) and low temperature limit is 48°F (adj). Alarm high and low.
    e. Steam Heating: Modulate steam valve.
    f. DX Cooling Coil: System stages the DX system to maintain supply-air temperature.

        1) To minimize compressor cycling, provide time delay logic.

            a) Minimum OFF time for a stage is five minutes
            b) Minimum ON time for a stage is five minutes (unless an alarm occurs).

        2) When the outside air temperature is 50°F or cooler, the mechanical cooling shall be disabled.

5. Air Volume Control

    a. Dump Box (BP-1): A pressure independent VAV terminal is provided to maintain a minimum airflow (See VAV box schedule) as needed by the AHU DX coil. This VAV terminal is located near the end of the run; "dumping" excess air (and pressure) to the return plenum.

        1) See VAV box schedule for additional control strategy.

    b. The dump box shall modulate to maintain constant AHU airflow. As VAV zones modulate open and exceed this minimum flow, the dump box CFM shall modulate to minimum CFM.

6. Minimum Outside Air Control for VAV Systems:

    a. As CO2 levels rise in the spaces, the AHU OA damper shall modulate open from zero to peak minimum OA flow (see VAV box schedule on plans).

        1) All zones shall be polled and the highest CO2 sensor reading shall be sent to the AHU OA damper controller. This CO2 reading shall be compared to the

CO2 setpoint at the AHU damper controller. If no zones are calling for max airflow from their VAV box and the reading is below the CO2 set point, the AHU OA damper shall be at minimum.

2) If any VAV box is at maximum airflow and requires more ventilation air and the CO2 reading is above the set-point for more than 5 minutes, the AHU OA damper controller shall modulate the OA dampers open (from zero to peak OA as scheduled) utilizing a PI loop to reduce the CO2 level in the space. Once the space CO2 level drops below the AHU CO2 set point, the OA dampers shall modulate toward set base ventilation rate.

7. Economizer cooling: existing Honeywell controls to be reused or replace with new as necessary.

   a. Air economizer system shall be capable of modulating OA and RA to provide up to 100% of the design SA quantity as OA for cooling.
   b. To save energy, economizer dampers shall be capable of being sequenced with the mechanical cooling equipment. To ensure proper sequencing, mixed air (MA) temperature shall not control the economizer. Instead, the dampers must be controlled by the same controller used to control the mechanical cooling (discharge air temperature)
   c. High Limit Shutoff: Economizer shall be capable of automatically reducing OA intake to the minimum OA quantity when OA intake will no longer reduce cooling energy usage.

D. Unoccupied mode:

1. OA, and EA dampers 100% closed, RA damper 100% open.
2. Associated exhaust fans do not operate.
3. Supply fan cycles and each zone terminal unit will modulate heating output to maintain night set back temperature at 62°F (adj). Note: due to the building's heavy construction the temperature will drop slowly at night ("thermal flywheel"). If is likely that minimal night setback heating will be required.
4. Systems shall have 2 hour (adj) unoccupied override ability. Associated exhaust fans shall also operate in override mode.

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2. Shall stop the supply fan; cause the system valves and dampers to return to their normal positions.
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8. Coil low temperature thermostat (Generate Alarms).
9. High and Low DA limit (Generate an Alarm).
10. Commanded heating-coil control-valve position.
11. Commanded cooling stage

END OF SECTION 230993