SECTION 23 09 93 - SEQUENCE OF OPERATIONS FOR HVAC CONTROLS

PART 1 - GENERAL

1.1 SUMMARY

A. The Engineer shall submit to the university for review and comment a complete sequence of operations two weeks before final documents are sent out to bid.

1.2 SYSTEM DESIGN REQUIREMENTS

A. All sequences shall be written to maximize energy conservation

B. All units that can be placed on a schedule shall have complete schedule control including optimum start and an optimized unoccupied turn on for unoccupied space heating and cooling.

C. Separate supply air temperature setpoints for heating components and cooling components in air handling unit shall be specified unless application makes impractical

D. Complete schedule control shall be included for terminal devices such as baseboard heating, VAV boxes that auditoriums, classrooms, conference rooms and other scheduled areas regardless of whether they are served by a dedicated air handler.

E. Separate room heating and room cooling setpoints shall be included for space comfort except where prohibited by space design parameters.

F. All conference rooms, all class rooms, and all other of 50 person occupancy or greater shall have demand controlled ventilation designed by the engineer using carbon dioxide sensing in the space. Areas served by economizer systems that are not practical for complete coverage with space CO2 sensors shall have CO2 sensors in the return duct. Air supply dampers shall close with unoccupied and room temperature set points have been met.

G. Sequences for the chilled water system shall conform to the university Metering Standard.

H. Typical VFD point set-up:
1. The virtual L2SL point changes state based upon the programming and the LDO is set to the value of the L2SL in programming.
2. Physical digital output point with VFD enable (LDO)
3. RA-L26-P-003-RVD-LDO
4. Physical digital input for alarming (LDI)
5. RA-L26-P-003-RVD-LDI
6. Virtual and physical point used for system alarming (L2SL)
7. RA-L26-P-003-RVD-ENA
8. LDO is virtual and LDI physical

I. Normal (Power Fail) positions for dampers and valves are as follows:
1. Outside air damper: Closed (NC)
2. Exhaust air damper: Closed (NC)
3. Return air damper: Open (NO)
4. Primary AHU HW or Steam Valves: Open (NO)
5. Primary AHU CHW Valves: Closed (NC)
6. Terminal Unit Reheat Valves: Closed (NC) or Fail to Last Position (FLP)
7. Chiller – Chilled Water Isolation Valves: Fail to Last Position (FLP)
8. Chiller – Condenser Water Isolation Valves: Fail to Last Position (FLP)

9. Cooling Tower Isolation Valves: Fail to Last Position (FLP)
10. Boiler Isolation Valves: Fail to Last Position (FLP)
11. Heating Water Mixing Valve: Fail to Heat
12. Steam Valves for Heat Exchangers: Closed (NC)
13. Heating coil valves for animal housing applications to fail closed. Verify with the University Project Manager.

1.3 STANDARD POINTS LIST

A. General
1. Simulated analog outputs such as tri-state digital output pairs or pulse width modulation shall not be allowed except in dedicated controllers.
2. Fan and pump status inputs shall be independent current switches, not contacts, on any VFD.
3. Alarm priorities are a starting point and can be adjusted by the university after project commissioning.
4. All VFDs shall have an RS485 communications port compatible with the BAS. Speed control, VFD speed, Fan start/stop, and VFD alarm points can be through this port.
5. Priorities 1 or 2 shall be set up to call the alpha numeric pagers.
6. This standard points list is a minimum only. The Engineer and BAS controls contractor are responsible for providing a complete BAS system.
7. VFDs to show actual speed and if in hand,
8. Fire alarm and trouble for each building.
9. Operable windows – closed.
10. High condensate tank level.
11. Fire pump and jockey pump status

B. Point Lists

Typical Physical Points - Mixed Air, VAV, Heating Water Preheat		
SUBPOINT NAME SUFFIX	TYPE	DESCRIPTION
RAT	LAI	RETURN TEMP
RHR	LAI	RETURN HUMIDITY (RH MEASUREMENT WILL BE MADE USING SPACE RH LEVEL/S.)
LSPA	LDI	LOW STATIC PRESS
ALM	LDI	RETURN VFD ALARM
ENA	LDO/LDI	RETURN VFD ENA
HND	LDI	RETURN VFD HOA
HZ	LAI	RETURN VFD HERTZ
LDI	LDI	RETURN VFD LDI
LDO	LDO	RETURN VFD LDO
SPD	LAO	RETURN VFD SPEED
CFM	LAI	RETURN CFM
ESP	LAI	RETURN STATIC
EAD	LAO	EXHAUST DAMPER
RAD	LAO	RETURN DAMPER
OAD	LAO	OUTSIDE DAMPER
OAD-CFM	LAI	OUTSIDE CFM
MOAD	LAO	MINIMUM DAMPER (IF REQUIRED AND CONTROL BY BAS)
MOAD-CFM	LAI	MINIMUM CFM (IF REQUIRED AND CONTROL BY BAS)
MAT	LAI	MIXED TEMP
PFLT	LAI	PRE-FILTER
FFLT	LAI	FINAL FILTER
FLT	LAI	FILTER (IF THERE IS ONLY ONE FILTER)

HCV	LAO	HEATING VALVE
HCPM	LDO/LDI	HEATING PUMP
HCT	LAI	HEATING TEMP
ALM	LDI	SUPPLY VFD ALARM
ENA	LDO/LDI	SUPPLY VFD ENA
HND	LDI	SUPPLY VFD HOA
HZ	LAI	SUPPLY VFD HERTZ
LDI	LDI	SUPPLY VFD LDI
LDO	LDO	SUPPLY VFD LDO
SPD	LAO	SUPPLY VFD SPEED
CFM	LAI	SUPPLY CFM
LTD	LDI	LOW TEMP DETECT
HSPA	LDI	LOW STATIC PRESS
CCV	LAO	COOLING VALVE
CCPM	LDO/LDI	COOLING PUMP (IF REQUIRED)
CCT	LAI	COOLING TEMP
EVPM	LDO/LDI	EVAP PUMP ENABLE
EVDV	LDO	FILL-DRAIN VALVE
EVCV	LDO	BLEED DOWN VALVE
EVBD	LAO	BYPASS DAMPER
EVC	LAI	EVAP CONDUCTIVTY
SAT	LAI	SUPPLY TEMP
SD	LDI	SMOKE DETECTOR
SSP	LAI	SUPPLY STATIC
BSP	LAI	BUILDING STATIC

TYPICAL PHYSICAL POINTS – 100% OUTSIDE AIR, VAV, STEAM PREHEAT		
SUBPOINT NAME SUFFIX	TYPE	DESCRIPTION
IID	LDI	INTAKE DAMPER (DAMPER CONTROLLED BT VFD)
PFLT	LAI	PRE-FILTER
FFLT	LAI	FINAL FILTER
FLT	LAI	FILTER (IF THERE IS ONLY ONE FILTER)
HRV	LAO	HEAT RECOV VALVE (3-WAY)
HRT	LAI	HEAT RECOV TEMP
HCV	LAO	HEATING VALVE
FBD	LAO	BYPASS DAMPER
HCPM	LDO/LDI	HEATING PUMP
HCT	LAI	HEATING TEMP
LSPA	LDI	LOW STATIC PRESS
ALM	LDI	SUPPLY VFD ALARM
ENA	LDO/LDI	SUPPLY VFD ENA
HND	LDI	SUPPLY VFD HOA
HZ	LAI	SUPPLY VFD HERTZ
LDI	LDI	SUPPLY VFD LDI
LDO	LDO	SUPPLY VFD LDO
SPD	LAO	SUPPLY VFD SPEED
CFM	LAI	SUPPLY CFM
LTD	LDI	LOW TEMP DETECT
HSPA	LDI	HIGH STATIC PRESS
CCV	LAO	COOLING VALVE
CCPM	LDO/LDI	COOLING PUMP (IF REQUIRED)
CCT	LAI	COOLING TEMP
EVPM	LDO/LDI	EVAP PUMP ENABLE
EVDV	LDO	FILL-DRAIN VALVE
EVCV	LDO	BLEED DOWN VALVE
EVBD	LAO	EVAP BYPASS DAMPER
EVC	LAI	EVAP CONDUCTIVITY
SAT	LAI	SUPPLY TEMP
SD	LDI	SMOKE DETECTOR
DID	LDI	DISCHARGE DAMPER (DAMPER CONTROLLED BT VFD)
SSP	LAI	SUPPLY STATIC
BSP	LAI	BUILDING STATIC
RHRM	LAI	RELATIVE HUMIDITY (RH MEASUREMENT WILL BE MADE USING SPACE RH LEVEL/S.)

Typical Physical Points - Heating water system fed from the CUP		
Subpoint Name SUFFIX	Type	Description
FLW	LDI	HW FLOW PROOF (HX #1)
HV	LAO	STEAM VALVE (HX #1)
HWR	LAI	HW RETURN TEMP (HX #1)
HWS	LAI	HW SUPPLY TEMP (HX #1)
IV	LAO	HW ISO VALVE (HX #1)
PRI-HWR	LAI	PRI HW RET TEMP
PRI-HWS	LAI	PRI HW SUP TEMP
FLW	LDI	HW FLOW PROOF (HX #2)

HV	LAO	STEAM VALVE (HX #2)
HWR	LAI	HW RETURN TEMP (HX #2)
HWS	LAI	HW SUPPLY TEMP (HX #2)
IV	LAO	HW ISO VALVE (HX #2)
ALM	LDI	HW VFD ALARM (PUMP #1)
ENA	LDO/LDI	HW VFD ENA (PUMP #1)
HND	LDI	HW VFD HOA (PUMP #1)
HZ	LAI	HW VFD HERTZ (PUMP #1)
LDI	LDI	HW VFD LDI (PUMP #1)
LDO	LDO	HW VFD LDO (PUMP #1)
SPD	LAO	HW VFD SPEED (PUMP #1)
ALM	LDI	HW VFD ALARM (PUMP #2)
ENA	LDO/LDI	HW VFD ENA (PUMP #2)
HND	LDI	HW VFD HOA (PUMP #2)
HZ	LAI	HW VFD HERTZ (PUMP #2)
LDI	LDI	HW VFD LDI (PUMP #2)
LDO	LDO	HW VFD LDO (PUMP #2)
SPD	LAO	HW VFD SPEED (PUMP #2)
DP	LAI	PRI HW DIFF PRES

Typical Physical Points - Chilled water system fed from the CUP		
Subpoint Name	Type	Description
SEC-DP	LAI	SEC CHW DP
CHWB	LAI	PRI CHW BYP TEMP
CHWR	LAI	PRI CHW RET TEMP
CHWRV1	LAO	PRI CHW RET VALVE
CHWRV2	LAO	PRI CHW RET VALVE
CHWS	LAI	PRI CHW SUP TEMP
PRI-DP	LAI	PRI CHW DP MAIN
FLW	LAI	PRI CHW FLOW
ALM	LDI	CHW VFD ALARM (PUMP #1)
ENA	LDO/LDI	CHW VFD ENA (PUMP #1)
HND	LDI	CHW VFD HOA (PUMP #1)
HZ	LAI	CHW VFD HERTZ (PUMP #1)
LDI	LDI	CHW VFD LDI (PUMP #1)
LDO	LDO	CHW VFD LDO (PUMP #1)
SPD	LAO	CHW VFD SPEED (PUMP #1)
ALM	LDI	CHW VFD ALARM (PUMP #2)
ENA	LDO/LDI	CHW VFD ENA (PUMP #2)
HND	LDI	CHW VFD HOA (PUMP #2)
HZ	LAI	CHW VFD HERTZ (PUMP #2)
LDI	LDI	CHW VFD LDI (PUMP #2)
LDO	LDO	CHW VFD LDO (PUMP #2)
SPD	LAO	CHW VFD SPEED (PUMP #2)
CHWR	LAI	SEC CHW RET TEMP
CHWS	LAI	SEC CHW SUP TEMP
FLW	LAI	SEC CHW FLOW

Typical Physical Points – Energy/Water Metering		
SUBPOINT NAME SUFFIX	TYPE	DESCRIPTION
KWH	LPACI	ELECTRIC CONSUMPTION (NOTE: PREFIX)
KW	AI	ELECTRIC DEMAND (NOTE: PREFIX)

FLW	AI	STEAM FLOW, CHILLED WATER FLOW
WM	LPACI	ALL OTHER WATER METER FLOW

FOR ALL BAS VFDS		
SUBPOINT NAME	TYPE	DESCRIPTION
ALM	LDI	* VFD ALARM
ENA	LDO/LDI	* VFD ENA (THE START/STOP IS THROUGH COMMUNICATION AND THE STATUS IS HARDWIRED)
HND	LDI	* VFD HOA
HZ	LAI	* VFD HERTZ
LDI	LDI	* VFD LDI
LDO	LDO	* VFD LDO
SPD	LAO	* VFD SPEED

1.4 SEQUENCE OF OPERATIONS

A. Secondary Chilled Water – Control Sequence

1. Chilled water pumps shall function in normal power mode. One pump (lowest run time) shall be functional in emergency power mode. Emergency power is limited, so BAS shall not allow other pumps to run.
2. Space cooling shall be provided via circulation of chilled water as provided by chilled water from central plant. Chilled water pumps are designed to as a parallel pumping system (n+1 redundancy).
3. Each chilled water pump is to have a hand-off auto (h-o-a) switch; units shall be in auto position when available for operation as controlled by the BAS.
4. The chilled water system shall operate at all times.
5. BAS shall alternate pumps weekly on Tuesday at 11:00 am based upon runtime, sequencing equipment in order of least to greatest accumulated yearly runtime, where the lowest runtime unit is indexed as lead/first, and highest runtime unit is indexed as lag/standby.
6. If units selected as duty pumps are unavailable for operation due to maintenance, failure, or selection of off position at unit (h-o-a) switch, the standby pump shall become one of the duty pumps.
7. During low water flow conditions, the large pumps shall be sequenced off and the smaller pump shall be energized to maintain required flow and temperature drop across the heat exchanger.
8. Upon failure of one of the duty chilled water pump, the BAS shall automatically initiate the startup of the standby pump, and signal an alarm to the bas.
9. Chilled water pump flow shall be maintained continuously.
10. Each pump shall be provided with a current sensor to operate as a flow proof of that pumping unit. Any pump energized through the EMS system which does not give positive indication of flow shall signal an alarm after 90 seconds. Continued lack of flow proof for an energized pump to a period of 180 seconds shall de-energize that pump and initiate the startup of the standby unit.
11. Two differential pressure sensors will provide input to the BAS. Each sensor shall have an adjustable set point (provided by TAB contractor). The BAS shall modulate the VFD's of both duty pumps to maintain dp setpoint for both sensors by calculating the difference between each sensor and its set point. The maximum difference shall be input into the VFD control loop.
12. Modulate the 1/3 and 2/3 two way control valves in sequence in the CUP chilled water return line to maintain a CUP CHWR flow set point measured at the chilled water meter. The CUP CHWR flow set point is varied to maintain the required the bldg CHWS temperature set point. Max flow shall be 2700 gpm (adj.) And min flow shall be 25 gpm (adj.).
13. Bldg CHWS temperature is modulated to maintain CUP CHWR temperature set point. Max set point shall be 47°F.

14. Return water temperature set point shall be 56°F (adj.) Or 0.1°F less than bldg CHWR temperature, whichever is greater. CUP CHWR temperature may float below 56°F in order to maintain the bldg CHWS maximum set point of 47°F.
15. In addition to the components and sequences described, provide an independent campus plant chilled water metering system. System shall consist of TC contractor provided chilled water flow meter, temperature transmitters and BTU totalizing meter.
16. Energize pony chilled water pump at low load conditions.

B. Hot Water – Control Sequence

1. One heating water pump (lowest run time) shall function in emergency power mode.
2. Space heating shall be provided via circulation of hot water as provided by a steam to hot water converters. Hot water pumps are designed to operate as duty-standby units for circulation of heating hot water to all points of use.
3. Each hot water pump is to have a hand-off auto (h-o-a) switch; units shall be in auto position when available for operation as controlled by the BAS.
4. Upon a call for heating, either by any air handler units, lab AHU's, cabinet unit heater, fan coil unit, terminal box or unit heater, the following shall occur.
    a. Pumps shall lead/lag on a weekly basis based upon runtime. (one pump is duty and one pump is stand-by)
    b. BAS shall alternate pumps weekly on Tuesday at 11:00 am based upon runtime, sequencing equipment in order of least to greatest accumulated yearly runtime, where the lowest runtime unit is indexed as lead/first, and highest runtime unit is indexed as lag/last.
    c. If unit selected as duty pump is unavailable for operation due to maintenance, failure, or selection of off position at unit (H-O-A) switch, the standby pump shall become the duty pump.
5. Upon failure of the duty hot water pump, the BAS shall automatically initiate the start-up of the standby pump, and signal an alarm to the BAS.
6. Hot water pump flow shall be maintained until there are no systems requesting heating. Each pump shall be provided with a current sensor to operate as a flow proof of that pumping unit. Any pump energized through the EMS system which does not give positive indication of flow shall signal an alarm after 90 seconds. Continued lack of flow proof for an energized pump to a period of 180 seconds shall de-energize that pump and initiate the startup of the standby unit.
7. Two differential pressure sensors will provide input to the BAS. Each sensor shall have an adjustable set point (provided by TAB contractor). The BAS shall modulate the VFD's of both duty pumps to maintain DP setpoint for both sensors by calculating the difference between each sensor and its set point. The maximum difference shall be input into the VFD control loop.
8. Heating hot water heat exchangers shall function in both normal and emergency power modes
9. Hot water for the heating system described above is to be provided by the steam to heating hot water converter. This is a shell and tube vertical unit served by steam routed from the central plant.
10. The two heat exchangers shall operate simultaneously. Upon initiation of heating system, the steam isolation valves shall slowly ramp open, and exchanger circulation pumps energized. The heat exchanger shall modulate condensate control valves to maintain hot water supply temperature based on an outdoor reset schedule. The ratio shall be 180°F HW at 5° of outside air and 130°F HW at 60°F of outside air (field adjustable).
11. Close steam isolation valve if discharge water temperature is +15°F (adj.) From setpoint, or on loss of water flow. Alarm BMS.
12. Upon a loss or inability to maintain hot water supply temperature, an alarm shall signal the BAS.
13. Incoming steam supply temperature and flow rate shall be monitored and totalized by the B.A.S. Provide vortex shedding type meter.
14. Snow Melt:
    a. The control panel shall continuously monitor the snow/ice sensor located in the slab. When snow, ice, or water are detected the melting mode shall be initiated, unless the warm weather or cold weather cut-off controls have been activated.
    b. The snow melt zone shall enter the warm weather cut-off mode if the outdoor air temperature is above the melting temperature setpoint. It shall remain in this mode until the

outdoor air temperature drops below the melting temperature setpoint. The warm weather cut-off mode shall deactivate the snow melt zone. The snow melt system shall enter the cold weather cut-off mode if the door air temperature falls below the cold weather cut-off setpoint. The cold weather cut-off mode shall deactivate the snow melt system.

c. The melting mode shall be capable of being activated either through the snow/ice sensor or through a remote signal. The control valve shall be energized when the melting mode is activated and the heat relay shall operate the control valve to maintained the slab surface at the melting temperature setpoint.

d. Maintain the slab at an idling temperature when the snow melt system is not in the melting mode. Control operation is similar to the melting mode except the slab is maintained at a higher idling temperature setpoint.

e. Alarm BMS if a sensor fault occurs.

f. Desired slab surface melting temperature, slab surface idling temperature, and cold weather cut-off temperature setpoints shall be adjustable.

C. Standard VAV AHU Sequence of Operation:

1. The variable volume air handling unit consists of a mixed air section with outdoor air, exhaust air and return air dampers, air blenders, pre-filter, preheat coil, evaporative section, cooling coil and supply and return fans with variable frequency drives. The unit is DDC controlled using electric actuation.
2. The occupancy mode (Occupied or Unoccupied) shall be determined through a user-adjustable, graphical, seven-day schedule with a holiday schedule. The start time shall be adjusted by a Start-Stop-Time-Optimization algorithm such that the unit is started at the latest possible time to allow the space temperatures to be at the occupied set point at the time of occupancy.
3. Before the Occupied mode, the system can enter the Morning Warm-Up mode when the space temperature is below set point or the Cool-Down mode when the space temperature is above set point. The system stays in the Warm-Up or Cool-down mode until the mode set point is satisfied or until the Occupied mode. Within the Unoccupied mode, Night-Heating and Night-Cooling is available when the space temperature drops below 65° F or is above 85° F. The latest start time is the scheduled occupancy for the space.
4. The air handling unit operates in Warm-Up, Cool-Down, Occupied, Unoccupied, Night-Heating, Night-Cooling and modes as follows with adjustable set points and settings.
5. Occupied mode:
6. The air-handling unit shall be controlled by a local dedicated DDC control panel interfaced with the Building Automation System. The system shall be complete with access through local or remote terminals.
7. Current-sensing relays shall be provided for status indication at each supply and return fan of each air handling unit.
8. The supply fan variable frequency drive modulates to maintain a constant duct static pressure of 1.0 in WC as sensed at least two-thirds of the way downstream of the supply fan in the longest or most critical duct. The static pressure set point shall be reset so that at least one of the VAV boxes is at 90% of its CFM flow set point and is maintaining its space temperature set point. In the event of loss of communication with any VAV controllers the system shall not include them in the calculation. The calculation will have capability to select how many boxes are used in the routine to deal with problem VAV controllers. A high limit function shall reduce the supply fan speed to keep the supply duct pressure from exceeding 1.0 in WC above the scheduled total fan static pressure or the test and balance setpoint, regardless of the demand from the VAV boxes. Whenever the supply fan is energized the return fan shall be energized. Air flow measuring station input to the BAS shall continuously monitor outside, return and supply air flow during unit operation.
9. The return fan speed shall be modulated through the local control panel and variable frequency drive to maintain a fixed percentage offset set point (adjustable) from the supply fan or building static pressure, which ever variable is greater. Provide building static pressure sensors for each AHU.
10. The primary discharge air set point is reset based upon demand from the space. The primary discharge air set point shall be reset so that at least one of the VAV boxes is at 90% of its cooling

flow set point and is maintaining its space temperature set point. In the event of loss of communication with any VAV controllers the system shall not include them in the calculation. The calculation will have capability to select how many boxes are used in the routine to deal with problem VAV controllers.

11. There shall be a primary discharge air control loop that resets the set points for individual loops for controlling the preheat coil temperature, mixed air temperature, evaporative section temperature and cooling coil temperature.
12. The preheat coil loop will modulate the preheat coil loop based upon the preheat coil temperature versus the preheat coil temperature set point which is reset from the primary temperature set point loop minus 3° F. The preheat coil loop shall have low and high limits (adjustable). Ramp the setpoint from high to low upon start-up when the outside air temperature is below 40° F.
13. The preheat coil pump shall start when the outside air temperature is below 40° F or if the preheat coil valve is open 10 percent. The preheat coil pump shall be off when the outside air temperature is above 45°F and the preheat coil valve is open less than 5 percent for 5 minutes.
14. The mixed air section loop will modulate the mixed air dampers based upon the mixed air temperature set point which is reset from the primary temperature set point loop. The mixed air loop shall have low and high limits (adjustable). Economizer operation shall be disabled when the outside air temperature is greater than the return air temperature with a dead-band of 2° F. Whenever the air handling unit supply fan is enabled, the mixed air dampers shall modulate to maintain a minimum outside air CFM.
15. CO2 sensors should be in all spaces that congregate people and the VAV box ventilation should be increased to control CO2 to maintain 900 PPM while maintaining temperature control. If the air handler is controlling a global CO2 sensor, then the minimum ventilation should be raised to maintain a maximum CO2 setpoint.
16. The evaporative cooling shall operate continuously as long as there is a call for cooling, except when there is a high humidity condition or during the dry out cycle. The outside air damper will be fully open whenever the evaporative section is in operation. The evaporative cooling pump shall operate when the outside air is above 55 deg f (adj.), supply fan is on, the calculated outside air dew-point temperature is below 50 (adj.) & the float switch has made, the sump is full, and there is a call for cooling. Provide 2 vertical sections on evaporative unit with pumps. On call for cooling, stage pump one on. If temperature is more than 3 deg f above setpoint for 10 minutes, stage pump two on. Provide minimum on and off timers that are adjustable for each pump. Pumps shall be interlocked with manufacture provided level switch to de-energize the pumps when the water level is low. If any space humidity is above 50% (adj.) then turn off stage 2, if any space humidity is above 54% (adj.) then turn off stage 1. After a high humidity condition ramp the chilled water valve closed and re-enable the evaporative cooling.
17. The evaporative cooling sump shall drain down when the outside air temperature is less than 40 deg f (adj.) for more than 30 minutes. The sump shall only fill when the outside air temperature is above 55 deg f (adj.) for more than 30 minutes and there is a call for cooling. Provide a 15 minute (adj.) delay to allow the sump to fill before enabling pumps.
18. There shall be a daily dry-out cycle of 60 minutes (adj.) during a university specified period of time (default of 2:00 am). Additionally, a weekly sump drainage cycle shall coincide with the dry-out cycle. Initiate dry-out only if evaporative section has been on for more than one hour (adj.) or more in the previous 24 hours. Initiate bleed if conductivity probe measures 1200 ppm, close drain-valve at 900 ppm. Locate probe in sump.
19. The cooling coil loop will modulate the cooling coil loop based upon the discharge air temperature set point which is reset from the master loop. The cooling coil loop shall have low and high limits (adjustable).
20. On detection of smoke from the unit or duct-mounted smoke detectors or on signal from the fire alarm system, the supply and return fans shall cycle off and the mixed air dampers shall close. The cooling coil valve will be closed and the preheat coil shall modulate to maintain a preheat set point of 70° F when the outside air temperature is below 35°F. An alarm shall be sent to the BAS.
21. On detection of low or high static pressure in the supply air or return air ductwork, the supply and return fans shall cycle off, the mixed air dampers shall close 100% to the outside air. The cooling coil valve will be closed and the preheat coil shall modulate to maintain a preheat set point of 70°

F when the outside air temperature is below 35° F and will be open a minimum position relative to the outside air temperature. An alarm shall be sent to the BAS.

22. Upon detection of low limit trip of the freeze-stat the supply and return fans shall stop and the mixed air dampers shall close. The cooling coil valve will open 10 percent and the preheat coil shall modulate to maintain a preheat set point of 70° F. Provide alarm to BAS.
23. Upon sensing excessive pressure differential across each filter bank (pre-filter and final filter), an alarm shall be sent to the BAS. Coordinate setpoints with test and balance contractor during start-up of the system.

D. Unoccupied mode:
1. The supply and return fans shall stop and the mixed air dampers will close to the outside air, and the cooling coil valve will be closed. The preheat coil shall modulate to maintain a preheat set point of 70° F when the outside air temperature is below 35° F and will be open a minimum position relative to the outside air temperature.

E. Morning Warm-Up:
1. If the space is below the occupied temperature set point and the outdoor air temperature is below 35° F, Morning Warm-Up shall be initiated by the Start-Stop-Time-Optimization algorithm. The optimum start-stop program shall start the unit at the latest possible time. The supply fan and return fan will be enabled and operate per the Occupied mode and mixed air dampers and cooling coil valve shall be closed during the Morning Warm-Up cycle. If the space temperature is below set point, the unit shall warm the space to set point by raising the unit discharge temperature to 70° F until the space is satisfied.
2. When the space has reached set point, the unit shall operate in the occupied mode. If occupancy occurs before the space reaches the heating set point, the system switches to occupied mode. Morning warm-up shall occur only once in a day.

F. Morning Cool-Down:
1. If the space is above the occupied temperature set point and the outdoor air temperature is above 60° F, Morning Cool-Down shall be initiated by the Start-Stop-Time-Optimization algorithm. The optimum start-stop program shall start the unit at the latest possible time. The supply fan and return fan will be enabled and operate per the Occupied mode and mixed air dampers and cooling coil valve shall modulate during the Morning Cool-Down cycle. The heating valve shall be closed and if the space temperature is above set point, the unit shall cool down the space to set point by lowering the unit discharge temperature to 55° F until the space is satisfied.
2. When the space has reached set point, the unit shall operate in the occupied mode. If occupancy occurs before the space reaches the heating set point, the system switches to occupied mode. Morning Cool-Down shall occur only once in a day.

G. Night Heating:
1. If the space is below the unoccupied temperature set point and the outdoor air temperature is below 35° F, Night Heating shall be initiated by the Start-Stop-Time-Optimization algorithm. The supply fan and return fan will be enabled and operate per the Occupied mode to maintain a minimum space temperature of 65° F and shall operate until the coldest space is 4° F above the unoccupied set point. The mixed air dampers remain closed to the outside air and the cooling coil valve remains closed. The heating shall modulate to maintain a supply air temperature set point of 70 ° F.

H. Night Cooling:
1. If the space is above the unoccupied temperature set point and the outdoor air temperature is above 60° F, Night Cooling shall be initiated by the Start-Stop-Time-Optimization algorithm. The supply fan and return fan will be enabled and operate per the Occupied mode to maintain a maximum space temperature of 85° F and shall operate until the warmest space is 4° F below the unoccupied set point. The heating valve shall be closed and the mixed air dampers and cooling coil valve shall modulate to maintain supply air temperature set point of 55° F.

I. Lab Variable Volume MAU Air Handling Unit - Control Sequences

1. Under Emergency Power Mode:
   a. De-energize all other supply fans, set drives to 0 hertz.
   b. Set cooling coil control valve to closed position.
   c. When OSA is above 45 deg F, set heating control valve(s) to closed position for units that do not run
   d. When OSA is 45 deg F or below, steam valve to open relative to heat recovery temperature and heating coil temperature to maintain heat in plenum with face and bypass closed.
   e. Shut all intake and supply dampers
2. The System Consists Of:
   a. Inlet section with isolation damper
   b. Merv 8 and Merv 14 filters
   c. Heat recovery coil
   d. Steam heating coil with 1/3, 2/3 modulating valves with integral face and
   e. Bypass dampers
   f. Evaporative cooling section
   g. Plenum fan with frequency inverter
   h. Chilled water coil with two way modulating valve
   i. Discharge section with isolation damper.
   j. Distributed variable volume terminal boxes
   k. Building exhaust fans (lab and general exhaust).
   l. Separate dual return/relief fans will be provided as part of the system.
   m. Smoke detectors
3. Provide for the air handler unit a controller containing all the required points for successful operation in accordance with these sequences. Provide a data jack at the controller to interface with user.
4. These air handlers will work in parallel supplying a manifolded ductwork system. The units shall operate as a single system, in unison as one fan system at all times.
5. A “watchdog” software algorithm using a matching pair of I/O points between the control panels in the building will be incorporated and used to determine if network communication is available and switch the control panel to local mode if a loss of communication is detected. In local mode all systems turn on and use sensors local to that control panel.
6. The supply fan will operate continuously; the frequency inverter will modulate maintain the duct static pressure as determined by the tab contractor. Locate duct static sensor 2/3 of distance to farthest VAV box in each supply riser. Locations were submitted for review. BAS shall monitor supply duct static pressure readings from each of the supply duct static pressure sensors located in each of the supply shafts. The BAS shall use PID loop control to adjust fan speed to satisfy sensors with the lowest speed possible. Each sensor shall have an adjustable set point (provided by TAB contractor). The BAS shall modulate the VFD's in unison to maintain a static setpoint for each sensor by calculating the difference between each sensor and its set point. The maximum difference shall be input into the VFD control loop. If a sensor fails, then transfer operation to other sensors.
7. The heat recovery coil, heating coil, cooling coil and evaporative section work in concert to maintain a constant discharge air temperature 55 deg F (adj.). The AHU shall maintain a 55 deg F (adj.) set point by resetting the individual set points for each section using one master loop and individual section loops. Each section will maintain a set point in order to maintain the final discharge air set point. Each section will have high and low limits (adj.). Upon a failure of any control section temperature element, transfer control function to adjacent AHU that is in operation and the associated alarming.
8. Heat Recovery: Enable the heat recovery system when the OSA temperature is 40 deg F <OSA> 70 deg F. Each heat recovery pump is to have a hand-off-auto (H-O-A) switch. Units shall be in "auto" position when available for operation for control by BAS. Upon a call for heat recovery, both pumps shall be energized per balancing requirements. Lead/lag the pumps on a weekly basis based upon runtime. The 3-way valve shall be closed when the pumps are off. During heating, modulate to maintain heat recovery setpoint of the heat recovery coil (see item f). If fluid

temperature to exhaust coils is 35 deg F or lower, override the individual 3-way valve control to maintain minimum fluid temperature of 35 deg F. During cooling, open the 3-way to 100%.

9. Heating Coil: On a call for heat, modulate steam valve to maintain heating coil setpoint (damper in full bypass). If steam valve is 100% open and heating coil setpoint cannot be maintained, modulate face and bypass dampers. Steam valve shall be 100% open when entering air temperature is below 36 deg F or outside air temperature is below 32 deg F for freeze protection. Ramp the setpoint from high to low upon start-up when outside air temperature is below 40 deg F.
10. Cooling Coil: On a call for cooling, modulate cooling valve to maintain cooling coil setpoint. The setpoint will be compensated due to the approach across the evaporative cooling section and the steam humidification coil.
11. The evaporative cooling pump shall operate when the outside air is above 52 deg F (adj.), supply fan is on, the calculated outside air dew-point temperature is below 50 (adj.) and the float switch has made. Provide 3 vertical sections on evaporative unit with pumps. The middle section will be Stage 1, the outside sections will be Stage 2, the outside and middle sections will be Stage 3. On call for cooling, turn on stage one. If DAT is more than 3 deg F above setpoint for 10 minutes (adj.), turn on Stage Two. If DAT is more than 3 deg F above setpoint for 10 minutes (adj.), turn on Stage Three. If any space humidity is above 50% (adj.) then turn off Stage 3, if any space humidity is above 53% (adj.) then turn off Stage 2, if any space humidity is above 56% (adj.) then turn off Stage 1. After a high humidity condition ramp the chilled water valve closed and re-enable the evaporative cooling. Vivarium AHU only – during temperate outside air conditions allow for the cooling coil to operate due to the swings in discharge air temperature.
12. The sump shall only fill when the outside air temperature is above 50 deg F (adj.) for more than 30 minutes and there is a call for cooling. Provide a 15 minute (adj.) delay to allow the sump to fill before enabling pumps.
13. There shall be a daily dry-out cycle of 60 minutes (adj.) during a university specified period of time (default of 2:00 am). Additionally, a weekly sump drainage cycle shall coincide with the dry-out cycle. Initiate dry - out only if evap. section has been on for more than one hour (adj.) or more in the previous 24 hours. Initiate bleed if conductivity probe measures 1200 ppm, close drain-valve at 900 ppm. Locate probe in sump. Locate bleed valve as gravity feed from the sump and not off the discharge of the pumps.
14. Monitor and alarm differential pressure drop across all filters of all air handlers. Coordinate setpoints with test and balance contractor during start up.
15. If there is no general exhaust, AHU to stop. Upon failure of supply system, exhaust fans to operate at fail safe setting of 30%.
16. Runtime hour totalization shall remain in the BAS for each unit. Upon a signal to switch to a reduced unit operation the BAS shall de-energize the unit with the highest runtime hours total at that time. Supply fan shall stop and the isolation dampers shall shut. Remaining unit(s) operation shall adjust to maintain duct static pressure by slowly ramping up to speed as is required to meet duct static pressure setpoint
17. Air handler operation shall continue until system duct static setpoint is no longer satisfied or until such time VFDs reach 95% for 10 minutes. At this time, an additional AHU shall be brought online into parallel operation. Upon a signal to bring on an additional AHU, the BAS shall select the unit with the lowest runtime to active. The BAS will bring operating AHU supply fan speed to the minimum value by slowly and evenly decreasing drive speed. At that time, initiate the additional AHU by opening its isolation dampers and slowly accelerating speed, increase speed to match the operating AHUs speed. AHU fans in parallel should then operate in unison gradually accelerating and decelerating under PID control to match duct static pressure requirements of the system. If the duct static setpoint is satisfied, VFDs are under 65% for 10 minutes. At this time, an AHU with the lowest runtime will be subtracted and taken offline.
18. Should an AHU fail or be taken out of service, the remaining units shall operate as a single unit and signal an alarm at the BAS. Should the BAS detect that no units have been added or removed from staging in over 7 days, the BAS shall index an additional unit on (if available), and then allow the staging algorithm to determine if the highest runtime unit can be removed from operation.
19. Supply fan shall stop when:

a. Inlet or outlet isolation damper has not proven open position by hard wired interlock to variable frequency drives
b. On low static pressure alarm
c. On high static pressure alarm
d. Activation of smoke detector or upon signal from the fire alarm system shall initial AHU shutdown
e. The stop / auto interlock is open
f. The VFD is in a fault condition.

20. Upon shut down, the heating and cooling valves shall be closed, the evaporative cooling section shall stop and the isolation dampers shall close.
21. When OSA is above 45 deg F, set heating control valve(s) to closed position for units that do not run
22. When OSA is 45 deg F or below, steam valve to open relative to heat recovery temperature and heating coil temperature to maintain heat in plenum with face and bypass closed.
23. On no lab/ general exhaust - stop all AHUs
24. On low temperature alarm open heat recovery valve to 100% and cooling coil valve to 30%.

J. Demand Control Ventilation (DCV) CO2 Control Sequence

1. When the CO2 measured in the room is higher than the CO2 setpoint for 30 seconds the program forces the VAV box controller to the heating mode and takes over control of the flow setpoint using proportional integral loop statements. A space cooling loop starts its calculations at the box cooling loop output value and uses the room temperature and the day cooling setpoint to calculate flow. The CO2 loop is based on the CO2 measurement and setpoint. The box flow setpoint is set at the higher of the two loops. Any additional boxes that serve the same room are also forced to the heating mode and the flow setpoints are set to the same percentage as the master box. If the CO2 measurement is more than 100 PPM below the setpoint for more than five minutes then control is returned to the box controllers.

K. Terminal Box Control Sequences:

1. Variable Air Volume Supply with Reheat (General): The thermostat shall control the damper operator on the variable volume, pressure independent terminal box to a position not exceeding the limits of the scheduled air quantities. On a rise in temperature above the cooling setpoint the damper shall modulate in-between the minimum and maximum CFM schedule value to maintain the cooling setpoint. On a drop in room temperature below the thermostat cooling set point, the thermostat shall modulate the airflow to the minimum scheduled air quantity, to satisfy thermostat cooling set point. On further drop in room temperature below thermostat heating set point, the controller shall modulate the reheat coil control valve and maintain the index the damper in-between minimum and maximum after the vale is open 100% On rise in temperature above the thermostat heating set point, the thermostat shall close the two-way control valve and modulate the airflow between the minimum and maximum scheduled air quantity.
2. Temperature Control
   a. Occupied setpoints = 70F to 75F (adj.).
   b. Unoccupied setpoints = 65F to 80F (adj.).
3. In spaces that are equipped with occupancy sensors for lighting and HVAC control, the VAV box damper and reheat valve shall close when the occupancy sensor determines vacancy and the temperatures are between the setpoints stated above.
4. In spaces with BAS scheduled occupancy the damper and heating valve shall be closed when unoccupied and room temperature us between the room temperature setpoints. If the entire space is scheduled a minimum number of dampers will stay open to prevent high duct static if the air handler is running.
5. VAV reheat valve shall be closed when the connected air handler is off

L. Lab Area Sequence of Operation

1. General
   a. All supply and exhaust VAV boxes that serve one lab area shall be programmed to be able to track the total cfm in a lab area.

b. The supply VAV boxes shall communicate with the exhaust VAV boxes to maintain a volumetric offset in order to keep the laboratory space negative relative to the adjacent space(s).
c. Occupied lab areas shall have an ACH rate from a minimum of 6 ACH to a maximum of (design) ACH.
d. Unoccupied areas shall have constant ACH of 4 and can revert back to occupied rates if the unoccupied setpoints cannot be maintained.
e. A flush mode of 10 ACH shall occur if the lab area has been at unoccupied ACH for more than 1 hour.
f. The priorities for controlling equipments are as follows:
   1) Pressurization
   2) Ventilation
   3) Temperature control
g. The ACH rate for a lab area is based upon the total area enclosed by walls and doors.
h. All fume hoods are to be VAV, when possible.
i.

VAV Size	Minimum velocity in FPM	Minimum CFM
6”	260	50
8”	260	90
10”	275	150
12”	320	250
14”	320	340
16”	320	445

j. Provide fan coil units in Linear Equipment Rooms for process cooling of constant temperature loads.

2. Occupied mode:
   a. Occupied hours: As determined by occupancy input from lighting system
   b. Each lab area shall maintain a 150 cfm negative pressure differential at each door to Linear Equipment Room or office. If a lab area is calculated by the DDC computer to have less than a 100 cfm negative pressure differential at each door, an alarm shall be generated at the computer.
   c. The Exhaust Air VAV Boxes shall be controlled per the schedules for Unoccupied and Occupied modes (CFM of each box vary based on whether or not a hood is installed in that particular Alcove). The Lab Module Supply Air VAV Boxes shall be controlled based on the offset shown in the schedules. In general, the Lab area air quantities were calculated based on the following formula:
   d. Total Supply CFM = Total Exhaust CFM + [(150 CFM/door)*(# of exit doors)]
   e. As thermostats call for additional cooling in each Module or Alcove, the corresponding Supply Air VAV Box(es) and Exhaust Air VAV Box(es) shall open concurrently (up to maximum flow) to satisfy occupied cooling setpoints in that particular Module or Alcove and maintain volumetric offset.
   f. As thermostats call for additional heating in each Module or Alcove the corresponding Supply Air VAV Box(es) and Exhaust Air VAV Box(es) shall modulate concurrently down to minimum CFM flow, while maintaining pressurization and ventilation, and modulate reheat valve to satisfy occupied cooling setpoints in that particular Module or Alcove and maintain volumetric offset.
   g. If required, all Alcove Supply Air VAV Boxes and Lab Module Exhaust Air VAV Boxes included in the sequence that close the dampers in occupied or unoccupied mode shall have a leakage amount measured at closure. The leakage amounts shall be included in the Lab area volumetric offset calculation. Coordinate leakage test with Test & Balance Contractor.
3. Unoccupied mode:
   a. Unoccupied hours: As determined by occupancy input from lighting system
   b. Alcove Exhaust Air VAV Boxes – Balance per schedule (CFM vary based on # of hoods in each Suite) - ~ 4 air changes per hour.
   c. Alcove Supply Air VAV Boxes – Closed position.
   d. Lab Module Exhaust Air VAV Boxes – Closed position.

e. Lab Module Supply Air VAV Boxes – Balance per schedule (Match exhaust cfm minus offset).
f. Approximate total Lab area air change rate ~ 4.0 air changes per hour. The intent is that the lab is operating in a constant volume mode without adding additional cooling and minimal heating.
g. If the temperature drifts outside of the unoccupied setpoints by 2 degrees the Lab area shall go into occupied mode until unoccupied temperature setpoints are achieved and after 15 minutes in occupied mode reset back to unoccupied mode.

4. Flush out mode:
   a. If the Lab area has been unoccupied for more than 1 hour, and the occupancy sensor establishes occupancy the lab shall enter the flush out mode before the occupancy mode.
   b. Flush out mode shall be at 10 ACH.
   c. The temperature setpoints for the Flush out mode shall be the same as the Occupied Mode
5. Graphics Overview - Show the following on the Lab area Overview
   a. Show the values from the each controller from the lab, alcove, and fume hood.
   b. Controller, supply CFM setpoint, supply CFM, exhaust CFM setpoint, exhaust CFM, differential CFM setpoint, differential CFM
   c. Show the temperature setpoints for the entire suite
   d. Suite occupied cooling setpoint, occupied heating setpoint, unoccupied cooling setpoint, and occupied heating setpoint.
   e. Show the occupancy inputs for the entire suite
   f. Suite occupancy input (from lighting system), suite override input, suite mode, and suite flush mode
   g. Show the values for the entire suite operation
   h. ACH , total supply, total exhaust, scheduled differential CFM setpoint, differential CFM

PART 2 - PRODUCTS

PART 3 - EXECUTION

3.1 SEQUENCE PROGRAMMING

A. Sequence logic shall be installed in a professional manner that demonstrates a full understanding of the sequence and maximizes energy conservation and smooth operation in strategies and techniques not covered by the sequence.

B. All setpoints and control parameters shall be adjustable

C. All control loops shall utilize PID control algorithms unless application dictates otherwise.
   1. The proportional and integral values which make up the PID output value shall be readable and modifiable to facilitate tuning of control loops.
   2. All PID loops serving critical equipment shall provide for operator control of loop starting point without program editing when control is returned to program control after being in operator control.
   3. All loops shall have a virtual output in the loop statement to allow knowledge of loop performance before changing output from manual to program control.

D. The outside air temperature sensor and other inputs that are used in multiple programs shall be attached to a single virtual point, which is used in the programs.

E. Mode changes shall be stable. Abrupt changes that cause unnecessary opening of valves should not be used. Example: Do not abruptly change the supply air temperature setpoint when going from warmup mode to occupied mode.

F. All logic statements or blocks shall be input with consistent naming conventions.

G. The logic for separate DDC controllers serving AHUs with identical sequences of operation, shall also be identical.

3.2 INSTALLATION GENERAL

A. All HVAC safeties shall be hardwired such that the shutdown will occur in Automatic and Hand and bypass modes at the BAS system and the starter.

B. Software safeties are not acceptable (exception: smoke control may be done through software if the control system is UL listed for smoke control).

END OF SECTION 23 09 93