NOTE: THIS MASTER SPEC INCLUDES HIDDEN TEXT AND COMMENTS. TO SEE THEM, MAKE SURE MS WORD IS CONFIGURED TO SEE HIDDEN TEXT (GO TO TOOLS/OPTIONS/VIEW AND CLICK ON "HIDDEN TEXT" CHECK-BOX.) DELETE THIS PARAGRAPH WHEN EDITING SPEC FOR PROJECTS.

SECTION 250000

BUILDING AUTOMATION SYSTEMS

PART 1 GENERAL

1.1 SUMMARY

A. Furnish and install a digital Building Automation System (BAS) as specified herein.

1.2 COORDINATION WITH OTHER TRADES

A. Consult all other Sections, determine the extent and character of related work and properly coordinate work specified herein with that specified elsewhere to produce a complete and operable installation. This section is provided to assist Contractor in coordination of work scope but shall not be construed to limit Contractor's scope of work encompassed by the contract documents.

B. The following table is intended to assist the Contractors in coordinating the scope of work between Division 25 Building Automation System (indicated as 25), and other Divisions as indicated. However, the General Contractor is ultimately responsible for coordination among his subcontractors regardless of what is listed in this Section.

INTERFACE / RESPONSIBILITY MATRIX					
System	Division under which the following is specified				Remarks
	Equipment	Installation	Power wiring (remark 1)	Control & interlock wiring (remark 1)	
A. FIRE & LIFE SAFETY SYSTEMS					
1. Fire alarm controls	26	26	26	26	
2. Duct mounted & in-duct mounted smoke detectors	26	23	26	26	
3. Other smoke detectors	26	26	26	26	
4. Smoke control interlocks to HVAC fans	26	26	26	26	2
5. Smoke dampers with electric actuators	23	23	26	26	
6. Smoke damper end switches	23	23	26	26	
B. MECHANICAL EQUIPMENT					
1. Unitary mechanical equipment	23	23	26	25	3
2. Chillers	23	23	26	25	3, 7
3. Variable speed drives, field mounted	23	26	26	25	
4. Motors, 3 phase	23	23	26	–	

INTERFACE / RESPONSIBILITY MATRIX					
System	Division under which the following is specified				Remarks
	Equipment	Installation	Power wiring (remark 1)	Control & interlock wiring (remark 1)	
5. Motor starters, 3 phase	26	26	26	25	4
6. Motors, 1 phase	23	23	26	26	5, 6
7. Other powered equipment	23	23	26	25	
8. Disconnects/circuit breakers	26/23	26/23	26	–	8
9. Refrigerant leak detector	25	25	26	25	9
10. Cooling tower vibration switch	23	23	–	25	
11. Cooling tower water treatment system	23	23	26	25	10
C. BUILDING AUTOMATION SYSTEM (BAS)					
1. Central control workstations & servers	–	–	–	–	Existing
2. College IT local area network	27	27	26	27	11
3. Control system network	25	25	25	25	11
4. Line voltage control devices to 120V motors	25	26	26	26	6
5. Window switches	25	25	–	25	
6. Control panels	25	25	26/25	25	12
7. Control devices	25	25	25	25	
D. ELECTRICAL SYSTEMS					
1. Lighting Control BACnet gateway	26	26	26	25	13
2. Lighting relay panels and low voltage switches	26	26	26	26	
3. Lighting occupancy sensors	26	26	26	26	
4. Daylighting sensors and controls	26	26	26	26	
5. Power monitoring sensors and gateway	26	26	26	26/25	14
E. PLUMBING SYSTEMS					
1. Gas and water flow meters	25	22	25	25	
2. Recirculation pumps or heat tape	22	22	26	25	
3. HHW to DHW heat exchangers	23	23	–	–	
4. HHW to DHW controls	25	22/23	25	25	
5. Pipe gauges, thermometers, test plugs	22	22	–	–	
6. Self-powered valves, pressure relief valves, liquid level controllers, etc.	22	22	–	–	
7. Sensor wells, meters and other pipe-mounted control devices	25	22	25	25	
F. HVAC HYDRONIC SYSTEMS					
1. Pipe gauges, thermometers, test plugs	23	23	–	–	
2. Self-powered valves, refrigerant powered head pressure control valves, pressure relief valves, liquid level controllers, etc.	23	23	–	–	
3. Automatic isolation and control valves	25	23	25	25	
4. Sensor wells, meters and other pipe-mounted control devices	25	23	25	25	
G. KITCHEN EXHAUST SYSTEMS					
1. Grease hoods	11	11	–	25	15
2. Grease hood fire control/alarm systems	11	11	26	11	16

INTERFACE / RESPONSIBILITY MATRIX					
System	Division under which the following is specified				Remarks
	Equipment	Installation	Power wiring (remark 1)	Control & interlock wiring (remark 1)	
3. Grease hood automatic gas shut-off valve	11	22	11	11	16
4. Grease hood pollution control unit (PCU)	23	23	26	25	
5. Grease hood PCU fire control/alarm systems	11/23	11/23	26	11	17
H. HVAC SHEET METAL					
1. Duct mounted sensors	25	23	25	25	
2. Control dampers	23	23	–	–	18
3. Control damper actuators	25	25	25	25	18, 19
I. PACKAGED VAV AIR CONDITIONING SYSTEMS					
1. AC unit including all controls	23	23	23	25	
2. Gateway to BAS	23	23	23	25	20
J. LABORATORY HVAC SYSTEMS					
1. Laboratory air valves, actuators, and controllers	23	23	25	25	
2. Fume hoods	11	11	26	–	
3. Snorkels with manual dampers	11	23	–	–	
4. Snorkels with control dampers	11/23	23	25	25	21
5. Fume hood ASHRAE 110 tests	11	11	–	–	
6. Fume hood sash closer and associated sensors	11	11	26	11	
7. Fume hood monitors – CAV hoods	11	11	26	25	
8. Fume hood monitors – VAV hoods	23	23	25	25	22
9. Fume hood sash position sensors	23	23	25	25	
K. HVAC TERMINAL BOXES					
1. Terminal box control transformer panel	25	25	26/25	25	12, 23
2. Terminal box with damper	23	23	–	–	
3. Digital controller and damper actuator	25	25	25	25	
4. Air-flow measurement pickup	23	23	–	–	
5. Air-flow measurement transducer and piping	25	25	25	25	
6. Wall sensor module	25	25	25	25	
7. Terminal fan	23	23	26	25	
8. Electric reheat coil, including control transformer, safeties & contactors	23	23	26	25	24
9. HW control valve and actuator	25	23	25	25	
L. MISCELLANEOUS					
1. Ceiling and wall access doors and panels	8	8	–	–	

NUMBERED REMARKS:

1. Wiring includes raceway, fittings, wire, boxes and related items, all voltages.
2. Wiring and controls to start and stop fans based on smoke detector status and smoke control logic specified under Division 26 Electrical.
3. Factory installed starters and variable speed drives are specified under Division 23 HVAC. Prewired control panel is specified under Division 23 HVAC; single point power connection (unless otherwise noted on drawings) specified by Division 23 HVAC.
4. Applies to motors that are not covered by note 3. Integral starter control devices such as HOA switches, 120V control transformers specified under Division 26 Electrical.

INTERFACE / RESPONSIBILITY MATRIX					
System	Division under which the following is specified				Remarks
	Equipment	Installation	Power wiring (remark 1)	Control & interlock wiring (remark 1)	

5. Single phase 120V motors with integral motor overload protection specified under Division 23 HVAC.
6. Line voltage control device such as thermostat or switch specified under Division 25 BAS; wiring and conduit between control device and motor specified under Division 26 Electrical.
7. Factory installed and wired chilled and condenser water flow switches are specified under Division 23 HVAC; no work is required under Division 25 BAS. Bi-directional (read/write) factory installed BACnet gateway between the BAS and chiller control panel specified with chiller under Division 23 HVAC; control wiring specified under Division 25 BAS. Chiller vendor to provide all necessary technical assistance to Division 25 BAS Contractor in mapping across chiller points to the BAS.
8. Disconnects or circuit breakers are specified under Division 23 HVAC where specifically called for in equipment schedules or specifications to be factory installed with equipment. Otherwise all disconnects are specified under Division 26 Electrical.
9. Emergency override switches, status lights and other refrigerant machinery room controls as required by CMC are specified under Division 25 BAS.
10. TDS controller, bleed valve, injector pump, make-up water flow meter, and all other water treatment system controls are specified under Division 23 HVAC. Field wiring of all components is specified under Division 25 BAS.
11. See Paragraph 1.10A System Architecture for coordination between College IT LAN and BAS networks.
12. 120V power to BAS control panels is specified under Division 26 for the panels shown on Drawings. Power to all other control panels that may be required is specified under Division 25 BAS, coordinated with Division 26 contractor for available circuits. Power to all BAS control panels is specified under Division 25 BAS, coordinated with Division 26 contractor for available circuits.
13. Lighting control vendor to provide all necessary technical assistance to Division 25 BAS Contractor in mapping across lighting control points to the BAS.
14. Power measuring sensors, installation and wiring to a single central controller with Modbus interface specified under Division 26 Electrical. Modbus gateway and network connection from gateway to BAS specified under Division 25 BAS. Power monitoring control vendor to provide all necessary technical assistance to Division 25 BAS Contractor in mapping across power monitoring control points to the BAS.
15. Hoods, including all required fire protection devices and integral listed balancing dampers, are specified under Division 11 Food Service.
16. Ansul type fire protection system is specified under Division 11 Food Service including all control wiring between Ansul hood and fire suppression panel, power wiring to fire suppression panel, fire alarm system monitoring intertie, gas shut-off valve interlock, and circuit breaker shunt-trips for all equipment located under the hoods.
17. PCUs with factory pre-piped fire suppression nozzles and fusible link detector brackets for Ansul type fire protection system is specified under Division 23. Field connection, tanks, controls, fusible link detectors, and commissioning is specified under Division 11 Food Service as part of hood fire protection system.
18. Duct access doors required for access to control devices where required specified under Division 23 HVAC.
19. Actuators for motorized dampers supplied with fans or hoods where scheduled on HVAC drawings are specified under Division 23 HVAC, mounted but not wired.
20. BACnet gateway to BAS specified in the Division 23 HVAC, factory installed, with connection of gateway to BAS specified under Division 25 BAS. AC vendor to provide all necessary technical assistance to Division 25 BAS Contractor in mapping AC control points to the BAS.
21. Snorkel specified under Division 11. Snorkel damper/air valve specified under Division 23.
22. Hood manufacturer shall provide knockout on face for hood monitor.

INTERFACE / RESPONSIBILITY MATRIX					
System	Division under which the following is specified				Remarks
	Equipment	Installation	Power wiring (remark 1)	Control & interlock wiring (remark 1)	
23. Control transformers for terminal boxes shall be centralized in control panels specified under Division 25 BAS.					
24. Factory wired control transformer, safeties and contactors with single point power wiring connection specified under Division 23 HVAC.					

1.3 INTEGRATION WITH EXISTING SYSTEM

A. Include all services required to integrate this building into existing BAS for a fully operational system.

B. Procedure

1. Obtain a copy of the campus database with access privileges.

2. Perform a database review with the Owner's Representative to ensure uniformity of point naming, graphic layout and style, BACnet device instance numbering scheme, IP addresses, BACnet Distribution Tables and BACnet Broadcast Management Devices.

3. BACnet devices

    a. Create new building database following the BACnet device instance numbering scheme specified under Paragraph 3.12B.4.

    b. Double check existing database to ensure there are no duplicate BACnet device instance numbers. This includes 3rd party equipment such as VFDs.

4. Graphics

    a. For standard applications, such as VAV boxes and VAV box summary pages, use the campus standard graphics file template, including using the same file template name.

    b. For new or modified graphics custom to the new building, ensure file template name do not duplicate any existing file names.

5. Programming

    a. For standard sequences covered by ASHRAE Guideline 36, use the programming provided by Automated Logic, first ensuring they have been updated by the manufacturer to reflect the latest issue and all addenda published when programming work is initiated.

b. For other typical applications, first review those used for similar applications in other campus buildings to use as a starting point, then edit to reflect sequences specified herein. The intent is to have standard programming throughout the campus to the extent possible.

c. Double check existing database to ensure program file names do not duplicate any existing file names.

6. If a BACnet/IP Broadcast Management Device (BBMD) router is required, check the existing Broadcast Distribution Tables (BDT) to ensure that a BBMD router is not already assigned to the relevant network before adding a new one.

7. Install building database and control programming on a temporary portable operator's terminal provided by the Contractor. The POT shall be used for start-up, testing, and commissioning. The POT shall remain the property of the Contractor after final completion of the project.

8. Once the building BAS has been fully commissioned and accepted by the College:

a. Create a new backup of the existing campus database.

b. Merge the new building database with the existing campus database.

c. Confirm that no communication issues (in the building and across the campus) have resulted from the merge.

d. Confirm that all new controllers have successfully bound to the server and that alarms and trends are being sent to the server.

e. Configure alarm page-out notifications (e.g. e-mail, SMS, etc.) per Paragraph 3.12F.

f. Make another backup of the merged database.

g. Load the merged database onto the campus Control System Server.

h. Integrate graphic screens into the Central Plant graphics including adding appropriate hyperlinks so that the system operates as one integrated system.

i. Confirm that the merge was successful by sample testing points and sequences

j. Perform a post-merge review 4 to 8 weeks following the merge. Review general system operation, problematic areas, alarms and trend histories. Identify and remediate any issues.

k. Receive College approve of the final installation in writing.

9. Provide high level password for College operator access to the system only at this point; College will not have access to the system prior to system acceptance and integration.

1.4 CONTRACTOR PROPOSALS

A. The system requirements described in this specification are generally performance based. Where requirements are prescriptive, the intent is to provide minimum quality, not to give unfair advantage to any given manufacturer or product. If a contractor finds that a certain requirement is unduly difficult or expensive to meet, contact the Engineer prior to bid due date and an addendum modifying the requirement will be considered.

B. Where requirements are unclear, the contractor shall clarify the requirements with the Engineer before the bid due date. Where requirements continue to be unclear, the contractor’s proposal must accurately describe what is included and excluded.

C. By submitting a proposal, contractor guarantees that their proposal is in full compliance with these specifications except as specifically excluded in their proposal.

1.5 REFERENCE STANDARDS

A. Nothing in Contract Documents shall be construed to permit Work not conforming to applicable laws, ordinances, rules, and regulations. When Contract Documents differ from requirements of applicable laws, ordinances, rules and regulations, comply with documents establishing the more stringent requirement.

B. The latest published or effective editions, including approved addenda or amendments, of the following codes and standard shall apply to the BAS design and installation as applicable.

C. State, Local, and City Codes

1. CBC − California Building Code

2. CMC − California Mechanical Code

3. CEC – California Electrical Code

4. Local City and County Codes

D. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)

1. ANSI/ASHRAE 135 – BACnet - A Data Communication Protocol for Building Automation and Control Networks

2. ANSI/ASHRAE Standard 135.1− Method of Test for Conformance to BACnet

3. ANSI/ASHRAE Standard 15 – Safety Standard for Refrigeration Systems

E. Electronics Industries Alliance

1. EIA-232 – Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange.

2. EIA-458 – Standard Optical Fiber Material Classes and Preferred Sizes.

3. EIA-485 – Standard for Electrical Characteristics of Generator and Receivers for use in Balanced Digital Multipoint Systems.

4. EIA-472 – General and Sectional Specifications for Fiber Optic Cable.

5. EIA-475 – Generic and Sectional Specifications for Fiber Optic Connectors and all Sectional Specifications.

6. EIA-573 – Generic and Sectional Specifications for Field Portable Polishing Device for Preparation Optical Fiber and all Sectional Specifications.

7. EIA-590 – Standard for Physical Location and Protection of Below-Ground Fiber Optic Cable Plant and all Sectional Specifications.

F. Underwriters Laboratories

1. UL 916 – Energy Management Systems.

G. National Electrical Manufacturers Association

1. NEMA 250 – Enclosure for Electrical Equipment.

H. Institute of Electrical and Electronics Engineers (IEEE)

1. IEEE 142 – Recommended Practice for Grounding of Industrial and Commercial Power Systems.

2. IEEE 802.3 – CSMA/CD (Ethernet – Based) LAN.

3. IEEE 802.4 – Token Bus Working Group (***ARCnet*** – Based) LAN.

1.6 DEFINITIONS

A. Acronyms

AAC	Advanced Application Controller
AH	Air Handler
AHU	Air Handling Unit
AI	Analog Input
ANSI	American National Standards Institute
AO	Analog Output
ASC	Application Specific Controllers
ASCII	American Standard Code for Information Interchange
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
A-to-D	Analog-to-Digital
BACnet	Data Communications Protocol for Building Automation and Control Systems
BC	Building Controller
BIBB	BACnet Interoperability Building Blocks
BTL	BACnet Testing Laboratory
CAD	Computer Aided Drafting

CHW	Chilled Water
CHWR	Chilled Water Return
CHWS	Chilled Water Supply
COV	Change of Value
CSS	Control Systems Server
CU	Controller or Control Unit
CV	Constant Volume
CW	Condenser Water
CWR	Condenser Water Return
CWS	Condenser Water Supply
DBMS	Database Management System
DDC	Direct Digital Control
DHW	Domestic Hot Water
DI	Digital Input
DO	Digital Output
D-to-A	Digital-to-Analog
BAS	Building Automation System
EMT	Electrical Metallic Tubing
EP	Electro-Pneumatic
ETL	Edison Testing Laboratories
GUI	Graphical User Interface
HHD	Hand Held Device
HOA	Hand-Off-Automatic
HVAC	Heating, Ventilating and Air-Conditioning
HTTP	Hyper-Text Transfer Protocol
I/O	Input/output
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LAN	Local Area Network
LANID	LAN Interface Device
MAC	Medium Access Control
MHz	Megahertz
MS/TP	Master-Slave/Token-Passing
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
ODBC	Open Database Connectivity
OI	Operator Interface
OWS	Operator Workstation
P	Proportional
PC	Personal Computer
PI	Proportional-Integral
PICS	Protocol Implementation Conformance Statement
PID	Proportional-Integral-Derivative
POT	Portable Operators Terminal
PTP	Point-to-Point
RAM	Random Access Memory
SOO	Sequence of Operation
SQL	Standardized Query Language

SSL	Secure Socket Layers
TAB	Test, Adjust, and Balance
TDR	Time Delay Relay
UFT	Underfloor Fan Terminal Box
UL	Underwriters' Laboratories, Inc.
XML	Extensible Markup Language

B. Terms

Term	Definition
Accessible	Locations that can be reached with no more than a ladder to assist access and without having to remove permanent partitions or materials. Examples include inside mechanical rooms, mechanical equipment enclosures, instrument panels, and above suspended ceilings with removable tiles.
BACnet Interoperability Building Blocks	A BIBB defines a small portion of BACnet functionality that is needed to perform a particular task. BIBBs are combined to build the BACnet functional requirements for a device in a specification.
BACnet/BACnet Standard	BACnet communication requirements as defined by the latest version of ASHRAE/ANSI 135 and approved addenda.
Change of Value	An event that occurs when a digital point changes value or an analog value changes by a predefined amount.
Client	A device that is the requestor of services from a server. A client device makes requests of and receives responses from a server device.
Concealed	Embedded in masonry or other construction, installed in furred spaces, within double partitions, above hung ceilings, in trenches, in crawl spaces, or in enclosures.
Continuous Monitoring	A sampling and recording of a variable based on time or change of state (such as trending an analog value, monitoring a binary change of state).
Contract Documents	Specifications, drawings, and other materials provided with request for bids.
Control Systems Server	A computer(s) that maintain(s) the systems configuration and programming database.
Controller	Intelligent stand-alone control device. Controller is a generic reference to BCs, AACs, and ASCs.
Direct Digital Control	Microprocessor-based control including Analog/Digital conversion and program logic.
Building Automation System	The entire integrated building management and control system.
Equal	Approximately equal in material types, weight, size, design, quality, and efficiency of specified product.
Exposed	Not installed underground or concealed.

Term	Definition
Furnish	To purchase, procure, acquire and deliver complete with related accessories.
Gateway	Bi-directional protocol translator connecting control systems that use different communication protocols.
Hand Held Device	Manufacturer's microprocessor based portable device for direct connection to a field Controller.
Inaccessible	Locations that do not meet the definition of accessible. Examples include inside furred walls, pipe chases and shafts, or above ceilings without removable tiles.
Indicated, shown or noted	As indicated, shown or noted on drawings or specifications.
Install	To erect, mount and connect complete with related accessories.
Instrumentation	Gauges, thermometers and other devices mounted in ductwork or piping that are not a part of the BAS.
College IT LAN	The Information Technology local area network furnished by the College or Division 27 Communications, used for normal business-related communication and may be used for interconnecting some BAS controllers and gateways where specified.
LAN Interface Device	Device or function used to facilitate communication and sharing of data throughout the BAS.
Local Area Network	Computer or control system communications network limited to local building or campus.
Master-Slave/Token Passing	Data link protocol as defined by the BACnet standard.
Motor Controllers	Starters, variable speed drives, and other devices controlling the operation of motors.
Native BACnet Device	A device that uses BACnet for communication. A device may also provide gateway functionality and still be described as a Native BACnet device.
Native BACnet System	A network composed only of Native BACnet Devices without gateways.
Open Database Connectivity	An open standard application-programming interface for accessing a database developed. ODBC compliant systems make it possible to access any data from any application, regardless of which database management system is handling the data.
Open Connectivity	OPC is an interoperability standard developed for industrial applications. OPC compliant systems make it possible to access or exchange data from any application, regardless of which database management system is handling the data.

Term	Definition
Operator Interface	A device used by the operator to manage the BAS including OWSs, POTs, and HHDs.
Operator Workstation	The user's interface with the BAS system. As the BAS network devices are stand-alone, the OWS is not required for communications to occur.
College	The College or their designated representatives.
Piping	Pipe, tube, fittings, flanges, valves, controls, strainers, hangers, supports, unions, traps, drains, insulation and related items.
Points	All physical I/O points, virtual points, and all application program parameters.
Point-to-Point	Serial communication as defined in the BACnet standard.
Portable Operators Terminal	Laptop PC used both for direct connection to a controller and for remote dial up connection.
Primary LAN	High speed, peer-to-peer controller LAN connecting BCs, AACs, and ASCs as well as some gateways. See System Architecture below.
Protocol Implementation Conformance Statement	A written document that identifies the particular options specified by BACnet that are implemented in a device.
Provide	Furnish, supply, install and connect up complete and ready safe and regular operation of particular work referred to unless specifically noted.
Protocol Translator	A device that converts BACnet from one network protocol to another.
Reviewed, approved, or directed	Reviewed, approved, or directed by or to College's Representative.
Router	A device that connects two or more networks at the network layer.
Secondary LAN	LAN connecting some gateways and networked sensors. See System Architecture below.
Server	A device that is a provider of services to a client. A client device makes requests of and receives responses from a server device.
Standardized Query Language	SQL - A standardized means for requesting information from a database.
Supervisory LAN	Ethernet-based LAN connecting Primary LANs with each other and OWSs, CSS, and THS. See System Architecture below.
Supply	Purchase, procure, acquire and deliver complete with related accessories.
Wiring	Raceway, fittings, wire, boxes and related items.

Term	Definition
Work	Labor, materials, equipment, apparatus, controls, accessories and other items required for proper and complete installation.

1.7 QUALITY ASSURANCE

A. Materials and Equipment

1. Manufacturer's Qualifications: See 2.1 for approved manufacturers.

B. Installer

1. The following are approved BAS contractors:

a. Sunbelt. Marc Annicchero mannicchero@sunbeltcontrols.com

b. Air Systems. Mike Putich Mike.Putich@airsystemsinc.com

c. ASG: Tony Skibinski tskibinski@asgbms.com

2. BAS Contractor's Project Manager Qualifications: Individual shall specialize in and be experienced with direct digital control system installation for not less than 3 years. Project Manager shall have experience with the installation of the proposed direct digital control equipment product line for not less than 2 projects of similar size and complexity. Project Manager must have proof of having successfully completed the most advanced training offered by the manufacturer of the proposed product line.

3. BAS Contractor's Programmer Qualifications: Individual(s) shall specialize in and be experienced with direct digital control system programming for not less than 3 years and with the proposed direct digital control equipment product line for not less than 1.5 years. Programmers must show proof of having successfully completed the most advanced programming training offered by the vendor of the programming application on the proposed product line.

4. BAS Contractor's Lead Installation Technician Qualifications: Individual(s) shall specialize in and be experienced with direct digital control system installation for not less than 3 years and with the proposed direct digital control equipment product line for not less than 1.5 years. Installers must show proof of having successfully completed the installation certification training offered by the vendor of the proposed product line.

5. BAS Contractor's Service Qualifications: The installer must be experienced in control system operation, maintenance and service. BAS Contractor must document a minimum 5-year history of servicing installations of similar size and complexity. Installer must also document at least a 1-year history of servicing the proposed product line.

6. Installer's Response Time and Proximity

a. Installer must maintain a fully capable service facility within 50 miles of the subject Project. Service facility shall manage the emergency service dispatches and maintain the inventory of spare parts.

b. Installer must demonstrate the ability to meet the emergency response times listed in Paragraph 1.13B.1.

7. Electrical installation shall be by manufacturer-trained electricians

a. Exception: Roughing in wiring and conduit and mounting panels may be subcontracted to any licensed electrician.

1.8 SUBMITTALS

A. No work may begin on any segment of this Project until the related submittals have been reviewed for conformity with the design intent and the Contractor has responded to all comments to the satisfaction of the College's Representative.

B. Submit drawings and product data as hereinafter specified. Conditions in this Section take precedence over conditions in Division 1 or Section 230501 Basic Mechanical Materials and Methods.

C. Submittal Schedule: Submittal schedule shall be as follows unless otherwise directed by the College's Representative:

1. Allow 10 working days for approval, unless College's Representative agrees to accelerated schedule.

2. Submittal Package 0 (Qualifications) shall be submitted with bid.

3. Submittal Package 1 (Hardware and Shop Drawings) shall be submitted in accordance with schedule established by the College in bid documents.

4. Submittal Package 2 (Programming and Graphics) and shall be submitted no less than 30 days before software is to be installed in field devices.

5. Submittal Package 3 (Pre-Functional Test Forms) shall be submitted no less than 30 days prior to conducting tests.

6. Submittal Package 4 (Pre-Functional Test Report) shall be submitted no less than 14 after conducting tests.

7. Submittal Package 5 (Post-Construction Trend Points List) shall be submitted 14 days prior to the start of the trend collection period.

8. Submittal Package 6 (Functional Test Report) shall be submitted no more than 7 days after conducting tests.

9. Submittal Package 7 (Training Materials) shall be submitted no less than 14 days prior to conducting first training class.

10. Submittal Package 8 (Post-Construction Trend Logs) shall be submitted after demonstration tests are accepted and systems are in full automatic operation.

D. Submission and Resubmission Procedure

1. Optional Pre-Submittals. At Contractor's option, electronic submittals indicated below may be submitted unofficially via email directly to the Engineer for review and comment prior to formal submission. Comments provided by the Engineer are not official and may be changed or additional comments may be provided on the formal submittal. The intent of pre-submittals is to reduce paperwork and review time.

2. Each submittal shall have a unique serial number that includes the associated specification section followed by a number for each sub-part of the submittal for that specification section, such as SUBMITTAL 250000-01.

3. Each resubmittal shall have the original unique serial number plus unique revision number such as SUBMITTAL 250000-01 REVISION 1.

4. Submit one copy of submittal in electronic format specified under each submittal package below. Submissions made in the wrong format will be returned without action.

5. Submittals shall have bookmarks for each subsection (e.g. Materials, Drawings) and for each drawing including drawing number and name.

6. College's Representative will return a memo or mark-up of submittal with comments and corrections noted where required.

7. Make corrections

    a. Revise initial submittal to resolve review comments and corrections.

    b. Clearly identify resubmittal by original submittal number and revision number.

    c. The cover page of resubmittals shall include a summary of prior comments and how they were resolved in the resubmittal.

    d. Indicate any changes that have been made other than those requested.

8. Resubmit revised submittals until no exceptions are taken.

    a. The cost of the Engineer's review of submittals after first resubmittal will be borne by Contractor at Taylor Engineering standard billing rates.

9. Once submittals are accepted with no exceptions taken, provide

    a. Complete submittal of all accepted drawings and products in a single electronic file.

    b. Photocopies or electronic copies for coordination with other trades, if and as required by the General Contractor or College's Representative.

E. Submittals Packages

1. Submittal Package 0 (Qualifications)

    a. Provide Installer and Key personnel qualifications as specified in Paragraph 1.7B.

    b. Format: Word-searchable format per Paragraph 1.9C.3.

2. Submittal Package 1 (Hardware and Shop Drawings)

    a. Hardware

        1) Organize by specification section and device tags as tagged in these specifications.

        2) Do not submit products that are not used even if included in specifications.

        3) Include a summary table of contents listing for every submitted device:

            a) Tab of submittal file/binder where submittal is located

            b) Device tag as tagged in these specifications (such as TS-1A, FM-1)

            c) Specification section number (down to the lowest applicable heading number)

            d) Whether device is per specifications and a listed product or a substitution

            e) Manufacturer

            f) Model number

            g) Device accuracy (where applicable)

            h) Accuracy as installed including wiring and A/D conversion effects (where applicable)

        4) Submittal shall include manufacturer's description and technical data, such as performance data and accuracy, product specification sheets, and installation instructions for all control devices and software.

        5) When manufacturer's cut-sheets apply to a product series rather than a specific product, the data specifically applicable to the Project shall be highlighted or clearly indicated by other means. Each submitted piece of literature and drawings shall clearly reference the specification or drawing that the submittal is to cover. General catalogs shall not be accepted as cut sheets to fulfill submittal requirements.

        6) A BACnet Protocol Implementation Conformance Statement (PICS) for each type of controller and operator interface.

        7) Format: Word-searchable format per Paragraph 1.9C.3.

    b. Shop Drawings

1) System architecture one-line diagram indicating schematic location of all control units, workstations, LAN interface devices, gateways, etc. Indicate address and type for each control unit. Indicate media, protocol, baud rate, and type of each LAN.

2) Schematic flow diagram of each air and water system showing fans, coils, dampers, valves, pumps, heat exchange equipment and control devices. The schematics provided on Drawings shall be the basis of the schematics with respect to layout and location of control points.

3) All physical points on the schematic flow diagram shall be indicated with names, descriptors, and point addresses identified as listed in the point summary table.

4) Label each input and output with the appropriate range.

5) Device table (Bill of Materials). With each schematic, provide a table of all materials and equipment including:

    a) Device tag as indicated in the schematic and actual field labeling (use tag as indicated in these specifications where applicable and practical)

    b) Device tag as indicated in these specifications where applicable and if it differs from schematic device tag

    c) Description

    d) Proposed manufacturer and model number

    e) Range

    f) Quantity

6) With each schematic or on separate valve sheet, provide valve and actuator information including pipe size, valve size, C_v, design flow, target pressure drop, actual design pressure drop, manufacturer, model number, close off rating, etc. Indicate normal positions of fail-safe valves and dampers.

7) Indicate all required electrical wiring. Electrical wiring diagrams shall include both ladder logic type diagram for motor starter, control, and safety circuits and detailed digital interface panel point termination diagrams with all wire numbers and terminal block numbers identified. Provide panel termination drawings on separate drawings. Ladder diagrams shall appear on system schematic. Clearly differentiate between portions of wiring that are factory-installed and portions to be field-installed.

8) Details of control panels, including controllers, instruments, and labeling shown in plan or elevation indicating the installed locations.

9) Floor plans: None required.

10) Format

a) Sheets shall be consecutively numbered.

b) Each sheet shall have a title indicating the type of information included and the mechanical/electrical system controlled.

c) Table of Contents listing sheet titles and sheet numbers.

d) Legend and list of abbreviations.

e) Schematics

1. Word searchable pdf format.

2. 21 inch x 15 inch or 17 inch x 11 inch.

c. Do not include sequence of controls on shop drawings or equipment submittals; they are included in Submittal Package 2.

3. Submittal Package 2 (Programming and Graphics)

a. A detailed description of point naming convention conforming to Paragraph 3.12B to be used for all software and hardware points, integrated with existing database convention.

b. A list of all hardware and software points identifying their full text names, device addresses and descriptions.

c. Control Logic Documentation

1) Submit control logic program listings (graphical programming) consistent with specified English-language Sequences of Operation for all control units.

2) Control logic shall be annotated to describe how it accomplishes the sequence of operation. Annotations shall be sufficient to allow an operator to relate each program component (block or line) to corresponding portions of the specified Sequence of Operation.

3) Include a MS Word file of the specified English-language Sequences of Operation of each control sequence updated to reflect any suggested changes made by the Contractor to clarify or improve the sequences. Changes shall be clearly marked. Also merge Guideline 36 sequences, where referenced, verbatim into the file; see Section 259000 Building Automation Sequences of Operation. SOOs shall be fully consistent with the graphical programming.

4) Include control settings, setpoints, throttling ranges, reset schedules, adjustable parameters and limits.

5) Submit one complete set of programming and operating manuals for all digital controllers concurrently with control logic documentation.

d. Graphic screens of all required graphics, provided in final colors.

e. Format

1) Points list: Word-searchable format per Paragraph 1.9C.3.

2) Programming: Native ALC Eikon.

3) Control sequences: MS Word

4) Programming and operating manual: Word-searchable format per Paragraph 1.9C.3.

5) Graphics: Graphical electronic format (pdf, png, etc.).

4. Submittal Package 3 (Pre-Functional Test Forms)

a. Provide pre-functional test forms as required by Paragraph 3.14D.2.a.

b. Format: Word-searchable format per Paragraph 1.9C.3.

5. Submittal Package 4 (Pre-Functional Test Report)

a. Provide Pre-Functional Test Report as required by Paragraph 3.14D.2.

b. Format: Word-searchable format per Paragraph 1.9C.3.

6. Submittal Package 5 (Post-Construction Trend Points List)

a. Provide a list of points being trended along with trend interval or change-of-value per Paragraph 3.14J.2.d.

b. Format: See Paragraph 2.11C.3.

7. Submittal Package 6 (Functional Test Report)

a. Provide completed functional test forms as required by Paragraph 3.14H.4.

b. Format: Word-searchable format per Paragraph 1.9C.3.

8. Submittal Package 7 (Training Materials)

a. Provide training materials as required by Paragraph 3.15.

b. Format: Word-searchable format per Paragraph 1.9C.3.

9. Submittal Package 8 (Post-Construction Trend Logs)

a. Provide trend logs as required by Paragraph 3.14J.

b. Format: See Paragraph 2.11C.3.

1.9 COMPLETION REQUIREMENTS

A. Procedure

1. Until the documents required in this Section are submitted and approved, the system will not be considered accepted and final payment to Contractor will not be made.

2. Before requesting acceptance of Work, submit one set of completion documents for review and approval of College.

3. After review, furnish quantity of sets indicated below to College.

B. Completion Documents

1. Operation and Maintenance (O & M) Manuals. Provide in both paper and electronic format per Paragraph 1.9C.

   a. Include the as-built version of all submittals (product data, shop drawings, control logic documentation, hardware manuals, software manuals, installation guides or manuals, maintenance instructions and spare parts lists) in maintenance manual. Submittal data shall be located in tabs along with associated maintenance information.

   b. Engineering, Installation, and Maintenance Manual(s) that explain how to design and install new points, panels, and other hardware; preventive maintenance and calibration procedures; how to debug hardware problems; and how to repair or replace hardware.

   c. Complete original issue documentation, installation, and maintenance information for all third-party hardware and software provided, including computer equipment and sensors.

   d. A list of recommended spare parts with part numbers and suppliers.

   e. Operators Manual with procedures for operating the control systems, including logging on/off, alarm handling, producing point reports, trending data, overriding computer control, and changing set points and other variables.

   f. Programming Manuals with a description of the programming language, control block descriptions (including algorithms and calculations used), point database creation and modification, program creation and modification, and use of the programming editor.

   g. Recommended preventive maintenance procedures for all system components, including a schedule of tasks (inspection, cleaning, calibration, etc.), time between tasks, and task descriptions.

   h. A listing and documentation of all custom software for the Project created using the programming language, including the set points, tuning parameters, and point and object database.

i. English language control sequences updated to reflect final programming installed in the BAS at the time of system acceptance. See Section 259000 Building Automation Sequences of Operation.

2. Complete original issue electronic copy for all software provided, including operating systems, programming language, operator workstation software, and graphics software.

3. Complete electronic copy of BAS database, user screens, setpoints and all configuration settings necessary to allow re-installation of system after crash or replacement of server, and resume operations with the BAS in the same configuration as during College sign-off.

4. Project Record Drawings

   a. As-built versions of the submittal drawings in reproducible paper and electronic format per Paragraph 1.9C.

   b. As-built network architecture drawings showing all BACnet nodes including a description field with specific controller and device identification, description and location information.

5. Commissioning Reports. Completed versions of all Pre-functional, Functional, and Demonstration Commissioning Test reports, calibration logs, etc., per Paragraph 3.14A.9.

6. Copy of inspection certificates provided by the local code authorities.

7. Written guarantee and warranty documents for all equipment and systems, including the start and end date for each.

8. Training materials as required by Paragraph 3.15.

9. Contact information. Names, addresses, and 24-hour telephone numbers of contractors installing equipment, and the control systems and service representatives of each.

C. Format of Completion Documents

1. Provide the type and quantity of media listed in table below.

2. Project database, programming source files, and all other files required to modify, maintain, or enhance the installed system shall be provided in their source format and compiled format (where applicable).

3. Where electronic copies are specified, comply with the following:

   a. Provide in word-searchable electronic format; acceptable formats are MS Word, Adobe Acrobat (pdf), and HTML; submit other formats for review and approval prior to submission; scanned paper documents not acceptable.

   b. For submittals, provide separate file for each type of equipment.

   c. Control sequences shall be in MS Word.

	Document	Paper (binder or bound)	Electronic	
			Loaded onto Flash Drive	Loaded onto CSS
1.	O&M Manual	2	1	1
2.	Original issue software	–	1	1
3.	Project database including all source files	–	1	1
4.	Project Record Drawings	2	1	1
5.	Control sequences	1	1	1
6.	Commissioning Reports	2	1	1
7.	Inspection Certificates	1	–	–
8.	Warranty documents	1	–	–
9.	Training materials	1 per trainee	1	1
10.	Contact information	1	–	–

D. Permanent On-site Documentation

1. In each panel, provide the following stored in clear plastic sleeve taped to the back of the panel door:

a. 8.5x11 printout of as-built points list

b. 21 inch x 15 inch or 17 inch x 11 inch set of as-built shop drawings for devices in panel

1.10 BAS DESIGN

A. System Architecture

1. General

a. The system provided shall incorporate hardware resources sufficient to meet the functional requirements specified in this Section. Include all items not specifically itemized in this Section that are necessary to implement, maintain, and operate the system in compliance with the functional intent of this Section.

b. The system shall be configured as a distributed processing network(s) capable of expansion as specified herein.

c. The existing Campus BAS consists of a control system server interconnected by the College IT LAN to each campus building and facility. This project includes integrating building level BCs and other control devices into the campus system.

1) Within the building, the BAS shall be standalone and not rely on any 3rd party networks, such as the College IT LAN, except as specifically allowed herein.

2) To communicate with the central CSS (and internet via VPN), the building Supervisory LAN shall connect via router, provided under Division 27, to the College IT LAN, provided by the Division 27. Locate in building ***MDF*** or other location as directed by the College IT group.

d. All control products provided for this Project shall comprise an interoperable Native BACnet System. All control products provided for this Project shall conform to ANSI/ASHRAE Standard 135.

e. Power-line carrier systems are not acceptable for BAS communications.

2. BAS Network Architecture

a. College IT LAN. Ethernet-based, 100 or 1000 Mbps BACnet/IP network specified under Division 27 Communications.

NOTE: new 4CD standard: IP network is used to connect BCs – no longer allow ARCnet or MS/TP. Include alternate for Division 27 to install if applicable.

b. Supervisory LAN: The LAN shall be an Ethernet-based, 100 or 1000 Mbps network interconnecting the server and OWS(s) to BCs and certain gateways as specified herein. LAN shall be IEEE 802.3 Ethernet with switches and routers that support 100 Mbps minimum throughput. This network shall be BACnet/IP as defined in the BACnet standard, and shall share a common network number for the Ethernet backbone, as defined in BACnet.

*NOTE: ARCnet is listed as optional here. This should only be used on new ALC jobs that cannot use ALC's new IP product line. If it's deleted, edit this section to pull Ethernet into the paragraph.*Primary LAN: High-speed, peer-to-peer communicating LAN used to connect AACs, ASCs, and certain gateways and sensors where specified herein. Acceptable technologies include and are limited to:

1) Ethernet (IEEE802.3) per the Supervisory LAN

2) ***ARCnet (IEEE802.4***)

NOTE: new 4CD standard: MS/TP only used for gateways and sensors where spec'd. No longer allowed for interconnecting controllers. Secondary LAN: Network used only to connect certain gateways and sensors where specified herein. It shall not be used to interconnect BCs, AACs, and ASCs. Network speed versus the number of devices on the LAN shall be dictated by the response time and trending requirements. Acceptable technologies include but are not limited to:

1) BACnet over Master Slave/ Token Passing (MS/TP)

2) Modbus RTU over RS-485

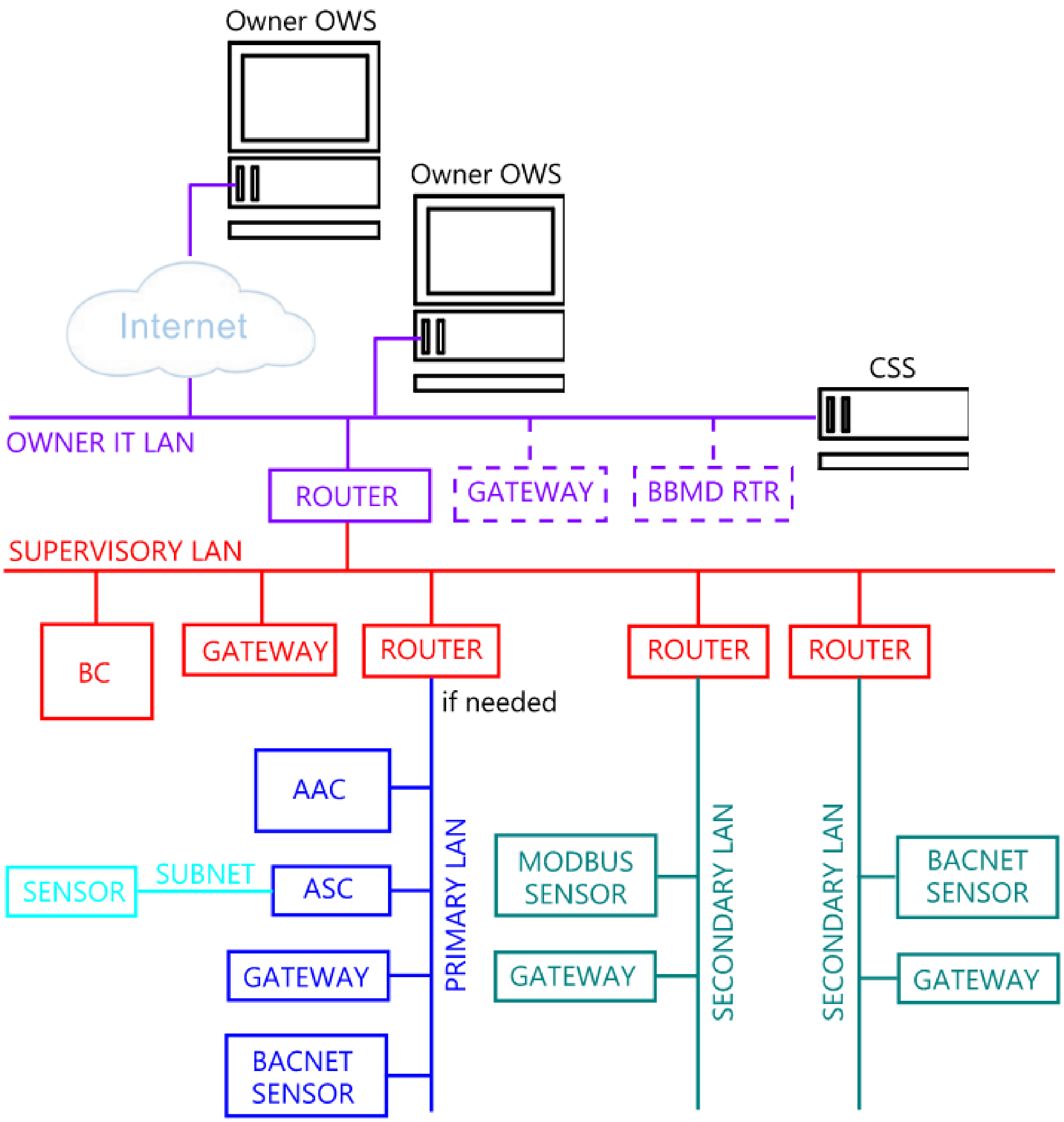
e. Subnets: Networks used to connect sensors and thermostats to AACs and ASCs. This network may as above for Secondary LANs or may be proprietary the manufacturer.

3. The figure below shows an example schematic of the desired network architecture. Note:

a. Not all devices shown will exist for this project.

b. Ethernet network installer shall be responsible for assigning IP addresses to all devices on the network.

c. If gateways are specified to be directly connected to the College IT LAN in Paragraph 2.4C, the gateway supplier shall also provide and install a BBMD Router (both shown dashed in the schematic) including all configuration and programming.



4. Operator Interfaces and Servers

a. The Control Systems Server (CSS) is existing. See Paragraph 1.3B.7 for temporary CSS requirements.

b. OWSs or POTs are either existing or will be provided by the College.

c. Remote monitoring and control shall be through use of a web browser through the College IT LAN and via the internet through the College IT LAN.

5. Controllers. The BCs, AACs, and ASCs shall monitor, control, and provide the field interface for all points specified.

6. Gateways

a. See Paragraph 2.4C for a list of gateways.

b. Where gateways are used, critical points may also be hardwired from the BAS to the controlled device, rather than using the gateway, to avoid problems with gateway failures. Where listed in Hardware Points tables, these points shall be hardwired even when available through gateway.

B. System Performance

1. The communication speed between the controllers, LAN interface devices, and operator interface devices shall be sufficient to ensure fast system response time under any loading condition. This includes when system is collecting trend data for commissioning and for long term monitoring. (See Paragraph 3.14J.) In no case shall delay times between an event, request, or command initiation and its completion be greater than those listed herein, assuming no other simultaneous operator activity. Reconfigure LAN as necessary to accomplish these performance requirements. This does not apply to gateways and their interaction with non-BAS-vendor equipment.

a. Object Command: The maximum time between an operator command via the operator interface to change an analog or binary point and the subsequent change in the controller shall be less than 5 seconds.

b. Object Scan: All changes of state and change of analog values will be transmitted over the network such that any data used or displayed at a controller or workstation will have been current within the previous 10 seconds.

c. Graphics Scan: The maximum time between an operator's selection of a graphic and it completely painting the screen and updating at least 10 points shall be less than 10 seconds.

d. Alarm Response Time: The maximum time from when an object goes into alarm to when it is annunciated at the workstation or broadcast (where so programmed) shall not exceed 10 seconds for a Level 1 alarm, 20 seconds for alarm levels 2 and 3, and 30 seconds for alarm levels 4 and 5. All workstations on the onsite network must receive alarms within 5 seconds of each other.

e. Program Execution Frequency: Custom and standard applications shall be capable of running as often as once every 5 seconds. Contractor shall be responsible for selecting execution times consistent with the mechanical process under control.

f. Control Loop Performance: Programmable controllers shall be able to execute DDC PID control loops at a selectable frequency of at least once per second. The controller shall scan and update the process value and output generated by this calculation at this same frequency.

2. Sensor selection, wiring method, use of transmitters, A-to-D conversion bits, etc. shall be selected and adjusted to provide end-to-end (fluid to display) accuracy at or better than those listed in the following table.

Measured Variable	**Reported Accuracy**
Space drybulb temperature	±1ºF
Ducted Air drybulb temperature	±0.5ºF
Mixed Air drybulb temperature	±1ºF
Outside Air drybulb temperature	±0.5ºF
Chilled and Condenser Water Temperature	±0.2ºF
Hot Water Temperature	±0.5ºF
Chilled/Hot Water Delta-T (supply to return) at building mains from central plant only	±0.15ºF
Relative Humidity − general	±5% RH
Relative Humidity − outdoor air	±3% RH
Water and Gas Flow	±1% of reading
Airflow (terminal)	±10% of reading
Airflow (measuring stations)	±5% of reading
Air Pressure (ducts)	±0.05 inches
Air Pressure (space)	±0.01 inches
Water Pressure	±2% of reading
Electrical power	1% of reading
Carbon Dioxide (CO_2)	±75 ppm

1.11 OWNERSHIP OF PROPRIETARY MATERIAL

A. All project-developed software and documentation shall become the property of the College. These include, but are not limited to:

1. Project graphic images
2. Record drawings
3. Project database
4. Project-specific application programming code
5. All documentation

1.12 WARRANTY

A. At the successful completion of the final testing, commissioning, and demonstration phase in accordance with the terms of this specification, if equipment and systems are operating satisfactorily to the College and if all completion requirements per Paragraph 1.9B have been fulfilled, the College shall certify in writing that the control system has been accepted. The date of acceptance shall be the start of the warranty period.

B. Guarantee all materials, equipment, apparatus and workmanship (including programming) to be free of defective materials and faulty workmanship for the following periods from date of acceptance:

1. BCs, AACs, and ASCs: two years

2. Valve and damper actuators: five years

3. All else: one year

C. Provide new materials, equipment, apparatus and labor to replace that determined by College to be defective or faulty.

D. Control system failures during the warranty period shall be adjusted, repaired, or replaced at no additional cost or reduction in service to the College. Contractor shall respond to the College's request for warranty service within 24 hours during normal business hours.

E. Operator workstation software, project-specific software, graphic software, database software, and firmware updates that resolve known software deficiencies shall be provided at no cost to the College during the warranty period.

F. Sequence of operation programming bugs (both due to programming misinterpretations and sequence errors) shall be corrected and any reasonable control sequence changes required to provide proper system operation shall be provided at no additional cost to the College during this period.

1.13 WARRANTY MAINTENANCE

A. The College reserves the right to make changes to the BAS during the warranty period. Such changes do not constitute a waiver of warranty. The Contractor shall warrant parts and installation work regardless of any such changes made by the College, unless the Contractor provides clear and convincing evidence that a specific problem is the result of such changes to the BAS.

B. At no cost to the College, provide maintenance services for software and hardware components during the warranty period as specified below:

1. Emergency Service: Any malfunction, failure, or defect in any hardware component or failure of any control programming that would result in property damage or loss of comfort control shall be corrected and repaired following notification by the College to the Contractor.

   a. Response by telephone or via internet connection to the BAS to any request for service shall be provided within two hours of the College's initial request for service.

   b. In the event that the malfunction, failure, or defect is not corrected, at least one technician, trained in the system to be serviced, shall be dispatched to the College's site within eight hours of the College's initial request for such services.

2. Normal Service: Any malfunction, failure, or defect in any hardware component or failure of any control programming that would not result in property damage or loss of

comfort control shall be corrected and repaired following notification by the College to the Contractor.

a. Response by telephone to any request for service shall be provided within eight working hours (contractor specified 40 hr. per week normal working period) of the College's initial request for service.

b. In the event that the malfunction, failure, or defect is not, at least one technician, trained in the system to be serviced, shall be dispatched to the College's site within three working days of the College's initial request for such services, as specified.

3. College's Telephonic Request for Service: Contractor shall specify a maximum of three telephone numbers for College to call in the event of a need for service. At least one of the lines shall be attended continuously (24/7). Alternatively, pagers/SMS can be used for technicians trained in system to be serviced. One of the three paged/texted technicians shall respond to every call within 15 minutes.

4. Technical Support: Contractor shall provide technical support by telephone throughout the warranty period.

5. Documentation: Record drawings and software documentation shall be updated as required to reflect any and all changes made to the system or programming during the warranty period.

PART 2 PRODUCTS

2.1 PRIMARY BAS MANUFACTURER

A. Automated Logic Corp.

B. No Equal

2.2 GENERAL

A. Materials shall be new, the best of their respective kinds without imperfections or blemishes and shall not be damaged in any way.

B. To the extent practical, all equipment of the same type serving the same function shall be identical and from the same manufacturer.

C. All controllers, associated hardware (repeaters, routers, etc.), sensors, and control devices shall be fully operational and maintain specified accuracy at the anticipated ambient conditions of the installed location as follows:

1. Outdoors or in harsh ambient conditions: -20°C to 55°C (-4°F to 130°F), 10% RH to 90% RH noncondensing.

2. Conditioned spaces or mechanical rooms: 0°C to 40°C (32°F to 104°F), 10% RH to 80% RH noncondensing.

2.3 CONTROLLERS

A. Building Controller (BC)

1. ALC OptiFlex line

B. Advanced Application Controller (AAC)

1. ALC OptiFlex line

2. *ALC SE-serie*s

C. Application Specific Controller (ASC)

1. ALC OptiFlex line

2. *ALC ZN-serie*s

2.4 COMMUNICATION DEVICES

A. Supervisory LAN Protocol Translators

1. ALC Optiflex line

B. BACnet Gateways & Protocol Translators

1. Gateways shall be provided to link non-BACnet control products to the BACnet inter-network. All of the functionality described in this Paragraph is to be provided by using the BACnet capabilities. Each Gateway shall have the ability to expand the number of BACnet objects of each type supported by 20% to accommodate future system changes.

2. Each Gateway shall provide values for all points on the non-BACnet side of the Gateway to BACnet devices as if the values were originating from BACnet objects. The Gateway shall also provide a way for BACnet devices to modify (write) all points specified by the Points List using standard BACnet services.

C. Gateways and Protocol Translators

Equipment/System	Interface			
	Type	Specified Under Division:	Location	Connect to this Network:
Variable Speed Drives	BACnet/MSTP	23	Each VFD	Secondary
Electronically Commutated Motors	Modbus RS-485	23	Each ECM	Secondary
Chillers	BACnet/IP	23	Each Chiller	Supervisory
Chillers	BACnet/MSTP	23	Each Chiller	Secondary
Water-to-Water Heat Pumps	BACnet/IP	23	Each Heat Pump	Supervisory
Water-to-Water Heat Pumps	BACnet/MSTP	23	Each Heat Pump	Secondary

Equipment/System	Interface			
	Type	Specified Under Division:	Location	Connect to this Network:
Air-to-Water Heat Pumps	BACnet/IP	23	Each Heat Pump	Supervisory
Air-to-Water Heat Pumps	BACnet/MSTP	23	Each Heat Pump	Secondary
Boilers	Modbus RS-485	23	Each Boiler	Secondary
Boilers	BACnet/MSTP	23	Each Boiler	Secondary
Lighting Controls	BACnet/IP	26	Electrical Room xxxx	College IT LAN
Lighting Controls	BACnet/IP	26	Electrical Room xxxx	Supervisory
Automatic Shade Controls	BACnet/IP	12	Electrical Room xxxx	College IT LAN
Automatic Shade Controls	BACnet/IP	12	Electrical Room xxxx	Supervisory
Power Monitoring	BACnet/IP	26	Electrical Room xxxx	College IT LAN
Power Monitoring	BACnet/IP	26	Electrical Room xxxx	Supervisory
Power Monitoring	Modbus RS-485	26	Electrical Room xxxx	Secondary
Switchgear Digital Power Meters	BACnet/IP	26	Electrical Room xxxx	College IT LAN
Switchgear Digital Power Meters	BACnet/IP	26	Electrical Room xxxx	Supervisory
BTU meters	BACnet/MSTP	25	Each BTU meter	Secondary
Refrigerant monitor	Modbus RS-485	25	RM-1	Secondary
Lab Air Valves	BACnet/MSTP	23	Each Air Valve	Secondary
Water Treatment System	BACnet/IP	23	WTS-1	Supervisory
Variable refrigerant flow (VRF) system	BACnet/IP	23	Room xxxx	Supervisory
Hydronic Heat Pumps	BACnet/MSTP	23	Each AC unit	Secondary
AC Units	BACnet/MSTP	23	Each AC unit	Secondary
AC Units	BACnet/IP	23	Each AC unit	Supervisory
Melink Hood DCV	BACnet/IP	23	Each Melink main controller	Supervisory
Emergency Generator	Modbus RS-485	26	Each generator	Secondary
UPS	Modbus RS-485	26	Each UPS	Secondary
DCW Booster pump	BACnet/MSTP	22	DCW Booster pump	Secondary
Wind Anemometer	Modbus RS-485	25	Roof	Secondary

2.5 BAS INTERFACE HARDWARE

A. Not required (existing)

2.6 AIR TUBING

A. Seamless copper tubing, Type L-ACR, ASTM B 88; with cast-bronze solder joint fittings, ANSI B1.18; or wrought-copper solder-joint fittings, ANSI B16.22; except brass compression-type fittings at connections to equipment. Solder shall be 95/5 tin antimony, or other suitable lead free composition solder.

B. Virgin polyethylene non-metallic tubing type FR, ASTM D 2737, and with flame-retardant harness for multiple tubing. Use compression or push-on brass fittings.

2.7 ELECTRIC WIRING AND DEVICES

A. All electrical work shall comply with Division 26.

B. Communication Wiring

1. Provide all communication wiring between Building Controllers, Protocol Translators, Gateways, AACs, ASCs and local and remote peripherals (such as operator workstations and printers).

2. Ethernet LAN: Use Fiber or Category 5e or 6 of standard TIA/EIA 68 (10baseT). Network shall be run with no splices and separate from any wiring over 30 volts.

3. ***ARCnet and*** RS-485 LAN: Communication wiring shall be individually 100% shielded pairs per manufacturers recommendations for distances installed, with overall PVC cover, Class 2, plenum-rated run with no splices and separate from any wiring over 30 volts. Shield shall be terminated and wiring shall be grounded as recommended by BC manufacturer.

C. Analog Signal Wiring

1. Input and output signal wiring to all field devices, including, but not limited to, all sensors, transducers, transmitters, switches, current or voltage analog outputs, etc. shall be twisted pair, 100% shielded if recommended or required by controller manufacturer, with PVC cover. Gauge shall be as recommended by controller manufacturer.

2.8 CONTROL CABINETS

A. All control cabinets shall be fully enclosed with hinged door.

1. For panels in mechanical rooms and other spaces that are secure and accessible only to BAS/MEP operators, provide quarter-turn slotted latch.

2. For panels located in electrical rooms, IDF rooms, and other spaces that may be accessible by persons other than BAS/MEP operators, provide key-lock latch. A single key shall be common to all panels within each building. Provide 3 keys.

B. Construction

1. Indoor:

a. Mechanical or electrical rooms etc.: NEMA 1

b. Air plenums: NEMA 12

2. Outdoor: NEMA 4NEMA 4X with 316 stainless steel

C. Interconnections between internal and face-mounted devices shall be pre-wired with color-coded stranded conductors neatly installed in plastic troughs or tie-wrapped. Terminals for field connections shall be UL Listed for service, individually identified per control-interlock drawings, with adequate clearance for field wiring. All control tubing and wiring shall be run neatly and orderly in open slot wiring duct with cover. Control terminations for field connection shall be individually identified per control Shop Drawings.

D. Provide ON/OFF power switch with over-current protection for control power sources to each local panel.

E. Provide with

1. Framed, plastic-encased point list for all points in cabinet.

2. Nameplates for all devices on face.

2.9 SENSORS AND MISCELLANEOUS FIELD DEVICES

A. The listing of several sensors or devices in this section does not imply that any may be used. Refer to points list in Paragraph 2.12 Points List for device specification. Only where two or more devices are specifically listed in points list (such as “FM-1 or FM-4”) may the Contractor choose among listed products.

B. Control Valves

1. Manufacturers

a. Belimo

b. Siemens

c. Schneider

d. Delta

e. JCI

f. Bray

g. Or equal

2. ***Plug-Type Globe Valves***

a. Valves shall have cage-type trim, providing seating and guiding surfaces for plug on top-and-bottom guided plugs.

b. Temperature Rating: 25ºF minimum, 250ºF maximum

c. Body: Cast Iron, flanged

d. Valve Trim: Bronze; Stem: Polished stainless steel

e. Packing: Spring Loaded Teflon or Synthetic Elastomer U-cups, self-adjusting

f. Plug: Brass, bronze or stainless steel, Seat: Brass

g. Disc: Replaceable Composition or Stainless Steel Filled PTFE

h. Close off rating: Bubble-tight shutoff greater or equal to 125% of pump shut-off head.

i. Ambient Operating Temperature Limits: -10 to 150ºF

3. Butterfly Valves

a. Body: Extended neck epoxy coated cast or ductile iron with full lug pattern, ANSI Class bolt pattern to match specified flanges.

b. Seat: EPDM replaceable, non-collapsible, phenolic backed.

c. Disc: Polished aluminum bronze or stainless steel, pinned or mechanically locked to shaft. Sanded castings are not acceptable.

d. Bearings: Bronze or stainless steel.

e. Shaft: 416 stainless steel supported at three locations with PTFE bushings for positive shaft alignment.

f. Close off rating: Bubble-tight shutoff greater or equal to 125% of pump shut-off head.

4. Modulating Characterized Ball Valves

a. Valves shall be specifically designed for modulating duty in control application with guaranteed average leak-free life span over 200,000 full stroke cycles.

b. Industrial quality with nickel plated forged brass body and female NPT threads.

c. Blowout proof stem design, glass-reinforced Teflon thrust seal washer and stuffing box ring with minimum 600 psi rating (2-way valves) or 400 psi rating (3-way valves). The stem packing shall consist of 2 lubricated O-rings designed for modulating service and requiring no maintenance.

d. Valves suitable for water or low-pressure steam shall incorporate an anti-condensation cap thermal break in stem design.

e. Close off rating: Bubble-tight shutoff greater or equal to 125% of pump shut-off head.

f. Characterizing disk held securely by a keyed ring providing equal percentage characteristic

g. Ball: stainless steel

h. Stem: stainless steel

5. Two Position Ball Valves

a. Same as Modulating Characterized Ball Valves except no characterization disks

6. Six-way Characterized Ball Valves

a. Valves shall be specifically designed for modulating duty in control application with guaranteed average leak-free life span over 200,000 full stroke cycles.

b. Industrial quality with nickel plated forged brass body and NPT threads.

c. Blowout proof stem design, glass-reinforced Teflon thrust seal washer and stuffing box ring with minimum 230 psi rating. The stem packing shall consist of 2 lubricated O-rings designed for modulating service and requiring no maintenance.

d. Valves suitable for water or low-pressure steam shall incorporate an anti-condensation cap thermal break in stem design.

e. Built-in pressure relief

f. Close off rating: 50 psi

g. Ball: chrome plated brass

h. Stem: nickel plated brass

i. Characterizing disk held securely by a keyed ring providing linear characteristic

7. Pressure Independent Control Valves

a. Manufacturers

1) Danfoss

2) Belimo

3) Bell & Gossett

4) Delta-P

5) Griswold

6) Bray

b. The modulating control valves shall be pressure independent.

1) The flow through the valve shall not vary more than ± 5% due to system pressure fluctuations across the valve in the selected operating range.

2) The control valves shall accurately control the flow from 0 to 100% full rated flow.

3) The valve shall have an equal percentage or linear characteristic.

4) Valve shall be regulator + valve type; ePICVs with flow meter shall not be acceptable.

c. No more than 5 psi differential pressure shall be required to operate the valve pressure independently.

d. Valves shall require no maintenance and shall not include replaceable cartridges.

e. Close off rating: Bubble-tight shutoff greater or equal to 125% of pump shut-off head.

f. Maximum flow rate setpoint shall be field adjustable.

8. Minimum valve assembly pressure ratings

a. Chilled water: 125 psi at 60ºF

b. Hot water: 125 psi at 200ºF

c. Condenser water: 125 psi at 100ºF

9. Valve Selection

a. Valve type

1) Modulating 2-way or 3-way valves

a) 6 inch and less: characterized ball type

b) 8 inch and greater: globe type

2) Bypass valve at primary-only variable flow pumping system outlet: Pressure independentSame as Modulating 2-way valve.

3) Chiller head pressure control: butterfly

4) Two-position isolation: butterfly or non-characterized ball type

5) Two-position 3-way changeover: butterfly or non-characterized ball type

b. Valve Characteristic

1) 2-way valves: equal percentage or modified equal percentage.

2) 3-way valves controlling cooling coils and condenser water heat exchangers: linear.

3) 3-way valves controlling heating coils: equal percentage or modified equal percentage.

4) 6-way valves: linear

5) Two-position valves: not applicable. For ball valves used for two-position duty, do not include characterizing disk.

c. Valve Sizing

1) Modulating Water: Size valve to achieve the following full-open pressure drop

a) Minimum pressure drop: equal to half the pressure drop of coil or exchanger.

b) Maximum pressure drop

1. Hot water at coils: 2 psi

2. Chilled water at coils: 5 psi

3. Chiller head pressure control: 1 psi

c) 3-way valves shall be selected for near minimum pressure drop. 2-way and 6-way valves shall be selected near maximum pressure drop.

d) Flow coefficient (C_v) shall not be less than 1.0 (to avoid clogging) ***unless protected by strainer. Verify from piping schematics that a strainer is being provided.***

e) Valve size shall match as close as possible the pipe size where C_v is available in that size.

2) Two-position valves: Line size unless otherwise indicated on Drawings.

3) Pressure independent valves: Line-size with flow limiting device selected for design flow maximum flow setpoint.

C. Control Dampers

1. See Section 233300 Duct Accessories and Section 237300 Air Handling Units & Coils.

D. Actuators

1. Manufacturers

a. Belimo

b. No equal

2. Warranty: Valve and damper actuators shall carry a manufacturer's 5-year warranty.

3. Electric Actuators

   a. Entire actuator shall be UL or CSA approved by a National Recognized Testing Laboratory.

   b. Enclosure shall meet NEMA 4X weatherproof requirements for outdoor applications.

   c. Dampers. The actuator shall be direct coupled over the shaft, enabling it to be mounted directly to the damper shaft without the need for connecting linkage. The clamp shall be steel of a V-bolt design with associated V-shaped, toothed cradle attaching to the shaft for maximum strength and eliminating slippage via cold weld attachment. Single bolt or set screw type fasteners are not acceptable. Aluminum clamps are unacceptable.

   d. Valves. Actuators shall be specifically designed for integral mounting to valves without external couplings.

   e. Actuator shall have microprocessor-based motor controller providing electronic cut off at full open so that no noise can be generated while holding open. Holding noise level shall be inaudible.

   f. Noise from actuator while it is moving shall be inaudible through a tee-bar ceiling.

   g. Actuators shall provide protection against actuator burnout using an internal current limiting circuit or digital motor rotation sensing circuit. Circuit shall insure that actuators cannot burn out due to stalled damper or mechanical and electrical paralleling. End switches to deactivate the actuator at the end of rotation or use of magnetic clutches are not acceptable.

   h. Modulating Actuators. Actuators shall accept a 0 to 10 VDC or 0 to 20 mA control signal and provide a 2 to 10 VDC or 4 to 20 mA operating range. Actuators shall have positive positioning circuit so that controlled device is at same position for a given signal regardless of operating differential pressure. Actuators that internally use a floating actuator with an analog signal converter are not acceptable.

   i. Where indicated on Drawings or Points List, actuators shall include

      1) 2 to 10 VDC position feedback signal

      2) Limit (end) position switches

   j. All 24 VAC/DC actuators shall operate on Class 2 wiring and shall not require more than 10 VA for AC. Actuators operating on 120 VAC power shall not require more than 10 VA. Actuators operating on 230 VAC power shall not require more than 11 VA.

   k. All modulating actuators shall have an external, built-in switch to allow the reversing of direction of rotation.

l. Actuators shall be provided with a conduit fitting an a minimum three-foot electrical cable and shall be pre-wired to eliminate the necessity of opening the actuator housing to make electrical connections.

m. Where fail-open or fail-closed (fail-safe) position is required by Paragraph 2.9D.5, an internal mechanical, spring return mechanism shall be built into the actuator housing. Electrical capacitor type fail-safe are also acceptable. All fail-safe actuators shall be capable of both clockwise or counterclockwise spring return operation by simply changing the mounting orientation. Spring return 2-position fail-safe valves shall not be used in noise sensitive locations; use either electronic fail-safe where available, or use floating point type actuator with drive-open and drive-close wiring for normal open/close operation (spring shall only be used to cause valve to drive to fail-safe position upon a loss of power) including position feedback.

n. Actuators shall be capable of being mechanically and electrically paralleled to increase torque where required.

o. All non-spring return actuators shall have an external manual gear release to allow manual positioning of the damper when the actuator is not powered. Spring return actuators with more than 60 inch-pound torque capacity shall have a manual crank for this purpose.

p. Actuators shall be designed for a minimum of 60,000 full cycles at full torque and be UL 873 listed.

q. Actuators shall provide clear visual indication of damper/valve position.

4. Electric Actuators for Large Butterfly Valves

a. Entire actuator shall be UL or CSA approved by a National Recognized Testing Laboratory.

b. The valve actuator shall consist of a capacitor-type reversible electric motor, gear train, limit switches and terminal block, all contained in a die cast aluminum enclosure.

c. Enclosure shall meet NEMA 4X weatherproof requirements for outdoor applications.

d. Output shaft shall be electroless nickel plated to prevent corrosion.

e. Actuator shall have a motor rated for minimum 75% duty cycle. Duty cycle shall be defined as running time divided by installed time at maximum torque.

f. Actuator shall be suitable for operation in ambient temperature ranging from -22°F to +150°F.

g. A pre-wired cable shall bring wiring outside enclosure to avoid necessity of opening cover.

h. Gears shall be hardened alloy steel, permanently lubricated. A self-locking gear assembly or a brake shall be supplied.

i. Actuator shall be equipped with a hand wheel for manual override to permit operation of the valve in the event of electrical power failure or system malfunction. Hand wheel must be permanently attached to the actuator. When in manual operation electrical power to the actuator will be permanently interrupted.

j. The hand wheel will not rotate while the actuator is electrically driven.

k. Actuator shall have heater and thermostat to minimize condensation within the actuator housing.

l. Provide limit (end) position switches where indicated on schematics.

m. Actuators shall provide clear visual indication of valve position.

5. Normal and Fail-Safe Position

a. Except as specified otherwise herein, the normal position (that with zero control signal) and the fail-safe position (that with no power to the actuator) of control devices and actuators shall be as indicated in table below. “Last” means last position. Actuators with a fail-safe position other than “Last” must have spring or electronic fail-safe capability.

Device	**Normal Position**	**Fail-Safe Position**
Outside air damper	CLOSED	CLOSED
Return air damper	OPEN	OPEN
Exhaust/relief air damper	CLOSED	CLOSED
Domestic hot water generator	CLOSED	CLOSED
Cooling tower makeup water valve	CLOSED	CLOSED
Cooling tower filtration water valves	CLOSED	CLOSED
Cooling tower filtration purge valve	CLOSED	CLOSED
AHU heating coil valves	OPEN	LAST
AHU cooling coil valves	CLOSED	LAST
Equipment isolation valves	OPEN	LAST
Hot water reheat coil valves	CLOSED	LAST
Minimum flow bypass valves	OPEN	LAST
Fan-coil HW and CHW valves	CLOSED	LAST
HW/CHW valves for changeover coils	Same as fail-safe	See Schematics
CRAH CHW valves	OPEN	LAST
HW/CHW 6-way valves for changeover coils	CLOSED to both	LAST
VAV box dampers	OPEN	LAST
Laboratory hood exhaust air valves	OPEN	LAST
Laboratory supply air valves	OPEN	LAST
Laboratory general exhaust valves	CLOSED	LAST
Laboratory fume hood exhaust minimum airflow damper	CLOSED	CLOSED

6. Valve Actuator Selection

a. Modulating actuators for valves shall have minimum rangeability of 50 to 1.

b. Water

1) 2-way, 6-way, and two-position valves

a) Tight closing against 125% of system pump shut-off head.

b) Modulating duty against 90% of system pump shut-off head.

2) 3-way shall be tight closing against twice the full open differential pressure for which they are sized.

7. Damper Actuator Selection

a. Actuators shall be direct coupled. For multiple sections, provide one actuator for each section; linking or jack-shafting damper sections shall not be allowed.

b. Provide sufficient torque as velocity, static, or side seals require per damper manufacturer's recommendations and the following:

1) Torque shall be a minimum 5 inch-pound per square foot for opposed blade dampers and 7 inch-pound per square foot for parallel blade dampers.

2) The total damper area operated by an actuator shall not exceed 80% of the manufacturer's maximum area rating.

E. General Field Devices

1. Provide field devices for input and output of digital (binary) and analog signals into controllers (BCs, AACs, ASCs). Provide signal conditioning for all field devices as recommended by field device manufacturers and as required for proper operation in the system.

2. It shall be the Contractor's responsibility to assure that all field devices are compatible with controller hardware and software.

3. Field devices specified herein are generally two-wire type transmitters, with power for the device to be supplied from the respective controller. If the controller provided is not equipped to provide this power, or is not designed to work with two-wire type transmitters, or if field device is to serve as input to more than one controller, or where the length of wire to the controller will unacceptably affect the accuracy, provide a transmitter and necessary regulated DC power supply, as required.

4. For field devices specified hereinafter that require signal conditioners, signal boosters, signal repeaters, or other devices for proper interface to controllers, furnish and install proper device, including 120V power as required. Such devices shall have accuracy equal to, or better than, the accuracy listed for respective field devices.

5. Accuracy: As used in this Section, accuracy shall include combined effects of nonlinearity, non-repeatability and hysteresis. Sensor accuracy shall be at or better than both that specifically listed for a device and as required by Paragraph 1.10B.2.

F. Temperature Sensors (TS)

1. General

a. Unless otherwise noted, sensors may be platinum RTD, thermistor, or other device that is commonly used for temperature sensing and that meets accuracy, stability, and resolution requirements.

b. When matched with A/D converter of BC, AAC, or ASC, sensor range shall provide a resolution of no worse than 0.3ºF (0.16 °C) (unless noted otherwise herein).

c. Sensors shall drift no more than 0.3ºF and shall not require calibration over a five-year period.

d. Manufacturers

1) Mamac

2) Kele Associates

3) Building Automation Products Inc.

4) Automated Logic Corp.

5) Or equal

2. Duct temperature sensors: Shall consist of sensing element, junction box for wiring connections and gasket to prevent air leakage or vibration noise.

a. TS-1A: Single point (use where not specifically called out to be averaging in points list). Sensor probe shall be 304 stainless steel.

b. TS-1B: Averaging, flexible. Sensor length shall be at least 1 linear foot for each 2 square feet of face area up to 25 feet maximum. Sensor probe shall be bendable aluminum.

c. TS-1C: Averaging, rigid. Sensor length shall be at least 2/3 the width of the duct and include at least four sensing elements, or one per 6 inches, whichever is greater.

3. Water Temperature Sensors

a. TS-2A: Well mounted immersion sensor, ¼” stainless steel probe, double encapsulated sensor, with enclosure suitable for location.

b. TS-2B: Same as TS-2A except provide extra precision (XP) temperature sensors to meet accuracy specified Paragraph 1.10B.2.

c. TS-2C. See BTU-1.

d. All piping immersion sensors shall be in one-piece machined brass or stainless steel wells that allow removal from operating system, with lagging extension equal to insulation thickness where installed in insulated piping. Wells shall be rated for maximum system operating pressure, temperature and fluid velocity. The well shall penetrate the pipe by the lesser of approximately half the pipe diameter or eight inches. The use of direct immersion or strap-on type sensors is not acceptable.

4. Room Sensors

a. Thermostat tags refer to the following:

Type:	Tag
Model	ZS2 Pro
Temperature only	TS-3C
With CO_2	TS-3CC

1) Display

a) LCD display of all sensors, temperature setpoint adjustment buttons, and schedule override button

2) CO2 Sensor

a) 400 to 1250 PPM/ ±30PPM or 3% of reading, whichever is greater.

b) The sensor shall include automatic background calibration (ABC) logic to compensate for the aging of the infrared source and shall not require recalibration for a minimum of 5 years, guaranteed. If sensor is found to be out of calibration, supplier shall recalibrate at no additional cost to the College within 5 years of purchase date.

c) Meet Title 24 requirements including calibration interval

d) Provide where CO_2 sensor called for on Drawings.

3) For room sensors connected to terminal box controllers (such as at VAV boxes) that require calibration: Include a USB port or some other means for connection of POT for terminal box calibration. Alternative means of terminal calibration are acceptable provided they result in no cost to Work performed under Section 230593 Testing, Adjusting, and Balancing.

b. TS-3E. “Button” temperature sensor. Titan Products TPWBS, or equal.

c. TS-3F. Radiant temperature sensor. Titan Products TPRS/BB, 4-20 mA signal.

5. TS-4: Outdoor Air Sensor

a. Enclose in fan-aspirated radiation shield that combines both active and passive aspiration to minimize the effects of radiation.

1) Motor-driven fan draws air through the sensor chamber and exhausts it through the top of the shield.

2) Triple-walled sensor chamber shielded by flow-through plates.

3) Aspiration rate: minimum is 220 feet per minute.

b. Sensor

1) Electronics mounted in watertight gasketed enclosure to prevent water seepage

2) TS-1A where only drybulb temperature is specified in points list

3) TS-1A and HT-2 where drybulb temperature and relative humidity is specified in points list

c. Manufacturer

1) Davis Instruments 7747

2) Kele A21

3) Or equal

d. Outdoor air sensors shall have a weather shade/sun shield, utility box, and watertight gasket to prevent water seepage.

6. Temperature Transmitters: Where required by the Controller or to meet specified end-to-end accuracy requirements, sensors as specified above shall be matched with transmitters outputting 4-20 mA linearly across the specified temperature range. Transmitters shall have zero and span adjustments, an accuracy of 0.1°F when applied to the sensor range.

G. BTU Meter (BTU-1)

1. Matched RTD or solid state temperature sensors with a differential temperature accuracy of +/-0.15°F.

2. Flow meter: FM-1 ***or FM-2***.

3. Unit accuracy shall be +/- 1% factory calibrated, traceable to NIST with certification.

4. NEMA 1 enclosure.

5. UL listed.

6. Provide BACnet/MSTP network connection that will allow all point data to be transmitted to BAS network.

7. I/O.

a. BACnet Points:

1) Supply Temperature

2) Return Temperature

3) Flow

4) Energy Rate (Btu/hr.)

8. Manufacturers

a. Onicon System 20

b. Siemens Sitrans

c. Or Equal

H. Pressure Transmitters (PT)

1. PT-1: Water, General Purpose

a. Fast-response stainless steel sensor

b. Two-wire transmitter, 4-20 mA output with zero and span adjustments

c. Accuracy

1) Overall Accuracy (at constant temp) ±0.5% full scale, includes non-linearity, repeatability, and hysteresis

d. Long Term Stability 0.5% FS per year

e. Pressure Limits

1) Rated pressure: see points list

2) Proof pressure = 3x rated pressure

3) Burst pressure = 5x rated pressure

f. Manufacturers

1) Setra 209

2) Kele & Associates P51 Series

3) Or equal

I. Differential Pressure Transmitters (DPT)

1. DPT-1: Water, General Purpose

a. Fast-response capacitance sensor

b. Two-wire transmitter, 4-20 mA output with zero and span adjustments

c. Accuracy

1) Overall Accuracy (at constant temp) ±0.25% full scale (FS).

2) Non-Linearity, BFSL ±0.22% FS.

3) Hysteresis 0.10% FS.

4) Non-Repeatability 0.05% FS.

d. Long Term Stability 0.5% FS per year

e. Only 316 stainless steel in contact with fluid

f. Pressure Limits

1) 0 to 100 psid range: 250 psig maximum static pressure rating, 250 psig maximum overpressure rating.

2) 100 to 300 psid range: 450 psig maximum static pressure rating, 450 psig maximum overpressure rating.

g. Include brass 5-valve assembly for single sensor devices. See Paragraph 3.11E.10.

h. Manufacturers

1) Setra 209 or 230

2) Modus W30

3) Or equal

2. DPT-2: Not used

3. DPT-3: Air, Duct Pressure:

a. General: Loop powered two-wire differential capacitance cell-type transmitter.

b. Output: two wire 4-20 mA output with zero adjustment.

c. Overall Accuracy: ±1% of range (not of maximum range/scale)

d. Switch selectable range:

1) ≥ 0.5 inches water column

2) ≤10 inches water column

3) Select range as specified in points list or, if not listed for specified setpoint to be between 25% and 75% full-scale.

e. Housing: Polymer housing suitable for surface mounting.

f. Static Sensing Element: Pitot-type static pressure sensing tips similar to Dwyer model A-301, Davis Instruments, or equal, with connecting tubing.

g. DPT-3A: Include LCD display of reading.

h. DPT-3B: Same as DPT-3 except with stainless steel pitot-type static pressure sensing tips similar to Dwyer model A-301-SS, or equal.

i. Manufacturers.

1) Setra

2) Modus

3) Dwyer

4) Or equal

4. DPT-4: Air, Low Differential Pressure

a. General: Loop powered, two-wire differential capacitance cell type transmitter.

b. Output: Two-wire 4-20 mA output with zero adjustment.

c. Overall Accuracy

1) General: ±1% FS

2) Underfloor: ±0.5% FS

3) Minimum outdoor air damper DP used for minimum outdoor airflow: ±0.25% FS

d. Range

1) Fixed (non-switch selectable)

2) Minimum Range: 0, -0.1, -0.25, -0.5, or -1.0 inches water column

3) Maximum Range: +0.1, 0.25, 0.5, or 1.0 inches water column

4) Range shall be as specified in points list or, if not listed, selected such that specified setpoint is between 25% and 75% full-scale.

e. Housing: Polymer housing suitable for surface mounting

f. Static Sensing Element

1) Ambient sensor: Dwyer A-306 or 420, BAPI ZPS-ACC-10, or equal

2) Space sensor:

a) Wall plate: Kele RPS-W, BAPI ZPS-ACC-01, Dwyer A-417 or 465 or equal

b) Ceiling or wall probe: BAPI ZPS-ACC06, Dwyer A-419A, Veris AA05 or equal

3) Filter or duct pressure sensor: Dwyer A-301 or equal

4) Plenum pressure sensor: Dwyer A-421 or equal

g. DPT-4A: Include LCD display of reading

h. Manufacturers

1) Setra 267

2) Modus

3) Air Monitor

4) Paragon

5) Or equal

5. DPT-5: VAV Velocity Pressure

a. General: Loop powered two-wire differential capacitance cell type transmitter.

b. Output: Two-wire, 4-20 mA output with zero adjustment.

c. Flow transducer (including impact of A-to-D conversion) shall be capable of stably controlling to a setpoint of 0.004 inches differential pressure or lower, shall be capable of sensing 0.002 inches differential pressure or lower, and shall have a ±0.001 inches or lower resolution across the entire scale.

d. Calibration software shall use a minimum of two field measured points, minimum and maximum airflow, with curve fitting airflow interpolation in between.

e. Range: 0 to 1 in.w.c.

f. Housing: Polymer housing suitable for surface mounting.

g. Manufacturer

1) Automated Logic

2) No equal

J. Flow switch (FS-1)

1. Calorimetric type or other device equally resistant to fouling and corrosion

2. Shall not require more than one pipe diameter (or 12 inches whichever is larger) of straight piping for proper operation

3. IFM or equal

K. Water Leak Detector (WLD)

1. Gold plated sensing probes

2. Encapsulated in epoxy or polymer – no exposed metals

3. Automatically resets when conductive fluid is no longer present

4. Relay contact outputs rated at 1amp at 24 Vdc

5. Powered with 12-24 Vac from BAS panel. Battery not acceptable.

6. Adjustable detection level

7. Manufacturers

   a. Veris SD-R01 or MX-1V

   b. Kele WD-1B

   c. Or equal

L. Differential Pressure Switches (DPS)

1. DPS-1: Water: Diaphragm with adjustable setpoint, 2 psig or adjustable differential, and snap-acting Form C contacts rated for the application. 60 psid minimum pressure differential range. 0ºF to 160ºF operating temperature range.

2. DPS-2: Air: Diaphragm with adjustable setpoint and differential and snap acting form C contacts rated for the application. Automatic reset. Provide manufacturer's recommended static pressure sensing tips and connecting tubing.

M. Level Sensor

1. Pressure Type

2. Wetted Materials:17-4 PH Stainless Steel.

3. Accuracy: RSS* (at constant temperature) ±0.25%. Non-linearity (BSFL) ±0.22% FS; Hysteresis 0.10% FS; Non-repeatability 0.05% FS

4. Temperature Limits:-40 to 185°F

5. Range 0-1 psi (0-2.31 feet)

6. Thermal Effects: Zero Shift: ±2.0% FS/100°F; Span Shift: ±1.5% FS/100°F; Warm-up Shift: ±0.1% FS total

7. Stability:0.5% FS/year
8. Response Time:5 ms
9. Power Requirements:9-30 VDC
10. Output:4-20 mA, 2-wire
11. Zero and Span Adjustment: Fixed
12. Loop Resistance:0 to 800 Ω.Shock:200
13. Vibration:20 g
14. Enclosure: Stainless Steel and Valox
15. Manufacturer
    a. Dwyer 673-1
    b. Equal

N. Current Switches (CS-1)

1. Clamp-on or solid-core
2. Range: as required by application
3. Trip Point: Automatic or adjustable
    a. Exception: Fixed setpoint (Veris H-600 or equal) may be used on direct drive constant speed fans that do not have backdraft or motorized shutoff dampers.
4. Switch: Solid state, normally open, 1 to 135 Vac or Vdc, 0.3 Amps. Zero off state leakage
5. Lower Frequency Limit: 6 Hz
6. Trip Indication: LED
7. Approvals: UL, CSA
8. May be combined with relay for start/stop
9. Where used for single-phase devices, provide the CS/CR in a self-contained unit in a housing with override switch. Kele RIBX, Veris H500, or equal
10. Manufacturers
    a. Veris Industries H-608/708/808/908
    b. Senva C-2320L

c. RE Technologies SCS1150A-LED

d. Or equal

O. Current Transformers (CT-1)

1. Clamp-On Design Current Transformer (for Motor Current Sensing)

2. Range: 1-10 amps minimum, 20-200 amps maximum

3. Trip Point: Adjustable

4. Output: 0-5 Vdc or 0-10 Vdc,

5. Accuracy: ±0.2% from 20 to 100 Hz.

6. Amperage range sizing and switch settings in accordance with the following and per manufacturer's instructions:

Motor HP	120V	277V	480V
≤1/2	0-10A	0-10A	−
3/4 – 1.5	−	0-10A	0-10A
2 – 5	−	−	0-10A
7.5 − 10	−	−	0-20A
15 − 20	−	−	0-30A
25 − 30	−	−	0-40A

7. Manufacturers

a. Veris Hx22 series

b. Kele SC100

c. Or equal

P. Flow Meter (FM)

1. FM-1: Magnetic Flow Tube Flow Meters

a. General Requirements

1) Sensor shall be a magnetic flow meter, which utilizes Faraday's Law to measure volumetric fluid flow through a pipe. The flow meter shall consist of 2 elements, the sensor and the electronics. The sensor shall generate a measuring signal proportional to the flow velocity in the pipe. The electronics shall convert this EMF into a standard current output.

2) Electronic replacement shall not affect meter accuracy (electronic units are not matched with specific sensors).

3) Provide a four-wire, externally powered, magnetic type flow transmitter with adjustable span and zero, integrally mounted to flow tube. Output signal shall be

a digital pulse proportional to the flow rate (to provide maximum accuracy and to handle abrupt changes in flow). Standard 4-20 mA or 0-10 Vdc outputs may be used on HVAC applications provided accuracy is as specified.

a) On applications where the output is wired to a BTU meter but flow is required also as a direct input to the DDC system, e.g. for minimum flow control loop, provide a secondary analog output for the DDC system.

4) Flow Tube

a) ANSI class 150 psig steel

b) ANSI flanges

c) Lined with

1. Heating hot water, glycol: PTFE, PFA, or ETFE liner rated for ≤-4°F to ≥212ºF fluid temperature

2. Chilled, condenser, domestic hot and cold water: Polypropylene, Ebonite, PTFE, PFA, or ETFE liner rated for ≤32°F to ≥140ºF fluid temperature

5) Electrode and grounding material

a) 316L Stainless steel or Hastelloy C

b) Electrodes shall be fused to ceramic liner and not require O-rings.

6) Electrical Enclosure: NEMA 4

7) Approvals

a) UL or CSA

b) NSF Drinking Water approval for domestic water applications

8) Performance

a) Accuracy shall be:

1. ±0.4% of reading from 3.3 to 33 ft/s

2. ±0.75% of reading from 1.3 to 3.3 ft/s

3. ±0.0075 ft/s at flow rates less than 1 ft/s

b) Stability: 0.1% of rate over six months.

c) Meter repeatability shall be ± 0.1% of rate at velocities > 3 feet per second.

d) Calibration: The sensor must be factory calibrated on an internationally accredited (such as NAMAS) water flow rig with accuracy better than 0.1%. Calibration shall be NIST traceable.

b. Manufacturers

1) Onicon F-3100 series

2) Siemens/Danfoss Magflo 3100

3) Krohne Optiflux 4000

4) Sparling TigermagEP FM656

5) Or equal

2. FM-2: Magnetic Insertion Type Flow Meters

a. Magnetic Faraday point velocity measuring device.

b. Insertion type complete with hot-tap isolation valves to enable sensor removal without water supply system shutdown.

c. 4-20 mA transmitter proportional to flow or velocity.

d. Accuracy: ± 1% of reading from 0.25 to 20 fps

e. Flow range: 0.25 to 20 fps

f. Each sensor shall be individually calibrated and tagged accordingly against the manufacturer's primary standards which must be accurate to within 0.1% and traceable to the U.S. National Institute of Standards and Technology (NIST).

g. Manufacturers:

1) Onicon F-3500

2) Onicon FSM-3

3) FloCat YD20-A

4) Marsh McBirney MultiMag 284

5) SeaMetrics 100/200 Series

6) Or equal

3. FM-3A: Displacement Gas Meter

a. Positive displacement, rotary type gas meter designed for volumetric measurement of widely varying flow rates of low pressure natural gas

b. Permanent, non-adjustable calibration, not affected by low or varying line pressure and independent of the gas specific gravity, temperature, and pressure

c. Manufactured in accordance with ANSI B109.3 for Rotary Type Gas Displacement Meters

d. Operating temperature range: -40°F to +140°F

e. Temperature compensating with a corrected reading for temperatures ranging from -20°F to +120°F

f. Low frequency pulse output

g. Rangeability at ±1% accuracy: Minimum 40 to 1

h. Glass enclosed 8 digit totalizer, re-zeroed with on-board device

i. Manufacturer

1) Dresser Roots B3

2) Or equal

4. FM-3B: Mass Flow Meter

a. Immersible thermal mass flow gas meter designed for measurement of widely varying flow rates of low pressure natural gas

b. Precision platinum resistance temperature detectors protected by a platinum-iridium sheath mounted in 316 SS probe

c. Operating temperature range: -40°F to +140°F

d. 4-20mA, 0-5 Vdc, or 0-10 Vdc output proportional to mass flow

e. NIST-traceable factory calibration

f. ±1% FS accuracy

g. Rangeability at ±1% accuracy: Minimum 40 to 1

h. Glass enclosed 8 digit totalizer, re-zeroed with on-board device

i. Manufacturer

1) Sierra Instruments 620S or 620S BT

2) Or equal

5. FM-4: Not used

6. FM-5: Not Used

7. FM-6: Domestic and makeup water meters

   a. 2 inches and smaller: Multi-jet water meter

      1) Multi-jet velocity type meter

      2) Magnetic drive – no gearing exposed to water

      3) 125 psi cast bronze body with integral strainer

      4) Meet all requirements of AWWA C-708 Multi-Jet Meter

      5) Accuracy: ±1.5% of reading

      6) Hall affect low voltage pulse output, with configurable volume per pulse set to 1 gallon per pulse or smallest value the controller will accept

      7) Odometer-type gallons totalizer dial face with cover

      8) Designed for vertical or horizontal piping

      9) For potable water: NSF-61 certified and in compliance with California Proposition 65

      10) Manufacturers:

         a) SeaMetrics MJE or MJHE

         b) Elster Amco M700

         c) Master Meter

         d) Equal

   b. 2.5 inches and larger: Compound-type water meter

      1) Shall consist of a combination of a turbine-type, mainline meter for measuring high rates of flow and a bypass meter of an appropriate size for measuring low rates of flow. The compound meter shall have an automatic valve mechanism for diverting low rates of flow through the bypass meter.

      2) Comply with ANSI and AWWA C702 standards.

      3) Comply with NSF/ANSI Standard 61, ANNEX G.

      4) Maximum operating pressure of 150 psi and maximum operating temperature of 120°F continuous (220°F peak).

      5) Low voltage pulse output, with configurable volume per pulse set to 1 gallon per pulse or smallest value the controller will accept

      6) Odometer-type gallons totalizer dial face with cover

7) Manufacturers:

a) Badger Recordall Series Meter

b) Neptune

c) Or equal

8) Or equal

Q. Airflow Measuring Stations (AFMS)

1. General. AFMS provided under this Section shall be licensed to bear the AMCA Certified Rating Seal for Airflow Measuring Stations. Ratings shall be based on tests and procedures performed in accordance with AMCA Publication 611 and comply with requirements of the AMCA Certified Ratings Program.

2. AFMS-1. Airflow measurement probes at fan inlet provided with air handling units. See Section 237300 Air Handling Units & Coils.

3. AFMS-1

a. Transverse probes factory mounted in each inlet bell.

b. The fan inlet airflow traverse probes shall contain multiple total and static pressure sensors placed at concentric area centers along the exterior surface of the cylindrical probes and internally connected to their respective averaging manifolds. Sensors shall not protrude beyond the surface of the probe, nor be adversely affected by particle contamination normally present in building system airflows. The fan inlet airflow traverse probes shall have symmetrical averaging signal takeoffs, and shall be of aluminum construction with hard anodized finish with galvanized steel mounting hardware.

c. The fan inlet airflow traverse probes shall not significantly impact fan performance or contribute to fan generated noise levels. The probes shall be capable of producing steady, non-pulsating signals of standard total and static pressure, without need for flow corrections or factors, with an accuracy of 3% of actual flow over a fan operating range of 6 to 1 capacity turndown.

d. Provide with DPT selected as close as possible to design maximum velocity pressure to provide high accuracy at low airflow rates. See equipment schedules for design airflow rate.

e. Manufacturers

1) Air Monitor VOLU-probe/FI

2) Paragon FE-1050

3) Or equal

4. AFMS-2. Airflow measurement device provided with air handling units. See Section 237300 Air Handling Units & Coils.

5. AFMS-2

   a. The AFMS shall be an array of thermal mass flow sensors mounted across the entire area of the duct in which the AFMS is mounted.

   b. Analog outputs for “standard” airflow (0.075 lb_{da}/ft3 density) and temperature

   c. Operating limits

      1) Humidity: 0% to non-condensing

      2) Temperature (devices in airstream): -20ºF to +120ºF

   d. Performance

      1) Sensors shall be calibrated to NIST-traceable standards for airflow/velocity.

      2) The installed total accuracy for airflow shall be better than ±3% of reading over the sensor probe operating ranges when installed in accordance with manufacturers’ guidelines. Installed accuracy shall include the probe itself plus the electronics for converting probe signal to an electronic signal proportional to airflow and shall be demonstrated at both maximum and minimum airflow rates of operating range. All tests shall be in accordance with AMCA 611 test procedures.

      3) Operating Range: 100 to 4,000 FPM.

      4) Pressure drop: The maximum allowable unrecovered pressure drop caused by the airflow measuring device shall not exceed .025 inches at 2000 FPM.

   e. Sensor Density Requirements:

      1) Published sensor density (#/area) data by the product manufacturer as required to achieve specified accuracy shall be submitted for approval.

      2) Should there be no published document indicating these relationships for a particular product, the number of individual sensor nodes provided for each rectangular location shall be as follows:

Duct or Plenum Area (ft2)	Total number of Nodes
<= 1	1 or 2
>1 to <4	4
4 to < 8	6
8 to < 12	8
12 to <16	12

>=16	16

3) The number of individual sensor nodes provided for each round or oval duct location shall approximate the total required for rectangular locations or be detailed in published documentation by the manufacturer.

f. Manufacturers

1) Ruskin EAMS

2) Ebtron Gold Series

3) Or equal

6. AFMS-3. Airflow measurement device and control damper provided with air handling units. See Section 237300 Air Handling Units & Coils.

7. AFMS-3 (including control damper)

a. Air monitoring station incorporates a low leakage control damper with air monitoring blades and air straightener section (where needed to meet accuracy requirements) in one unit, fully factory assembled.

b. Damper construction

1) See Paragraph 2.9C Control Dampers.

c. Air Straightener Section: 3000 series aluminum alloy honeycomb contained in 5 inch long, 16 gage galvanized steel sleeve attached to monitoring blade frame.

d. Airflow sensing

1) Strategically placed airflow sensing blades measure airstream velocity.

2) Air tubing and piping connections connect sensing blades to transducer.

3) Transducer

a) Accuracy: ± 1% full scale (includes non-linearity, hysteresis and non-repeatability)

b) Range: 0 to 1 inch w.c.

c) Can resolve less than 0.00001 inch w.c.

d) Generates an analog signal (4-20mA or 0-10Vdc) proportional to airflow rate or velocity

e) NEMA 4 enclosure

e. Operating limits

1) Humidity: 0% to non-condensing

2) Temperature (devices in airstream): -20ºF to +120ºF

f. Performance

1) Accuracy: 5% of reading.

2) Velocity range: 400 fpm to 2000 fpm.

3) Bear AMCA Certified Ratings Seal for Airflow Measurement Performance

g. Manufacturers

1) Ruskin Model AMS-050 with RU-274 transducer

2) Greenheck IAQ 42

3) Or equal

8. AFMS-4

a. Differential pressure type with uniframe DP sensor

1) Provide quantity of DP sensors per manufacturer’s recommendations

b. Station mounted with expanded metal screen

c. Analog outputs for “standard” airflow (0.075 lb_{da}/ft3 density) and temperature

d. Manufacturers

1) Air Monitor

a) Transmitter: OAM-II-2121-1BMMM

b) Airflow Measuring System: OAM-II-AFS-(XX)A-111-013 where “XX” varies with the associated opening dimensions.

2) No known equal

9. AFMS-5. Venturi DP type with transmitter provided with lab exhaust fans. See Section 233400 Fans & Hoods.

10. AFMS-5

a. Venturi DP type with ports at inlet and outlet of venturi. Anemometers with probes in airstream not acceptable

b. Differential pressure sensor with LCD

1) NEMA-4 enclosure

2) Linear differential pressure output signal, 4-20 mA or 2-10 VDC

3) Accuracy: ± 0.5% of full scale at 77°F (25°C)

4) 24-volt AC or DC

c. Stainless steel compression fittings internally and brass fittings externally

d. Manufacturers

1) Greenheck SureAire

2) Or equal

R. Electric Control Components

1. Line-Voltage Wall Thermostat: Wall-mounted thermostat shall consist of SPDT contacts rated for 120V and current as required for application, temperature setpoint range of 50 to 90ºF.

2. Control Relays: All control relays shall be UL listed, with contacts rated for the application, and mounted in minimum NEMA-1 enclosure for indoor locations, NEMA-4 for outdoor locations.

a. Control relays for use on electrical systems of 120 volts or less shall have, as a minimum, the following:

1) AC coil pull-in voltage range of +10%, -15% or nominal voltage.

2) Coil sealed volt-amperes (VA) not greater than 4 VA.

3) Silver cadmium Form C (SPDT) contacts in a dustproof enclosure, with 8 or 11 pin type plug.

4) Pilot light indication of power-to-coil and coil retainer clips.

b. Relays used for across-the-line control (start/stop) of 120V motors, 1/4 HP, and 1/3 HP, shall be rated to break minimum 10 Amps inductive load.

c. Relays used for stop/start control shall have low voltage coils (30 VAC or less), and shall be provided with transient and surge suppression devices at the controller interface.

3. General Purpose Power Contactors: NEMA ICS 2, AC general-purpose magnetic contactor. ANSI/NEMA ICS 6, NEMA type 1 enclosure. Manufacturer shall be Square D, Cutler-Hammer, or equal.

4. Control Transformers and Power Supplies

a. Control transformers shall be UL Listed. Furnish Class 2 current-limiting type, or furnish over-current protection in both primary and secondary circuits for Class 2 service per NEC requirements. Mount in minimum NEMA-1 enclosure.

b. Transformer shall be proper size for application. Limit connected loads to 80% of rated capacity.

c. DC power supply output shall match output current and voltage requirements. Unit shall be full-wave rectifier type with output ripple of 5.0 mV maximum peak-to-peak. Regulation shall be 1.0% line and load combined, with 100 microsecond response time for 50% load changes. Unit shall have built-in over-voltage and over-current protection, and shall be able to withstand a 150% current overload for at least 3 seconds without trip-out or failure.

d. Separate power transformer shall be used for controllers and for actuators and other end devices that use half wave rectification.

e. Unit shall operate between 0°C and 50°C [32°F and 120°F]. EM/RF shall meet FCC Class B and VDE 0871 for Class B, and MIL-STD 810C for shock and vibration.

f. Line voltage units shall be UL Recognized and CSA Approved.

5. Electric Push Button Switch: Switch shall be momentary contact, oil tight, push button, with number of N.O. or N.C. contacts as required. Contacts shall be snap-action type, and rated for minimum 120 Vac operation. Switch shall be 800T type, as manufactured by Allen Bradley, Kele, or equal.

6. Mechanical Timer Switch: Switch shall be mechanically spring wound with a N.O. contact or N.C. contacts as required. Timer shall be 0-60 minutes and shall not include a "hold" feature, which allows switch contacts to remain closed. Contacts shall be rated for minimum 120 VAC operation. Switch shall be C560M type, as manufactured by NSI Industries or equal.

7. Pilot Light: Panel-mounted pilot light shall be NEMA ICS 2 oil tight, transformer type, with screw terminals, push-to-test unit, LED type, rated for 120 VAC. Unit shall be 800T type, as manufactured by Allen-Bradley, Kele, or equal.

8. Alarm Horn: Panel-mounted audible alarm horn shall be continuous tone, Sonalert solid-state electronic signal, as manufactured by Mallory, Kele, or equal.

9. Potentiometer. Wall box mounted single turn with knob numbered 0 to 10 or 0 to 100. Wall plate cover to match electrical.

10. Window switch (WS)

    a. Surface mount magnetic burglar alarm switch.

    b. Screw mount, magnet on window, switch on frame.

    c. Sealed to prevent dirt or dust contact.

d. Color to match electrical and lighting switch plates in the room. See Division 26 and Electrical Drawings.

S. Refrigerant Monitor (RM-1)

1. Non-dispersive or photo-acoustic infrared multi-point stationary refrigerant gas leak monitor system designed to continuously measure refrigerants used in chiller equipment installed under Division 23. The alarm system shall comply with Mechanical Code and ASHRAE Standard 15 requirements including:

   a. The refrigerant detector shall perform automatic self-testing of sensors. Where a failure is detected, a trouble signal shall be activated.

   b. The refrigerant detector as installed, including any sampling tubes, shall activate responses within a time not to exceed 30 seconds after exposure to refrigerant concentration exceeding the Alarm (Evacuate) setpoint value specified herein.

2. The refrigerant monitor shall be capable of monitoring refrigerant in concentrations of 0 PPM to a minimum of 1000 PPM. The Monitor shall have a low range resolution of 1 PPM and an accuracy of ±10 ppm in the range of 1 PPM through 100 PPM. Readings above 100 PPM must have an accuracy of ±10% of reading.

3. The refrigerant monitor shall have a minimum of one sample port or sensor for each chiller in the chiller room. See floor plans.

4. The monitor shall be factory tested and calibrated for the specified refrigerant or refrigerants. Factory certification of the calibrations shall be provided with the O&M manuals.

5. The display shall continuously display the refrigerant concentration level and alarm status.

6. The monitor shall be equipped with the following outputs.

   a. One binary output shall indicate a monitor malfunction alarm.

   b. A minimum of three alarm levels with separate binary outputs, each programmable to adjustable user-defined refrigerant concentration setpoints and user-defined reset (manual or auto).

   c. RS485 Modbus RS-485 with 16 or 32 bit registers, or BACnet MSTP interface, with read/write capability of all control points and setpoints.

7. The monitor shall have a NEMA-1 enclosure. The enclosure shall have a rust and corrosion resistant finish.

8. Include:

   a. Unit mounted strobe and alarm horn

   b. Remote strobe(s) and horn(s) for each chiller room entrance

c. Break-glass fan switch(es) for the primary chiller room entrance

d. Break-glass emergency off switch(es) for the primary chiller room entrance

e. Fan on and off status pilot lights for the primary chiller room entrance

9. Alarm horns shall be capable of providing a sound pressure level of not less than 15 dB above the operating ambient noise sound pressure level of the space in which they are installed, 85 dBA minimum.

10. Manufacturer

    a. Bacharach

    b. MSA Chillgard

    c. OI Analytical/General Analysis Corporation

    d. Or equal

T. Kitchen Hood Demand Ventilation Controls

1. Controls shall automatically control the speed of the exhaust fan to ensure cooking effluent is captured by the hood at the minimum exhaust rate.

2. The system shall include the following at minimum:

    a. System controller, quantity as required

    b. Touchpad GUI, one per kitchen

    c. Hood controller, one per hood

        1) Temperature sensors mounted in each exhaust collar

        2) Temperature sensors mounted in each hood canopy

        3) Optic sensors mounted inside the ends of each hood with air purge units mounted on top

3. Controller shall

    a. Include auto-off capability to automatically shut off the fan when hood conditions indicate they are not in use.

    b. Include auto-on capability to automatically start the fan when hood conditions indicate they are in use.

    c. Not require a minimum speed higher than 50%.

    d. Include BACnet/IP interface to system controller with following read-only points, minimum

1) System fault

2) For each hood

a) Exhaust temperature

b) Canopy temperature

c) Optical sensor on/off

d) Alarms

1. Temperature fault

2. Optic fault

3. Exhaust temperature alarm

3) For each exhaust fan

a) Fan on or off requirement

b) Commanded fan %-speed

4. Manufacturer

a. Melink Intelli-Hood

b. Halton MARVEL

c. Or equal. (Systems that use temperature only without IR sensing are not considered equal.)

U. Wind Anemometer

1. Ultrasonic, solid state sensors

2. Accuracy

a. Wind Speed: ±3% up to 35 m/s

b. Wind Direction: Less than 3°RSME at 1.0 m/s or greater

3. Sensor Housing Protection Class: IP65 or greater

4. Mast per manufacturer’s recommendations. See also Paragraph 3.11J.

5. RS-485 Serial Output

6. Manufacturers

a. Lufft WS200

b. Gill WindSonic

c. RM Young 86000

2.10 CALIBRATION & TESTING INSTRUMENTATION

A. Provide instrumentation required to verify readings, calibrate sensors, and test the system and equipment performance.

B. All equipment used for testing and calibration shall be NIST/NBS traceable and calibrated within the preceding 6-month period. Certificates of calibration shall be submitted.

C. Test equipment used for testing and calibration of field devices shall be at least twice as accurate as respective field device (for example if field device is ±0.5% accurate, test equipment shall be ±0.25% accurate over same range).

2.11 SOFTWARE

A. General

1. System software shall be the latest version of ALC WebCTRL.

B. Licensing

1. Include licensing and hardware keys for all software packages at all workstations (OWSs and POTs) and servers.

2. Within the limitations of the server, provide licenses for any number of users to have web access to the CSS at any given time.

3. All operator interface, programming environment, networking, database management and any other software used by the Contractor to install the system or needed to operate the system to its full capabilities shall be licensed and provided to the College.

4. All operator software, including that for programming and configuration, shall be available on all workstations. Hardware and software keys to provide all rights shall be installed on all workstations.

C. Graphical User Interface Software

1. Graphics

a. The GUI shall make extensive use of color in the graphic pane to communicate information related to setpoints and comfort. Animated graphics and active setpoint graphic controls shall be used to enhance usability.

b. Graphics tools used to create Web Browser graphics shall be non-proprietary and provided and installed on each OWS.

c. Graphical display shall be 1280 x 1024 pixels or denser, 256 color minimum.

d. Links

1) Graphics shall include hyperlinks which when selected (clicked on with mouse button) launch applications, initiate other graphics, etc.

2) Screen Penetration: Links shall be provided to allow user to navigate graphics logically without having to navigate back to the home graphic. See additional discussion in Paragraph 3.12E.

3) Information Links

a) On each MEP system and subsystem graphic, provide links to display in a new window the information listed below.

1. English-language as-built control sequence associated with the system. See Paragraph 1.9B.

2. O&M and submittal information for the devices on the graphic. See Paragraph 1.9B. This includes links to electronic O&M and submittal information for mechanical equipment supplied under Section 230501 Basic Mechanical Materials and Methods.

b) The display shall identify the target of the link by file name/address.

c) Information shall be displayed in electronic format that is text searchable.

d) Window shall include software tools so that text, model numbers, or point names may be found. Source documents shall be read-only (not be editable) with this software.

e. Point Override Feature

1) Every real output or virtual point displayed on a graphic shall be capable of being overridden by the user (subject to security level access) by mouse point-and-click from the graphic without having to open another program or view.

2) When the point is selected to be commanded

a) Dialog box opens to allow user to override the point (Operator Mode) or release the point (Automatic Mode). Operator Mode will override automatic control of the point from normal control programs.

b) Dialog box shall have buttons (for digital points) or a text box or slide bar (for analog points) to allow user to set the point’s value when in operator mode. These are grayed out when in automatic mode.

c) When dialog box is closed, mode and value are sent to controller.

d) Graphic is updated upon next upload scan of the actual point value.

3) A list of points that are currently in an operator mode shall be available through menu selection.

f. Point override status (if a digital point is overridden by the supervised manual override per Paragraph 2.3A or if a point is in operator mode per Paragraph 2.11C.1.e) shall be clearly displayed on graphics for each point, such as by changing color or flag.

g. The color of symbols representing equipment shall be able to change color or become animated based on status of binary point to graphically represent on/off status.

2. Alarms

a. ALC WebCTRL Enterprise Integration advanced alarm package configured as indicated below.

3. Trends

a. ALC WebCTRL Enterprise Integration trend package configured as indicated below.

b. Trend Data Storage

1) The database shall allow applications to access the data while the database is running. The database shall not require shutting down in order to provide read-write access to the data. Data shall be able to be read from the database without interrupting the continuous storage of trend data being carried by the BAS using SQL queries.

2) Data shall be stored in an SQL compliant database format and shall be available through the College’s intranet or internet (with appropriate security clearance) without having to disable BAS access to the database.

3) The database shall not be inherently limited in size, e.g. due to software limitations or lack of a correct license. Database size shall be limited only by the size of the provided storage media (hard drive size).

4. Security Access

a. Standard ALC WebCTRL security package

5. Report Software

a. ALC WebCTRL Enterprise Integration advanced reporting package.

b. Standard reports. Prepare the following standard reports, accessible automatically without requiring definition by user.

1) Tenant or department after-hour usage. System must be capable of monitoring tenant override requests and generating a monthly report showing the daily total time in hours that each tenant has requested after-hours HVAC services.

2) Monthly and annual energy usage and cost. See Utility cost calculation in Paragraph 3.12.

3) Alarm events and status.

4) Points in Hand (Operator Override) via Workstation command (including name of operator who made the command) or via supervised HOA switch at output, including date and time.

D. Control Programming Software

1. Standard ALC WebCTRL Eikon programming.

E. Miscellaneous Software

1. Provide a context-sensitive, on-line help system to assist the operator in operating and editing the system. On-line help shall be available for all applications and shall provide relevant data for the application or object that help is being called from.

2. Provide software for viewing (but not editing) electronic versions of as-built shop drawings of

a. Mechanical, electrical, and plumbing systems in Adobe pdf format

b. BAS drawings in Adobe pdf format

3. Automatic Demand Response (ADR) Control Software

a. Provide ALC WebCTRL Automated Demand Response Add-on or other certified OpenADR 2.0a or OpenADR 2.0b Virtual End Node (VEN) software, as specified under Clause 11, Conformance, in the applicable OpenADR 2.02 Specification.

b. The software shall allow OpenADR communication from PG&E's Demand Response Automation Server through the College's LAN to the CSS, communicating at least the minimum points shown in Paragraph 2.12C.8.

2.12 CONTROL POINTS

A. Table Column Definitions

1. Point description

2. Type (number in point schedule after each type refers to tag on schematics)

a. AO: analog output

b. AI: analog input

c. DO: digital or binary output

d. DI: digital or binary input

3. Device description

   a. See Paragraph 2.9 for device definition.

4. Trend Logging

   a. Commissioning: Where listed, point is to be trended at the basis listed for commissioning and performance verification purposes.

   b. Continuous: Where listed, point is to be trended at the basis listed continuously, initiated after system acceptance, for the purpose of future diagnostics.

   c. Trend Basis

      1) Where range of engineering units is listed, trend on a change of value (COV) basis (in other words record time stamp and value when point value changes by engineering unit listed).

      2) Where time interval is listed, trend on a time basis (in other words record time stamp and value at interval listed). All points relating to a specific piece of equipment shall be trended at the same initiation time of day so data can be compared in text format.

5. Calibration

   a. F = factory calibration only is required (no field calibration)

   b. HH = field calibrate with handheld device. See Paragraph 3.14D.6.a.2)

B. Note that points lists below are for each system of like kind. Refer to drawings for quantity of each.

C. Points mapped through gateways and network interfaces. Note that points listed herein are intended to indicate the level of effort required for point mapping for bid purposes; the points lists are not exclusive and exhaustive. The exact point names and types may vary since the points available vary by equipment manufacturer and model. A final list of available points must be obtained from the manufacturer during the shop drawing development phase. If the available points differ from the points lists herein, the desired points to be mapped shall be confirmed by the Engineer prior to issuing Submittal Package 2. Unless the quantity of points is significantly different from those shown herein, the changes shall be made at no additional costs to the College.

1. Variable speed drives

Description	**Type**	**Device**	**Trend Logging**		**Calibra-tion**
			Comm-issioning	**Contin-uous**	
Fault reset	DO	Through network	COV	COV	–
On/off status	DI	Through network	COV	COV	–
Fault (critical alarm)	DI	Through network	COV	COV	–
Minor alarm	DI	Through network	COV	COV	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Fault text	AI	Through network (convert code to plain English text)	COV	COV	–
Alarm text	AI	Through network (convert code to plain English text)	COV	COV	–
Keypad in hand/auto	DI	Through network	COV	COV	–
Minimum frequency setpoint	AO	Through network	±5%	±5%	–
Maximum frequency setpoint	AO	Through network	±5%	±5%	–
Acceleration rate	AO	Through network	±5%	±5%	–
Deceleration rate	AO	Through network	±5%	±5%	–
Actual frequency	AI	Through network	1 min	15 min	–
DC bus voltage	AI	Through network	±10%	±10%	F
AC output voltage	AI	Through network	±10%	±10%	F
Current	AI	Through network	15 min	60 min	F
VFD temperature	AI	Through network	60 min	60 min	F
Power, kW	AI	Through network	1 min	15 min	F
Energy, MWh	AI	Through network	15 min	60 min	–

2. Electronically Commutated Motors

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Fault reset	DO	Through network	COV	COV	–
Minimum speed setpoint	AO	Through network	±5%	±5%	–
Maximum speed setpoint	AO	Through network	±5%	±5%	–
Acceleration rate	AO	Through network	±5%	±5%	–
Deceleration rate	AO	Through network	±5%	±5%	–
Actual speed	AI	Through network	1 min	15 min	–
DC-link voltage	AI	Through network	±10%	±10%	F
Current	AI	Through network	15 min	60 min	F
Fault text	AI	Through network (convert code to plain English text)	COV	COV	–
Warning text	AI	Through network (convert code to plain English text)	COV	COV	–
Motor temperature, °F	AI	Through network	15 min	60 min	F
Power, kW	AI	Through network	1 min	15 min	F

3. Chillers

Description	**Type**	**Device**	**Trend Logging**		**Calibra-tion**
			Comm-issioning	**Contin-uous**	
On/off status	DI	Through network	COV	COV	–
Alarm	DI or AI	Through network. (May have multiple integer values depending on alarm type – see chiller BACnet panel submittal.)	COV	COV	–
Call for condenser water pump	DI	Through network	COV	COV	–
Condenser water flow status	DI	Through network	COV	COV	–
Call for chilled water pump	DI	Through network	COV	COV	–
Chilled water flow status	DI	Through network	COV	COV	–
Chiller in local mode	DI	Through network	COV	COV	–
Chiller in surge	DI	Through network	COV	COV	–
Chilled water temperature setpoint reset	AO	Through network	1 min.	±2°F	–
Demand limit setpoint	AO	Through network	±5%	±5%	–
Total number of surge events	AI	Through network	+1	+1	–
Chilled water supply temperature	AI	Through network	1 min.	10 min.	F
Chilled water return temperature	AI	Through network	1 min.	10 min.	F
Condenser water supply temperature	AI	Through network	1 min.	10 min.	F
Condenser water return temperature	AI	Through network	1 min.	10 min.	F
Condenser temperature	AI	Through network	–	10 min.	F
Evaporator temperature	AI	Through network	–	10 min.	F
Condenser (head) pressure	AI	Through network	–	10 min.	F
Evaporator pressure	AI	Through network	–	10 min.	F
Anti-recycle time remaining	AI	Through network	–	10 min.	–
Variable speed drive speed	AI	Through network	1 min.	10 min.	–
Inlet guide vane signal	AI	Through network	1 min.	10 min.	–
Operating hours	AI	Through network	–	–	–
Oil pressure	AI	Through network	–	–	F
Oil sump temperature	AI	Through network	–	–	F
Power, kW	AI	Through network	1 min.	10 min.	F
Percent of full load current (%FLA)	AI	Through network	–	–	F
Chilled water differential pressure	AI	Through network	1 min.	10 min.	F

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Condenser water differential pressure	AI	Through network	1 min.	10 min.	F

4. Heat Pump/Chillers: Not all points available with all manufacturers. Include points listed from each refrigerant circuit.

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Evap. outlet temperature	AI	Through network	10 min.	10 min.	F
Evap. inlet temperature	AI	Through network	10 min.	10 min.	F
Common Evap. outlet temperature	AI	Through network	10 min.	10 min.	F
Common Evap. inlet temperature	AI	Through network	10 min.	10 min.	F
Recovery outlet temperature	AI	Through network	10 min.	10 min.	F
Recovery inlet temperature	AI	Through network	10 min.	10 min.	F
External air temperature	AI	Through network	10 min.	10 min.	F
Refrigerant gas temperature	AI	Through network	10 min.	10 min.	F
Refrigerant liquid temperature	AI	Through network	10 min.	10 min.	F
System dead zone	AO	Through network	10 min.	10 min.	F
Recovery dead zone	AO	Through network	10 min.	10 min.	
Defrost current Delta LP	AI	Through network	10 min.	10 min.	F
Auto. Differential HP only	AO	Through network	10 min.	10 min.	
Auto. Differential chiller only	AO	Through network	10 min.	10 min.	
Current system setpoint	AI	Through network	10 min.	10 min.	
Total recovery set-point	AO	Through network	10 min.	10 min.	
Total recovery differential	AO	Through network	10 min.	10 min.	
System summer differential	AO	Through network	10 min.	10 min.	
System winter differential	AO	Through network	10 min.	10 min.	
Setpoint summer	AO	Through network	10 min.	10 min.	
Setpoint winter	AO	Through network	10 min.	10 min.	
System On/Off Mode	AO	Through network	10 min.	10 min.	
Recovery On/Off Mode	AO	Through network	10 min.	10 min.	
Summer winter selection	AO	Through network	10 min.	10 min.	
Mode duration minimum time	AO	Through network	10 min.	10 min.	

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
System active power	AI	Through network	10 min.	10 min.	F
Recovery active power	AI	Through network	10 min.	10 min.	F
Unit state	AI	Through network	10 min.	10 min.	
Total power request	AI	Through network	10 min.	10 min.	
Fan speed	AI	Through network	10 min.	10 min.	
Total power request	AI	Through network	10 min.	10 min.	
defrost State	AI	Through network	10 min.	10 min.	
Unit On/Off	DI	Through network	COV	COV	
Summer/Winter request	DO	Through network	COV	COV	
Reset alarms	DO	Through network	COV	COV	
System On/Off	DO	Through network	COV	COV	
Recovery On/Off	DO	Through network	COV	COV	
Evaporative pump status	DI	Through network	COV	COV	
Recovery pump status	DI	Through network	COV	COV	
Compressor status	DI	Through network	COV	COV	
Fan status	DI	Through network	COV	COV	
Reversing valve	DI	Through network	COV	COV	
Defrost valve	DI	Through network	COV	COV	
All alarms	DI	Through network	COV	COV	

5. Boilers (not all points available with all manufacturers)

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Status/fault code 1-47	AI	Through network	±1	±1	–
Unit Status code 0-5	AI	Through network	±1	±1	–
HW supply temperature	AI	Through network	1 min.	10 min.	F
HW return temperature	AI	Through network	10 min.	10 min.	F
Exhaust temperature	AI	Through network	10 min.	10 min.	F
FFWD temperature	AI	Through network	10 min.	10 min.	F
Firing rate %	AI	Through network	1 min.	10 min.	F
O2 level	AI	Through network	10 min.	10 min.	F
CO level	AI	Through network	10 min.	10 min.	F
Flame strength %	AI	Through network	10 min.	10 min.	F
Active HWST setpoint	AI	Through network	1 min.	10 min.	F
HWST Setpoint command	AO	Through network	±1°F	±1°F	–

1. Single Zone Packaged Heat Pumps/AC units

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Space temperature	AI	Through network	1 min	15 min	F
Discharge-air temperature	AI	Through network	1 min	15 min	F
Space temperature cooling setpoint	AO	Through network	±1ºF	±1ºF	–
Space temperature heating setpoint	AO	Through network	±1ºF	±1ºF	–
Cooling status	DI	Through network	COV	COV	–
Heating status	DI	Through network	COV	COV	–
Low temperature sensor alarm	DI	Through network	COV	COV	–
Low pressure sensor alarm	DI	Through network	COV	COV	–
High pressure switch alarm	DI	Through network	COV	COV	–
Condensate sensor alarm	DI	Through network	COV	COV	–
High/low voltage alarm	DI	Through network	COV	COV	–
Unoccupied/occupied command	DO	Through network	COV	COV	–
Cooling command	DO	Through network	COV	COV	–
Heating command	DO	Through network	COV	COV	–
Fan "ON/AUTO" command	DO	Through network	COV	COV	–
Fault reset command	DO	Through network	COV	COV	–
Itemized fault code revealing reason for specific shutdown fault	AI	Through network	COV	COV	–

2. Packaged VAV AC units

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Unit on/off	DO	Through network	COV	COV	–
Cooling enable	DO	Through network	COV	COV	–
Economizer enable	DO	Through network	COV	COV	–
Supply air temperature setpoint	AO	Through network	±0.5°F	±1°F	–
Supply static pressure setpoint	AO	Through network	±0.1”	±0.1”	–
Outdoor airflow cfm setpoint	AO	Through network	5 min	15 min	–
Building static pressure setpoint	AO	Through network	15 min	15 min	–
General trouble alarm	DI	Through network	COV	COV	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	**Contin-uous**	
Compressor #x status	DI	Through network, typical of each compressor	COV	COV	–
Supply fan status	DI	Through network	COV	COV	–
Relief fan status	DI	Through network	COV	COV	–
Communications alarm	DI	Through network	COV	COV	–
Supply air temperature	AI	Through network	5 min	15 min	F
Return air temperature	AI	Through network	5 min	15 min	F
Outdoor air temperature	AI	Through network	5 min	15 min	F
Supply duct static pressure	AI	Through network. Extend tip to ***bottom of shaft***.	5 min	15 min	F
Filter pressure drop	AI	Through network	5 min	15 min	F
Building static pressure	AI	Through network. Extend high port tube to ***2nd floor interior*** zone	1 min	15 min	F
Supply fan speed	AI	Through network	5 min	15 min	F
Relief fan speed	AI	Through network	5 min	15 min	F
Economizer damper position	AI	Through network	5 min	15 min	F
Conductivity Setpoint	AO	Through network	±10 µOhm	±10 µOhm	–
Water make-up enabled	DI	Through network	COV	COV	–
High conductivity alarm	DI	Through network	COV	COV	–
Bleed valve on/off	DI	Through network	COV	COV	–
Water treatment failure alarm	DI	Through network	COV	COV	–
Evaporative condenser fan status	DI	Through network	COV	COV	–
Condenser water pump status	DI	Through network	COV	COV	–
Water conductivity	AI	Through network	±10 µOhm	±10 µOhm	F
CWR temperature	AI	Through network	1 min.	15 min	F
CWS temperature	AI	Through network	1 min.	15 min	F
Condenser fan speed	AI	Through network	1 min.	15 min	–

3. Electrical System Monitoring. See Division 26 Drawings for quantity of meters and location of network connection.

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	**Contin-uous**	
Real kW	AI	Through network	15 min	15 min	–
Volts (each phase)	AI	Through network	±10%	±10%	–
Power factor	AI	Through network	±10%	±10%	–
Amps (each phase)	AI	Through network	–	–	–

4. BTU Meter (BTU-1)

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Return Temperature	AI	Through network	1 min	15 min	F
Supply Temperature	AI	Through network	1 min	15 min	F
Flow	AI	Through network	1 min	15 min	F
Btu/h	AI	Through network	1 min	15 min	–

5. Refrigerant Monitor

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Alarm Setpoint – caution	AO	Through network	±100 PPM	±100 PPM	–
Alarm Setpoint – warning	AO	Through network	±100 PPM	±100 PPM	–
Alarm Setpoint – alarm	AO	Through network	±100 PPM	±100 PPM	–
Temperature Tolerance	AO	Through network	±1°F	±1°F	–
Alarm condition – caution	DI	Through network	COV	COV	–
Alarm condition – warning	DI	Through network	COV	COV	–
Alarm condition – alarm	DI	Through network	COV	COV	–
Unit failure/trouble alarm	DI	Through network	COV	COV	–
Communications alarm	DI	Through network	COV	COV	–
Refrigerant concentration	AI	Through network	±50 PPM	±50 PPM	F

6. Water Treatment System

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Conductivity Setpoint	AO	Through network	±10 µOhm	±10 µOhm	–
Biocide 1 setpoint	AO	Through network	–	–	–
Biocide 2 setpoint	AO	Through network	–	–	–
High conductivity alarm	DI	Through network	COV	COV	–
Bleed on/off	DI	Through network	COV	COV	–
Inhibitor feed on/off	DI	Through network	COV	COV	–
Biocide 1 feed on/off	DI	Through network	COV	COV	–
Biocide 2 feed on/off	DI	Through network	COV	COV	–
Unit failure alarm	DI	Through network	COV	COV	–
Communications alarm	DI	Through network	COV	COV	–
Water conductivity	AI	Through network	±10 µOhm	±10 µOhm	F
Water make-up flow	AI	Through network	15 min	15 min	F
Bleed water flow	AI	Through network	15 min	15 min	F

7. Laboratory Air Valves

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Airflow Setpoint	AO	Through network	1 min	15 min	–
Alarm	DI	Through network	COV	COV	–
Hood Alarm (VAV hoods)	DI	Through network	COV	COV	–
Purge (VAV hoods)	DI	Through network	COV	COV	–
Actuator command	AI	Through network	1 min	15 min	–
Actual actuator position	AI	Through network	1 min	15 min	–
Measured airflow	AI	Through network	1 min	15 min	F

8. Automated Demand Response

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Demand Response Level	AI	Level 1, 2, or 3 from OpenADR Virtual End Node	±1	±1	–
Minutes until next occurrence of Demand Level 1	AI	From OpenADR Virtual End Node	±1 min	±1 min	–
Minutes until next occurrence of Demand Level 2	AI	From OpenADR Virtual End Node	±1 min	±1 min	–
Minutes until next occurrence of Demand Level 3	AI	From OpenADR Virtual End Node	±1 min	±1 min	–

9. Lighting Controls

a. Global

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Demand Shed 1	DO	Through network	COV	COV	–
Demand Shed 2	DO	Through network	COV	COV	–
Demand Shed 3	DO	Through network	COV	COV	–

b. For each lighting zone

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Occupancy Sensor State	DI	Through network	COV	COV	–

10. Emergency Generator

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Status normal power	DI	Through network	COV	COV	–
Status generator power	DI	Through network	COV	COV	–
Generator running	DI	Through network	COV	COV	–
Generator not in auto	DI	Through network	COV	COV	–
Shut-down summary alarm	DI	Through network	COV	COV	–
Fuel tank alarm – low level	DI	Through network	COV	COV	–
Fuel tank alarm – high level	DI	Through network	COV	COV	–
Fuel tank alarm – rupture	DI	Through network	COV	COV	–
Water temperature alarm	DI	Through network	COV	COV	–
Low DC battery voltage	DI	Through network	COV	COV	–
Battery charger malfunction	DI	Through network	COV	COV	–
Ground fault	DI	Through network	COV	COV	–
Low coolant level	DI	Through network	COV	COV	–
Pre-alarm Low fuel	DI	Through network	COV	COV	–
Pre-alarm high water temperature	DI	Through network	COV	COV	–
Pre-alarm low oil pressure	DI	Through network	COV	COV	–
Over-speed alarm	DI	Through network	COV	COV	–
Over-crank alarm	DI	Through network	COV	COV	–
High water temperature alarm	DI	Through network	COV	COV	–
Low oil pressure alarm	DI	Through network	COV	COV	–
Emergency stop alarm	DI	Through network	COV	COV	–
Pre-overload alarm	DI	Through network	COV	COV	–
Overload alarm	DI	Through network	COV	COV	–
AC current Phase 1	AI	Through network	±10%	±10%	–
AC current Phase 2	AI	Through network	±10%	±10%	–
AC current Phase 3	AI	Through network	±10%	±10%	–
AC voltage neutral	AI	Through network	±10%	±10%	–
AC voltage Phase 1	AI	Through network	±10%	±10%	–
AC voltage Phase 2	AI	Through network	±10%	±10%	–
AC voltage Phase 3	AI	Through network	±10%	±10%	–

11. UPS System

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Input phase A current	AI	Through network	±10%	±10%	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Input phase B current	AI	Through network	±10%	±10%	–
Input phase C current	AI	Through network	±10%	±10%	–
Input phase A voltage	AI	Through network	±10%	±10%	–
Input phase B voltage	AI	Through network	±10%	±10%	–
Input phase C voltage	AI	Through network	±10%	±10%	–
UPS phase A current	AI	Through network	±10%	±10%	–
UPS phase B current	AI	Through network	±10%	±10%	–
UPS phase C current	AI	Through network	±10%	±10%	–
UPS neutral current	AI	Through network	±10%	±10%	–
UPS phase A voltage	AI	Through network	±10%	±10%	–
UPS phase B voltage	AI	Through network	±10%	±10%	–
UPS phase C voltage	AI	Through network	±10%	±10%	–
UPS frequency	AI	Through network	±10%	±10%	–
DC battery charge/discharge current	AI	Through network	±10%	±10%	–
DC battery voltage	AI	Through network	±10%	±10%	–
Battery elapsed time	AI	Through network	±10%	±10%	–
Peak kW demand	AI	Through network	±10%	±10%	–
Inverter output overload	DI	Through network	COV	COV	–
Overload shutdown	DI	Through network	COV	COV	–
Charger over-temperature	DI	Through network	±10%	±10%	–
Inverter over-temperature	DI	Through network	±10%	±10%	–
Charger fuse failure	DI	Through network	COV	COV	–
Inverter fuse failure	DI	Through network	COV	COV	–
Blower failure	DI	Through network	COV	COV	–
Battery disconnect open	DI	Through network	COV	COV	–
Battery discharging	DI	Through network	COV	COV	–
Low battery voltage	DI	Through network	COV	COV	–
DC over voltage	DI	Through network	COV	COV	–
DC ground fault	DI	Through network	COV	COV	–
Input power failed	DI	Through network	COV	COV	–
Control power failed	DI	Through network	COV	COV	–
Emergency OFF	DI	Through network	COV	COV	–
Output over voltage/under voltage	DI	Through network	COV	COV	–
Summary alarm	DI	Through network	COV	COV	–
Loss of communication alarm	DI	Through network	COV	COV	–
Static switch failure	DI	Through network	COV	COV	–
Load on bypass	DI	Through network	COV	COV	–
Bypass not available	DI	Through network	COV	COV	–
Reverse power	DI	Through network	COV	COV	–
UPS input breaker open	DI	Through network	COV	COV	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
DC battery breaker open	DI	Through network	COV	COV	–
UPS output breaker open	DI	Through network	COV	COV	–
UPS output breaker open	DI	Through network	COV	COV	–
Module on	DI	Through network	COV	COV	–
Module OK	DI	Through network	COV	COV	–
AC Static Switch breaker open	DI	Through network	COV	COV	–
AC bypass breaker open	DI	Through network	COV	COV	–
AC output breaker open	DI	Through network	COV	COV	–

12. DCW Booster Pump

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Pump 1 status	DI	Through network	COV	COV	–
Pump 2 status	DI	Through network	COV	COV	–
Alarm	DI	Through network	COV	COV	–
Unit failure/trouble alarm	DI	Through network	COV	COV	–
Communications alarm	DI	Through network	COV	COV	–
Pump 1 speed	AI	Through network	1 min	15 min	–
Pump 2 speed	AI	Through network	1 min	15 min	–
Pump 1 VFD kW	AI	Through network	1 min	15 min	–
Pump 2 VFD kW	AI	Through network	1 min	15 min	–
Difference pressure	AI	Through network	1 min	15 min	–
Difference pressure setpoint	AO	Through network	1 min	15 min	–

13. Wind Anemometer

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Alarm	DI	Through network	COV	COV	–
Wind speed	AI	Through network	1 min	15 min	–
Wind direction	AI	Through network	1 min	15 min	–

14. VRF Indoor Units

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
On/off command	DO	Through network	COV	COV	–
On/off status	DI	Through network	COV	COV	–

Space temperature	AI	Through network	1 min	15 min	F
Discharge air temperature	AI	Through network	1 min	15 min	F
Space temperature	AI	Through network	1 min	15 min	F
Discharge air temperature	AI	Through network	1 min	15 min	F
Return air temperature	AI	Through network	1 min	15 min	F
Operation mode status	AI	Through network	COV	COV	–
Operation mode setting	AO	Through network	COV	COV	–
Air Direction	AI	Through network	COV	COV	–
Itemized fault code revealing reason for specific shutdown fault	AI	Through network	COV	COV	–
Room Cooling Setpoint	AO	Through network	±1ºF	±1ºF	–
Room Heating Setpoint	AO	Through network	±1ºF	±1ºF	–
Fan Speed Setpoint	AO	Through network	1 min	15 min	–
Fan Speed Status	AI	Through network	1 min	15 min	–
Fan status	DI	Through network	COV	COV	–
Cooling status	DI	Through network	COV	COV	–
Heating status	DI	Through network	COV	COV	–
Low temperature sensor alarm	DI	Through network	COV	COV	–
Condensate sensor alarm	DI	Through network	COV	COV	–
High/low voltage alarm	DI	Through network	COV	COV	–
Window switch status	DI	Through network	COV	COV	–
Occupancy sensor status	DI	Through network	COV	COV	–
Unoccupied/occupied command	DO	Through network	COV	COV	–
Fault reset command	DO	Through network	COV	COV	–

15. VRF Outdoor Units

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Communication Status	DI	Through network	COV	COV	–
Operation Mode	AI	Through network	1 min	15 min	–
Outdoor Unit Alarm Status	DI	Through network	COV	COV	–
Defrost Mode	DI	Through network	COV	COV	–
Oil Return	AI	Through network	1 min	15 min	–
Electric Power	AI	Through network	1 min	15 min	–
Electric Current	AI	Through network	1 min	15 min	–
System Capacity Code	AI	Through network	1 min	15 min	–
Outdoor Air Temperature	AI	Through network	1 min	15 min	–
Condensing Pressure	AI	Through network	1 min	15 min	–
Evaporating Pressure	AI	Through network	1 min	15 min	–

Condensing Temperature	AI	Through network	1 min	15 min	–
Evaporating Temperature	AI	Through network	1 min	15 min	–
Inverter Compressor 1 Speed	AI	Through network	1 min	15 min	–
Inverter Compressor 2 Speed	AI	Through network	1 min	15 min	–
Fan Step	AI	Through network	1 min	15 min	–
EV Position 1	AI	Through network	1 min	15 min	–
EV Position 2	AI	Through network	1 min	15 min	–
Hot Gas Temperature (Compressor 1)	AI	Through network	1 min	15 min	–
Hot Gas Temperature (Compressor 2)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (HX Upper)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (HX Lower)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (Deicer)	AI	Through network	1 min	15 min	–
Gas Pipe Temperature (HX Upper)	AI	Through network	1 min	15 min	–
Gas Pipe Temperature (HX Lower)	AI	Through network	1 min	15 min	–
Suction Temperature	AI	Through network	1 min	15 min	–
Compressor Suction Temperature	AI	Through network	1 min	15 min	–
Subcool Inlet Temperature	AI	Through network	1 min	15 min	–
Subcool Outlet Temperature	AI	Through network	1 min	15 min	–
Subcool EV Position	AI	Through network	1 min	15 min	–
Condensing Pressure	AI	Through network	1 min	15 min	–
Evaporating Pressure	AI	Through network	1 min	15 min	–
Condensing Temperature	AI	Through network	1 min	15 min	–
Evaporating Temperature	AI	Through network	1 min	15 min	–
Inverter Compressor 1 Speed	AI	Through network	1 min	15 min	–
Inverter Compressor 2 Speed	AI	Through network	1 min	15 min	–
Fan Step	AI	Through network	1 min	15 min	–
EV Position 1	AI	Through network	1 min	15 min	–
EV Position 2	AI	Through network	1 min	15 min	–
Hot Gas Temperature (Compressor 1)	AI	Through network	1 min	15 min	–

Hot Gas Temperature (Compressor 2)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (HX Upper)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (HX Lower)	AI	Through network	1 min	15 min	–
Liquid Pipe Temperature (Deicer)	AI	Through network	1 min	15 min	–
Gas Pipe Temperature (HX Upper)	AI	Through network	1 min	15 min	–
Gas Pipe Temperature (HX Lower)	AI	Through network	1 min	15 min	–
Suction Temperature	AI	Through network	1 min	15 min	–
Compressor Suction Temperature	AI	Through network	1 min	15 min	–
Subcool Inlet Temperature	AI	Through network	1 min	15 min	–
Subcool Outlet Temperature	AI	Through network	1 min	15 min	–
Subcool EV Position	AI	Through network	1 min	15 min	–

D. Hardwired Points

1. VAV Box - Cooling only

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	**Contin-uous**	
VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–
Local Override	DI	TS-3x – where applicable (see Paragraph 2.9F).	COV	COV	–
Supply Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see §230593)
Zone Temperature Setpoint Adjustment	AI	TS-3x – where applicable (see Paragraph 2.9F).	15 min	60 min	F
Zone Temperature	AI	TS-3x (see Paragraph 2.9F)	1 min	15 min	F

2. Ventilation Zone VAV Box

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	**Contin-uous**	
VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see §230593)
Window switch	DI	WS (where indicated on Drawings)	COV	COV	–
Zone CO2 Concentration	AI	TS-3x (see Paragraph 2.9F)	5 min	15 min	F

3. VAV Box with reheat

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–
HW valve signal	AO	2-way valve (occasional 3-way valve – see equipment schedule)	1 min.	15 min	
Local Override	DI	TS-3x – where applicable (see Paragraph 2.9F).	COV	COV	–
Window switch	DI	WS (where indicated on Drawings)	COV	COV	–
Supply Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see §230593)
Supply air temperature	AI	TS-1A	1 min	15 min	F
Zone Temperature Setpoint Adjustment	AI	TS-3x – where applicable (see Paragraph 2.9F).	15 min	60 min	F
Zone Temperature	AI	TS-3x (see Paragraph 2.9F)	1 min	15 min	F
Zone CO_2 Concentration	AI	TS-3x (see Paragraph 2.9F)	5 min	15 min	F

4. Fan-powered VAV Box (Parallel or Series) with reheat and constant volume fan

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Start Fan	DO	Dry contact to contactor on VAV box	COV	COV	–
VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–
HW valve signal	AO	2-way valve (occasional 3-way valve – see equipment schedule)	1 min.	15 min	
Supply fan status	DI	CS-1	COV	COV	See 3.11G

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Window switch	DI	WS (where indicated on Drawings)	COV	COV	–
Local Override	DI	TS-3x – where applicable (see Paragraph 2.9F).	COV	COV	–
Supply Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see §230593)
Supply air temperature	AI	TS-1A	1 min	15 min	F
Zone Temperature Setpoint Adjustment	AI	TS-3x – where applicable (see Paragraph 2.9F).	15 min	60 min	F
Zone Temperature	AI	TS-3x (see Paragraph 2.9F)	1 min	15 min	F
Zone CO_2 Concentration	AI	TS-3x (see Paragraph 2.9F)	5 min	15 min	F

5. "Slow" Lab Zone (Not Fume Hood Dominated)

a. Use one controller per lab so that network operation does not affect lab performance. This can be a standard VAV box controller on the supply air VAV box with a dual duct auxiliary controller on the exhaust VAV box. Alternatively, standard VAV box controllers can be provided on both with exhaust setpoint hardwired from the supply air box controller to the exhaust controller and all setpoint logic residing in the supply air box controller.

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Hood alarm (any hood)	DI	Connect to hood monitor alarm contact, in parallel if more than one hood	COV	COV	–
Supply VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–
Exhaust VAV Box Damper Position	AO	Modulating actuator	1 min	15 min	–
CHW/HW valve position	AO	Modulating actuator, 6-way valve	1 min.	15 min	
Supply Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see 230593)
General Exhaust Airflow	AI	DPT-5 connected to box manufacturer supplied flow cross	1 min	15 min	HH (see 230593)
Hood Exhaust Airflow (each hood)	AI	Air valve CFM feedback	1 min	15 min	F
Supply air temperature	AI	TS-1A	1 min	15 min	F
Zone Temperature Setpoint Adjustment	AI	TS-3C	15 min	60 min	F

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Zone Temperature	AI	TS-3C	1 min	15 min	F

6. "Fast" Lab Zone (Fume Hood Dominated)

   a. Laboratory Air Valves

   b. Sash Position Sensor

   c. Fume Hood Monitor

      1) Designed to integrate with air valve controller

      2) LCD with velocity indication

      3) Visual and audible low and high velocity alarms with message display and mute button

      4) Button to activate and deactivate emergency purge that causes air valve to operate at full airflow regardless of sash position

      5) Equal to Accutrol FHM3

   d. See Section 233600 Air Terminal Units for air valve controllers

   e. Use one controller per lab so that network operation does not affect lab performance.

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Close sash (all hoods)	DO	Wire to sash controller emergency close contact; include multi-pole relay if more than one hood	COV	COV	–
Hood alarm (any hood)	DI	Connect to hood monitor alarm contact, in parallel if more than one hood	COV	COV	–
Supply airflow setpoint	AO	To air valve	1 min	15 min	–
General exhaust airflow setpoint	AO	To air valve	1 min	15 min	–
CHW/HW valve position	AO	Modulating actuator, 6-way valve	1 min.	15 min	
Supply Airflow	AI	Air valve CFM feedback	1 min	15 min	F
General Exhaust Airflow	AI	Air valve CFM feedback	1 min	15 min	F
Hood Exhaust Airflow (each hood)	AI	Air valve CFM feedback	1 min	15 min	F
Supply air temperature	AI	TS-1A	1 min	15 min	F

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Zone Temperature Setpoint Adjustment	AI	TS-3C	15 min	60 min	F
Zone Temperature	AI	TS-3C	1 min	15 min	F

7. VAV Air Handler with Relief Fan

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Relief damper -1 open/close	DO	Two position actuator	COV	COV	–
Relief damper -2 open/close	DO	Two position actuator	COV	COV	–
Relief Fan 1 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Relief Fan 2 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Supply Fan 1 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Supply Fan 2 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Supply fan high static alarm reset	DO	Dry contact to 120V or 24V control circuit ─see control schematics for details	COV	COV	–
Economizer Outdoor Air Damper	AO	Modulating actuator	1 min	15 min	–
Relief Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Return Air Damper	AO	Modulating actuator	1 min	15 min	–
Hot Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Chilled Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Supply Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Outdoor Airflow	AI	AFMS-3 cfm output	1 min	15 min	F
Outdoor Air Temperature	AI	AFMS-3 temperature output	1 min	15 min	F
Mixed Air Temperature	AI	TS-1B across filter bank	1 min	15 min	F
Filter Pressure Drop	AI	DPT-3A, 0 to 1 inch	–	60 min	F
Return Air Temperature	AI	TS-1A	1 min	15 min	F
Supply Air Temperature	AI	TS-1B	1 min	15 min	HH
Duct Static Pressure	AI	DPT-3A, 0 to 2 inches	1 min	15 min	F
Building Pressure	AI	DPT-4, ±0.25	1 min	15 min	F

8. VAV Air Handler with Return Fan

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Fan 1 Start/Stop	DO	Connect to VFD Run	COV	COV	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Fan 2 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Return Fan 1 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Return Fan 2 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Return fan high static alarm reset	DO	Dry contact to 120V or 24V control circuit –see control schematics for details	COV	COV	–
Supply fan high static alarm reset	DO	Dry contact to 120V or 24V control circuit –see control schematics for details	COV	COV	–
Exhaust Air Damper	AO	Modulating actuator	1 min	15 min	–
Economizer Outdoor Air Damper	AO	Modulating actuator	1 min	15 min	–
Return Air Damper	AO	Modulating actuator	1 min	15 min	–
Return Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Hot Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Chilled Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Supply Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Return Fan Static Pressure	AI	DPT-3, 0 to 1 inch	1 min	15 min	F
Outdoor Airflow	AI	AFMS-3 cfm output	1 min	15 min	F
Outdoor Air Temperature	AI	AFMS-3 temperature output	1 min	15 min	F
Mixed Air Temperature	AI	TS-1B across filter bank	1 min	15 min	F
Filter Pressure Drop	AI	DPT-3A, 0 to 1 inch	–	60 min	F
Return Air Temperature	AI	TS-1A	1 min	15 min	F
Supply Air Temperature	AI	TS-1B	1 min	15 min	HH
Duct Static Pressure	AI	DPT-3A, 0 to 2 inches.	1 min	15 min	F
Building Pressure	AI	DPT-4, ±0.25	1 min	15 min	F

9. Dedicated Outdoor Air VAV Air Handler

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Fan 1 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Supply Fan 2 Start/Stop	DO	Connect to VFD Run	COV	COV	–
Supply fan high static alarm reset	DO	Dry contact to 120V or 24V control circuit –see control sequences for details	COV	COV	–
Hot Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Chilled Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Outdoor Air Temperature	AI	TS-1A	1 min	15 min	F
Filter Pressure Drop	AI	DPT-3A, 0 to 1 inch	–	60 min	F
Supply Air Temperature	AI	TS-1A	1 min	15 min	HH
Duct Static Pressure	AI	DPT-3A, 0 to 2 inches.	1 min	15 min	F

10. Single Zone VAV Air Handler

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Supply Fan Start/Stop	DO	Connect to VFD Run	COV	COV	–
Economizer Dampers	AO	Modulating actuator, linked to both return air and outdoor air parallel blade dampers	1 min	15 min	–
Hot Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Chilled Water Control Valve	AO	Modulating 2-way valve	1 min	15 min	–
Supply Fan Speed	AO	Connect to VFD Speed, all VFDs	1 min	15 min	–
Mixed Air Temperature	AI	TS-1B	1 min	15 min	F
Filter Pressure Drop	AI	DPT-3A, 0 to 1 inch	–	60 min	F
Supply Air Temperature	AI	TS-1A	1 min	15 min	HH

11. 2-Pipe Variable Speed Fan-Coil

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Fan on/off	DO	May be deleted if 0-10Vdc to ECM less than 2V shuts off fan	COV	COV	–
Fan speed	AO	0-10Vdc to ECM	1 min	15 min	–
CHW valve signal	AO	2-way valve	1 min.	15 min	
Supply fan status	DI	CS-1	COV	COV	See 3.11G
Supply air temperature	AI	TS-1A	1 min	15 min	F
Local Override	DI	TS-3x – where applicable (see Paragraph 2.9F).	COV	COV	–
Window switch	DI	WS (where indicated on Drawings)	COV	COV	–
Zone Temperature Setpoint Adjustment	AI	TS-3x – where applicable (see Paragraph 2.9F).	15 min	60 min	F

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Zone Temperature	AI	TS-3x (see Paragraph 2.9F)	1 min	15 min	F
Zone CO2 Concentration	AI	TS-3x (see Paragraph 2.9F)	5 min	15 min	F

12. Packaged Single Zone AC Units/Heat Pumps

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Start Fan	DO	Dry contact to contactor on control panel	COV	COV	–
Cooling stages	Mult-iple DOs	See AC/HP unit schedule and submittals for quantity	1 min	15 min	–
Heating stages	Mult-iple DOs	See AC/HP unit schedule and submittals for quantity	1 min	15 min	–
Supply fan status	DI	Current switch	COV	COV	See 3.11G
Supply air temperature	AI	TS-1A	1 min	15 min	F
Local Override	DI	TS-3x – where applicable (see Paragraph 2.9F).	COV	COV	–
Window switch	DI	WS (where indicated on Drawings)	COV	COV	–
Zone Temperature Setpoint Adjustment	AI	TS-3x – where applicable (see Paragraph 2.9F).	15 min	60 min	F
Zone Temperature	AI	TS-3x (see Paragraph 2.9F)	1 min	15 min	F
Zone CO2 Concentration	AI	TS-3x (see Paragraph 2.9F)	5 min	15 min	F

13. Packaged VAV AC Unit

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Start/stop	DO	Hard wired (dry contact to 24V control circuit)	COV	COV	–

14. Toilet Exhaust Fan

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Fan Start/Stop	DO	Dry contact to 120V starter control circuit	COV	COV	–

Description	**Type**	**Device**	**Trend Logging**		**Calibra-tion**
			Comm-issioning	**Contin-uous**	
Fan Status	DI	CS-1	COV	COV	See 3.11G

15. Laboratory Exhaust Air System

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Bypass control damper	AO	Connect to damper actuator	1 min.	±5%	–
Exhaust Fan Speed	AO	Connect to VFD speed, all VFDs	1 min.	±5%	–
LEF-1 start/stop	DO	Connect to VFD Run	COV	COV	–
LEF-2 start/stop	DO	Connect to VFD Run	COV	COV	–
LEF-1 Status	DI	Connect to VFD status contacts	COV	COV	–
LEF-2 Status	DI	Connect to VFD status contacts	COV	COV	–
Exhaust Plenum static	AI	DPT-3B transmitter, 0 to 5”	1 min.	10 min.	F
Duct static –x. See plans for quantity	AI	DPT-3B transmitter, 0 to 2.5”	1 min.	10 min.	F

16. Laboratory Exhaust Air System

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Bypass control damper	AO	Connect to damper actuator	1 min.	±5%	–
Exhaust Fan Speed	AO	Connect to VFD speed, all VFDs	1 min.	±5%	–
LEF-1 start/stop	DO	Connect to VFD Run	COV	COV	–
LEF-2 start/stop	DO	Connect to VFD Run	COV	COV	–
LEF-3 start/stop	DO	Connect to VFD Run	COV	COV	–
LEF-1 Status	DI	Connect to VFD status contacts	COV	COV	–
LEF-2 Status	DI	Connect to VFD status contacts	COV	COV	–
LEF-3 Status	DI	Connect to VFD status contacts	COV	COV	–
Exhaust fan cfm, LEF-1	AI	AFMS-4	1 min.	10 min.	F
Exhaust fan cfm, LEF-2	AI	AFMS-4	1 min.	10 min.	F
Exhaust fan cfm, LEF-3	AI	AFMS-4	1 min.	10 min.	F
Exhaust Plenum static	AI	DPT-3B transmitter, 0 to 5”	1 min.	10 min.	F
Duct static –x. See plans for quantity	AI	DPT-3B transmitter, 0 to 2.5”	1 min.	10 min.	F

17. Water-Cooled Chiller Plant

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
CH-1 on/off	DO	Connect to chiller enable contact on chiller panel	COV	COV	–
CH-2 on/off	DO	Connect to chiller enable contact on chiller panel	COV	COV	–
Start CHP-1	DO	Connect to VFD Run	COV	COV	–
Start CHP-2	DO	Connect to VFD Run	COV	COV	–
Start CWP-1	DO	Connect to motor starter auto	COV	COV	–
Start CWP-2	DO	Connect to motor starter auto	COV	COV	–
Start CT-1	DO	Connect to VFD Run	COV	COV	–
Start CT-2	DO	Connect to VFD Run	COV	COV	–
CH-1 CW isolation valve	AO	Modulating butterfly valve, line size	1 min	5 min	–
CH-2 CW isolation valve	AO	Modulating butterfly valve, line size	1 min	5 min	–
CH-1 CHW isolation valve	AO	Modulating butterfly valve, line size	1 min	5 min	–
CH-2 CHW isolation valve	AO	Modulating butterfly valve, line size	1 min	5 min	–
CHW Bypass valve	AO	Modulating valve, sized for minimum flow of one chiller at 5 psi DP	1 min	5 min	–
CHP speed	AO	Connect to VFD Speed on CHP-1, 2	1 min	5 min	–
CT-1 speed	AO	Connect to VFD Speed on CT-1A, 1B	1 min	5 min	–
Chiller emergency off	DI	Break-glass switch	COV	COV	
CWP-1 status	DI	CS-1	COV	COV	See 3.11G
CWP-2 status	DI	CS-1	COV	COV	See 3.11G
CWS temperature from towers	AI	TS-2B	5 min	15 min	HH
CWR temperature from towers	AI	TS-2B	5 min	15 min	HH
CHWR temperature before bypass	AI	TS-2B	5 min	15 min	HH
CHW supply flow	AI	FM-1 (connected to FM-1 auxiliary output)	5 min	15 min	F
CHW differential pressure	AI	DPT-1, 0 to 20 psi, located at end of piping system	5 min	15 min	F
CHW system gauge pressure	AI	PT-1, 0 to 60 psi (located near expansion tank)	15 min	1 hr	F

18. Air-Cooled Series Chiller Plant

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
CH-1 on/off	DO	Connect to chiller enable contact on chiller panel	COV	COV	–
CH-2 on/off	DO	Connect to chiller enable contact on chiller panel	COV	COV	–
Start CHP-1	DO	Connect to VFD Run	COV	COV	–
Start CHP-2	DO	Connect to VFD Run	COV	COV	–
CH-1 bypass valve	DO	2-position butterfly valve, line size	COV	COV	–
CH-2 bypass valve	DO	2-position butterfly valve, line size	COV	COV	–
CHW Bypass valve	AO	Modulating valve, sized for minimum flow of one chiller at 5 psi DP	1 min	5 min	–
CHP speed	AO	Connect to VFD Speed on CHP-1, 2	1 min	5 min	–
CHWR temperature before bypass	AI	TS-2B	5 min	15 min	HH
CHW supply flow	AI	FM-1 (connected to FM-1 auxiliary output)	5 min	15 min	F
CHW differential pressure	AI	DPT-1, 0 to 20 psi, located at end of piping system	5 min	15 min	F
CHW system gauge pressure	AI	PT-1, 0 to 60 psi (located near expansion tank)	15 min	1 hr	F

19. 2-Pipe and 4-Pipe Air-Source Heat Pump/Chiller Plant

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
HRHP-1 cooling on/off	DO	Connect to 4-pipe HP/chiller enable contact on chiller panel	COV	COV	–
HRHP-1 heating on/off	DO	Connect to 4-pipe HP/chiller enable contact on chiller panel	COV	COV	–
HPCH-1 on/off	DO	Connect to 2-pipe HP/chiller enable contact on chiller panel	COV	COV	–
HPCH-1 mode	DO	Connect to 2-pipe HP/chiller heat/cool mode contact on chiller panel	COV	COV	–
HPCH-2 on/off	DO	Connect to 2-pipe HP/chiller enable contact on chiller panel	COV	COV	–
HPCH-2 mode	DO	Connect to 2-pipe HP/chiller heat/cool mode contact on chiller panel	COV	COV	–
Start HWP-1	DO	Connect to VFD Run	COV	COV	–

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Start HWP-2	DO	Connect to VFD Run	COV	COV	–
Start CHWP-1	DO	Connect to VFD Run	COV	COV	–
Start CHWP-2	DO	Connect to VFD Run	COV	COV	–
HPCH-1 changeover valves	DO	2-position 2-way valves, line size, spring return	COV	COV	–
HPCH-2 changeover valves	DO	2-position 2-way valves, line size, spring return	COV	COV	–
HWP speed	AO	Connect to VFD Speed on HWP-1, 2	1 min	5 min	–
CHP speed	AO	Connect to VFD Speed on CHP-1, 2	1 min	5 min	–
HW differential pressure	AI	DPT-1, 0 to 20 psi, located at end of piping system	5 min	15 min	F
HW system gauge pressure	AI	PT-1, 0 to 60 psi (located near expansion tank)	15 min	1 hr	F
CHW differential pressure	AI	DPT-1, 0 to 20 psi, located at end of piping system	5 min	15 min	F
CHW system gauge pressure	AI	PT-1, 0 to 60 psi (located near expansion tank)	15 min	1 hr	F

20. Hot Water Plant

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Boiler B-1 enable	DO	Connect to boiler enable contact	COV	COV	–
Boiler B-2 enable	DO	Connect to boiler enable contact	COV	COV	–
Start HWP-1	DO	Connect to VFD Run	COV	COV	–
Start HWP-2	DO	Connect to VFD Run	COV	COV	–
B-1 HW isolation valve	DO	2-position valve, line size	COV	COV	–
B-2 HW isolation valve	DO	2-position valve, line size	COV	COV	–
HWP speed	AO	Connect to VFD Speed on HWP-1, 2	1 min	5 min	–
Common HWS temperature	AI	TS-2A	1 min.	±2°F	HH
HWR temperature	AI	TS-2A	1 min.	±2°F	HH
HW flow	AI	FM-1	1 min.	10 min	F
Common gas flow	AI (pulse)	FM-3 – locate in common gas line serving both boilers	1 min.	10 min	F
HW differential pressure	AI	DPT-1, 0 to 20 psi, located at end of piping system	5 min	15 min	F
HW system gauge pressure	AI	PT-1, 0 to 60 psi (located near expansion tank)	15 min	1 hr	F

21. Radiant Water Zone Manifold

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Manifold Flow Valve	DO	2-position 2-way valve	COV	COV	–
Slab temperature	AI	TS-2B. Mount in floor box between radiant piping	1 min	10 min	–
Zone Temperature (provide only if the radiant manifold zone is not also served by an airside VAV zone(s))	AI	TS-3C	1 min	10 min	–

22. Radiant Water Loops

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Pump Start/Stop	DO	Connect to contactor or Motor Starter	COV	COV	–
HW/TCHW Changeover Valve Command	DO	2-position 2-way valves with end switches, 1 control point to power all valves; see schematics	COV	COV	–
Pump Status	DI	CS-1	COV	COV	–
Modulating HW/TCHW Control Valve Command	AO	Modulating 2-way valve with end switches sized per design flow rates, 1 control point for both; see schematics	1 min	10 min	–
Loop return temperature	AI	TS-2B	1 min	10 min	–
Loop supply temperature	AI	TS-2B	1 min	10 min	–

23. Domestic Water Heaters (gas, electric, or heat pump)

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
DHW-1 System Re-Circulation Pumps Start/Stop	DO	Line voltage contact to pump power circuit	COV	COV	–
DHW-2 System Re-Circulation Pumps Start/Stop	DO	Line voltage contact to pump power circuit	COV	COV	–
DHW-1 Supply Temperature	AI	TS-2A	5 min	15 min	F
DHW-2 Supply Temperature	AI	TS-2A	5 min	15 min	F
DHW-1 System Re-Circulation Pump Status	DI	CS-1	COV	COV	See 3.11G

Description	Type	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
DHW-2 System Re-Circulation Pump Status	DI	CS-1	COV	COV	See 3.11G
DHW-1 heater Alarm	DI	Install relay wired downstream of DHW heater safeties with NC relay contact wired as alarm input.	COV	COV	–
DHW-2 heater Alarm	DI	Install relay wired downstream of DHW heater safeties with NC relay contact wired as alarm input.	COV	COV	–

24. Domestic Hot Water Generator from Heating HW

Description	Type/ Tag	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
DHW System Re-Circulation and Storage Re-Circulation Pumps Start/Stop	DO	Line voltage contact to pump power circuit	COV	COV	–
HW Valve	AO	2-way valve	1 min	15 min	–
DHW System Re-Circulation Pump Status	DI	CS-1	COV	COV	See 17051
DHW Storage Re-Circulation Pump Status	DI	CS-1	COV	COV	See 17051
HW Return Temperature	AI	TS-2A	5 min	15 min	F
DHW Supply Temperature	AI	TS-2A	1 min	15 min	F

25. Hot Water and Chilled Water Plant Connection

Description	Type/ Tag	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Pump #1 Start/Stop	DO	Connect to VFD “Run”	COV	COV	–
Pump #2 Start/Stop	DO	Connect to VFD “Run”	COV	COV	–
Pump #1 and #2 Speed	AO	Connect to VFD Speed on P-1, 2	1 min	15 min	–
Central Plant CHW/HW System Differential Pressure	AI	DPT-1, 0 to 15 psi	5 min	15 min	F
Building Differential Pressure	AI	DPT-1, 0 to 25 psi	1 min	15 min	F

26. Miscellaneous Meters

Description	Type/ Tag	Device	Trend Logging		Calibra-tion
			Comm-issioning	Contin-uous	
Building domestic water flow	AI (pulse)	FM-6	1 min	15 min	F
Irrigation water flow	AI (pulse)	FM-6	1 min	15 min	F
Natural gas flow	AI (pulse)	FM-3	1 min.	10 min	F

PART 3 EXECUTION

3.1 INSTALLATION - GENERAL

A. Install systems and materials in accordance with manufacturer's instructions, roughing-in drawings and details indicated on Drawings.

B. Coordinate Work and Work schedule with other trades prior to construction.

C. Examine areas and conditions under which control systems are to be installed. Do not proceed with work until unsatisfactory conditions have been corrected in manner acceptable to Installer.

3.2 DELIVERY, STORAGE, AND HANDLING

A. Provide factory-shipping cartons for each piece of equipment and control device. Maintain cartons during shipping, storage and handling as required to prevent equipment damage, and to eliminate dirt and moisture from equipment.

B. Store equipment and materials inside and protect from weather.

3.3 IDENTIFICATION

A. General

1. Manufacturers' nameplates and UL or CSA labels to be visible and legible after equipment is installed.

2. Identifiers shall match record documents.

3. All plug-in components shall be labeled such that removal of the component does not remove the label.

B. Wiring and Tubing

1. All wiring and cabling, including that within factory-fabricated panels, shall be labeled at each end within 2 inches of termination with the BAS address or termination number.

2. Permanently label or code each point of field terminal strips to show the instrument or item served.

3. All pneumatic tubing shall be labeled at each end within 2 inches of termination with a descriptive identifier.

C. Equipment and Devices

1. Valve and damper actuators: None required.

2. Sensors: Provide 1 inch x 3 inches x 1/8 inches black micarta or lamacoid labels with engraved white lettering, ¼ inches high. Indicate sensor identifier and function (for example “CHWS Temp”).

3. Panels

a. Provide 2 inches x 5 inches 1/8 inches black micarta or lamacoid labels with engraved white lettering, ½ inches high. Indicate panel identifier and service.

b. Provide permanent tag indicating the electrical panel and circuit number from which panel is powered.

4. Identify room sensors relating to terminal box or valves with indelible marker on sensor hidden by cover.

3.4 CUTTING, CORING, PATCHING AND PAINTING

A. Provide canning for openings in concrete walls and floors and other structural elements prior to their construction.

B. Penetrations through rated walls or floors shall be filled with a listed material to provide a code compliant fire-stop.

C. All damage to and openings in ductwork, piping insulation, and other materials and equipment resulting from Work in this Section shall be properly sealed, repaired, or re-insulated by experienced mechanics of the trade involved. Repair insulation to maintain integrity of insulation and vapor barrier jacket. Use hydraulic insulating cement to fill voids and finish with material matching or compatible with adjacent jacket material.

D. At the completion of Work, all equipment furnished under this Section shall be checked for paint damage, and any factory-finished paint that has been damaged shall be repaired and repainted to original finish.

3.5 CLEANING

A. Clean up all debris resulting from its activities daily. Remove all cartons, containers, crates, and other debris generated by Work in this Section as soon as their contents have been removed. Waste shall be collected and legally disposed of.

B. Materials stored on-site shall be protected from weather and stored in an orderly manner, neatly stacked, or piled in the designated area assigned by the College's Representative.

C. At the completion of work in any area, clean all work and equipment of dust, dirt, and debris.

D. Use only cleaning materials recommended by the manufacturer of the surfaces to be cleaned and on surfaces recommended by the cleaning material manufacturer.

3.6 CONTROLLERS

A. General

1. Install systems and materials in accordance with manufacturer's instructions, specifications roughing-in drawings and details indicated on Drawings.

2. Regardless of application category listed below, each Control Unit shall be capable of performing the specified sequence of operation for the associated equipment. Except as listed below, all physical point data and calculated values required to accomplish the sequence of operation shall reside within the associated CU. Listed below are point data and calculated values that shall be allowed to be obtained from other CUs via LAN.

a. Global points such as outdoor air temperature

b. Requests, such as heat/cool requests, used to request operation or for setpoint reset from zones to systems and systems to plants

c. Modes, such as system modes, used to change operating logic from plants to systems and systems to zones

3. Where associated control functions involve functions from different categories identified below, the requirements for the most restrictive category shall be met.

B. Controller Application Categories

1. Controllers shall comply with the application table below (X under controller type indicates acceptable controller type).

Application Category	**Examples**	**Acceptable Controller**		
		ASC	**AAC**	**BC**
0	Monitoring of variables that are not used in a control loop, sequence logic, or safety, such as status of sump pumps or associated float switches, temperatures in monitored electrical rooms.	X	X	X
1	Miscellaneous heaters Constant speed exhaust fans and pumps	X	X	X
2	Fan Coil Units Terminal Units (such as VAV Boxes)	X		

Application Category	Examples	Acceptable Controller		
		ASC	AAC	BC
	Unitary AC and HP units			
3	“Slow” Lab Zone –Non-Hood Dominated	X (note 1)	X	X
4	Air Handling Units Central Hot Water Plant “Fast” Lab Zone –Hood Dominated Air-Cooled Chilled Water Plant		X (note 1)	X
5	Water-Cooled Chilled Water Plant			X
Notes: Controller may be used only if all control functions and physical I/O associated with a given unit resides in one AAC/ASC				

2. ASC Installation

    a. ASCs that control equipment located above accessible ceilings shall be mounted on the equipment in an accessible enclosure and shall be rated for plenum use if ceiling attic is used as a return air plenum.

    b. ASCs that control equipment mounted in a mechanical room may either be mounted in or on the equipment, or on the wall of the mechanical room at an adjacent, accessible location.

    c. ASCs that control equipment mounted outside or in occupied spaces shall either be located in the unit or in a proximate mechanical/utility space.

3. AAC and BC Installation

    a. AACs/BCs shall be located in a temperature control cabinets constructed per Paragraph 2.8.

3.7 COMMUNICATION DEVICES

A. General

1. Install systems and materials in accordance with manufacturer’s instructions, roughing-in drawings and details indicated on Drawings.

2. Provide all interface devices and software to provide an integrated system.

B. LANID and LAN Routers

1. Provide as required

2. Connect networks to both sides of device

3. Thoroughly test to ensure proper operation

4. Interruptions or fault at any point on any Primary LAN shall not interrupt communications between other nodes on the network. If a LAN is severed, two separate networks shall be formed and communications within each network shall continue uninterrupted. The system shall automatically monitor the operation of all network devices and annunciate any device that goes off-line because it is failing to communicate.

C. Gateways and Protocol Translators to Equipment Controllers

1. See Paragraph 2.4C for network connection of Gateways and Protocol Translators.

2. Wire to networks on both sides of device.

3. Map across all monitoring and control points listed in Paragraph 2.12C.

4. Thoroughly test each point to ensure that mapping is accurate.

5. Initiate trends of points as indication in Paragraph 2.12C.

D. External Communications

1. Provide an Ethernet second port on the CSS to which the College can connect their College IT LAN, by others. Contractor shall coordinate with the College's Representative to establish an IP address and communications parameters to assure proper operation. This connection shall also provide access to Internet through College's firewall to Internet Services Provider procured by College.

3.8 CONTROL AIR TUBING

A. Sensor air tubing shall be sized by the Contractor.

B. All control air piping shall be concealed except in equipment rooms or unfinished areas.

C. Installation methods and materials

1. Concealed and Inaccessible: Use copper tubing or FR plastic in metal raceway. Exception: Room thermostat drops in stud walls in areas with lay-in ceiling may be FR plastic tubing.

2. Concealed and Accessible tubing (including ceiling return air plenums) shall be copper tubing or FR plastic tubing, subject to the following limitations

    a. FR tubing shall be enclosed in metal raceway when required by local code.

    b. Quantity of FR tubing per cubic foot of plenum space shall not exceed manufacturer's published data for Class 1 installation.

3. Exposed to view or damage: Use hard-drawn copper or FR plastic in metal raceway.

a. Where copper tubing is used, a section 12 inches or less of FR plastic tubing is acceptable at final connection to control device.

D. Mechanically attach tubing to supporting surfaces. Sleeve through concrete surfaces in minimum 1 inch sleeves, extended 6 inches above floors and 1 inch below bottom surface of slabs.

E. Pneumatic tubing shall not be run in raceway containing electrical wiring.

F. Where FR tubing exits the end of raceway or junction box, provide a snap-in nylon bushing. Where pneumatic tubing exits control panels, provide bulkhead fittings. Where copper tubing exits junction boxes or panels, provide bulkhead fittings.

G. All tubing shall be number coded on each end and at each junction for easy identification.

H. All control air piping shall be installed in a neat and workmanlike manner parallel to building lines with adequate support.

I. Piping above suspended ceilings shall be supported from or anchored to structural members or other piping or duct supports. Tubing shall not be supported by or anchored to electrical raceways or ceiling support systems.

J. Brass-barbed fittings shall be used at copper-to-FR tubing junctions. Plastic slipped-over copper tubing is not acceptable.

K. Number-code or color-code tubing, except local individual room control tubing, for future identification and servicing of control system. Code shall be as indicated on approved installation drawings.

3.9 CONTROL POWER

A. Power wiring and wiring connections required for Work in this Section shall be provided under this Section unless specifically indicated on Division 26 Drawings or Specifications. See Paragraph 1.2.

B. Extend power to all BAS devices, including 120V power to panels, from an acceptable power panel.

1. See Division 26 Electrical Drawings for power locations pre-allocated for BAS system.

2. Where no power source is indicated on drawings, for bid purposes only, assume a dedicated circuit is available within an average of 20 feet of panel location. If this is not the case, request additional cost prior to submission of shop drawings or no additional costs will be reimbursed.

3. Coordinate with Division 26 during shop drawing development for final connection location.

C. General requirements for obtaining power include the following:

1. Electrical service to controls panels and control devices shall be provided by isolated circuits, with no other loads attached to the circuit, clearly marked at its source. The location of the breaker shall be clearly identified in each panel served by it.

2. Obtain power from a source that feeds the equipment being controlled such that both the control component and the equipment are powered from the same panel. Where equipment is powered from a 460V source, obtain power from the electrically most proximate 120V source fed from a common origin.

3. Where control equipment is located inside a new equipment enclosure, coordinate with the equipment manufacturer and feed the control with the same source as the equipment. If the equipment's control transformer is large enough and of the correct voltage to supply the controls, it may be used. If the equipment's control transformer is not large enough or not of the correct voltage to supply the controls, provide separate transformer(s).

4. Where a controller controls multiple systems on varying levels of power reliability (normal, emergency, or interruptible), the controller, and any associated switches and devices necessary its operation, shall be powered by the highest level of reliability served.

D. Unless transformers are provided with equipment as specified in related Division 23 and 26 equipment Sections, Contractor shall provide transformers for all low voltage control devices including non-powered terminal units such as cooling-only VAV boxes and VAV boxes with hot water reheat. Transformer(s) shall be located in control panels in readily accessible locations such as Electrical Rooms.

E. Power line filtering. Provide transient voltage and surge suppression for all workstations and BCs either internally or as an external component.

3.10 CONTROL AND COMMUNICATION WIRING

A. Control and Signal Wiring

1. Comply with Division 26.

2. Line Voltage Wiring

    a. All line-voltage wiring shall meet NEC Class 1 requirements.

    b. All Class 1 wiring shall be installed in UL Listed approved raceway per NEC requirements and shall be installed by a licensed electrician.

    c. Class 1 wiring shall not be installed in raceway containing pneumatic tubing.

3. Low Voltage Wiring

    a. All low-voltage wiring shall meet NEC Class 2 requirements. (Low-voltage power circuits shall be sub-fused when required to meet Class 2 current-limit.)

    b. Class 2 wiring shall be installed in UL Listed approved raceway as follows:

1) Where located in unconcealed or inaccessible locations, such as:

a) Equipment rooms

b) Exposed to weather

c) Exposed to occupant view

d) Inaccessible locations such as concealed shafts and above inaccessible ceilings

2) Class 2 wiring shall not be installed in raceway containing Class 1 wiring.

c. Class 2 wiring need not be installed in raceway as follows:

1) Where located in concealed and easily accessible locations, such as:

a) Inside mechanical equipment enclosures and control panels

b) Above suspended accessible ceilings (e.g. lay-in and spline)

c) Above suspended drywall ceilings within reach of access panels throughout

d) In shafts within reach of access panels throughout

e) Nonrated wall cavities

2) Wiring shall be UL Listed for the intended application. For example, cables used in floor or ceiling plenums used for air transport shall be UL Listed specifically for that purpose.

3) Wiring shall be supported from or anchored to structural members neatly tied at 10 foot intervals and at least 1 foot above ceiling tiles and light fixtures. Support or anchoring from straps or rods that support ductwork or piping is also acceptable. Cables shall not be supported by or anchored to ductwork, electrical raceways, piping, or ceilings.

4) Install wiring in sleeves where it passes through walls and floors. Maintain fire rating at all penetrations.

d. Boxes and panels containing high-voltage wiring and equipment shall not be used for low-voltage wiring except for the purpose of interfacing the two (for example relays and transformers).

4. All wire-to-device connections shall be made at a terminal block or terminal strip. All wire-to-wire connections shall be at a terminal block.

5. All field wiring shall be properly labeled at each end, with self-laminating typed labels indicating device address, for easy reference to the identification schematic. All power wiring shall be neatly labeled to indicate service, voltage, and breaker source.

6. Use coded conductors throughout with different colored conductors.

7. All wiring within enclosures shall be neatly bundled and anchored to permit access and prevent restriction to devices and terminals.

8. Maximum allowable voltage for control wiring shall be 120 V. If only higher voltages are available, the Contractor shall provide step-down transformers.

9. All wiring shall be installed as continuous lengths, with no splices permitted between termination points.

10. Size of raceway and size and type of wire shall be the responsibility of the Contractor, in keeping with the manufacturer's recommendation and NEC requirements.

11. Include one pull string in each raceway 1 inch or larger.

12. Control and status relays are to be located in designated enclosures only. These enclosures include packaged equipment control panel enclosures unless they also contain Class 1 starters.

13. Conceal all raceways, except within mechanical, electrical, or service rooms. Install raceway to maintain a minimum clearance of 6 inches from high-temperature equipment (for example steam pipes or flues).

14. Secure raceways with raceway clamps fastened to the structure and spaced according to code requirements. Raceways and pull boxes may not be hung on flexible duct strap or tie rods. Raceways may not be run on or attached to ductwork.

15. Install insulated bushings on all raceway ends and openings to enclosures. Seal top end of all vertical raceways.

16. Terminate all control or interlock wiring.

17. Maintain updated as-built wiring diagrams with terminations identified at the jobsite.

18. Flexible metal raceways and liquid-tight, flexible metal raceways shall not exceed 3 feet in length and shall be supported at each end. Flexible metal raceway less than ½ inches electrical trade size shall not be used. In areas exposed to moisture liquid-tight, flexible metal raceways shall be used.

19. Raceway must be rigidly installed, adequately supported, properly reamed at both ends, and left clean and free of obstructions. Raceway sections shall be joined with couplings per code. Terminations must be made with fittings at boxes and ends not terminating in boxes shall have bushings installed.

20. Wire digital outputs to either the normally-closed or normally-open contacts of binary output depending on desired action in case of system failure. Unless otherwise indicated herein, wire to the NO contact except the following shall be wired to the NC contact

    a. Hot water pumps

b. Coil recirculation pumps provided for freeze protection.

21. Hardwire Interlocks

a. The devices referenced in this Section are hardwire interlocked to ensure equipment shutdown occurs even if control systems are down. Do not use software (alone) for these interlocks.

b. Hardwire device NC contact to air handler fan starter upstream of HOA switch, or to VFD enable contact.

c. Where multiple fans (or BAS DI) are controlled off of one device and the device does not have sufficient contacts, provide a relay at the device to provide the required number of contacts.

d. Provide for the following devices where indicated on Drawings or in Sequences of Operation:

1) Duct smoke detector

2) High discharge static pressure

3) Low mixing plenum pressure

4) Freeze-stats

5) Cooling tower vibration switch

22. Shielded cable shield shall be grounded only at one end. Signal wiring shield shall be grounded at controller end only unless otherwise recommended by the controller manufacturer.

B. Communication Wiring

1. Adhere to the requirements of Paragraph 3.10A in addition to this Paragraph.

2. Communication and signal wiring may be run without conduit in concealed, accessible locations as permitted by Paragraph 3.10A only if noise immunity is ensured. Contractor is fully responsible for noise immunity and rewire in conduit if electrical or RF noise affects performance.

3. All cabling shall be installed in a neat and workmanlike manner. Follow all manufacturers’ installation recommendations for all communication cabling.

4. Do not install communication wiring in raceway and enclosures containing Class 1 or other Class 2 wiring.

5. Maximum pulling, tension, and bend radius for cable installation as specified by the cable manufacturer shall not be exceeded during installation.

6. Verify the integrity of the entire network following the cable installation. Use appropriate test measures for each particular cable.

7. All runs of communication wiring shall be unspliced length when that length is commercially available.

8. All communication wiring shall be labeled to indicate origination and destination data.

9. Grounding of coaxial cable shall be in accordance with NEC regulations Article on Communications Circuits, Cable and Protector Grounding.

10. Power-line carrier signal communication or transmission is not acceptable.

3.11 SENSORS AND MISCELLANEOUS FIELD DEVICES

A. Install sensors in accordance with the manufacturer's recommendations.

B. Mount sensors rigidly and adequately for the environment within which the sensor operates.

C. Sensors used as controlled points in control loops shall be hardwired to the controller to which the controlled device is wired and in which the control loop shall reside.

D. Temperature Sensors

1. Room temperature sensors and thermostats shall be installed with back plate firmly secured to the wall framing or drywall anchors.

   a. For sensors mounted in exterior walls or columns, use a back plate insulated with foam and seal all junction box openings with mastic sealant.

   b. For sensors on exposed columns, use Wiremold or equal enclosures that are the smallest required to enclose wiring (e.g. Wiremold 400 BAC or equal) and Wiremold or equal junction boxes that are the narrowest required to enclose the temperature sensor and wiring connections (e.g. Wiremold 2348S/51 or equal). Color or raceway and boxes shall be per the architect; submit for approval prior to installation.

2. All wires attached to sensors shall be air sealed in their raceways or in the wall to stop air transmitted from other areas affecting sensor readings.

3. Flexible averaging sensors shall be installed in a serpentine manner vertically across duct. Each bend shall be supported with a capillary clip. Where located in front of filters (such as mixed air sensors), access for filter removal shall be maintained.

4. Rigid averaging sensors shall be installed in the centerline of the duct from the side or bottom of the duct.

5. Temperature sensors downstream of coils shall be located as far from the coil fins as possible, 6 inches minimum. Temperature sensors upstream of coils shall be a minimum of 6 inches away from the coil fins. No part of the sensor or its support elements or conduit shall be in contact with the coil, coil framing or coil support elements. Discharge temperature sensors on VAV boxes shall be mounted as far from the coil as possible but

upstream of the first diffuser with the probe located as near as possible to the center of the duct both vertically and horizontally.

6. For sensors specified to be calibrated using a dry well bath (see points list), install sensors with a sufficient wiring/flexible conduit lead that sensor may be removed from well or duct and placed in an ice bath or dry well for calibration. The spare wiring/flexible conduit shall be no less than 3 feet in length.

7. All pipe-mounted temperature sensors shall be installed in wells. For small piping, well shall be installed in an elbow into pipe length. Install the sensor in the well with a thermal-conducting grease or mastic. Use a closed-cell insulation patch that is integrated into the pipe insulation system to isolate the top of the well from ambient conditions but allow easy access to the sensor. Install a test plug adjacent to all wells for testing and calibration.

8. Unless otherwise noted on Drawings or Points List, temperature sensors/thermostats, humidity sensors/humidistats, CO_2 sensors, and other room wall mounted sensors shall be installed at same centerline elevation as adjacent electrical switches, 4 feet above the finished floor where there are no adjacent electrical switches, and within ADA limitations.

9. Unless otherwise noted on Drawings or Points List, install outdoor air temperature sensors on north wall where they will not be influenced by building exhaust, exfiltration, or solar insolation. Do not install near intake or exhaust air louvers.

10. Slab Temperature Sensors

    a. Mount sensor in receptacle box flush with floor top and accessible from floor for ready access and replacement of sensor.

    b. Mount sensor in a thermowell with thermal-conducting grease or mastic; direct burial of sensor in slab shall not be acceptable.

    c. Locate thermowell equidistant between embedded hydronic tubing, a minimum of 1 inch deep and no deeper than the hydronic tubing embedded in the slab.

    d. Wiring from receptacle box shall be in conduit to wall or other interstitial space from which signal wiring can run to controller. Secure conduit before slab is poured.

E. Differential Pressure Sensors

1. Supply Duct Static Pressure

    a. Mount transmitter in temperature control panel near or in BAS panel to which it is wired.

    b. Low pressure port of the pressure sensor

        1) Pipe to either

            a) Building pressure (high) signal of the building static pressure transmitter.

b) Open to a conditioned space inside the building

c) Open to the BAS panel in which the DPT is mounted provided the panel is inside the building envelope and not in an air plenum.

c. High-pressure port of the pressure sensor

1) Pipe to the duct using a static pressure tip located as indicated on Drawings; if no location is indicated, locate at end of duct riser or main as far out in the system as possible but upstream of all smoke and fire dampers.

2) Install pressure tips securely fastened with tip facing upstream in accordance with manufacturer's installation instructions.

2. Return Fan Discharge Plenum Pressure

a. Mount transmitter in temperature control panel near or in BAS panel to which it is wired.

b. Low pressure port of the pressure sensor

1) Pipe to either

a) Building pressure (low) signal of the building static pressure transmitter.

b) Separate ambient static pressure probe located on the outside of the relief damper through a high-volume accumulator or otherwise protected from wind fluctuations.

c. High-pressure port of the pressure sensor

1) Pipe to the duct using a static pressure tip located at the discharge of the return fan.

2) Install pressure tips securely fastened with tip facing upstream in accordance with manufacturer's installation instructions.

3. Building Static Pressure

a. Mount transmitter in temperature control panel near or in BAS panel to which it is wired.

b. Low pressure port of the pressure sensor

1) Pipe to the ambient static pressure probe located on the outside and at high point of the building through a high-volume accumulator or otherwise protected from wind fluctuations.

c. High-pressure port of the pressure sensor

1) Pipe to either

a) Behind a BAS temperature sensor cover in an interior zone (provided sensor has openings to allow ambient air to freely flow through it)

b) Wall plate sensor or wall/ceiling probe sensor as scheduled

2) Do not locate near elevators, exterior doors, atria, or (for ceiling sensor applications) near diffusers.

4. Filter Differential Pressure

a. Install static-pressure tips upstream and downstream of filters with tips oriented in direction of flow. If there is a Magnehelic gauge installed by the AHU manufacturer, it may be removed and discarded with its pressure tips used for the DPT provided the DPT has an LCD so it can double as a visual gauge.

b. Mount transmitter on outside of filter housing or filter plenum in an accessible position with LCD display clearly visible. This sensor is used in lieu of an analog gauge and thus must be readily viewable.

5. Minimum Outdoor Air Damper Differential Pressure

a. Install plenum static-pressure sensors upstream and downstream of minimum outdoor air damper in a location where air velocity is minimal.

b. Mount transmitter on inside or outside of economizer plenum (whichever is most accessible while out of weather) in an accessible position with LCD display clearly visible.

6. High/Low Static Pressure Safeties

a. High static

1) Install DPS-2 on side of supply air duct in accessible location.

2) High port shall be open to supply air duct downstream of fan.

3) Reference low port pressure shall be that at DP location.

b. Low static

1) Install DPS-2 inside or outside of mixed air plenum whichever is most accessible.

2) Low port shall be open to mixed air plenum.

3) Reference high port pressure shall be pressure on other side of mixed air plenum with the highest pressure, e.g. ambient pressure for systems with relief fans or non-powered relief, or relief air plenum for systems with return fans.

7. Underfloor Plenum Pressure

a. Mount transmitter under floor below low-pressure port location.

b. Low-pressure port of the pressure sensor: Pipe to either

1) Behind associated BAS temperature sensor cover (provided sensor has openings to allow ambient air to freely flow through it)

2) Wall plate sensor located adjacent to associated temperature sensor

c. High pressure port of the pressure sensor: open to plenum below associated temperature sensor. Do not locate near plenum supply outlet where velocity pressure can affect plenum pressure reading.

8. All pressure transducers, other than those controlling VAV boxes, shall be located where accessible for service without use of ladders or special equipment. If required, locate in field device panels and pipe to the equipment monitored or ductwork.

9. The piping to the pressure ports on all pressure transducers (both air and water) shall contain a capped test port located adjacent to the transducer.

10. Piping differential pressure transducers shall have one of the following:

a. Five valve manifold, brass, two valves to allow removal of sensor without disrupting the hydronic system, an equalizing valve to allow the sensor to be zeroed and to prevent sensor from experiencing full static (as opposed to differential), and two valves used as air vents that also can be used as test plugs for calibration.

b. For sensors using two separate sensors, install test plugs on each connection for calibration and also used as vents.

F. Flow Switches: Install per manufacturer’s instructions.

G. Current Switches and Current Transformers for Motor Status Monitoring

1. For CTs, create a software binary point for fan status triggered at a setpoint determined below and ~10% deadband.

2. Adjust the setpoint so that it is below minimum operating current and above motor no load current. For fans with motorized discharge dampers, adjust so that fan indicates off if damper is closed while fan is running. For pumps, adjust so that pump indicates off if valve is closed while pump is running.

H. Airflow Measuring Stations: Install per manufacturer’s recommendations for unobstructed straight length of duct both upstream and downstream of sensor, except those installations specifically designed for installation in fan inlet. For installations in fan inlets, provide on both inlets of double inlet fans and provide inlet cone adapter as recommended by AFMS manufacturer.

I. Fluid Flow Meters: Install per manufacturer’s recommendations for unobstructed straight length of pipe both upstream and downstream of sensor. Commission per the manufacturer’s startup and commissioning recommendations. Complete all manufacturer's startup documentation and include this in prefunctional commissioning report.

J. Wind Anemometer

1. Mount to mast that terminates ***30 feet*** above the ***main roof***.

2. Secure to the ***west wall of the penthouse at column lines 06 and C.5***.

K. Window Switches

1. Wiring

a. All wiring concealed in mullions and wall cavity to the extent possible. Review wiring routing details in mullions with window manufacturer.

b. Wiring that cannot be enclosed in mullions and walls shall be installed in Wiremold; location shall be reviewed and approved by College prior to installation.

2. Where there is more than one switch in a zone, wire in series so that windows are indicated as open when any window is open and indicated as closed when all are closed.

L. Water Leak Detector

1. Adjust leak detection level per manufacturer's recommendations as follows:

a. Where located in a secondary drain pan or other location where water is not expected to be present (i.e. any water indicates an alarm), adjust the water level to be ~zero inches above the pan.

b. Where located in the primary drain pan or other location where water is expected to be present (i.e. only a high water level indicates an alarm), adjust the water level to be just below the overflow pipe or other high water level indicator.

M. Refrigerant Monitor

1. Meet all requirements of Chapter 11 of the CMC.

2. Monitor Installation and Configuration

a. Install in accordance with the manufacturer's instructions.

b. Piping (for pumped sample draw type): Materials and installation shall be as per pneumatic control piping.

c. Locate sample ports in likely locations for refrigerant leaks from chillers, one port per chiller. Locate port in accordance with chiller manufacturer installation instructions. Where these instructions do not recommend a location, locate port 18 inches off the floor adjacent to the chiller on the side closest to the exhaust intake and furthest from the makeup air supply.

d. Alarm Configuration

1) For each refrigerant in room, set the three refrigerant monitor alarm setpoints as follows:

	Caution (Leak)	Warning (Spill)	Alarm (Evacuate)
Action	Display	Display Horn Strobe	Display Horn Strobe Exhaust Fan
Reset	Auto	Manual	Manual
Refrigerant	Setpoint (ppm)		
1233zd(E)	50	300	600
11	40	100	110
12	50	300	700
22	50	300	700
123	25	35	50
134a	50	300	700
404A	50	300	700
407C	50	300	700
410A	50	300	700

2) Manual reset shall be only possible from panel face within chiller room.

3. Alarm Controls

a. Inside the chiller room, provide:

1) Visual and audible alarms. Alarms may be integral to the refrigerant monitor.

b. Outside each chiller room entrance, provide:

1) Visual and audible alarms

c. Outside the primary chiller room entrance, provide:

1) Visual and audible alarms

2) Manual fan-on break-glass

3) Manual emergency-chiller-off break-glass switch

4) Fan on (green) and off (red) status lights wired to current switch to indicate fan status

d. Hardwire refrigerant alarm contact and break-glass switch to start exhaust fan (on high speed if motor is multi-speed). The BAS shall not be used for this purpose.

e. Also wire manual wind-up timer on-off switch inside primary entry to start fan (for comfort ventilation) on low speed if motor is multi-speed. Provide label at switch indicating “Ventilation Fan”.

f. Hardwire a contact that indicates emergency- chiller-off break-glass manual alarm to the BAS. Program BAS to stop all refrigeration equipment in room when contact indicates alarm.

g. Generate trouble alarm when monitor detects a malfunction. Trouble alarm shall not initiate horn and strobe.

N. Actuators

1. Type: All actuators shall be electric.

2. Mount and link control damper actuators per manufacturer's instructions.

3. Dampers

a. To compress seals when spring-return actuators are used on normally closed dampers, power actuator to approximately 5° open position, manually close the damper, and then tighten the linkage, or follow manufacturer's instructions to achieve same effect.

b. Check operation of damper-actuator combination to confirm that actuator modulates damper smoothly throughout stroke to both open and closed positions.

c. Provide all mounting hardware and linkages for actuator installation.

4. Control Valves: Install so that actuators, wiring, and tubing connections are accessible for maintenance. Where possible, mount the valve so that the position indicator is visible from the floor or other readily accessible location. However, do not install valves with stem below horizontal or down. The preferred location for the valve and actuator is on lowest point in the valve train assembly for ease of access and inspection. If this is on the coil supply piping, the control valve may be located there even if schematics (and standard practice) show valves located on the coil return piping. This comment applies to both 2−way valves and 3-way valves (which would become diverting valves rather than mixing valves in this location).

O. Laboratory Fume Hoods:

1. See Section 233600 Air Terminal Units for fume hood air valves, hood monitors, and sash position sensors.

2. Install fume hoof monitor in knock-out opening provided with hood.

3. Install sash sensors on each VAV fume hood. Reel-type sash sensors and their stainless steel cables shall be hidden from view. Bar-type sash sensors shall be affixed to the individual sash panels.

3.12 SOFTWARE INSTALLATION

A. System Configuration

1. Thoroughly and completely configure BAS system software, supplemental software, network software etc. on OWS, POTs, and servers.

B. Point Structuring and Naming

1. The intent of this Paragraph is to require a consistent means of naming points across the BAS. The following requirement establishes a standard for naming points and addressing Buildings, Networks, Devices, Instances, etc.

2. Point Summary Table

a. The term “Point” includes all physical I/O points, virtual points, and all application program parameters.

b. With each schematic, provide a Point Summary Table listing

1) Building number and abbreviation

2) System type

3) Equipment type

4) Point suffix

5) Full point name (see Point Naming Convention Paragraph)

6) Point description

7) Ethernet backbone network number

8) Network number

9) Device ID

10) Device MAC address

11) Object ID (object type, instance number)

12) Engineering units

13) Device make and model number; include range of device if model number does not so identify.

14) Device physical location description; include floor and column line intersection to one decimal place (for example line 6.2 and line A.3).

c. Point Summary Table shall be provided in both hard copy and in a relational database electronic format (ODBC-compliant).

d. Coordinate with the College’s representative and compile and submit a proposed Point Summary Table for review prior to any object programming or Project startup.

e. The Point Summary Table shall be kept current throughout the duration of the Project by the Contractor as the Master List of all points for the Project. Project closeout documents shall include an up-to-date accurate Point Summary Table. The Contractor shall deliver to the College the final Point Summary Table prior to final acceptance of the system. The Point Summary Table shall be used as a reference and guide during the commissioning process.

3. Point Naming Convention

a. All point names shall adhere to the format as established below, unless otherwise agreed to by the College. New categories and descriptors may be created with approval of the College.

b. Format:

1) Building.Category.System.EquipmentTag.Component.Property.

2) Example: 001.HVAC.Heatplant.B-1.HWS.Temperature

<table>
<tr><th>Building</th><th>Category</th><th>System</th><th>Equipment Tag</th><th>Component</th><th>Property</th><th>Typical units</th></tr>
<tr><td rowspan="4">Building number</td><td>ELCT</td><td>Lighting
Plug
Generator
Misc</td><td rowspan="4">(from equipment schedules)</td><td rowspan="4">SWITCH
PHOTO
CB

CWS
CWR
HWS
HWR
CHWS
CHWR
OA
SA
RA
EA

GAS
FLUID</td><td rowspan="4">Command
Status
Light
Power
Voltage
Current
ValvePos
DamperPos
Temperature
Humidity
Pressure
Flow
Energy
Speed
Signal</td><td rowspan="4">On/off
On/off
Footcandles
Watts
Volts
Amps
%open
%open
°F
%RH
Psig, “H_2O
Cfm, gpm
Btu
%, Hz
%</td></tr>
<tr><td>HVAC</td><td>Airhandling
Exhaust
Heatplant
Coolplant
Misc</td></tr>
<tr><td>PLMB</td><td>Domwater
Air
Natgas
N2
O2
Irrigation
Waste
Misc</td></tr>
<tr><td>MISC</td><td>Weather</td></tr>
</table>

4. Device Addressing Convention

a. BACnet network numbers and Device Object IDs shall be unique throughout the network.

b. All assignment of network numbers and Device Object IDs shall be coordinated with the College to ensure there are no duplicate BACnet device instance numbers.

c. Each Network number shall be unique throughout all facilities and shall be assigned in the following manner: VVVNN, where: VVV = 0-999 for BACnet Vendor ID, NN = 00 - 99 for building network.

d. Each Device Object Identifier property shall be unique throughout the system and shall be assigned in the following manner: VVVNNDD , where: VVV = number 0 to 999 for BACnet Vendor ID , NN = 00 - 99 for building network, DD = 01-99 for device address on a network.

e. Coordinate with the College or a designated representative to ensure that no duplicate Device Object IDs occur.

f. Alternative Device ID schemes or cross-project Device ID duplication if allowed shall be approved before Project commencement by the College.

5. I/O Point Physical Description

a. Each point associated with a hardware device shall have its BACnet long-name point description field filled out with:

1) The device manufacturer and model number. Include range of device if model number does not so identify.

2) For space sensors, include room number in which sensor is located.

C. Point Parameters

1. Provide the following minimum programming for each analog input

a. Name

b. Address

c. Scanning frequency or COV threshold

d. Engineering units

e. Offset calibration and scaling factor for engineering units

f. High and low value reporting limits (reasonableness values), which shall prevent control logic from using shorted or open circuit values.

g. Default value to be used when the actual measured value is not reporting. This is required only for points that are transferred across the Primary or Secondary networks and used in control programs residing in control units other than the one in which the point resides. Events causing the default value to be used shall include failure of the control unit in which the point resides or failure of any network over which the point value is transferred.

2. Provide the following minimum programming for each analog output

a. Name

b. Address

c. Engineering units

d. Offset calibration and scaling factor for engineering units

e. Output Range

f. Default value to be used when the normal controlling value is not reporting.

3. Provide the following minimum programming for each digital input

a. Name

b. Address

c. Engineering units (on/off, open/closed, freeze/normal, etc.)

d. Debounce time delay

e. Message and alarm reporting as specified

f. Reporting of each change of state, and memory storage of the time of the last change of state

g. Totalization of on-time (for all motorized equipment status points), and accumulated number of off-to-on transitions.

4. Provide the following minimum programming for each digital output

a. Name

b. Address

c. Output updating frequency

d. Engineering units (on/off, open/closed, freeze/normal, etc.)

e. Direct or Reverse action selection

f. Minimum on-time

g. Minimum off-time

h. Status association with a DI and failure alarming (as applicable)

i. Reporting of each change of state, and memory storage of the time of the last change of state.

j. Totalization of on-time (for all motorized equipment status points), and accumulated number of off-to-on transitions.

k. Default value to be used when the normal controlling value is not reporting.

D. Site-Specific Application Programming

1. All site specific application programming shall be written in a manner that will ensure programming quality and uniformity. Contractor shall ensure:

    a. Programs are developed by one programmer, or a small group of programmers with rigid programming standards, to ensure a uniform style.

    b. Programs for like functions are identical, to reduce debugging time and to ease maintainability.

    c. Programs are thoroughly debugged before they are installed in the field.

2. Massage and tune application programming for a fully functioning system. It is the Contractor’s responsibility to request clarification on sequences of operation that require such clarification.

3. All site-specific programming shall be fully documented and submitted for review and approval

    a. Prior to downloading into the panel (see Submittal Package 2, Paragraph 1.8.)

    b. At the completion of functional performance testing, and

    c. At the end of the warranty period (see Warranty Maintenance, Paragraph 1.13).

4. All programming, graphics and data files must be maintained in a logical system of directories with self-explanatory file names. All files developed for the Project will be the property of the College and shall remain on the workstations/servers at the completion of the Project.

E. Graphic Screens

1. All site specific graphics shall be developed in a manner that will ensure graphic display quality and uniformity among the various systems.

2. Schematics of MEP systems

    a. Schematics shall be 2-D or 3-D and shall be based substantially on the schematics provided on Drawings.

    b. All relevant I/O points and setpoints being controlled or monitored for each piece of equipment shall be displayed with the appropriate engineering units. Include appropriate engineering units for each displayed point value. Verbose names (English language descriptors) shall be included for each point on all graphics; this may be accomplished by the use of a pop-up window accessed by selecting the displayed point with the mouse.

    c. Animation or equipment graphic color changes shall be used to indicate on/off status of mechanical components.

d. Indicate all adjustable setpoints and setpoint high and low limits (for automatically reset setpoints), on the applicable system schematic graphic or, if space does not allow, on a supplemental linked-setpoint screen.

3. Displays shall show all points relevant to the operation of the system, including setpoints.

4. The current value and point name of every I/O point and setpoint shall be shown on at least one graphic and in its appropriate physical location relative to building and mechanical systems.

5. Show weather conditions (local building outside air temperature and humidity) in the upper left hand corner of every graphic.

6. CAD Files: The contract document drawings will be made available to the Contractor in AutoCAD format upon request for use in developing backgrounds for specified graphic screens, such as floor plans and schematics. However the College does not guarantee the suitability of these drawings for the Contractor’s purpose.

7. Provide graphics for the following as a minimum

    a. Site homepage: Background shall be a campus map, approximately to scale. Include links to each building, central plant, etc.

    b. Building homepage: Background shall be a building footprint, approximately to scale, oriented as shown on the campus homepage architectural Drawings. Include links to each floor and mechanical room/area, and to summary graphics described below. Include real-time site utility data such as building electrical demand, domestic cold water flow, and natural gas demand shown roughly on the map where the utilities connect to the site.

    c. Electricity demand limiting

        1) Demand limit. Include entries for sliding window interval and a table of Off-Peak, On-Peak or Partial-Peak demand time periods, both Summer and non-Summer, with three adjustable demand level limits for each and adjustable deadband.

        2) Electricity demand calculation. For each month, show actual peak kW and kWh for each time-of-day rate period. Show side-by-side as month-this-year and month-last-year, and month-to-date and year-to-date data.

    d. Natural gas demand page. For each month, show actual peak therms/hr and therms for each rate period. Show side-by-side as month-this-year and month-last-year, and month-to-date and year-to-date data. Include adjustable conversion of gas volumetric flow rate to therms.

    e. Each occupied floor plan, to scale

        1) HVAC: Floor plan graphics shall show heating and cooling zones throughout the buildings in a range of colors, which provide a visual display of temperature relative to their respective setpoints. The colors shall be updated dynamically as a

zone's actual comfort condition changes. In each zone, provide links to associated terminal equipment.

2) CO (garage levels): Floor plan graphic showing CO sensors throughout the garage with colors mapped to the CO levels in the area covered by each sensor. The colors shall be updated dynamically as the area's actual CO level changes. For each sensor, provide a link to a graphic for the fan and sensor group associated with that sensor.

3) If multiple floor plans are necessary to show all areas, provide a graphic building key plan. Use elevation views or plan views as necessary to graphically indicate the location of all of the larger scale floor plans. Link graphic building key plan to larger scale partial floor plans. Provide links from each larger scale graphic floor plan screen to the building key plan and to each of the other graphic floor plan screens.

f. Each equipment floor/area plan: To scale, with links to graphics of all BAS controlled/monitored equipment.

g. Each air handler and fan-coil: Provide link to associated HW and CHW plants where applicable.

h. Each trim & respond reset: Next to the display of the setpoint that is being reset, include a link to page showing all trim & respond points (see Section 259000) plus the current number of requests, current setpoint, and status indicator point with values "trimming," "responding," or "holding." Include a graph of the setpoint trend for the last 24 hours. Trim & respond points shall be adjustable from the graphic except for the associated device.

i. Each zone terminal

1) See Sample Graphics – VAV Reheat Zone

2) See Sample Graphics – VAV Cooling-Only Zone

3) Include a non-editable graphic (picture) showing the design airflow setpoints from the design drawings adjacent to the editable airflows setpoints. The intent is that the original setpoints be retained over time despite "temporary" adjustments that may be made over the years.

j. Each lab zone terminal:

1) Provide link to associated air handling unit where applicable and to floor plan where terminal is located.

2) Include supply air temperature from AHU serving terminal unit.

3) Include a non-editable graphic (picture) showing the design airflow setpoints from the design drawings adjacent to the editable airflows setpoints. The intent is that the original setpoints be retained over time despite "temporary" adjustments that may be made over the years.

4) Include room air change rate calculated from zone volume and either supply airflow rate if differential is positive, or exhaust airflow rate if differential is negative.

k. Electrical power monitoring system: Show a schematic of the electrical system based on one-line diagrams with meter current kW reading and month-to-date kWh shown in actual locations. Show side-by-side kWh and peak demand as month-this-year and month-last-year, and month-to-date and year-to-date data. Power flow shall change on the diagram (by changing line color or width) to show which power line is active.

l. Water meters: Show side-by-side gallons and peak demand gpm as month-this-year and month-last-year, and month-to-date and year-to-date data.

m. Central plant equipment including chilled water system, cooling tower system, hot water system, steam system, generators, etc.: The flow path shall change on the diagram (by changing piping line color or width) to show which piping has active flow into each boiler, chiller, tower, etc. as valve positions change.

n. Summary graphics: Provide a single text-based page (or as few as possible) for each of the following summary screens showing key variables listed in columns for all listed equipment. Include hyperlinks to each zone imbedded in the zone tag:

1) Air handling units: operating mode; on/off status; supply air temperature; supply air temperature setpoint; fan speed; duct static pressure; duct static pressure setpoint; outdoor air and return air damper position; coil valve positions; etc. (all key operating variables); Cooling CHWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Heating HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier (if HW coil)

2) Zone Groups

a) Separate zone terminal summary for each Zone Group.

b) See Sample Graphics –Zone Group Summary

3) VAV Zone terminal units: operating mode; airflow rate; airflow rate setpoint; zone temperature; active heating setpoint; active cooling setpoint; damper position; HW valve position (reheat boxes); supply air temperature (reheat boxes); supply air temperature setpoint (reheat boxes); CO2 concentration and CO2 loop output (where applicable); Fan start/stop command, speed, and status (fan-powered); Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Cooling SAT Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Heating HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier (HW reheat); Heating Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier (dual duct); Heating SAT Reset current requests, cumulative %-request-hours, and request Importance Multiplier (dual duct).

4) Laboratory Supply Terminals: operating mode; airflow rate; airflow rate setpoint; zone temperature; active heating setpoint; active cooling setpoint; damper position; HW valve position; ***CHW valve position;*** supply air temperature; supply air temperature setpoint; Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Cooling SAT Reset current requests, cumulative %-request-hours, and request Importance Multiplier; HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier; ***CHWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier***.

1) Laboratory Exhaust Terminals: differential airflow rate, differential airflow rate setpoint; general exhaust airflow rate, airflow rate setpoint, damper position, Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; hood exhaust airflow rate, airflow rate setpoint, damper position, Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; any hood alarm.

2) Fan-coil units: operating mode; zone temperature; active heating setpoint; active cooling setpoint; supply air temperature; supply air temperature setpoint (where applicable); fan status; fan speed (where applicable); HW/CHW valve position; Cooling CHWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Heating HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier.

3) AC and Heat Pumps: operating mode; zone temperature; active heating setpoint; active cooling setpoint; supply air temperature; fan status; fan speed (where applicable); Cooling stages; Heating stages.

4) UFT Zone terminal units: operating mode; fan speed (expressed as percentage of cooling maximum speed); zone temperature; active heating setpoint; active cooling setpoint; supply air temperature (reheat boxes); supply air temperature setpoint (reheat boxes); fan status; HW valve position; CO_2 concentration; CO_2 loop output; Cooling SAT Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Heating HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier.

5) Lab Zone terminal units: operating mode; supply airflow rate; supply airflow rate setpoint; zone temperature; active heating setpoint; active cooling setpoint; supply air temperature; supply air temperature setpoint; fume hood status; exhaust airflow rate; Supply Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Exhaust Static Pressure Reset current requests, cumulative %-request-hours, and request Importance Multiplier; Cooling SAT Reset current requests, cumulative %-request-hours, and request Importance Multiplier; CHWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier; HWST Reset current requests, cumulative %-request-hours, and request Importance Multiplier.

6) Electrical meters and switches: Volts, current, kW, switch positions.

o. For all equipment with runtime alarms specified, show on graphic adjacent to equipment the current runtime, alarm setpoint (adjustable), alarm light, date of last runtime counter reset, and alarm reset/acknowledge button which resets the runtime counter.

p. For all equipment with lead/lag or lead/standby operation specified, show on graphic adjacent to equipment the current lead/lag order and manual buttons or switches to allow manual lead switching by the operator per Section 259000 Building Automation Sequences of Operation.

q. For all controlled points used in control loops, show the setpoint adjacent to the current value of the controlled point.

r. All other BAS controlled/monitored equipment.

s. On all system graphics, include a “note” block that allows users to enter comments relevant to system operation.

t. All equipment shall be identified on the graphic screen by the unit tag as scheduled on the drawings.

F. Alarm Configuration

1. Program alarms and alarm levels per Sequence of Operations.

2. Each programmed alarm shall appear on the alarm log screen and shall be resettable or acknowledged from those screens. Equipment failure alarms shall be displayed on the graphic system schematic screen for the system that the alarm is associated with (for example, fan alarm shall be shown on graphic air handling system schematic screen). For all graphic screens, display values that are in a Level 1 or 2 condition in a red color, Level 3 and higher alarm condition in a blue color, and normal (no alarm) condition in a neutral color (black or white).

3. For initial setup, Contractor shall configure alarms as follows:

	Level 1	**Level 2**	**Level 3**	**Level 4**
Criticality	Critical	Not Critical	Not Critical	Not Critical
Acknowledgement	Required	Required	Not Required	Not Required
Acknowledgement of Return to Normal	Not Required	Not Required	Not Required	Not Required
Print to alarm printer	Y	Y	N	N
Email to building engineer(s)	Y	Y	Y	N
SMS text to building engineer(s)	Y	Y	N	N
Pop-up dialog box on OWS	Y	Y	N	N
Remove from alarm log	After Acknowledged	After Acknowledged	After 2 weeks	After 2 weeks

3.13 SEQUENCES OF OPERATION

A. See Section 259000 Building Automation Sequences of Operation.

3.14 SYSTEM COMMISSIONING

A. Sequencing. The following list outlines the general sequence of events for submittals and commissioning:

1. Submit Submittal Package 0 (Qualifications) and receive approval.

2. Submit Submittal Package 1 (Hardware and Shop Drawings) and receive approval.

3. Initiate installation of BAS hardware, devices and wiring.

4. Develop point database and application software.

5. Simulate sequencing and debug programming off-line to the extent practical.

6. Submit Submittal Package 2 (Programming and Graphics) and receive approval.

7. Complete installation of BAS hardware, devices and wiring.

8. Install point database and application software in field panels.

9. Submit Submittal Package 3 (Pre-Functional Test Forms) and receive approval.

10. Perform BAS Pre-functional Tests (start up, calibration and tuning) and submit completed forms as Submittal Package 4 (Pre-Functional Test Report) for approval.

11. Receive BAS Pre-functional Test Report approval and approval to schedule Functional Tests.

12. Field test application programs prior to functional testing.

13. Submit Package 5 (Post-Construction Trend Points List) in format specified for review and approval.

14. Receive approval of successful Trend Log configuration, or reconfigure as required.

15. Prepare and initiate commissioning Trend Logs.

16. Perform and record functional tests and submit Submittal Package 6 (Functional Test Report) for approval.

    a. Some tests may not be possible due to weather conditions. These tests may be deferred to post-occupancy period.

17. Assist in TAB tests and determining setpoints as specified in Section 230593 Testing, Adjusting and Balancing.

18. Assist in Title 24 Acceptance Testing as specified in Section 230800 Mechanical System Commissioning.

19. Submit Package 7 (Training Materials) and receive approval.

20. Receive BAS Functional Test Report approval and approval to schedule Demonstration Tests.

21. Perform Demonstration Tests to Commissioning Provider and College's Representatives and submit Demonstration Test Report.

22. Receive acceptance of Demonstration Tests.

23. Train College personnel on BAS operation and maintenance.

24. Substantial Completion

25. Submit Package 8 (Post-Construction Trend Logs) in format specified for review and approval.

26. Receive approval of successful Trend Log tests, or retest as required.

27. Complete all items in Completion Requirements per Paragraph 1.9B.

28. Provide administration level password access to the College.

29. Final Acceptance

30. Begin Warranty Period.

31. Prepare and initiate continuous Trend Logs per Paragraph 2.12A.4.

32. Perform deferred alternate season functional tests (see Paragraph 16.a and H.3.a) and submit amended Functional Test Report for approval.

33. Receive amended BAS Functional Test Report approval.

34. Update all software as specified.

35. End of Warranty Period

B. Assist Commissioning Provider/Coordinator as specified in Section 019100 Commissioning, including attending commissioning meetings.

C. Coordinate with Work specified in Section 230800 Mechanical Commissioning and Division 26 Electrical Commissioning.

D. Pre-functional tests

1. General

a. Inspect the installation of all devices. Review the manufacturer's installation instructions and validate that the device is installed in accordance with them.

b. Verify proper electrical voltages and amperages, and verify that all circuits are free from faults.

c. Verify integrity/safety of all electrical connections.

d. Verify that shielded cables are grounded only at one end.

e. Verify that all sensor locations are as indicated on drawings and are away from causes of erratic operation.

2. Test Documentation

a. Prepare forms to document the proper startup of the BAS components.

b. All equipment shall be included on test forms including but not limited to

1) Wiring: End-to-end checkout of all wiring at terminations. Power to all controllers and actuators. Confirmation of emergency power where specified.

2) Digital Outputs: Proper installation, normal position, response to command at CU

3) Digital Inputs: Proper installation, device test, response at CU

4) Analog Outputs: Proper installation of devices, verification of maximum and minimum stroke.

5) Analog Inputs: Proper installation of sensors, calibration

6) Panels: Confirmation of location, power source (electrical circuit used), confirmation of emergency power where specified.

7) Alarms and Safeties: Verification of alarm routing to all specified devices and correct hierarchy. Example: confirm alarm routing to cell phones, email, servers, remote workstations. Confirm that appropriate alarm levels are routed to appropriate devices.

8) Loop Tuning: Document setting of P/I parameters for all loops, chosen setpoints, time delays, loop execution speed.

9) Network Traffic: Document speed of screen generation, alarm and signal propagation in system with all required commissioning trends active.

c. Each form shall have a header or footer where the technician performing the test can indicate his/her name and the date of the test.

d. Submit blank forms for approval in Submittal Package 3.

e. Complete work, document results on forms, and submit for approval as Submittal Package 4 (Pre-Functional Test Report).

3. Digital Outputs

a. Verify that all digital output devices (relays, solenoid valves, two-position actuators and control valves, magnetic starters, etc.) operate properly and that the normal positions are correct.

4. Digital Inputs

a. Adjust setpoints, where applicable.

1) For current switches used as status on fans, adjust current setpoint so that fan status is OFF when fan discharge damper (if present) is fully closed and when belt is broken (temporarily remove belt).

2) For current switches used as status on pumps, adjust current setpoint so that pump status is OFF when pump is dead-headed (temporarily close discharge valve).

3) For differential pressure sensors on pumps and fans, set so that status is on when pump operating with all valves open (out on its curve).

5. Analog Outputs

a. Verify start and span are correct and control action is correct.

b. Check all control valves and automatic dampers to ensure proper action and closure. Make any necessary adjustments to valve stem and damper blade travel.

c. Check all normal positions of fail-safe actuators.

d. For outputs to reset other manufacturer's devices (for example, chiller setpoint) and for feedback from them, calibrate ranges to establish proper parameters.

6. Analog Input Calibration

a. Sensors shall be calibrated as specified on the points list. Calibration methods shall be one of the following:

1) Factory: Calibration by factory, to standard factory specifications. Field calibration is not required.

2) Handheld: Field calibrate using a handheld device with accuracy meeting the requirements of Paragraph 2.9U.

b. The calibrating parameters in software (such as slope and intercept) shall be adjusted as required. A calibration log shall be kept and initialed by the technician indicating date and time, sensor and hand-held readings, and calibration constant adjustments and included in the Pre-functional Test Report.

c. Inaccurate sensors must be replaced if calibration is not possible.

7. Alarms and Interlocks

a. A log shall be kept and initialed by the technician indicating date and time, alarm/interlock description, action taken to initiate the alarm/interlock, and resulting action, and included in the Pre-functional Test Report.

b. Check each alarm separately by including an appropriate signal at a value that will trip the alarm.

c. Coordinate with Division 26 to test fire and life safety systems alarm contacts.

d. Interlocks shall be tripped using field contacts to check the logic, as well as to ensure that the fail-safe condition for all actuators is in the proper direction.

e. Interlock actions shall be tested by simulating alarm conditions to check the initiating value of the variable and interlock action.

8. Variable Frequency Drive Minimum Speed

a. Minimum speed for VFD-driven fans and pumps shall be determined in accordance with this Paragraph. Tests shall be done for each piece of equipment, except that for multiple pieces of identical equipment used for identical applications, only one piece of equipment need be tested with results applied to all. Note that for fans and pumps, there is no minimum speed required for motor cooling. Power drops with cube of speed, causing motor losses to be minimal at low speeds.

b. This work shall be done only after fan/pump system is fully installed and operational.

c. Determine minimum speed setpoint as follows:

1) Start the fan or pump.

2) Manually set speed to 6 Hz (10%) unless otherwise indicated in control sequences. For cooling towers with gear boxes, use 20% or whatever minimum speed is recommended by tower manufacturer.

3) Observe fan/pump in field to ensure it is visibly rotating.

a) If not, gradually increase speed until it is.

4) The speed at this point shall be the minimum speed setpoint for this piece of equipment.

5) Record minimum speeds in log and store in software point as indicated in Guideline 36.

9. Tuning

a. Tune all control loops to obtain the fastest stable response without hunting, offset or overshoot. Record tuning parameters and response test results for each control loop in the Pre-functional Test Report. Except from a startup, maximum allowable variance from set point for controlled variables under normal load fluctuations shall be as follows. Within 3 minutes of any upset (for which the system has the capability to respond) in the control loop, tolerances shall be maintained (exceptions noted)

Controlled Variable	Control Accuracy
Duct Pressure	±0.1 inches w.g.
Building and relief plenum	±0.01 inches w.g.
Airflow and water flow	±10%
Space Temperature	±1.5ºF
Condenser Water Temperature	±2ºF
Chilled Water Temperature	±1ºF
Hot Water Temperature	±3ºF
Duct Temperature	±2ºF
Water Differential Pressure	±1.5 psi
Others	±2 times reported accuracy

10. Interface and Control Panels

a. Ensure devices are properly installed with adequate clearance for maintenance and with clear labels in accordance with the Record Drawings.

b. Ensure that terminations are safe, secure and labeled in accordance with the Record Drawings.

c. Check power supplies for proper voltage ranges and loading.

d. Ensure that wiring and tubing are run in a neat and workman-like manner, either bound or enclosed in trough.

e. Check for adequate signal strength on communication networks.

f. Check for standalone performance of controllers by disconnecting the controller from the LAN. Verify the event is annunciated at Operator Interfaces. Verify that the controlling LAN reconfigures as specified in the event of a LAN disconnection.

g. Ensure that buffered or volatile information is held through power outage.

h. With all system and communications operating normally, sample and record update and annunciation times for critical alarms fed from the panel to the Operator Interface.

i. Check for adequate grounding of all BAS panels and devices.

11. Operator Interfaces

a. Verify that all elements on the graphics are functional and are properly bound to physical devices or virtual points, and that hot links or page jumps are functional and logical.

b. Verify that the alarm ***printing,*** logging, paging, emailing etc. are functional and per requirements.

E. Testing, Adjusting, and Balancing (TAB) Coordination

1. Coordinate with Work performed under Section 230593 Testing, Adjusting, and Balancing. Some balancing procedures require the BAS to be operational and require Contractor time and assistance.

2. Calibration Software

   a. Software shall be provided free of charge on at least a temporary basis to allow calibration of terminal box airflow controls and other Work specified under Section 230593 Testing, Adjusting, and Balancing.

   b. Software shall be provided for installation on POT(s) provided by Others or Contractor shall loan a POT or handheld device with software installed for the duration of Work specified under Section 230593 Testing, Adjusting, and Balancing.

   c. Provide sufficient training to those performing Work specified under Section 230593 Testing, Adjusting, and Balancing to allow them to use the software for balancing and airflow calibration purposes. Contractor shall include a single training session for this purpose.

3. Setpoint Determination

   a. Perform pre-functional tests described in Paragraph 3.14D before assisting in setpoint determination.

   b. Coordinate with Work performed under Section 230593 Testing, Adjusting, and Balancing to determine fan and pump differential pressure setpoints, outdoor air damper minimum positions and DP setpoints, etc. as indicated in Section 230593 Testing, Adjusting and Balancing.

4. Coil Valve Leak Check

   a. Coordinate with Work performed under Section 230593 Testing, Adjusting, and Balancing to provide control valve leak check tests.

F. Cooling Tower Level Sensor

1. Coordinate with Work performed under Section 236500 Cooling Towers.

2. Test conditions

   a. All pumps off

   b. Towers filled to a level roughly between minimum level and overflow level, as specified by the tower manufacturer

   c. All equalizer isolation valves open

   d. Makeup water and bleed valves closed

3. Test and record

   a. Through the BAS, record current level sensor reading. ***(For LS-2, convert psi to inches of water in all BAS displays.)***

   b. Measure actual tower level inside the basin from the same point referenced in the tower manufacturer's level recommendations

   c. Calibrate level sensor to match actual reading

4. Configure tower level minimum alarm, maximum alarm, fill start level, and fill stop level setpoints in the BAS. These points shall be displayed and be adjustable from the cooling tower graphic.

G. Melink DCV Startup

1. A Factory-Authorized Service Representative shall perform DCV startup service including:

   a. Inspection of installed components to verify correct installation and operation.

   b. Programming of system parameters for proper detection of cooking conditions.

   c. Programming of system parameters for proper operation of control input/output points.

   d. Verification of DCV controller functionality.

2. Results shall be captured in a written report, submitted for approval.

H. Functional Tests

1. Test schedule shall be coordinated with the Commissioning Provider, Commissioning Coordinator, and College's Representative.

2. Functional tests may be witnessed by College's Representative at the College's option.

3. All approved Functional Tests shall be conducted by the Contractor with results confirmed and signed by the Contractor's start-up technician.

   a. ***Seasonal Impacts: It shall be assumed that not all tests will be possible due to weather conditions. Those that are not possible shall be deferred until the next season, performed during the warranty period***.

4. Test documentation

   a. College's Representatives will prepare functional testing forms after Submittal Package 2 has been reviewed and approved. Tests will be designed to test all sequences in a formal manner with simulations and expected outcomes.

b. Review tests and recommend changes that will improve ease of testing or avoid possible system damage, etc. and provide to College's Representative.

c. Complete work, document results on forms, and submit for approval as Submittal Package 6 Functional Test Report. Tutorials for using the functional test Excel workbook can be found here.

I. Demonstration Test

1. Demonstration tests consist of a small representative sample of functional tests and systems randomly selected by the Commissioning Provider. Tests will be designed to occur over no longer than ***2*** working days.

2. Schedule the demonstration with the Commissioning Provider and College's Representative at least 1 week in advance. Demonstration shall not be scheduled until the Functional Test Report has been approved.

3. The Contractor shall supply all personnel and equipment for the demonstration, including, but not limited to, instruments, ladders, etc. Contractor-supplied personnel shall be those who conducted the Functional tests or who are otherwise competent with and knowledgeable of all project-specific hardware, software, and the HVAC systems.

4. The system will be demonstrated following procedures that are the same or similar to those used in the Pre-Functional and Functional Tests. The Commissioning Provider will supply the test forms at the site at the start of the tests.

5. Demonstration tests may be witnessed by College's Representative at the College's option.

6. Contractor shall conduct tests as directed by and in the presence of the Commissioning Provider and complete test forms. Commissioning Provider will document the test results as the Demonstration Test Report after tests are complete.

7. Demonstration Tests shall be successfully completed and approved prior to Substantial Completion.

J. Trend Log Tests

1. Trends shall be fully configured to record and store data to the server for the points and at the interval listed in Paragraph 2.11 as follows:

a. Commissioning: Configure trends prior to functional testing phase. Retain configuration until post-construction commissioning trend review has been completed successfully and accepted by the College's representative. Trends shall be deactivated after acceptance.

b. Continuous: After system acceptance, configure trends for the purpose of long term future diagnostics. Configure trends to overwrite the oldest trends at the longest interval possible without filling the server hard disk beyond 80%.

2. Post-Construction Trend Test

a. Trend logging shall not commence until Demonstration Tests are successfully completed.

b. Hardware Points. Contractor shall configure points to trend as indicated in the Commissioning Trend column listed in Paragraph 2.11 points.

c. Software Points. Include the following in trends of systems and zones whose hardware points are being trended as called for above. Time interval shall be the same as associated hardware point.

   1) All setpoints and limits that are automatically reset, such as supply air temperature and fan static pressure setpoints, plus the points that are driving the reset, such as zone level cooling and static pressure requests

   2) All setpoints that are adjustable by occupants

   3) Outputs of all control loops, other than those driving a single AO point that is already being trended

   4) System mode points (e.g. Warm-up, Occupied, etc.)

   5) Global overrides such as demand shed signals

   6) Calculated performance monitoring points, such as chiller efficiency

d. Submit for review and approval by the Commissioning Provider a table of points to be trended along with trend intervals or change-of-value a minimum of 14 days prior to trend collection period, as Submittal Package 5.

e. Trends shall be uploaded to the CSS in data format specified in Paragraph 2.11C.3.

f. Trend logs of all points indicated above shall be collected for a ***3*** week Trend Period.

g. At the completion of the Trend Period, data shall be reviewed by the Contractor to ensure that the system is operating properly. If so, data shall be submitted to the College in an electronic format agreed to by the College and Contractor (such as flash drive or via direct access to the CSS via the internet) as Submittal Package 8.

h. Data will be analyzed by the Commissioning Provider.

i. The system shall be accepted only if the trend review indicates proper system operation without malfunction, without alarm caused by control action or device failure, and with smooth and stable control of systems and equipment in conformance with these specifications. If any but very minor glitches are indicated in the trends, steps f to h above shall be repeated for the same Trend Period until there is a complete Trend Period of error free operation.

j. After successfully completing the Post-Construction Trend Tests, the Contractor shall configure all points to trend as indicated in the Continuous Trend column listed in Paragraph 2.11 points list.

K. Remedial Work

1. Repair or replace defective Work, as directed by College's Representative in writing, at no additional cost to the College.

2. Restore or replace damaged Work due to tests as directed by College's Representative in writing, at no additional cost to the College.

3. Restore or replace damaged Work of others, due to tests, as directed by College's Representative in writing, at no additional cost to the College.

4. Remedial Work identified by site reviews, review of submittals, demonstration test, trend reviews, etc. shall be performed to the satisfaction of the College's Representative, at no additional cost to the College.

5. Contractor shall compensate College's Representatives and Commissioning Provider on a time and material basis at standard billing rates for any additional time required to witness additional demonstration tests or to review additional BAS trends beyond the initial tests, at no additional cost to the College.

3.15 TRAINING

A. Coordinate schedule and materials with Commissioning Provider.

B. Interim Training

1. Provide minimal training so the operating staff can respond to occupant needs and other operating requirements during start-up and commissioning phase.

C. Formal Training

1. Training shall be conducted after all commissioning is complete and systems are fully operational.

2. Training materials, including slides, shall be submitted prior to any training in Submittal Package 7.

3. ALC Training

a. It may be assumed that College building engineers have been previously trained on the existing ALC system.

b. Include training on ALC system operations only for new features installed at CSS/OWS as a part of this project.

4. Jobsite Training

a. Include ***40*** hours total of on-site training to assist personnel in becoming familiar with job-specific issues, systems, control sequences, etc.

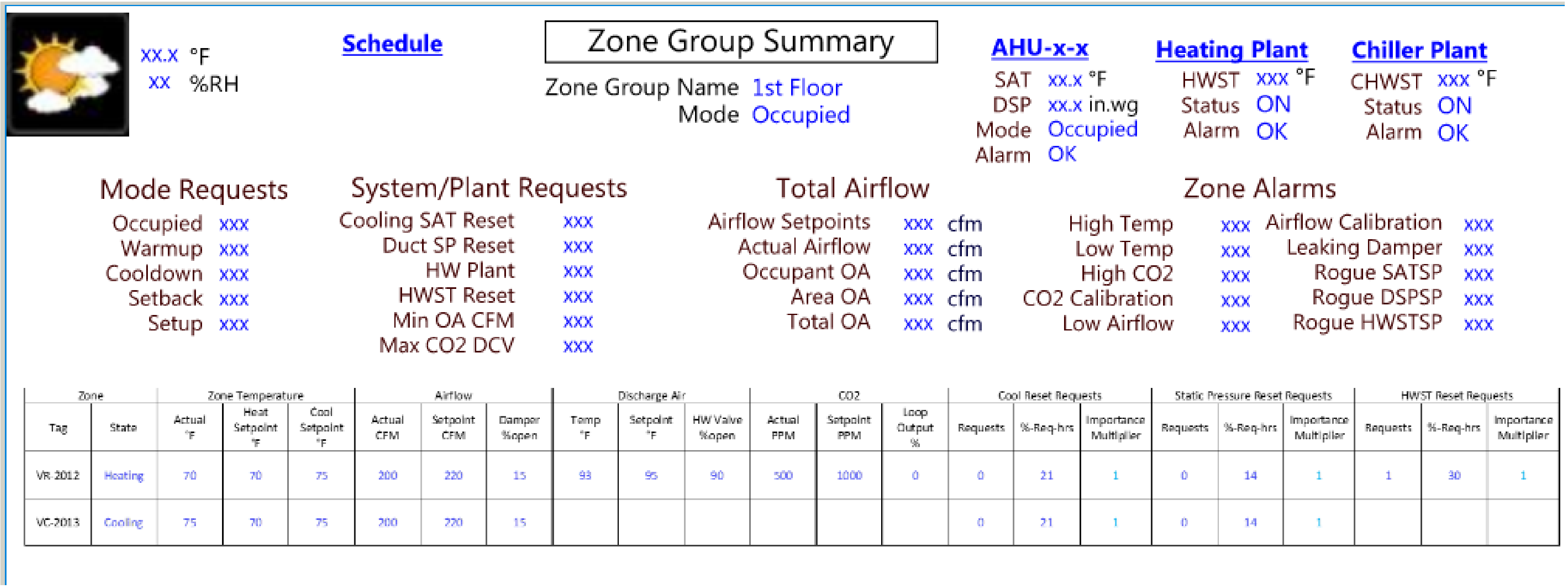
b. College shall be permitted to videotape training sessions.

5. Training may be in non-contiguous days at the request of the College.

6. During the warranty period, provide unlimited telephone support for all trained operators.

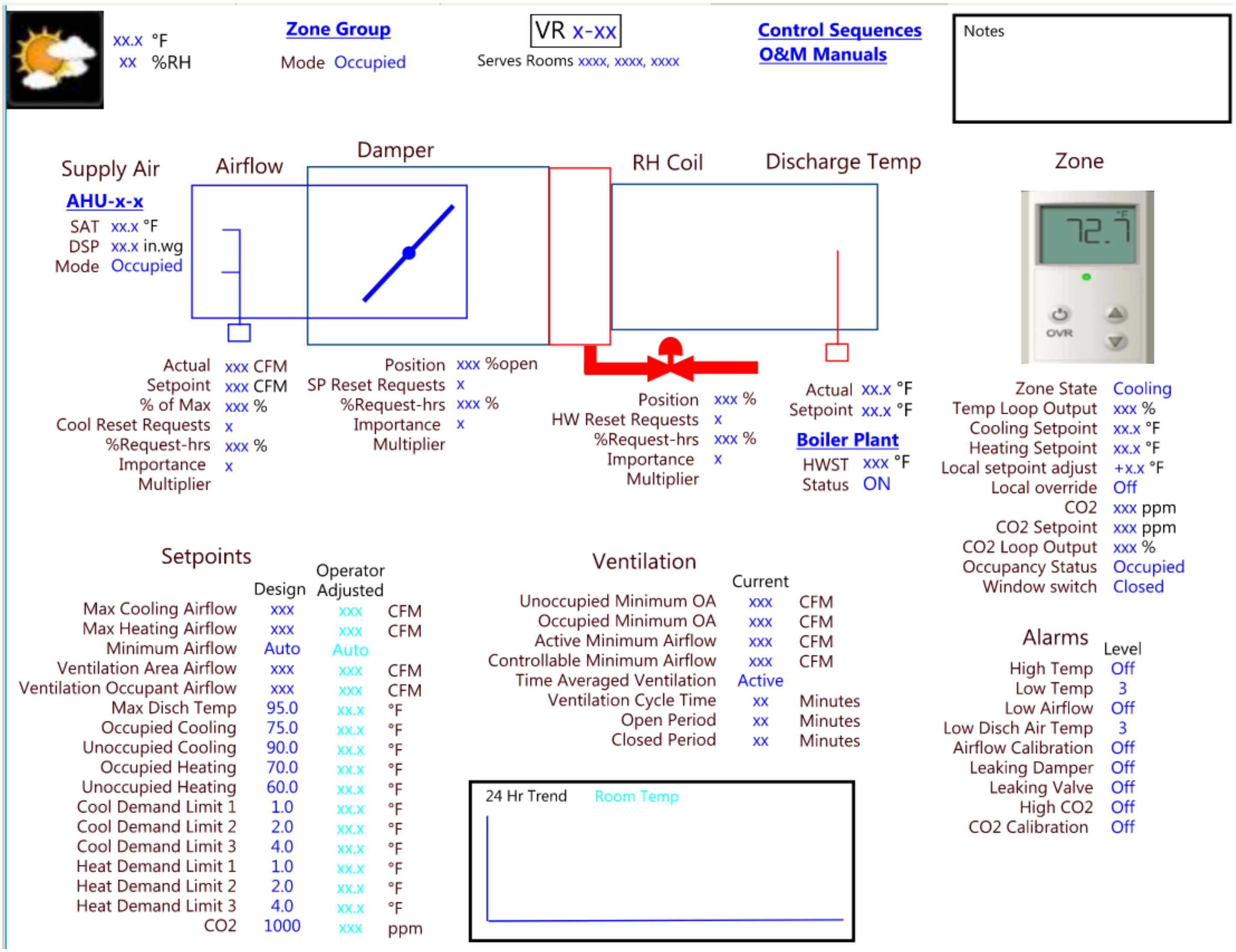
END OF SECTION 250000

ZONE GROUP SUMMARY

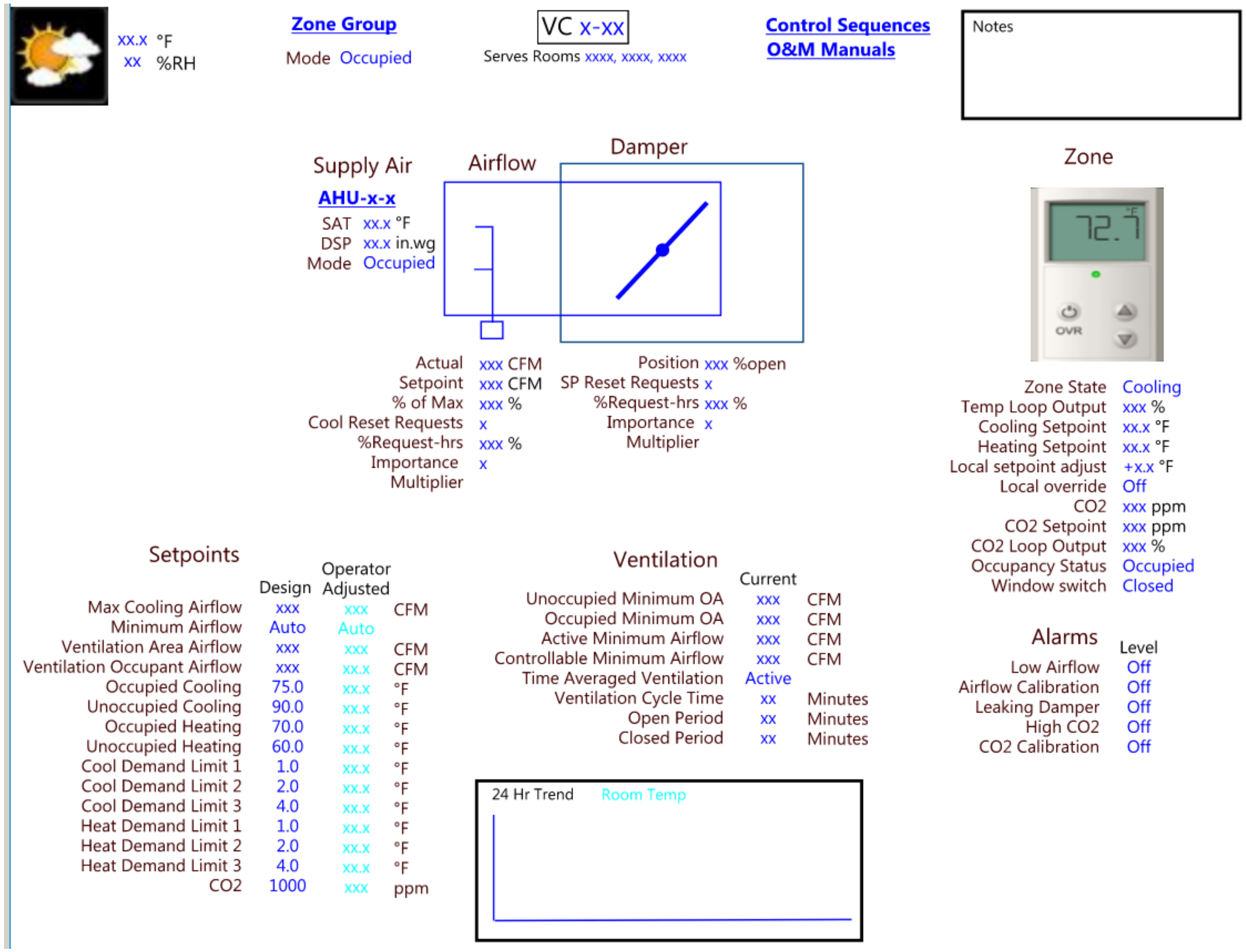


Zone		Zone Temperature			Airflow			Discharge Air			CO2			Cool Reset Requests			Static Pressure Reset Requests			HWST Reset Requests		
Tag	State	Actual °F	Heat Setpoint °F	Cool Setpoint °F	Actual CFM	Setpoint CFM	Damper %open	Temp °F	Setpoint °F	HW Valve %open	Actual PPM	Setpoint PPM	Loop Output %	Requests	%-Req-hrs	Importance Multiplier	Requests	%-Req-hrs	Importance Multiplier	Requests	%-Req-hrs	Importance Multiplier
VR-2012	Heating	70	70	75	200	220	15	93	95	90	500	1000	0	0	21	1	0	14	1	1	30	1
VC-2013	Cooling	75	70	75	200	220	15							0	21	1	0	14	1			

VAV REHEAT ZONE



VAV COOLING-ONLY ZONE



NOTE: THIS MASTER SPEC INCLUDES HIDDEN TEXT AND COMMENTS. TO SEE THEM, MAKE SURE MS WORD IS CONFIGURED TO SEE HIDDEN TEXT (GO TO TOOLS/OPTIONS/VIEW AND CLICK ON "HIDDEN TEXT" CHECK-BOX.) DELETE THIS PARAGRAPH WHEN EDITING SPEC FOR PROJECTS.

SECTION 259000

BUILDING AUTOMATION SEQUENCES OF OPERATION

PART 1 GENERAL

1.1 SUMMARY

A. Program and commission the Building Automation System (BAS) to execute the Sequences of Operation specified herein.

B. See Section 250000 Building Automation Systems for general requirements.

C. These control sequences include references to ASHRAE Guideline 36 and approved addenda. Where sequences are verbatim from Guideline 36, they are shown in green text. Not all informative text has been included. Sequences have been customized to include only Title 24 options where they take precedence over ASHRAE 90.1 and 62.1 requirements.

D. Guideline 36 sequences shall be programmed to exactly match the specified sequences verbatim. The Contractor may use "equivalent" alternative sequences only with formal approval by the Engineer. Proposed changes in sequences shall be clearly identified and included as a part of Submittal Package 2.

E. This file shall be maintained by the Contractor to include all approved changes to sequences made during testing and commissioning and shall become the final as-built sequences of operation installed on the CSS per Section 250000 Building Automation Systems.

1.2 INFORMATION PROVIDED BY DESIGNER

A. See equipment schedules on drawings for all setpoints unless otherwise noted below.

B. General Zone Information

1. Zone Temperature Setpoints

a. Default setpoints shall be based on zone type as shown in Table 3.1.1.1.

Table 3.1.1.1 Default Setpoints

	Occupied		Unoccupied	
Zone Type	Heating	Cooling	Heating	Cooling
General (unless listed below)	70ºF	75ºF	60ºF	90ºF
General with ceiling fans	70ºF	79ºF	60ºF	90ºF

Laboratory spaces	70ºF	75ºF	60ºF	80ºF
Server	–	80ºF	–	80ºF
IDF/MDF	–	78ºF	–	78ºF

2. Outdoor Air Ventilation Setpoints

   a. All zone minimum outdoor air setpoints are scheduled on Drawings.

      1) Vocc-min. Zone minimum outdoor airflow for occupants.

      2) Varea-min. Zone minimum outdoor airflow for building area.

      3) Indicate where occupied-standby mode is allowed based on the zone occupancy category.

3. CO2 Setpoints

   a. The CO2 setpoint for all occupancy types is 1000 ppm.

C. VAV Box Design Information

1. All VAV box setpoints are scheduled on Drawings except as indicated below.

2. VAV Cooling-Only Terminal Unit

   a. Zone maximum cooling airflow setpoint (Vcool-max)

   b. Zone maximum heating airflow setpoint (Vheat-max) = Vcool-max

   c. Zone minimum airflow setpoint (Vmin). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, Vmin will be calculated automatically and dynamically to meet ventilation requirements.

3. VAV Reheat Terminal Unit

   a. Zone maximum cooling airflow setpoint (Vcool-max)

   b. Zone minimum airflow setpoint (Vmin. This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, Vmin will be calculated automatically and dynamically to meet ventilation requirements.

   c. Zone maximum heating airflow setpoint (Vheat-max)

   d. Zone maximum DAT above heating setpoint (MaxΔT) = 25ºF

   e. The heating minimum airflow setpoint (Vheat-min) = 0

4. Parallel Fan-Powered Terminal Unit, Variable-Volume Fan

a. Zone maximum cooling (primary) airflow setpoint (Vcool-max)

b. Zone minimum primary airflow setpoint (Vmin). This is an optional entry. If no value is scheduled, or a value of "AUTO" is scheduled, Vmin will be calculated automatically and dynamically to meet ventilation requirements.

c. Parallel fan maximum heating airflow setpoint (Pfan-htgmax)

d. Zone maximum DAT above heating setpoint (MaxΔT) = 15ºF

5. Series Fan-Powered Terminal Unit, Constant-Volume Fan

a. Zone maximum cooling airflow setpoint (Vcool-max)

b. Zone minimum airflow setpoint (Vmin). This is an optional entry. If no value is scheduled, or a value of "AUTO" is scheduled, Vmin will be calculated automatically and dynamically to meet ventilation requirements.

c. Zone maximum DAT above heating setpoint (MaxΔT) = 15ºF

D. Laboratory Zone Design Information

Pressurization airflow offset setpoints are often estimated during the design phase, e.g. based on the number of entry doors and wall area but it can also be adjusted empirically in the field. This can be done under TAB work scope, e.g.
A. Room Pressurization Balancing
1. The CFM Offset indicated in the schedule is only an initial value and the final value will be determined by work under this section.
2. Determine airflow offsets required to achieve the room pressurization of 0.02" to 0.05" positive or negative as indicated in the Laboratory Zone Room Schedules. In no case, however, shall the offset be larger than 200% of scheduled offset.
3. Coordinate with Division 250000 BAS contractor to determine and program required room offsets.
If this is not done, delete second sentence:

1. Pressurization offset (Voffset). Initial pressurization offsets shall be shown on schedules. For some zones, final pressurization offsets shall be determined as specified under Section 230593 Testing, Adjusting, and Balancing.

2. Supply air valve(s). For pressure zones with multiple supply air valves, the first listed supply air valve controller is the master and setpoint adjustments (e.g. Vmin*) only apply to that zone. The other zones respond to temperature controls only. Total supply air is the sum of all supply air rates.

a. Maximum airflow setpoint (Vmax)

b. Minimum occupied airflow setpoint (Vmin-occ)

c. Minimum unoccupied airflow setpoint (Vmin-unocc)

d. Zone maximum cooling airflow setpoint (Vcool-max)

e. Maximum heating airflow setpoint (Vheat-max)

f. Design heating coil leaving air temperature (SATmax)

g. Minimum zone discharge air temperature (SATmin)

3. Hood exhaust air valve

a. Hood exhaust is controlled by on-board controllers (with sash sensors and fume hood monitors, where specified.). None of the control logic resides in the BAS, other than monitoring alarms and, commissioning overrides., and setpoint adjustments where used, all performed via the BACnet connection.

b. The following setpoints must be configured in the exhaust air valve controller with the capability of being written to the controller via BACnet.

1) Maximum airflow setpoint (Vhex-max)

2) Minimum airflow setpoint (Vhex-min)

In hood dominated labs, the lab may become too negative for safe exiting door pressures if the supply air system is lost. There are various means to mitigate this problem, one of which is to temporarily reduce hood exhaust rates, often (and most safely) used with automatic sash closers. These reduced rates must be determined empirically in conjunction with the BAS and TAB subcontractors. Example language for Section 230593 Testing, Adjusting and Balancing specs:
A. Emergency Exit Tests
1. Tests shall be performed separately for each lab with fume hoods.
2. Coordinate with Division 250000 contractor to conduct tests.
3. Procedure:
a) Simulate failure of supply air to the lab by fully shutting off all supply air valves.
b) Verify that BAS causes hood closers to close hoods immediately after supply air failure is detected.
c) Test door opening force. If more than 15 pounds, gradually reduce minimum hood exhaust setpoints uniformly for all hoods until 15 pounds is reached.
4. Report
a) Initial door opening force at design hood exhaust rates
b) Percent of design hood exhaust rates needed to reduce door opening force to 15 pounds
c) Initials of BAS installer to indicate that percent hood multiplier was transmitted to them
If not specified, set %hood-reduction to 100%:

3) Percentage reduction multiplier to all fume hood exhaust setpoints to reduce zone pressure enough to allow for safe exit door pressures (%hood-reduction). See Section 230593 Testing, Adjusting and Balancing and Paragraph **Error! Reference source not found.** and **Error! Reference source not found.**.

4. General exhaust (GEX) air valve

a. Maximum airflow setpoint (Vgex-max)

5. Other exhaust airflows, e.g. canopy/cabinet/snorkel etc. if applicable, see plans for quantity and airflow rates (Vother)

E. Zone Group Assignments

1. Unless otherwise specified by Owner, the following Zone Groups shall be created:

Zone Group Name	AH Tag	Terminal Unit Tags	Miscellaneous Equipment Tags	Default Schedule
First-floor assembly	AH-1	VAV-1-1 through 11	EF-1	WD: 6 am to 8pm WE: 8 am to 10pm HOL: off
Second-floor office	AH-1	VAV-2-1 through 15	EF-2	WD: 7 am to 7 pm SAT: 9 am to 2 pm SUN: off HOL: off
IDF rooms	AH-1	VAV-1-12, VAV-2-16		ALL: 12 am to 12 am
First-floor lobby	AH-2		EF-1	WD: 6 am to 8 pm WE: 8 am to 10 pm HOL: off

F. Multiple-Zone VAV Air-Handler Design Information

1. Temperature Setpoints

a. Min_ClgSAT, lowest cooling supply air temperature setpoint = scheduled cooling coil leaving air temperature plus 3°F

b. Max_ClgSAT, highest cooling supply air temperature setpoint = 65°F

c. OAT_Min, the lower value of the OAT reset range = 55°F

d. OAT_Max, the higher value of the OAT reset range = 70°F

2. Ventilation Setpoints

a. All AHU outdoor airflow setpoints are scheduled on Drawings.

1) AbsMinOA, the design outdoor air rate when all zones with CO2 sensors or occupancy sensors are unpopulated

2) DesMinOA, the design minimum outdoor airflow with areas served by the system are occupied at their design population, including diversity where applicable

3. Economizer High Limit

a. California Title 24 economizer high limit

1) California climate zone = ***3***

2) High limit option:

a) Fixed dry bulb + differential dry bulb

4. DP100, filter high limit differential pressure at design airflow = 1 in.w.c. or value from manufacturer's submittal whichever is lower

5. Pressure Zone Group Assignments

Return/relief fans and building pressure sensors must be assigned to pressure Zone Groups, using table below
A pressure zone is defined as an enclosed area with interconnected return paths. The appropriate boundaries for pressure zones, establishing which return/relief fan run together, and which building pressure sensors are used will need to be determined by the engineer based on building geometry.

Pressure Zone Group Name	AHU Tag	RF Tag	Building Pressure Sensor Location(s)
East Pressure Zone	AHU-1, AHU-2	RF-1, RF-2	Rm. 123E
West Pressure Zone	AHU-3, AHU-4	RF-3, RF-4	Rm. 112W, Rm. 124W

G. Single-Zone VAV Air-Handler Design Information

1. Temperature Setpoints

a. Cool_SAT, lowest cooling supply air temperature setpoint = scheduled cooling coil leaving air temperature plus 2°F

b. Heat_SAT, highest heating supply air temperature setpoint = scheduled heating coil leaving air temperature

c. MaxDPT, maximum supply air dew-point temperature = 75°F

2. Ventilation Setpoints

a. For projects complying with the California Title 24 Ventilation Standards:

1) MinOA, the design outdoor air rate when the zone with a CO2 sensor served by the system is unpopulated. MinOA shall equal Varea-min.

2) DesOA, the design outdoor air rate when the zone served by the system is occupied at its design population, including diversity where applicable. DesOA shall equal the larger of Varea-min and Vocc-min.

3. Economizer High Limit

a. California Title 24 economizer high limit

1) California climate zone = ***3***

2) High limit option:

a) Fixed dry bulb + differential dry bulb

4. DP100, filter high limit differential pressure at design airflow = 1 in.w.c. or value from manufacturer's submittal whichever is lower

H. Dedicated Outdoor Air-Handler Design Information

1. Temperature Setpoints

a. Heat_SAT = 50°F

b. Cool_SAT = 65°F

2. Economizer High Limit

a. California Title 24 economizer high limit

1) California climate zone = ***3***

2) High limit option:

a) Fixed dry bulb + differential dry bulb

3. DP100, filter high limit differential pressure at design airflow = 1 in.w.c. or value from manufacturer's submittal whichever is lower

I. Packaged Multiple Zone VAV AC Unit Design Information

1. Temperature Setpoints

a. Min_ClgSAT, lowest cooling supply air temperature setpoint: 55°F.

b. Max_ClgSAT, highest cooling supply air temperature setpoint: 65°F.

c. OAT_Min, the lower value of the OAT reset range: 50°F.

d. OAT_Max, the higher value of the OAT reset range: 70°F.

2. Ventilation Setpoints

a. AbsMinOA: the design outdoor airflow rate when all zones with CO2 sensors or occupancy sensors are unpopulated: per AC unit schedule

b. DesMinOA: the design minimum outdoor airflow with areas served by the system are occupied at their design population: per AC unit schedule

3. Economizer High Limit

a. California Title 24 economizer high limit

1) California climate zone = ***3***

2) High limit option:

a) Fixed dry bulb + differential dry bulb

J. Chilled Water Plant

1. Temperature Setpoints

a. CHWSTminX, the lowest chilled water supply temperature setpoint for Chiller X = scheduled chiller leaving chilled water temperature

b. CHWSTmax, the maximum chilled water supply temperature setpoint used in plant reset logic = 60°F

c. CWRTdesX, the condenser water return (chiller condenser leaving) temperature at chiller selection conditions for Chiller X = scheduled chiller leaving condenser water temperature

d. CWSTdesX, the condenser water supply (chiller condenser entering) temperature at chiller selection conditions for Chiller X= scheduled chiller leaving condenser water temperature

e. CH-LOT, the outdoor air lockout temperature below which the chiller plant is prevented from operating = 60°F

The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g., due to Plant Request from a zone or AHU with unusually cold setpoint. It is typically 60°F for plants serving systems with airside economizers. To keep the plant enabled under all conditions, make the setpoint below the coldest expected outdoor air temperature.

2. Differential Pressure Setpoints

a. CHW-DPmin, the minimum differential pressure setpoint used in plant reset logic = 5 psi

3. Chiller Flow Setpoints

a. CHW-MinFlowX, the minimum chiller chilled water flowrate per manufacturer's recommendations for Chiller X, in gpm = scheduled chilled water minimum flow rate

b. CHW-DesFlowX, the design chiller chilled water flowrate for Chiller X, in gpm = scheduled design chilled water flow rate

c. CW-DesFlowX, the design chiller condenser water flowrate for Chiller X, in gpm = scheduled design condenser water flow rate

4. Chiller Lift Setpoints

a. LIFTminX, the minimum allowable lift at minimum load for Chiller X, as determined from the manufacturer's recommendations, where lift is the difference between condenser water return temperature and chilled water supply temperature.

1) CH-1: 0°F

2) CH-2: 10°F

Except for some magnetic bearing chillers, a minimum differential pressure must be maintained between the condenser and evaporator, aka head pressure. These sequences require at a minimum that the user identify the minimum allowable lift at minimum load for each chiller, LIFTminX, per the chiller manufacturer's recommendations. These variables are used to reset condenser water temperature setpoint from the cooling tower.
LIFTminX values can also be used to control minimum head pressure indirectly when direct control head pressure control is not available. Most chillers have head pressure control loops built into the chiller's controller, but not all do.
When chillers have built in head pressure control, an analog head pressure output from the chiller panel can be used to control a device that reduces flow through the condenser when condenser water temperature is too cold, e.g., on initial start when the cooling tower basin is cold. The chiller's head pressure output should be hardwired to the control system, rather than directly to any device. This allows the control sequences to use this signal to maintain minimum lift via both tower speed limiting and condenser water flow control (e.g., via valve throttling or pump speed limiting for variable speed CW pumps), ensuring that the tower fan speed control sequence maintaining condenser water temperature and the head pressure control sequence do not "fight" one another. When chillers do not have built-in head pressure control, the BAS can instead run a head pressure control loop for each chiller that maintains lift at LIFTminX. This loop output is then used to limit tower speed, CW pump speed, and/or throttle CW isolation valve in the same way that a chiller's internal head pressure control loop otherwise would.

b. LIFTmaxX, design lift at design load for Chiller X = CWRTdesX minus CHWSTminX

5. Capacity

a. QchX, design capacity of Chiller X, in tons = scheduled chiller capacity

b. PCHWFdesign, design primary loop flow, in gpm = ***[typically the sum of scheduled primary pump flow rates excluding redundant pumps – designer to determine value since not always self-apparent from drawings especially is pumps sized for excess flow (e.g. 60% instead of 50%)]***

c. SCHWFdesign, design secondary loop flow, in gpm (for each loop) = ***[typically the sum of scheduled secondary pump flow rates excluding redundant pumps – designer to determine value since not always self-apparent from drawings especially is pumps sized for excess flow (e.g. 60% instead of 50%)]***

6. Minimum Cycling Load

a. MinUnloadCapX, the load below which Chiller X will engage hot gas bypass (HGB) or begin cycling (if the chiller does not have HGB), in tons.

1) CH-1: 10% of Qch1

2) CH-2: 15% of Qch1

MinUnloadCapX should be provided by the chiller manufacturer.

7. Waterside Economizer Design Information

a. DAHX, design heat exchanger approach = ***[designer to enter value since HX approach not always clear from HX schedule if ΔT not the same on both sides.]***

b. DTWB, design cooling tower wetbulb temperature = cooling tower scheduled wetbulb temperature

c. DACT, design cooling tower approach = the cooling tower scheduled leaving water temperature minus the wetbulb temperature

d. HXFdesign, design waterside economizer chilled water flow in gpm = ***[designer to enter value there may be multiple WSE HXs that total above the design WSE CHW flow rate]***

e. HXDP-Design, design waterside economizer chilled water pressure drop = the WSE heat exchanger scheduled CHW pressure drop

f. HXCWFdesign, design waterside economizer condenser water flow in gpm = ***[designer to enter value there may be multiple WSE HXs that total above the design WSE CW flow rate]***

8. Cooling Tower Level Control

a. T-level-high-alarm, maximum level just below overflow = level determined in the field by contractor in accordance with cooling tower IOM

b. T-level-low-alarm, minimum level = level determined in the field by contractor in accordance with cooling tower IOM

c. T-level-min-fill, lowest normal operating level = level determined in the field by contractor in accordance with cooling tower IOM

d. T-level-max-fill, highest normal operating level = level determined in the field by contractor in accordance with cooling tower IOM

9. Headered Pump Design Quantities

a. N-PCHWP, the number of primary chilled water pumps that operate at design conditions = ***2***

b. N-SCHWP, the number of secondary chilled water pumps that operate at design conditions = ***2***

K. Hot Water Plant

1. Temperature Setpoints

a. HWSTmax, the highest hot water supply temperature setpoint = scheduled leaving water temperature

b. HWSTmax-cond, the design hot water supply temperature of the condensing boilers = scheduled condensing boiler leaving water temperature

c. HW-LOT, the outdoor air lockout temperature above which the boiler plant is prevented from operating = 75°F

The Lockout temperature is a safety to prevent plant operation when it should not be needed, e.g. due to a Plant Request from a zone or AHU with unusually high setpoint. It is typically 75°F for systems with zone level reheat. It can be lower, e.g. 65°F, for dual fan dual duct systems and systems that use fan powered terminal units to meet heating loads since they do not require reheat to prevent over-cooling zones with low, or no, cooling loads.
To keep the plant enabled under all conditions, make the setpoint above the hottest expected outdoor air temperature.

2. Boiler Flow Setpoints

a. HW-MinFlowX, the design minimum Boiler water flowrate as recommended by the manufacturer for Boiler X, in gpm = scheduled boiler minimum flow rate

b. HW-DesFlowX, the design boiler hot water flowrate for Boiler X, in gpm = scheduled boiler design flow rate

3. Minimum Boiler Firing Rate

a. B-FiringMinX, the lowest %-firing rate of Boiler X before cycling = ***20%***

4. Capacity

a. QbX, design output capacity of Boiler X, in KBtu/h = scheduled boiler capacity

b. PHWFdesign, design primary loop flow, in gpm (each loop) = ***[typically the sum of scheduled primary pump flow rates excluding redundant pumps – designer to determine value since not always self-apparent from drawings especially is pumps sized for excess flow (e.g. 60% instead of 50%)]***

c. SHWFdesign, design secondary loop flow, in gpm (each loop) = ***[typically the sum of scheduled secondary pump flow rates excluding redundant pumps – designer to determine value since not always self-apparent from drawings especially is pumps sized for excess flow (e.g. 60% instead of 50%)]***

5. Headered Pump Design Quantities

a. N-PHWP, the number of primary hot water pumps that operate at design conditions = ***2***

b. N-SHWP, the number of secondary hot water pumps that operate at design conditions = ***2***

L. Fan Coil Unit (FCU) Design Information

1. Cool_SAT, lowest cooling supply air temperature setpoint = scheduled cooling coil leaving air temperature

2. Heat_SAT, highest heating supply air temperature setpoint = scheduled heating coil leaving air temperature

3. DP100, filter high limit differential pressure at design airflow = 0.5 in.w.c. or value from manufacturer's submittal whichever is lower

1.3 INFORMATION PROVIDED BY (OR IN CONJUNCTION WITH) THE TESTING, ADJUSTING, AND BALANCING CONTRACTOR

A. Coordinate with Section 230593 Testing, Adjusting and Balancing for setpoint determination. Any work not specifically listed in Section 230593 shall be provided under this Section.

B. Multiple-Zone Air-Handler Information

1. Duct Design Maximum Static Pressure, Max_DSP

2. Minimum Fan Speed

a. Minimum speed setpoints for all VFD-driven equipment shall be determined in accordance with Section 250000 Building Automation System specifications for the following, as applicable:

1) Supply fan

2) Return fan

3) Relief fan

3. Ventilation Plenum Pressures. (For minimum outdoor air control with separate outdoor air damper and differential pressure [DP] control, see Section 3.15D.)

a. For projects complying with California Title 24 Ventilation Standards:

1. AbsMinDP, the absolute minimum outdoor air damper DP that provides an outdoor airflow equal to the absolute minimum outdoor airflow AbsMinOA

2. DesMinDP, the design minimum outdoor air damper DP that provides the design minimum outdoor airflow DesMinOA.

4. Return-Fan Discharge Static Pressure Setpoints. (For return-fan direct building pressure control, see Section 3.15I.)

a. RFDSPmin. That required to deliver the design return air volume across the return air damper when the supply air fan is at design airflow and on minimum outdoor air. This setpoint shall be no less than 2.4 Pa (0.01 in. of water) to ensure outdoor air is not drawn backwards through the relief damper.

b. RFDSPmax. That required to exhaust enough air to maintain building static pressure at setpoint 12 Pa (0.05 in. of water) when the supply air fan is at design airflow and on 100% outdoor air.

5. Return-Fan Airflow Tracking Setpoints. (For return-fan airflow tracking control, see Section 3.15J.)

a. S-R-DIFF. The airflow differential between supply air and return air fans required to maintain building pressure at desired pressure (e.g., 12 Pa [0.05 in. of water]) using a handheld sensor if a permanent sensor is not provided. All exhaust fans that normally operate with the air handler should be on.

b. Vrf-max. The maximum return fan airflow rate, = scheduled design airflow rate

C. Single-Zone Air-Handler Information

1. Fan Speed Setpoints

a. MinSpeed. The speed that provides supply airflow equal to DesOA (see Section1.2G.2) with the economizer outdoor air damper fully open.

b. MaxHeatSpeed. The speed that provides supply airflow equal to the design heating airflow scheduled on plans. If no heating airflow is provided on plans, default to half of the maximum cooling speed.

c. MaxCoolSpeed. The speed that provides supply airflow equal to the design cooling airflow scheduled on plans.

2. Minimum Outdoor Air Damper Positions (for systems without outdoor airflow measuring stations; See Section 3.16F.2.)

a. MinPosMin. The outdoor air damper position required to provide MinOA when the supply fan is at MinSpeed.

b. MinPosMax. The outdoor air damper position required to provide MinOA when the supply fan is at MaxCoolSpeed.

c. DesPosMin. The outdoor air damper position required to provide DesOA when the supply fan is at MinSpeed.

d. DesPosMax. The outdoor air damper position required to provide DesOA when the supply fan is at MaxCoolSpeed.

3. Relief-Damper Positions (for relief using motorized dampers; see Section 3.16H.)

a. MinRelief. The relief-damper position that maintains a building pressure of 12 Pa (0.05 in. of water) while the system is at MinPosMin (i.e., the economizer damper is positioned to provide MinOA while the supply fan is at minimum speed).

b. MaxRelief. The relief-damper position that maintains a building pressure of 12 Pa (0.05 in. of water) while the economizer damper is fully open and the fan speed is at cooling maximum.

4. Return-Fan Speed Differential (for Return Fan Speed Tracking Control, see Section 3.16J). The speed differential between supply air and return air fans, S-R-SPD-DIFF, required to maintain building pressure at desired pressure (e.g., 12 Pa [0.05 in. of water]) using a handheld sensor if a permanent sensor is not provided. All exhaust fans that normally operate with the air handler should be on.

5. Return fan discharge static pressure setpoints (for Return Fan Direct Building Pressure Control, see Section 3.16J.2).

    a. RFDSPmin: That required to deliver the design return air volume across the return air damper when the supply air fan is at design airflow and on minimum outdoor air. This setpoint shall be no less than 2.4 Pa (0.01 inches) to ensure outdoor air is not drawn backwards thru the relief damper.

    b. RFDSPmax: That required to exhaust enough air to maintain building static pressure at setpoint 12 Pa (0.05 inches) when the supply air fan is at design airflow and on 100% outdoor air.

D. Dedicated Outdoor Air-Handler Information

1. Duct Design Maximum Static Pressure, Max_DSP

2. Minimum Fan Speed

    a. Minimum speed setpoints for all VFD-driven equipment shall be determined in accordance with Section 250000 Building Automation System specifications for the following, as applicable:

        1) Supply fan

E. Packaged Multiple Zone VAV AC Unit Information

1. Duct Design Maximum Static Pressure, Max_DSP

2. Minimum Fan Speed

    a. Minimum speed setpoints for all VFD-driven equipment shall be determined in accordance with Section 250000 Building Automation System specifications for the following, as applicable:

        1) Supply fan

        2) Return fan

        3) Relief fan

F. Chilled Water Plant

1. CHW-DPmax, the maximum chilled water differential pressure setpoint, in psi

2. LocalCHW-DPmax, the maximum chilled water differential pressure setpoint local to the plant, in psi

3. Cw-DesPumpSpdStage, the condenser water pump speed that delivers design condenser water flow through the chillers and waterside heat exchangers, CW-DesFlowX and HXCWFdesign, operating in a chiller stage.

4. MinCWVlvPos, minimum head pressure control valve position = 0%

Minimum head pressure can be maintained by modulating condenser water isolation valves (for constant speed CW pumps) or limiting pump speed (for variable speed CW pumps). If chillers are provided with condenser water flow switches, a minimum head pressure control valve position is needed to ensure minimum flow is maintained while the head pressure control loop is enabled. Performance is improved if calorimetric type switches are used since they can have a much lower flow setpoint than paddle switches and are more reliable when subjected to corrosive open condenser water. If condenser water flow switches are not provided, or they are jumpered out as allowed by many manufacturers, MinCWVlvPos can be set to 0%.

5. MinCWPspeed, minimum condenser water pump speed = determined per Section 1.3F.9

Minimum head pressure can be maintained by modulating condenser water isolation valves (for constant speed CW pumps) or limiting pump speed (for variable speed CW pumps). If chillers are provided with condenser water flow switches, a minimum head pressure control valve position is needed to ensure minimum flow is maintained while the head pressure control loop is enabled. Performance is improved if calorimetric type switches are used since they can have a much lower flow setpoint than paddle switches and are more reliable when subjected to corrosive open condenser water. If condenser water flow switches are not provided, or they are jumpered out as allowed by many manufacturers, MinCWPspeed can be set to the minimum speed determined per Section 1.3F.9 but no lower.

6. HxPumpDesSpd, the waterside economizer heat exchanger pump speed that delivers design heat exchanger flow, HXFdesign, through the CHW side of the waterside economizer heat exchanger

7. Ch-MaxPriPumpSpdStage, the primary chilled water pump speed necessary to deliver design chilled water flow, CHW-DesFlowX, through the operating chiller(s) in the stage

8. Ch-MinPriPumpSpdStage, the primary chilled water pump speed necessary to deliver minimum chilled water flow, CHW-MinFlowX, through the operating chiller(s) in the stage

9. Minimum Speeds

   a. Where minimum speeds are not required for flow control per other balancer provided setpoints above, minimum speed setpoints for all VFD-driven pumps and tower fans shall be determined in accordance with Section 250000 Building Automation System for the following as applicable:

      1) Cooling Tower Fans

      2) Condenser Water Pumps

      3) Chilled Water Pumps

G. Hot Water Plant

1. HW-DPmax, the maximum hot water differential pressure setpoint, in psi

2. LocalHW-DPmax, the maximum hot water differential pressure setpoint local to the plant, in psi

3. B-MinPriPumpSpdStage, the primary hot water pump speed necessary to deliver minimum hot water flow, HW-MinFlowX, through the operating boiler(s) in the stage.

4. Minimum Speeds

   a. Where minimum speeds are not required for flow control per other balancer provided setpoints above, minimum speed setpoints for all VFD-driven pumps and tower fans shall be determined for hot water pumps in accordance with Section 250000 Building Automation System.

H. Fan Coil Unit Information

   a. MinHeatSpeed. The speed that provides supply airflow equal to the design heating minimum airflow scheduled on plans. If no minimum airflow is provided on plans, default to 20% of the maximum heating speed.

   b. MinCoolSpeed. The speed that provides supply airflow equal to the design cooling minimum airflow scheduled on plans. If no minimum airflow is provided on plans, default to 20% of the maximum cooling speed.

   c. DeadbandSpeed. If the fan is desired to operate when the zone is in deadband, set this value to less than or equal to MinSpeed. If the fan is to shut off when the zone is in deadband, set this value to 0.

   d. MaxHeatSpeed. The speed that provides supply airflow equal to the design heating airflow scheduled on plans. If no heating airflow is provided on plans, default to half of the maximum cooling speed.

   e. MaxCoolSpeed. The speed that provides supply airflow equal to the design cooling airflow scheduled on plans.

I. VAV Cooling-only boxes to Thermafuser

1. DP-setpoint = as determined under 230593 Testing, Adjusting and Balancing

1.4 INFORMATION DETERMINED BY CONTROL CONTRACTOR

A. VAV Box Controllable Minimum

1. This section is used to determine the lowest possible VAV box airflow setpoint (other than zero) allowed by the controls (Vm) used in VAV box control sequences. The minimums shall be stored as software points that may be adjusted by the user but need not be adjustable via the graphical user interface.

2. The minimum setpoint *Vm* shall be determined from the table below for the VAV box manufacturer from approved submittals:

Inlet	**Titus**	**Krueger**	**Price**	**MetalAire High Gain**	**ETI**	**Greenheck**
4	15	15	20	15	15	18
6	30	35	30	30	30	35

Inlet	Titus	Krueger	Price	MetalAire High Gain	ETI	Greenheck
8	55	60	55	50	55	63
10	90	90	95	85	90	105
12	120	130	135	110	130	149
14	190	175	195	155	180	206
16	245	230	260	210	235	259
24x16	455	445	490	N/A	415	N/A

B. Lab Air Valve Controllable Minimum

1. This section is used to determine the lowest possible valve airflow setpoint allowed by the controls used in lab control sequences. The minimums shall be stored as software points that may be adjusted by the user but need not be adjustable via the graphical user interface. If not listed, obtain data from manufacturer with review and approval by Engineer.

2. The valve controllable minimum shall be determined from the table:

Inlet	AccuValve
8	80
10	120
12	180
14	250
12x18	260
12x24	350
12x36	520
12x48	700

PART 2 PRODUCTS

2.1 NOT USED

PART 3 EXECUTION

3.1 GENERAL

A. Contractor shall review sequences prior to programming and suggest modifications where required to achieve the design intent. Contractor may also suggest modifications to improve performance and stability or to simplify or reorganize logic in a manner that provides equal or better performance. Proposed changes in sequences shall be clearly identified and included as a part of Submittal Package 2.

B. Include costs for minor program modifications if required to provide proper performance of the system.

C. Unless otherwise indicated, control loops shall be enabled and disabled based on the status of the system being controlled to prevent windup.

D. When a control loop is enabled or reenabled, it and all its constituents (such as the proportional and integral terms) shall be set initially to a neutral value.

E. A control loop in neutral shall correspond to a condition that applies the minimum control effect, i.e., valves/dampers closed, VFDs at minimum speed, etc.

F. When there are multiple outdoor air temperature sensors, the system shall use the valid sensor that most accurately represents the outdoor air conditions at the equipment being controlled.

1. Outdoor air temperature sensors at air-handler outdoor air intakes shall be considered valid only when the supply fan is proven on and the unit is in Occupied Mode or in any other mode with the economizer enabled.

2. The outdoor air temperature used for optimum start, plant lockout, and other global sequences shall be the average of all valid sensor readings. If there are four or more valid outdoor air temperature sensors, discard the highest and lowest temperature readings.

G. The term "proven" (i.e., "proven on"/"proven off") shall mean that the equipment's DI status point (where provided, e.g., current switch, DP switch, or VFD status) matches the state set by the equipment's DO command point.

H. The term "software point" shall mean an analog variable, and "software switch" shall mean a digital (binary) variable, that are not associated with real I/O points. They shall be read/write capable (e.g., BACnet analog variable and binary variable).

I. The term "control loop" or "loop" is used generically for all control loops. These will typically be PID loops, but proportional plus integral plus derivative gains are not required on all loops. Unless specifically indicated otherwise, the guidelines in the following subsections shall be followed.

1. Use proportional only (P-only) loops for limiting loops (such as zone CO2 control loops, etc.).

2. Do not use the derivative term on any loops unless field tuning is not possible without it.

J. To avoid abrupt changes in equipment operation, the output of every control loop shall be capable of being limited by a user adjustable maximum rate of change, with a default of 25% per minute.

K. All setpoints, timers, deadbands, PID gains, etc. listed in sequences shall be adjustable by the user with appropriate access level whether indicated as adjustable in sequences or not. Software points shall be used for these variables. Fixed scalar numbers shall not be embedded in programs except for physical constants and conversion factors.

L. Values for all points, including real (hardware) points used in control sequences shall be capable of being overridden by the user with appropriate access level (e.g., for testing and commissioning). If hardware design prevents this for hardware points, they shall be equated to a software point, and the software point shall be used in all sequences. Exceptions shall be made for machine or life safety.

M. Alarms

1. There shall be 4 levels of alarm
   a. Level 1: Life-safety message
   b. Level 2: Critical equipment message
   c. Level 3: Urgent message
   d. Level 4: Normal message
2. Maintenance Mode. Operators shall have the ability to put any device (e.g., AHU) in/out of maintenance mode.
   a. All alarms associated with a device in maintenance mode will be suppressed. Exception: Life safety alarms shall not be suppressed.
   b. If a device is in maintenance mode, issue a Level 3 alarm at a scheduled date and time indicating that the device is still in maintenance mode.
3. Exit Hysteresis
   a. Each alarm shall have an adjustable time-based hysteresis (default: 5 seconds) to exit the alarm. Once set, the alarm does not return to normal until the alarm conditions have ceased for the duration of the hysteresis.
   b. Each analog alarm shall have an adjustable percent-of-limit-based hysteresis (default: 0% of the alarm threshold, i.e., no hysteresis; alarm exits at the same value as the alarm threshold) the alarmed variable required to exit the alarm. Alarm conditions have ceased when the alarmed variable is below the triggering threshold by the amount of the hysteresis.
4. Latching. A latching alarm requires acknowledgment from the operators before it can return to normal, even if the exit deadband has been met. A nonlatching alarm does not require acknowledgment. Default latching status is as follows:
   a. Level 1 alarms: latching
   b. Level 2 alarms: latching
   c. Level 3 alarms: nonlatching
   d. Level 4 alarms: nonlatching
5. Post-exit Suppression Period. To limit alarms, any alarm may have an adjustable suppression period such that once the alarm is exited, its post-exit suppression timer is triggered and the alarm may not trigger again until the post-exit suppression timer has expired. Default suppression periods are as follows:
   a. Level 1 alarms: 0 minutes
   b. Level 2 alarms: 5 minutes

c. Level 3 alarms: 24 hours

d. Level 4 alarms: 7 days

N. VFD Speed Points

To avoid operator confusion, the speed command point (and speed feedback point, if used) for VFDs should be configured so that a speed of 0% corresponds to 0 Hz, and 100% corresponds to maximum speed set in the VFD, not necessarily 60 Hz. The maximum speed may be limited below 60 Hz to protect equipment, or it may be above 60 Hz for direct drive equipment. Drives are often configured such that a 0% speed signal corresponds to the minimum speed programmed into the VFD, but that causes the speed AO value and the actual speed to deviate from one another.

1. The speed AO sent to VFDs shall be configured such that 0% speed corresponds to 0 Hz, and 100% speed corresponds to maximum speed configured in the VFD.

It is desirable that the minimum speed reside in the VFD to avoid problems when the VFD is manually controlled at the drive. But minimums can also be adjusted inadvertently in the VFD to a setpoint that is not equal to the minimum used in software. The following prevents separate, potentially conflicting minimum speed setpoints from existing in the BAS software and the drive firmware.

2. For each piece of equipment, the minimum speed shall be stored in a single software point; in the case of a hard-wired VFD interface, the minimum speed shall be the lowest speed command sent to the drive by the BAS. See Section 1.3 for minimum speed setpoints. The active minimum speed parameter shall be read every 60 minutes via the drive's network interface. When a mismatch between the drive's active minimum speed and the minimum speed stored in the software point is detected, the minimum speed stored in the software point shall be written to the VFD via the network interface to restore the active minimum speed parameter to its default value, and generate a Level 4 alarm.

The minimum speed parameter is read via the network interface to detect any changes in the minimum speed parameter. Upon detecting a change in the minimum speed setting, the correct minimum speed stored in a BAS software point is written back to the drive via the network interface to override any changes that are made locally to the minimum speed parameter at the VFD.

O. Trim & Respond Set-Point Reset Logic

1. T&R set-point reset logic and zone/system reset requests, where referenced in sequences, shall be implemented as described below.

2. A "request" is a call to reset a static pressure or temperature setpoint generated by downstream zones or air-handling systems. These requests are sent upstream to the plant or system that serves the zone or air handler that generated the request.

   a. For each downstream zone or system, and for each type of set-point reset request listed for the zone/system, provide the following software points:

      1) Importance-Multiplier (default = 1)

Importance-Multiplier is used to scale the number of requests the zone/system is generating. A value of zero causes the requests from that zone or system to be ignored. A value greater than one can be used to effectively increase the number of requests from the zone/system based on the critical nature of the spaces served.

2) Request-Hours Accumulator. Provided SystemOK (see Section 3.1R) is true for the zone/system, every x minutes (default 5 minutes), add x divided by 60 times the current number of requests to this request-hours accumulator point.

3) System Run-Hours Total. This is the number of hours the zone/system has been operating in any mode other than Unoccupied Mode.

Request-Hours accumulates the integral of requests (prior to adjustment of Importance-Multiplier) to help identify zones/systems that are driving the reset logic. Rogue zone identification is particularly critical in this context, because a single rogue zone can keep the T&R loop at maximum and prevent it from saving any energy.

4) Cumulative%-Request-Hours. This is the zone/system Request-Hours divided by the zone/system run-hours (the hours in any mode other than Unoccupied Mode) since the last reset, expressed as a percentage.

5) The Request-Hours Accumulator and System Run-Hours Total are reset to zero as follows:

a) Reset automatically for an individual zone/system when the System Run-Hours Total exceeds 400 hours.

b) Reset manually by a global operator command. This command will simultaneously reset the Request-Hours point for all zones served by the system.

6) A Level 4 alarm is generated if the zone Importance-Multiplier is greater than zero, the zone/system Cumulative% Request Hours exceeds 70%, and the total number of zone/system run hours exceeds 40.

b. See zone and air-handling system control sequences for logic to generate requests.

c. Multiply the number of requests determined from zone/system logic times the Importance-Multiplier and send to the system/plant that serves the zone/system. See system/plant logic to see how requests are used in T&R logic.

3. For each upstream system or plant setpoint being controlled by a T&R loop, define the following variables. Initial values are defined in system/plant sequences below. Values for trim, respond, time step, etc. shall be tuned to provide stable control. See Table 5.1.14.3.

Table 5.1.14.3 Trim & Respond Variables

Variable	Definition
Device	Associated device (e.g., fan, pump)

SP0	Initial setpoint
SPmin	Minimum setpoint
SPmax	Maximum setpoint
Td	Delay timer
T	Time step
I	Number of ignored requests
R	Number of requests from zones/systems
SPtrim	Trim amount
SPres	Respond amount (must be opposite in sign to SPtrim)
SPres-max	Maximum response per time interval (must be same sign as SPres)

Informative Note: The number of ignored requests (I) should be set to zero for critical zones or air handlers.

4. Trim & Respond logic shall reset the setpoint within the range SPmin to SPmax. When the associated device is off, the setpoint shall be SP0. The reset logic shall be active while the associated device is proven on, starting Td after initial device start command. When active, every time step T, if R≤I, trim the setpoint by SPtrim. If there are more than I requests, respond by changing the setpoint by SPres*(R – I), (i.e., the number of requests minus the number of ignored requests) but no more than SPres-max. In other words, every time step T.

   If R≤I, change Setpoint by SPtrim
   If R > I, change setpoint by (R – I)*SPres but no larger than SPres-max

P. Equipment Staging and Rotation

1. Parallel equipment shall be lead/lag or lead/standby rotated to maintain even wear.

2. Two runtime points shall be defined for each equipment:

   a. Lifetime Runtime: The cumulative runtime of the equipment since equipment start-up. This point shall not be readily resettable by operators.

Lifetime Runtime should be stored to a software point on the control system server so the recorded value is not lost due to controller reset, loss of power, programming file update, etc.

   b. Staging Runtime: An operator resettable runtime point that stores cumulative runtime since the last operator reset.

Staging Runtime provides a resettable runtime counter, which allows for reset of the staging runtime hours used for lead/lag or lead/standby rotation between maintenance intervals or equipment replacement while maintaining a separate log of the Lifetime Runtime. If runtime were not resettable, and logic relied only on Lifetime Runtime for determining staging lead/lag position, newly added equipment could run for years as the lead equipment before swapping rotation positions with older equipment per the logic below.

3. Lead/lag equipment: Unless otherwise noted, identical parallel staged equipment (such as CHW pumps and cooling towers) shall be lead/lag alternated when more than one is off or more than one is on so that the equipment with the most operating hours as determined by Staging Runtime is made the last stage equipment and the one with the least number of hours is made the lead stage equipment.

This strategy effectively makes it such that equipment are not "hot swapped", e.g., a pump would not be started and another stopped during operation just for runtime equalization. For example, assume there are two equipment and only one is on, but the operating equipment has exceeded the run hours of the disabled equipment. The equipment will not rotate positions until either a stage up or down occurs. If the plant stages up, then both equipment will be on and lead/lag position will switch; when the plant next stages down, the former lead equipment with more run hours will then turn off.

Expanding further, for a plant with three equipment, if all three are off or all are on, the staging order will simply be based on run hours from lowest to highest. If two equipment are on, the one with more hours will be set to be stage 2 while the other is set to stage 1; this may be the reverse of the operating order when the equipment were started. If two of the equipment are off, the one with the more hours will be set to be stage 3 while the other is set to stage 2; this may be the reverse of the operating order when the equipment were stopped.

Example with three pumps:

1. *P-1 (1000 hours), 2 (950 hours), and 3 (900 hours) are all off. Staging logic makes lead/lag order: 3, 2, 1.*
2. *P-3 starts. Logic does not change its order since it is on by itself.*
3. *P-3 runs for 51 hours. Since it is on and others off, the lead/lag order does not change. It can run this way indefinitely and the order does not change.*
4. *There is then a stage-up command. P-2 (the next in lead/lag order) is started. So, both P-2 and P-3 are on. P-3 now has more run hours than P-2. So, the Lead/lag order changes to: 2, 3, 1.*
5. *These two pumps run another 51 hours. Run times are P-1 (1000 hours), P-2 (1001), and P-3 (1002). No changes are made to lead/lag order because P-1 is off alone.*
6. *There is a stage down command. P-2 is now lead so it stays on. P-3 is shut off. The order for the two off pumps is now adjusted because P-1 has fewest run hours. Lead/lag order is now: 2, 1, 3.*
7. *P-2 runs for 100 more hours. It now has the longest runtime, but order does not change since it is on alone. Order is still 2, 1, 3.*
8. *There is a stage down or plant-off command. P-2 shuts off. Run times are P-1 (1000 hours), P-2 (1101), and P-3 (1002). Since all are off, order is switched to: 1, 3, 2.*

4. Lead/standby equipment:

   a. Unless equipment runs continuously, parallel equipment that are 100% redundant shall be lead/standby alternated when more than one of the equipment is off so that the equipment with the most operating hours as determined by Staging Runtime is made the last stage equipment and the one with the least number of hours is made the earlier stage equipment.

For example, assuming there are three equipment, if all three are off, the staging order will be based on run hours from lowest to highest.

b. If equipment runs continuously, lead/standby positions shall switch at an adjustable day of the week and time (e.g., every Tuesday at 10:00 am) based on Staging Runtime; standby equipment shall first be started and proven on before former lead equipment is changed to standby and shut off.

1) Variable speed fans and pumps shall have a deceleration rate of 1 Hz/second or slower set in BAS logic when disabled to prevent nuisance trips of operating equipment (e.g., chillers).

5. Exceptions to Lead/lag and Lead/standby rotation

a. Operators with appropriate access level shall be able to manually command staging order via software points, but not overriding the In-Alarm or Hand-Operation logic in the following subsections.

1) Staging order changes initiated via operator override shall be instituted as part of normal staging events.

2) Staging order shall remain overridden until released by operators.

b. Faulted Equipment:

1) A faulted equipment is any equipment commanded to run that is either not running when it should or unable to perform its required duty. If an operating equipment has any fault condition described subsequently, a Level 2 alarm shall be generated and a response shall be triggered as defined below.

a) Fans and Pumps

1. Status point not matching its on/off point for 3 seconds after a time delay of 15 seconds while the equipment is commanded on.

b) Chillers

1. Safety shutdown alarm condition either through network or hardwired alarm contact

2. Chiller is manually shut off as indicated by the status of the Local/Auto switch from chiller gateway, or

3. Chiller status remains off 5 minutes after command to start (note: this condition only applies when a chiller first starts, i.e., once status is proven, then status is no longer used as a fault condition because status will come and go if chiller cycles on low load), or

4. CHW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or

5. CHW isolation valve feedback indicates valve is not closed 90 seconds after valve is commanded closed, or

6. CW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or

7. For 10 minutes, chilled water return temperature has been at least 3°C (5°F) above the CHWST setpoint, and delta-T across the chiller, as determined based on the difference between chilled water return temperature and chilled water supply temperature measured at the chiller (i.e., not common CHWST), has been less than 2°C (3°F).

c) Boilers

1. Safety shutdown alarm condition either through network or hardwired alarm contact, or

2. HW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or

3. If boiler leaving water temperature remains 8.3°C (15°F) below setpoint for 15 minutes and delta-T across the boiler, as determined based on the difference between hot water supply temperature and hot water return temperature measured at the boiler (i.e., not common HWST), has been less than 6°C (10°F).

d) Cooling Towers

1. Tower fan has failed as defined above, or

2. Inlet end switch indicates valve is not open 90 seconds after valve is commanded open, or

3. Outlet end switch indicates valve is not open 90 seconds after valve is commanded open.

2) Upon identification of a fault condition or when equipment is in Maintenance Mode:

a) For fans, pumps, and cooling towers:

1. The next commanded off equipment in the staging order, Equipment “B”, shall be commanded on while alarming Equipment “A” remains commanded on.

2. If Equipment “B” fails to prove status (i.e., it also goes into alarm), it shall remain commanded on and the preceding step shall be repeated until the quantity of equipment called for by the current stage has proven on, or there are no more available equipment.

3. Set alarming equipment to the last positions in the lead/lag or lead/standby staging order sequenced reverse chronologically (i.e., the equipment that alarmed most recently is sent to last position).

4. Staging order of non-alarming equipment shall follow the even wear logic. Equipment in alarm can only automatically move up on the staging order if another equipment goes into alarm.

5. Equipment in alarm shall run if so called for by the lead/lag or lead/standby staging order and present stage.

b) For chillers and boilers:

1. The next commanded off equipment in the staging order, Equipment “B”, shall be commanded on while alarming Equipment “A” is commanded off and set to the last position in the lead/lag staging order.

2. If Equipment B fails to prove status (i.e., it also goes into alarm), repeat the preceding step until the quantity of equipment called for by the lead/lag logic have proven on or until all equipment has been tried.

3. If all equipment has been tried and the quantity of non-alarming equipment is less than called for then the most recently alarmed equipment will remain commanded on.

4. Staging order of non-alarming equipment shall follow the even wear logic. Equipment in alarm can only automatically move up in the staging order if another equipment goes into alarm.

5. Equipment in alarm shall run if so called for by the lead/lag staging order and present stage.

The sequence for chillers and boilers differs from that used for pumps and cooling towers in that the alarming equipment does not remain commanded on until the next equipment proves status. The pump and tower logic mitigates the risk of lost loads and/or chain reaction trips of chillers and boilers by still taking advantage of any capacity the alarming equipment may provide until the lag equipment proves. This approach does not however typically work for chillers and boilers because bringing on the lag equipment while still commanding the alarming equipment to run may prevent a successful startup of the lag equipment. For example, in a parallel variable primary chilled water plant under low load conditions, starting a lag chiller while keeping the alarming chiller enabled may cause both chillers to trip on either low chilled water flow or low condenser water flow unless the minimum chilled water flow setpoint is changed to maintain minimum chilled water flow and condenser water pumps are staged to maintain minimum condenser flow through both chillers.
Example: For a set of (4) lead/lag equipment, the current staging order is Equipment A, B, C, then D. The current stage requires two equipment, so A and B are running. Then A goes into alarm. A is then commanded off at the same time as C is commanded on. If C then goes into alarm it is commanded off at the same time that D is commanded on. If D then goes into alarm it remains commanded on since all equipment has been tried. If B (the last equipment not in alarm) also goes into alarm then it remains commanded on (as the last alarming equipment with no non-alarming equipment available). At this point all equipment are in alarm and only B and D will remain commanded on until an equipment comes out of alarm. The staging order is B, D, A, C. Note that staging up/down is disabled in this condition per Sections 3.26D.13 and 3.27C.8.

c. Hand Operation. If a piece of equipment is on-in-hand (e.g., via an HOA switch or local control of VFD), the equipment shall be set to the lead device, and a Level 4 alarm shall be generated. The equipment will remain as lead until. Hand operation is determined by the following:

Any condition in which equipment appears to continue to run after being commanded off is considered a case of hand operation; in practice, this condition may arise due to other circumstances (e.g., a bad current transducer).

1) Fans and Pumps

a) Status point not matching its on/off point for 15 seconds after a time delay of 60 seconds when the equipment is commanded off.

Logic for hand operation of chillers, boilers, and cooling towers is not provided because sequences cannot stably respond to overrides by operators in all possible scenarios. For example, if a chiller is turned on in hand in a variable primary system with only one other chiller currently running, the control system would need to react by opening the isolation valves of the chiller placed in hand and either (1) immediately shutting down the former lead chiller or (2) changing the minimum chilled water flow setpoint, opening isolation valves, and possibly staging on condenser water pumps and cooling towers. Chillers, boilers, and cooling towers should only be placed in hand by changing the staging sequence manually via the control system interface; they cannot be safely or stably operated in hand at the chiller/boiler/tower controllers.

Q. Air Economizer High Limits

1. Economizer shall be disabled whenever the outdoor air conditions exceed the economizer high-limit setpoint as specified. Setpoints shall be automatically determined by the control sequences (to ensure they are correct and meet code) based on energy standard, climate zone, and economizer high-limit-control device type selected by the design engineer in Section 1.2F.3 or 1.2G.2. Setpoints listed below are for current California Energy Standards.

2. Title 24-2019

Device Type	California Climate Zones	Required High Limit (Economizer off when)
Fixed dry bulb	1, 3, 5, 11 to 16	TOA > 24°C (75°F)
	2, 4, 10	TOA > 23°C (73°F)
	6, 8, 9	TOA > 22°C (71°F)
	7	TOA > 21°C (69°F)
Differential dry bulb	1, 3, 5, 11 to 16	TOA > TRA
	2, 4, 10	TOA > TRA – 1°C (2°F)
	6, 8, 9	TOA > TRA –2°C (4°F)
	7	TOA > TRA – 3°C (6°F)

Fixed enthalpy + fixed dry bulb	All	hOA > 66 kJ/kg (28 Btu/lb) or TOA > 24°C (75°F)

R. Hierarchical Alarm Suppression

1. For each piece of equipment or space controlled by the BAS, define its relationship (if any) to other equipment in terms of “source,” “load,” or “system.”

   a. A component is a “source” if it provides resources to a downstream component, such as a chiller providing chilled water (CHW) to an AHU.

   b. A component is a “load” if it receives resources from an upstream component, such as an AHU that receives CHW from a chiller.

   c. The same component may be both a load (receiving resources from an upstream source) and a source (providing resources to a downstream load).

   d. A set of components is a “system” if they share a load in common (i.e., collectively act as a source to downstream equipment, such as a set of chillers in a lead/lag relationship serving air handlers).

      1) If a single component acts as a source for downstream loads (e.g., an AHU as a source for its VAV boxes), then that single-source component shall be defined as a “system” of one element.

      2) For equipment with associated pumps (chillers, boilers, cooling towers):

         a) If the pumps are in a one-to-one relationship with equipment they serve, the pumps shall be treated as part of the system to which they are associated (i.e., they are not considered loads), as a pump failure will necessarily disable its associated equipment.

         b) If the pumps are headered to the equipment they serve, then the pumps may be treated as a system, which is a load relative to the upstream equipment (e.g., chillers) and a source relative to downstream equipment (e.g., air handlers).

2. For each system as defined in Section 3.1R.1.d, there shall be a SystemOK flag, which is either true or false.

3. SystemOK shall be true when all of the following are true:

   a. The system is proven on.

   b. The system is achieving its temperature and/or pressure setpoint(s) for at least 5 minutes

   c. The system is ready and able to serve its load

4. SystemOK shall be false while the system is starting up (i.e., before reaching setpoint) or when enough of the system's components are unavailable (in alarm, disabled, or turned off) to disrupt the ability of the system to serve its load. This threshold shall be defined by the design engineer for each system.

    a. By default, Level 1 through Level 3 component alarms (indicating equipment failure) shall inhibit SystemOK. Level 4 component alarms (maintenance and energy efficiency alarms) shall not affect SystemOK.

    b. The operator shall have the ability to individually determine which component alarms may or may not inhibit SystemOK.

5. The BAS shall selectively suppress (i.e., fail to announce; alarms may still be logged to a database) alarms for load components if SystemOK is false for the source system that serves that load.

    a. If SystemOK is false for a cooling water system (i.e., chiller, cooling tower, or associated pump), then only high-temperature alarms from the loads shall be suppressed.

    b. If SystemOK is false for a heating water system (i.e., boiler or associated pump), then only low temperature alarms from the loads shall be suppressed.

    c. If SystemOK is false for an air-side system (air handler, fan coil, VAV box, etc.), then all alarms from the loads shall be suppressed.

6. This hierarchical suppression shall cascade through multiple levels of load-source relationship such that alarms at downstream loads shall also be suppressed.

7. The following types of alarms will never be suppressed by this logic:

    a. Life/safety and Level 1 alarms

    b. Failure-to-start alarms (i.e., equipment is commanded on, but status point shows equipment to be off)

    c. Failure-to-stop/hand alarms (i.e., equipment is commanded off, but status point shows equipment to be on)

S. Time-Based Suppression

1. Calculate a time-delay period after any change in setpoint based on the difference between the controlled variable (e.g., zone temperature) at the time of the change and the new setpoint. The default time delay period shall be as follows:

    a. For thermal zone temperature alarms: 18 minutes per °C (10 minutes per °F) of difference but no longer than 120 minutes

    b. For thermal zone temperature cooling requests: 9 minutes per °C (5 minutes per °F) of difference but no longer than 30 minutes

c. For thermal zone temperature heating requests: 9 minutes per °C (5 minutes per °F) of difference but no longer than 30 minutes

T. Occupancy Sensor Status

1. Occupancy status of all spaces shall be via the Lighting Control BACnet interface.

2. Where a zone serves more than one room, “unoccupied” (or “unpopulated” per Guideline 36 terminology) means all rooms are unoccupied and “occupied” (populated) means any room is occupied.

3. In case of the network connection with the Lighting Controls is lost:

a. For lab zones, occupancy status shall default to “occupied” (for safety reasons)

b. For all other zones, occupancy status shall default to “occupied” if the Zone Group is in Occupied Mode and “unoccupied” for any other Zone Group Mode.

U. Pandemic Mode

1. Provide a software switch on the Home Page graphic for Pandemic Mode on/off. The switch shall include a timer that can be manually set by the operator for a period of up to 60 weeks, after which the Mode shall be shut off and control logic and setpoints returned to normal.

2. When the Pandemic Mode timer is on:

a. All CO2 DCV setpoints shall be set to 800 ppm.

b. Occupancy sensors used for Occupied Standby logic shall be not reset zone ventilation rates; with respect to ventilation, the zone shall be considered “populated”.

c. All Zone Group time schedules shall indicate Occupied Mode one hour prior to the scheduled time. This earlier time shall be reflected in optimum start logic.

V. Wildfire Mode

1. Provide a 2-position software switch on the Home Page graphic for Wildfire Mode:

a. Off. Locks Wildfire Mode off.

b. On. Turns Wildfire Mode on for a preset period of time, after which the Mode shall be shut off. The preset time shall be operator adjustable for up to 1 week.

2. Provide a 3-position software switch on the Home Page graphic for Wildfire Mode:

a. Off. Locks Wildfire Mode off.

b. On. Turns Wildfire Mode on for a preset period of time, after which the Mode shall be shut off. The preset time shall be operator adjustable for up to 1 week.

c. Auto. Turns Wildfire Mode on when PM2.5 as indicated by the APMS sensor is greater than a preset concentration limit for 15 minutes until it drops below that limit for 30 minutes, after which the Mode shall be shut off. The preset concentration limit shall default to 90 µg/m3 and be operator adjustable from 50 to 120 µg/m3.

To improve indoor air quality further during wildfire events, activated carbon filters should be installed in the prefilter rack upstream of the MERV 13/15 filters for the duration of the event, then discarded.
When the Wildfire Mode timer is on:

a. Disable all economizers (lock High Limit to off).

3.2 ELECTRICITY DEMAND LIMITING

*Automatic Demand Response is required by Title 24 for all non-healthcare systems with DDC to the zone.*Demand Response

1. On home page, provide three software switches: Demand Limit Level 1 to 3.

   a. These switches shall have AUTO, ON, and OFF positions. AUTO position shall set the Demand Limit Level's status to enabled or disabled based on an OpenADR 2.0 signal from the utility (see Section 250000 Building Automation Systems) or the Owner Initiated Electricity Demand Limiting logic below with enabled taking precedence; ON shall manually enable the Demand Limit Level; and OFF shall disable and lockout the Demand Limit Level.

   b. The Highest Demand Limit Level signal currently enabled, either via an ON or AUTO command, shall be given priority.

   c. These signals are used at the zone level (see Zone Control sequences) to adjust setpoints to reduce demand.

2. Include Demand Shed commands to the lighting control system via BACnet interface for each Demand Level. The response to each Demand Shed command shall be programmed into the lighting control system under Division 26.

3. When any Demand Limit Level is on, generate a Level 4 alarm.

B. Owner-Initiated Electricity Demand Limiting

1. Sliding Window: The demand control function shall utilize a sliding window method selectable in increments of one minute, up to 60 minutes, 15 minute default.

2. Demand Levels: Demand time periods shall be set up as per utility rate schedule. For each On/Off/Partial-Peak period, three demand kW thresholds can be defined and mapped to the Demand Limit Levels, 1 to 3. When the measured demand exceeds a threshold, and the software switch described above for the associated Demand Limit Level is set to AUTO, the Demand Limit Level shall be enabled; when demand is more than 10% (adjustable) below the limit for a minimum of 15 minutes, or the time is no longer within the On/Off/Partial-Peak window, the Demand Limit Level command shall be disabled.

3.3 GENERIC VENTILATION ZONES

A. Zone Minimum Outdoor Air and Minimum Airflow Setpoints

1. For every zone that requires mechanical ventilation, the zone minimum outdoor airflows and setpoints shall be calculated depending on the governing standard or code for outdoor air requirements.

2. See Section 1.2C for zone minimum airflow setpoint Vmin.

3. For compliance with California Title 24, outdoor air setpoints shall be calculated as follows:

    a. See Section 1.2B.2 for zone ventilation setpoints.

    b. Determine the zone minimum outdoor air setpoints Zone-Abs-OA-min and Zone-Des-OA-min.

Zone-Abs-OA-min is used in terminal-unit sequences and air-handler sequences. Zone-Des-OA-min is used in air-handler sequences only.

        1) Zone-Abs-OA-min shall be reset based on the following conditions in order from highest to lowest priority:

            a) Zero if the zone has a window switch and the window is open.

            b) Zero if the zone has an occupancy sensor and is unpopulated and is permitted to be in occupied-standby mode per Section 1.2B.2.a.3).

            c) Varea-min if the zone has a CO2 sensor.

            d) Zone-Des-OA-min otherwise.

        2) Zone-Des-OA-min is equal to the following, in order from highest to lowest priority:

            a) Zero if the zone has a window switch and the window is open.

            b) Zero if the zone has an occupancy sensor, is unpopulated, and is permitted to be in occupied-standby mode per Section 1.2B.2.a.3).

            c) The larger of Varea-min and Vocc-min otherwise.

    c. Vmin

        1) Shall be equal to Zone-Abs-OA-min if Vmin in Section 1.2C is “AUTO”;

        2) Else shall be equal to Vmin as entered in Section 1.2C.

    d. The occupied minimum airflow Vmin* shall be equal to Vmin except as noted below, in order from highest to lowest priority:

        1) If the zone has an occupancy sensor and is permitted to be in occupied-standby mode per Section 1.2B.2.a.3), Vmin* shall be equal to zero when the room is unpopulated.

2) If the zone has a window switch, Vmin* shall be zero when the window is open.

3) If the zone has a CO2 sensor:

a) See Section 1.2B.2.a.3) for CO2 setpoints.

b) During Occupied Mode, a P-only loop shall maintain CO2 concentration at setpoint; reset from 0% at setpoint minus 200 PPM and to 100% at setpoint.

c) Loop is disabled and output set to zero when the zone is not in Occupied Mode.

d) For cooling-only VAV terminal units, reheat VAV terminal units, constant-volume series fan-powered terminal units, dual-duct VAV terminal units with mixing control and inlet airflow sensors, dual-duct VAV terminal units with mixing control and a discharge airflow sensor, or dual-duct VAV terminal units with cold-duct minimum control:

1. The CO2 control loop output shall reset the occupied minimum airflow setpoint Vmin* from the zone minimum airflow setpoint Vmin at 0% up to maximum cooling airflow setpoint Vcool-max at 50%, as shown in Figure 5.2.1.4-1. The loop output from 50% to 100% will be used at the system level to reset outdoor air minimum; see AHU controls.

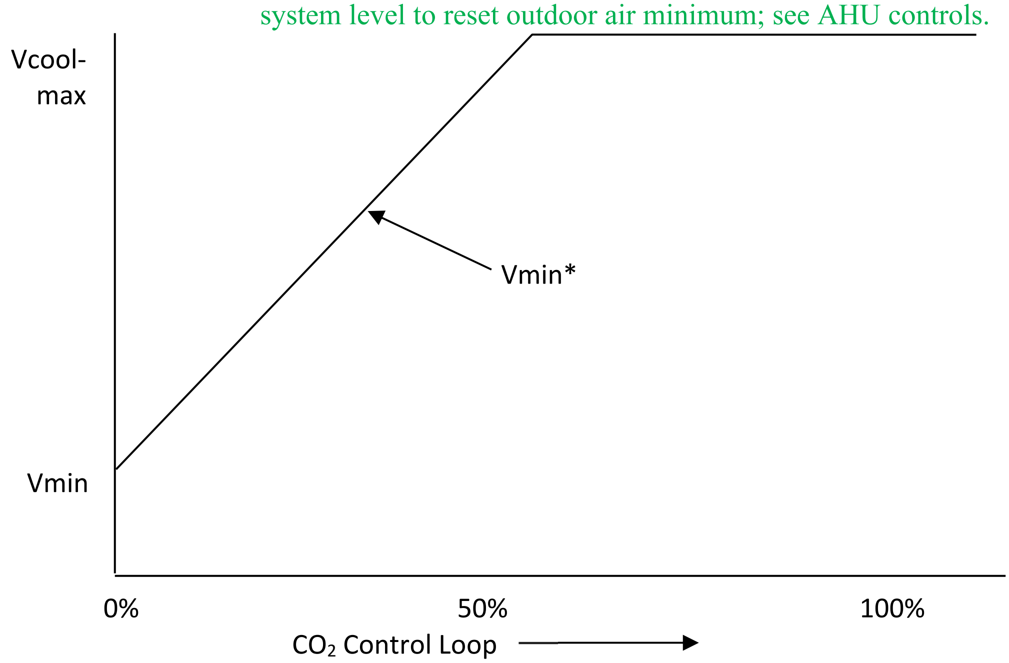


Figure 5.2.1.4-1 Vmin* reset with CO2 loop.

e) For parallel fan-powered terminal units:

1. Determine VCO2-max as follows:

a. When the Zone State is cooling, VCO2-max is equal to the maximum cooling airflow setpoint Vcool-max.

b. When the Zone State is heating or deadband, VCO2-max is equal to Vcool-max minus the parallel fan airflow

This logic prevents the total supply airflow from exceeding Vcool-max, which could create diffuser noise problems.

2. The CO2 control loop output shall reset the occupied minimum airflow setpoint Vmin* from the zone minimum airflow setpoint Vmin at 0% up to maximum cooling airflow setpoint VCO2-max at 50%, as shown in Figure 5.2.1.4-2. The loop output from 50% to 100% will be used at the system level to reset outdoor air minimum; see AHU controls.

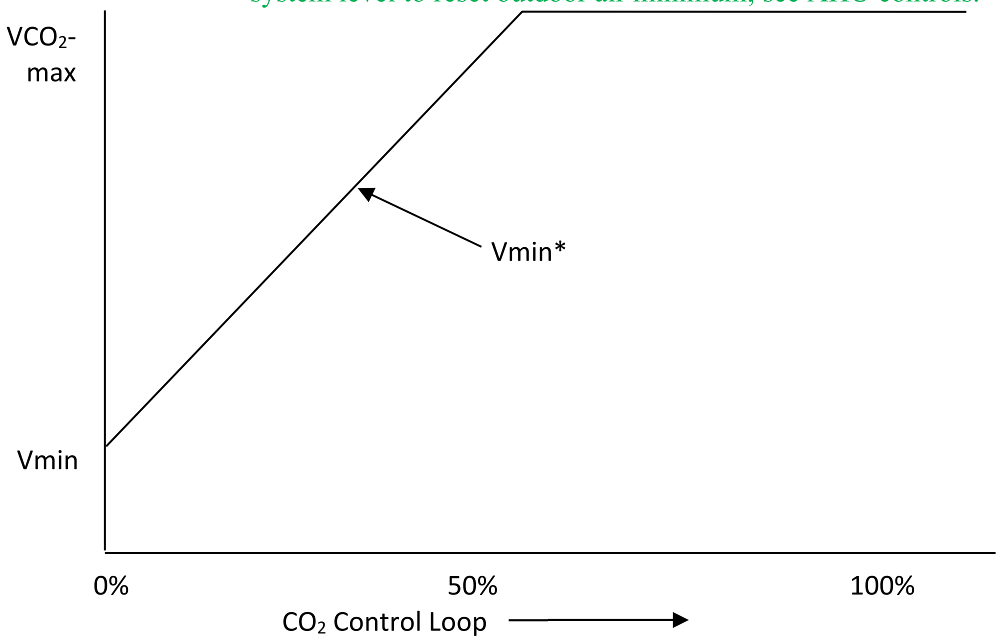


Figure 5.2.1.4-2 Vmin* reset with CO2 loop (parallel fan-powered).

f) For SZVAV AHUs:

1. The minimum outdoor air setpoint MinOAsp shall be reset based on the zone CO2 control-loop signal from MinOA at 0% signal to DesOA at 100% signal. See Figure 5.2.1.4-3.

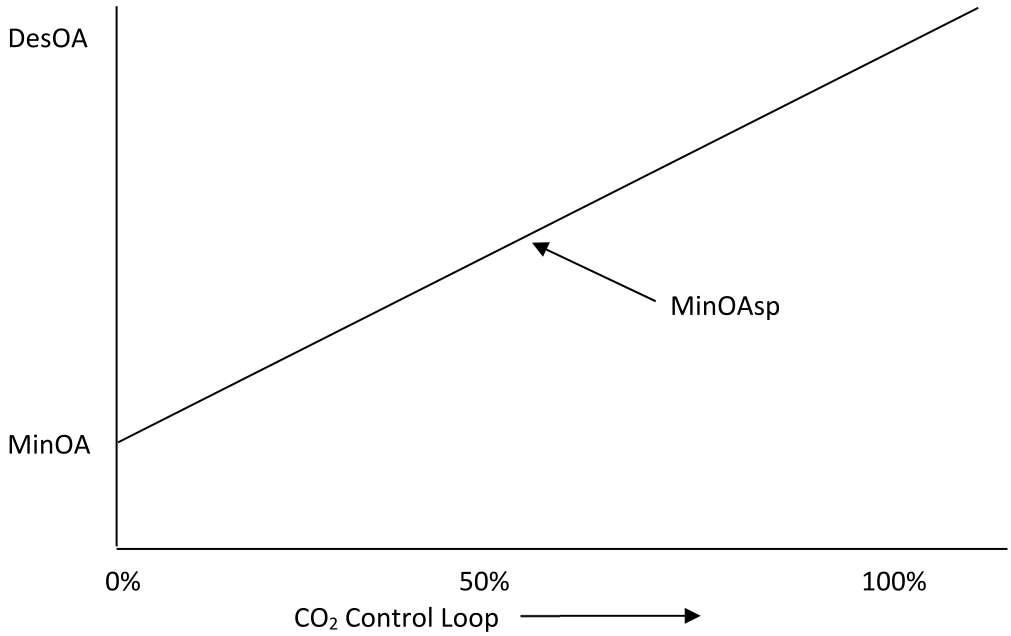


Figure 5.2.1.4-3 Vmin* reset with CO2 loop (SZVAV).

B. Time-Averaged Ventilation

ASHRAE Standard 62.1 and California Title 24 allow for ventilation to be provided based on average conditions over a specific period of time. This time-averaging method allows for zone airflows to effectively be controlled to values below the VAV box controllable minimum value, which may reduce energy use and the risk of overcooling when the zone ventilation requirement is less than the VAV box controllable minimum.

1. When the active airflow setpoint Vspt is nonzero and is less than the lowest possible airflow setpoint allowed by the controls (Vm), the airflow setpoint shall be pulse width modulated as follows:

   a. The time-averaged ventilation (TAV) ratio shall be determined as TAVratio = Vspt/Vm

   b. The total cycle time (TCT) shall be 15 minutes (adjustable)

   c. Open period. During the open period, the TAV airflow setpoint Vspt* shall be equal to Vm for a period of time OP, which is the larger of the following:

   d. 1.5 minutes or

   e. TCT multiplied by TAVratio

   f. Closed period. During the closed period, Vspt* shall be set to 0 for a period of time CP, where CP = TCT – OP. The VAV damper control loop shall be disabled with output set equal to 0 during the closed period. At the end of each closed period, the VAV damper shall be commanded to the last position from the previous open period prior to reenabling the control loop.

   g. During TAV mode, each cycle shall consist of an open and closed period that alternate until Vspt is greater than Vm.

The following logic ensures that multiple zones do not enter TAV mode at the same time, avoiding the synchronized opening and closing of VAV dampers. Where there are a small number of zones and the majority may potentially be in TAV mode synchronously, avoiding this issue may be more reliably achieved by sequencing the VAV terminal units deterministically so that each VAV terminal unit always opens at a specific minute into the total cycle time. The aim of this sequencing is to ensure that the total airflow is as constant as possible over the total cycling time even if all of the VAV terminal units enter TAV mode at the same time (e.g., when a building-wide temperature setback occurs).
For example, the total open cycle for VAV terminal-unit A opens at minute 1 of the total cycle time, VAV terminal-unit B opens at minute x of the total cycle time, etc.
The random number for each terminal unit, RNDM, can be determined using a random number generator each time the unit enters TAV mode or set manually to a fixed value. If configured manually, set RNDM for each terminal unit to a unique value within the range of 0.0 to 1.0 such that the values are evenly distributed across the terminal units within a system.

h. When first entering TAV mode, start with an initial open period of duration RNDM*OP, where RNDM is a random number between 0.0 and 1.0.

2. When in TAV mode, the active airflow setpoint, Vspt, shall be overridden to Vspt*.

C. For zones with CO2 sensors:

1. If the CO2 concentration is less than 300 ppm, or the zone is in Unoccupied Mode for more than 2 hours and zone CO2 concentration exceeds 600 ppm, generate a Level 3 alarm. The alarm text shall identify the sensor and indicate that it may be out of calibration.

2. If the CO2 concentration exceeds setpoint plus 10% for more than 10 minutes, generate a Level 3 alarm.

3.4 GENERIC THERMAL ZONES

A. This section applies to all single-zone systems and subzones of air-handling systems, such as VAV boxes, fan-powered boxes, etc.

B. Setpoints

1. See Section 1.2B.1 for zone temperature setpoints.

2. Each zone shall have separate occupied and unoccupied heating and cooling setpoints.

3. The active setpoints shall be determined by the operating mode of the Zone Group (see Section 3.5F).

The following is from addendum e to G36-2021:

a. During occupied mode:

1) The cooling set point shall be the occupied cooling set point.

2) The heating set point shall be the occupied heating set point.

b. During warm-up mode:

1) The cooling set point shall be the unoccupied cooling set point.

2) The heating set point shall be the unoccupied heating set point until the time remaining until the zone group's occupied start time is less than the zone's required warm-up time, tz-warmup, at which point the heating set point shall be the occupied heating set point.

c. During cool-down mode:

1) The cooling set point shall be the unoccupied cooling set point until the time remaining until the zone group's occupied start time is less than the zone's required cool-down time, tz-cooldown, at which point the cooling set point shall be the occupied cooling set point.

2) The heating set point shall be the unoccupied heating set point.

d. During setback mode:

1) The cooling set point shall be the unoccupied cooling set point.

2) The heating set point shall be 2°C (3°F) above the unoccupied heating set point.

e. During setup mode:

1) The cooling set point shall be 2°C (3°F) below the unoccupied cooling set point.

2) The heating set point shall be the unoccupied heating set point.

f. During unoccupied mode:

1) The cooling set point shall be the unoccupied cooling set point.

2) The heating set point shall be the unoccupied heating set point.

4. The software shall prevent the following:

a. The heating setpoint from exceeding the cooling setpoint minus 0.5°C (1°F) (i.e., the minimum difference between heating and cooling setpoints shall be 0.5°C [1°F]).

b. The unoccupied heating setpoint from exceeding the occupied heating setpoint.

c. The unoccupied cooling setpoint from being less than the occupied cooling setpoint.

5. Where the zone has a local setpoint adjustment knob/button:

a. The setpoint adjustment offsets established by the occupant shall be software points that are persistent (e.g., not reset daily), but the actual offset used in control logic shall be adjusted based on limits and modes as describe below.

b. The adjustment shall be capable of being limited in software.

These are absolute limits imposed by programming, which are in addition to the range limits (e.g., ±4°F) of the thermostat adjustment device.

1) As a default, the active occupied cooling setpoint shall be limited between 22°C (72°F) and 27°C (80°F).

2) As a default, the active occupied heating setpoint shall be limited between 18°C (65°F) and 22°C (72°F).

c. The active heating and cooling setpoints shall be independently adjustable, respecting the limits and anti-overlap logic described in Sections 3.4B.3.a and 3.4B.5.b. If zone thermostat provides only a single set-point adjustment, then the adjustment shall move both the active heating and cooling setpoints upward or downward by the same amount, within the limits described in Section 3.4B.5.b.

d. The adjustment shall only affect occupied setpoints in Occupied Mode, Warmup Mode, and Cooldown Mode and shall have no impact on setpoints in all other modes.

e. At the onset of demand limiting, the local set-point adjustment value shall be frozen. Further adjustment of the setpoint by local controls shall be suspended for the duration of the demand-limit event.

6. Cooling Demand Limit Set-Point Adjustment. The active cooling setpoints for all zones shall be increased when a demand limit is imposed on the associated Zone Group. The operator shall have the ability to exempt individual zones from this adjustment through the normal BAS user interface. Changes due to demand limits are not cumulative.

a. At demand-limit Level 1, increase setpoint by 0.5°C (1°F).

b. At demand-limit Level 2, increase setpoint by 1°C (2°F).

c. At demand-limit Level 3, increase setpoint by 2°C (4°F).

7. Heating Demand-Limit Set-Point Adjustment. The active heating setpoints for all zones shall be decreased when a demand limit is imposed on the associated Zone Group. The operator shall have the ability to exempt individual zones from this adjustment through the normal BAS user interface. Changes due to demand limits are not cumulative.

a. At demand-limit Level 1, decrease setpoint by 0.5°C (1°F).

b. At demand-limit Level 2, decrease setpoint by 1°C (2°F).

c. At demand-limit Level 3, decrease setpoint by 2°C (4°F).

Heating demand limits may be desirable in buildings with electric heat or heat pumps or in regions with limited gas distribution infrastructure.

8. Window Switches. For zones that have operable windows with indicator switches, when the window switch indicates the window is open, the heating setpoint shall be temporarily set to 4°C (40°F) and the cooling setpoint shall be temporarily set to 49°C (120°F). When the window switch indicates that the window is open during other than Occupied Mode, a Level 4 alarm shall be generated.

9. Occupancy Sensors. For zones that have an occupancy switch:

   a. When the switch indicates that the space has been unpopulated for 5 minutes continuously during the Occupied Mode, the active heating setpoint shall be decreased by 0.5°C (1°F) and the cooling setpoint shall be increased by 0.5°C (1°F).

   b. When the switch indicates that the space has been populated for 1 minute continuously, the active heating and cooling setpoints shall be restored to their previous values.

10. Hierarchy of Set-Point Adjustments. The following adjustment restrictions shall prevail in order from highest to lowest priority:

    a. Setpoint overlap restriction (Section 3.4B.3.a)

    b. Absolute limits on local setpoint adjustment (Section 3.4B.5.b)

    c. Window switches

    d. Demand limit

       1) Occupancy sensors. Change of setpoint by occupancy sensor is added to change of setpoint by any demand limits in effect.

       2) Local set-point adjustment. Any changes to setpoint by local adjustment are frozen at the onset of the demand limiting event and remain fixed for the duration of the event. Additional local adjustments are ignored for the duration of the demand limiting event.

    e. Scheduled setpoints based on Zone Group mode

C. Local Override. When thermostat override buttons are depressed, the call for Occupied Mode operation shall be sent to the Zone Group control for 60 minutes. Local Override shall be capable of being enabled and disabled separately for each thermostat via the graphical user interface; default to disabled.

Local overrides will cause all zones in the Zone Group to operate in Occupied Mode to ensure that the system has adequate load to operate stably.

D. Control Loops

1. Two separate control loops, the Cooling Loop and the Heating Loop, shall operate to maintain space temperature at setpoint.

   a. The Heating Loop shall be enabled whenever the space temperature is below the current zone heating set-point temperature and disabled when space temperature is above the current zone heating setpoint temperature and the loop output is zero for 30 seconds. The loop may remain active at all times if provisions are made to minimize integral windup.

   b. The Cooling Loop shall be enabled whenever the space temperature is above the current zone cooling set-point temperature and disabled when space temperature is below the current zone cooling set-point temperature and the loop output is zero for

30 seconds. The loop may remain active at all times if provisions are made to minimize integral windup.

2. The Cooling Loop shall maintain the space temperature at the active cooling setpoint. The output of the loop shall be a software point ranging from 0% (no cooling) to 100% (full cooling).

3. The Heating Loop shall maintain the space temperature at the active heating setpoint. The output of the loop shall be a software point ranging from 0% (no heating) to 100% (full heating).

4. Loops shall use proportional + integral logic or other technology with similar performance. Proportional-only control is not acceptable, although the integral gain shall be small relative to the proportional gain. P and I gains shall be adjustable by the operator.

5. See other sections for how the outputs from these loops are used.

E. Zone State

1. Heating. When the output of the space Heating Loop is nonzero and the output of the Cooling Loop is equal to zero.

2. Cooling. When the output of the space Cooling Loop is nonzero and the output of the Heating Loop is equal to zero.

3. Deadband. When not in either heating or cooling.

F. Zone Alarms

1. Zone Temperature Alarms

a. High-temperature alarm

1) If the zone is 2°C (3°F) above cooling setpoint for 10 minutes, generate a Level 4 alarm.

2) If the zone is 3°C (5°F) above cooling setpoint for 10 minutes, generate a Level 3 alarm.

b. Low-temperature alarm

1) If the zone is 2°C (3°F) below heating setpoint for 10 minutes, generate a Level 4 alarm.

2) If the zone is 3°C (5°F) below heating setpoint for 10 minutes, generate a Level 3 alarm.

Default time delay for zone temperature alarm (10 minutes) is intentionally long to minimize nuisance alarms. For critical zones, such as IT closets, consider reducing time delay or setting delay to zero.

c. Suppress zone temperature alarms as follows:

1) After zone setpoint is changed per Section 3.1S.

2) While Zone Group is in Warmup Mode or Cooldown Mode.

The following is from addendum e to G36-2021:

G. Zone Group Mode Requests

1. Zone Group Mode Requests shall be generated by the conditions in each zone and sent to the Zone Group of which the zone is a member.

2. Warm-up Mode Requests

   a. An algorithm provided with the BAS shall calculate the required zone warm-up time, tz-warmup, which shall be less than 3 hours, based on the zone's occupied heating set point, the current zone temperature, the outdoor air temperature, and a heating mass/capacity factor for each zone.

   b. The heating mass/capacity factor may be either manually adjusted or automatically self-tuned by the BAS. If automatic, the tuning process shall be turned ON or OFF by a software switch to allow tuning to be stopped after the system has been trained.

   c. If the zone group is in any mode other than occupied mode, zone window switch(es) indicate that all windows are closed, and the time remaining until the zone group's occupied start time is less than the zone's required warm-up time, tz-warmup, send 1 Warm-up Mode Request; else, send 0 Warm-up Mode Requests.

3. Cooldown Mode Requests

   a. An algorithm provided with the BAS shall calculate the required zone cool-down time, tz-cooldown, which shall be less than 3 hours, based on the zone's occupied heating set point, the current zone temperature, the outdoor air temperature, and a cooling mass/capacity factor for each zone.

   b. The cooling mass/capacity factor may be either manually adjusted or automatically self-tuned by the BAS. If automatic, the tuning process shall be turned ON or OFF by a software switch to allow tuning to be stopped after the system has been trained.

   c. If the zone group is in any mode other than occupied mode, zone window switch(es) indicate that all windows are closed, and the time remaining until the zone group's occupied start time is less than the zone's required cool-down time, t-cooldown, send 1 Cooldown Mode Request; else, send 0 Cooldown Mode Requests.

Warm-up and cooldown modes are used to bring the zone groups up to temperature based on their scheduled occupancy period. The algorithms used in these modes (often referred to as "optimal start") predict the shortest time to achieve occupied set point to reduce the central system energy use based on past performance.
It is recommended to use a global outdoor air temperature not associated with any AHU to determine warm-up start time. This is because unit-mounted OA sensors, which are usually placed in the outdoor air intake stream, are often inaccurate (reading high) when the unit is off due to air leakage from the space through the OA damper.

4. Setback Mode Requests

a. If the zone group is in unoccupied or setback mode, zone window switch(es) indicate that all zone windows are closed, and zone temperature is less than the unoccupied heating setpoint for 5 minutes, send 1 Setback Mode Request; else, send 0 Setback Mode Requests.

5. Setup Mode Requests

a. If the zone group is in unoccupied or setup mode, zone window switch(es) indicate that all zone windows are closed, and zone temperature is greater than the unoccupied cooling setpoint for 5 minutes, send 1 Setup Mode Requests; else, send 0 Setup Mode Requests.

3.5 ZONE GROUPS

Zone scheduling groups, or Zone Groups, are sets of zones served by a single air handler that operate together for ease of scheduling and/or in order to ensure sufficient load to maintain stable operation in the upstream equipment. A Zone Group is equivalent to an isolation area as defined in ASHRAE/IES Standard 90.1 and Title 24.

A. Each system shall be broken into separate Zone Groups composed of a collection of one or more zones served by a single air handler. See Section 1.2D for Zone Group assignments.

B. Each Zone Group shall be capable of having separate occupancy schedules and operating modes from other Zone Groups.

Note that, from the user's point of view, schedules can be set for individual zones, or they can be set for an entire Zone Group, depending on how the user interface is implemented. From the point of view of the BAS, individual zone schedules are superimposed to create a zone-group schedule, which then drives system behavior.
The schedule may govern operation of other integrated systems such as lights, daylighting, or other, in addition to the HVAC system.

C. All zones in each Zone Group shall be in the same zone-group operating mode as defined in Section 3.5F. If one zone in a Zone Group is placed in any zone-group operating mode other than Unoccupied Mode (due to override, sequence logic, or scheduled occupancy), all zones in that Zone Group shall enter that mode.

Occupied-standby mode applies to individual zones, is considered a zonal subset of Occupied Mode, and shall not be considered a zone-group operating mode.

D. A Zone Group may be in only one mode at a given time.

E. For each Zone Group, provide a set of testing/commissioning software switches that override all zones served by the Zone Group. Provide a separate software switch for each of the zone-level override switches listed under "Testing and Commissioning Overrides" in terminal unit sequences. When the value of a Zone Group's override switch is changed, the corresponding override switch for every zone in the Zone Group shall change to the same value. Subsequently, the zone-level override switch may be changed to a different value. The value of the zone-level switch has no effect on the value of the zone-group switch, and the value of the zone-group switch only affects the zone-level switches when the zone-group switch is changed.

The testing and commissioning overrides will be specified for each type of terminal unit and system in subsequent sequences. These overrides allow a commissioning agent to, for example, force a zone into cooling or drive a valve all the way open or closed.
Zone-group override switches allow a commissioning agent to apply a zone-level override to all zones in a Zone Group simultaneously. This greatly accelerates the testing and commissioning process.

F. Zone-Group Operating Modes. Each Zone Group shall have the modes shown in the following subsections.

The modes presented in this section are to enable different setpoints and ventilation requirements to be applied to Zone Groups based on their operating schedule, occupancy status, and deviation from current setpoint.
See ASHRAE Guideline 13 for best practices in locating zone-group operating mode programming logic based on network architecture.

1. Occupied Mode. A Zone Group is in the Occupied Mode when any of the following is true:

   a. The time of day is between the Zone Group's scheduled occupied start and stop times.

   b. The schedules have been overridden by the occupant override system.

   c. Any zone local override timer (initiated by local override button) is nonzero.

The following is from addendum e to G36-2021:

2. Warm-Up Mode. Warm-up mode shall start when the number of Warm-Up Mode Requests > I (I = ignores, default = 5), and shall end at the zone group's scheduled occupied start time or Warm-Up Mode Requests <MT (MT=minimum threshold, default = 1) after a minimum of 10 minutes in this mode.

3. Cool-down Mode. Cool-down mode shall start when the number of Cool-down Mode Requests > I (I = ignores, default to 5), and shall end at the zone group's scheduled occupied start time or Cool-down Mode Requests <MT (MT=minimum threshold, default = 1) after a minimum of 10 minutes in this mode.

4. Setback Mode. Setback mode shall start when the number of Setback Mode Requests > I (I = ignores, default to 4), and shall end when Setback Mode Requests <MT (MT=minimum threshold, default = 1) after a minimum of 10 minutes in this mode.

5. Setup Mode. Setup mode shall start when the number of Setup Mode Requests > I (I = ignores, default to 4), and shall end when Setup Mode Requests <MT (MT=minimum threshold, default = 1) after a minimum of 10 minutes in this mode.

Setback and setup modes are used to keep zone temperatures (and mass) from straying excessively far from occupied set points so that the cooldown and warm-up modes can achieve set point when initiated. The number of ignored zones (set at 4 here) are to ensure that the central systems (fans, pumps, heating sources, or cooling sources) can operate stably. Obviously, the size of the zones and the characteristics of the central systems are a factor in choosing the correct number of zones in each group.

6. When zones in one Zone Group are generating requests for different modes, the hierarchy in Section 5.15.1 shall be used to determine Zone Group Operating Mode.

3.6 VAV TERMINAL UNIT—COOLING ONLY

A. See "Generic Thermal Zones" (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See "Generic Ventilation Zones" (Section 3.3) for calculation of zone minimum outdoor airflow.

C. See Section 1.2C.1 for zone minimum airflow setpoint Vmin, zone maximum cooling airflow setpoint Vcool-max, and zone maximum heating airflow setpoint Vheat-max.

Delete if no IDF rooms also have VAV boxes to supplement auxiliary cooling:

D. For zones serving MDFs and IDFs etc. that are also served by fan-coils or AC units:

The next sequence is if the cooling load of the MDF/IDF was not included in the AHU loads to reduce costs.

1. If the static pressure setpoint of the VAV system serving the VAV box is at the maximum of the reset range DPmax, limit the airflow to 15% (adjustable) of the zone maximum until the setpoint is reset 0.15" (adjustable) below DPmax.

2. This zone shall have an Importance Multiplier of 0 for both Duct Static Pressure and Supply Temperature Reset so that it does not generate any System Requests.

E. Active endpoints used in the control logic depicted in Figure 5.5.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.5.4).

Table 5.5.4 Endpoints as a Function of Zone Group Mode

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Minimum	Vmin*	0	0	0	0	0
Heating maximum	Vheat-max	0	0	Vcool-max	Vcool-max	0

F. Control logic is depicted schematically in Figure 5.5.5 and described in the following subsections.

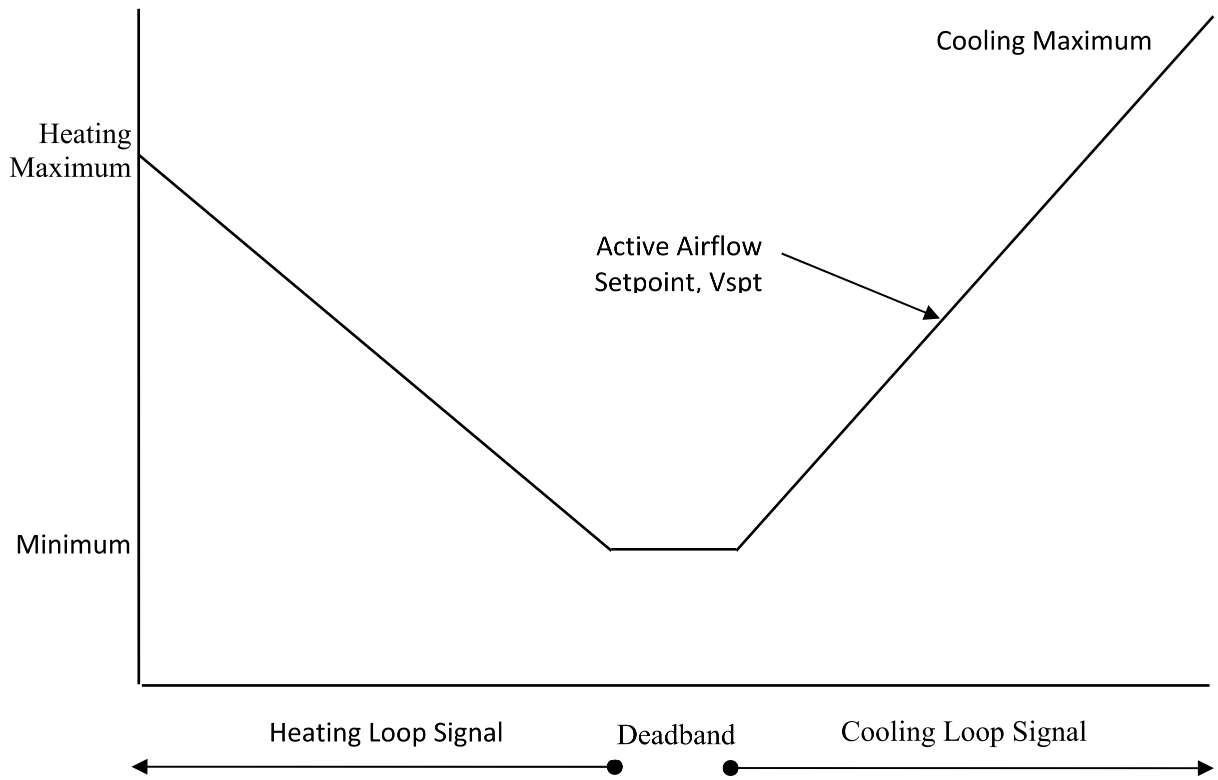


Figure 5.5.5 Control logic for cooling-only VAV zone.

1. When the Zone State is cooling, the cooling-loop output shall be mapped to the active airflow setpoint from the minimum endpoint to the cooling maximum endpoint.

    a. If supply air temperature from the air handler is greater than room temperature, the active airflow setpoint shall be no higher than the minimum endpoint.

2. When the Zone State is deadband, the active airflow setpoint shall be the minimum endpoint.

3. When the Zone State is heating, the Heating Loop output shall be mapped to the active airflow setpoint from the minimum endpoint to the heating maximum endpoint.

    a. If supply air temperature from the air handler is less than 3°C (5°F) above the room temperature, the active airflow setpoint shall be no higher than the minimum endpoint.

4. The VAV damper shall be modulated by a control loop to maintain the measured airflow at the active setpoint.

G. Alarms

1. Low Airflow

    a. If the measured airflow is less than 70% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 4 alarm.

b. If the measured airflow is less than 50% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 3 alarm.

c. If a zone has an importance multiplier of 0 (see Section 3.1O.2.a.1)) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

2. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

3. Leaking Damper. If the damper position is 0%, and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 10 minutes while the fan serving the zone is proven on, generate a Level 4 alarm.

H. Testing/Commissioning Overrides. Provide software switches that interlock to a system-level point to

a. force zone airflow setpoint to zero,

b. force zone airflow setpoint to Vcool-max,

c. force zone airflow setpoint to Vmin,

d. force damper full closed/open, and

e. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

I. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone’s cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 3 requests.

b. Else if the zone temperature exceeds the zone’s cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 2 requests.

c. Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.

d. Else if the Cooling Loop is less than 95%, send 0 requests.

2. Static Pressure Reset Requests

a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.

b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.

c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.

d. Else if the damper position is less than 95%, send 0 requests.

3.7 VAV TERMINAL UNIT WITH REHEAT

A. See “Generic Thermal Zones” (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See “Generic Ventilation Zones” (Section 3.3) for calculation of zone minimum outdoor airflow.

C. See Section 1.2C.3 for zone minimum airflow setpoints Vmin, zone maximum cooling airflow setpoint Vcool-max, zone maximum heating airflow setpoint Vheat-max, zone minimum heating airflow setpoint Vheat-min, and the maximum DAT rise above heating setpoint MaxΔT.

D. Active endpoints used in the control logic depicted in Figure 5.6.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.6.4).

Table 5.6.4 Endpoints as a Function of Zone Group Mode

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Cooling minimum	Vmin*	0	0	0	0	0
Minimum	Vmin*	0	0	0	0	0
Heating minimum	Max (Vheat-min, Vmin*)	Vheat-min	0	Vheat-max	Vheat-max	0
Heating maximum	Max (Vheat-max, Vmin*)	Vheat-max	0	Vcool-max	Vcool-max	0

E. Control logic is depicted schematically in Figure 5.6.5 (modified from Guideline 36) and described in the following subsections.

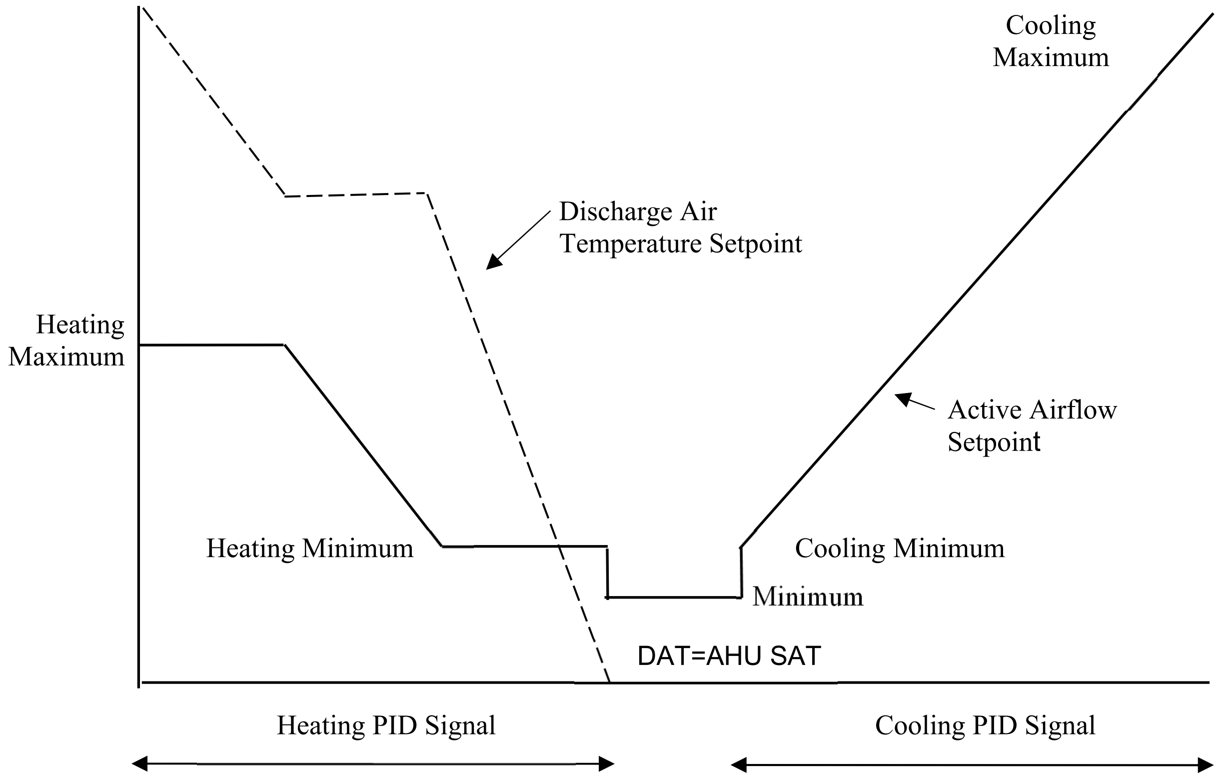


Figure 5.6.5 Control logic for VAV reheat zone modified from Guideline 36.

1. When the Zone State is cooling, the cooling-loop output shall be mapped to the active airflow setpoint from the cooling minimum endpoint to the cooling maximum endpoint. Heating coil is disabled unless the DAT is below the minimum setpoint (see Section 3.7E.4).

    a. If supply air temperature from the air handler is greater than room temperature, the active airflow setpoint shall be no higher than the minimum endpoint.

2. When the Zone State is deadband, the active airflow setpoint shall be the minimum endpoint. Heating coil is disabled unless the DAT is below the minimum setpoint (see Section 3.7E.4).

3. When the Zone State is heating, the Heating Loop shall maintain space temperature at the heating setpoint as follows:

    a. From 0 to 33%, the Heating Loop output shall reset the discharge air temperature DAT from the current AHU SAT setpoint to a setpoint equal to MaxΔT above space temperature setpoint. The airflow setpoint shall be the Heating Minimum.

    b. From 33% to 66%, if the DAT is greater than the room temperature plus 5ºF, the Heating Loop output shall reset the zone airflow setpoint from the Heating Minimum to the Heating Maximum endpoint.

    c. From 66% to 100%, the Heating Loop output shall reset the DAT setpoint to 115°F.

d. The heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heating off the zone temperature control loop is not acceptable).

1) When the airflow setpoint is pulse-width modulated per Section 3.3B, the heating coil and PID loop shall be disabled, with output set to 0 during closed periods.

4. In Occupied Mode, the heating coil shall be modulated to maintain a DAT no lower than 10°C (50°F).

5. The VAV damper shall be modulated by a control loop to maintain the measured airflow at the active setpoint.

F. Alarms

1. Low Airflow

a. If the measured airflow is less than 70% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 4 alarm.

b. If the measured airflow is less than 50% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

2. Low-Discharge Air Temperature

a. If heating hot-water plant is proven on, and the DAT is 8.3°C (15°F) less than setpoint for 10 minutes, generate a Level 4 alarm.

b. If heating hot-water plant is proven on, and the DAT is 17°C (30°F) less than setpoint for 10 minutes, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

3. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

4. Leaking Damper. If the damper position is 0%, and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 10 minutes while the fan serving the zone is proven on, generate a Level 4 alarm.

5. Leaking Valve. If the valve position is 0% for 15 minutes, DAT is above AHU SAT by 3°C (5°F), and the fan serving the zone is proven on, generate a Level 4 alarm.

G. Testing/Commissioning Overrides. Provide software switches that interlock to a system level point to

a. force zone airflow setpoint to zero,

b. force zone airflow setpoint to Vcool-max,

c. force zone airflow setpoint to Vmin,

d. force zone airflow setpoint to Vheat-max,

e. force damper full closed/open,

f. force heating to off/closed, and

g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

H. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone’s cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 3 requests.

b. Else if the zone temperature exceeds the zone’s cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 2 requests.

c. Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.

d. Else if the Cooling Loop is less than 95%, send 0 requests.

2. Static Pressure Reset Requests

a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.

b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.

c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.

d. Else if the damper position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the DAT is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

b. Else if the DAT is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.

c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil and Heating Hot-Water Plant, Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the zone a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.8 PARALLEL FAN-POWERED TERMINAL UNIT −VARIABLE-VOLUME FAN

A. See “Generic Thermal Zones” (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See “Generic Ventilation Zones” (Section 3.3) for calculation of zone minimum outdoor airflow.

C. See Section 1.2C.4 for zone minimum airflow setpoint Vmin, zone maximum cooling airflow setpoint Vcool-max, the parallel fan maximum heating airflow setpoint Pfan-htgmax, and the maximum DAT rise above heating setpoint MaxΔT.

1. Pfan-z is the lowest rate at which the fan will operate when it is turned on but has the lowest possible speed signal from the BAS.

D. Active endpoints used in the control logic depicted in Figure 5.8.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.8.4).

Table 5.8.4 Endpoints as a Function of Zone Group Mode

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Minimum	Vmin*	0	0	0	0	0

E. Control logic is depicted schematically in Figure 5.8.5 and described in the following subsections. In Figure 5.8.5, OA-min is Zone-Abs-OA-min.

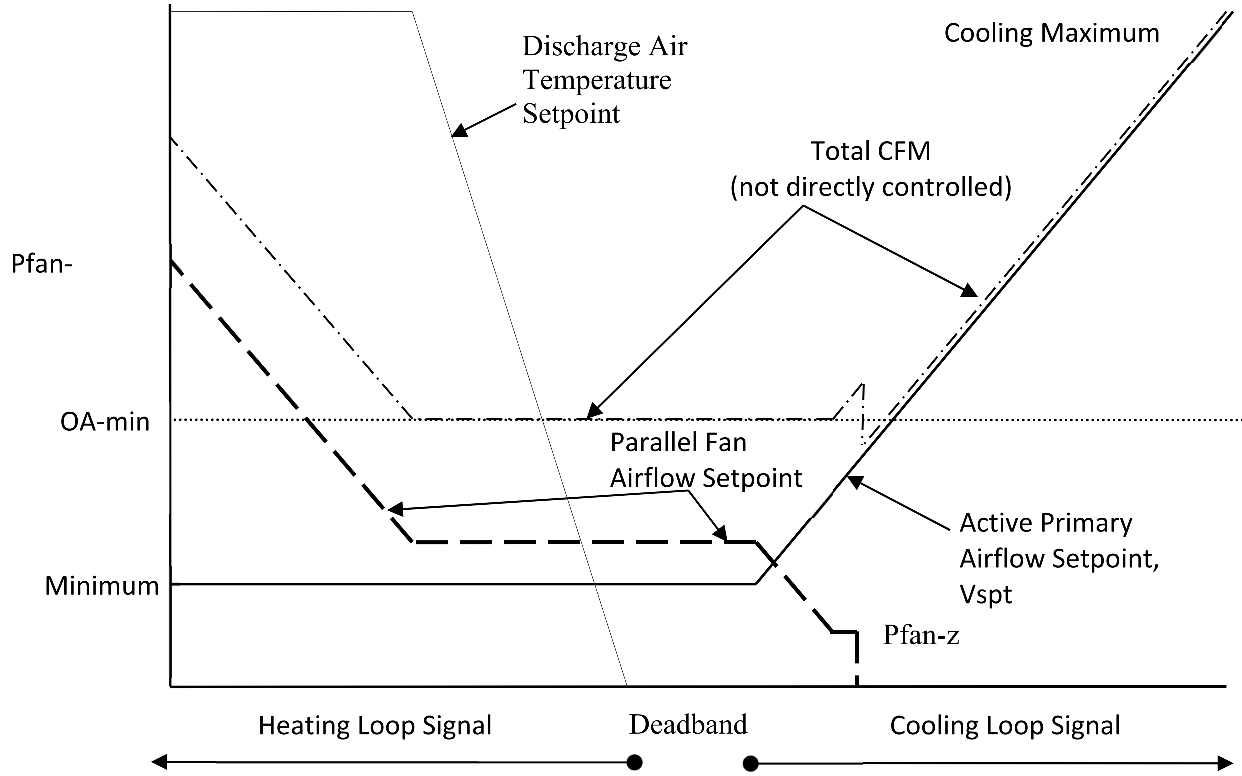


Figure 5.8.5 Control logic for variable-volume parallel fan-powered VAV zone.

1. When the Zone State Is Cooling

   a. The cooling-loop output shall be mapped to the active airflow setpoint from the minimum endpoint to the cooling maximum endpoint.

      1) If supply air temperature from the air handler is greater than room temperature, the active primary airflow setpoint shall be no higher than the minimum endpoint.

   b. Heating coil is off.

   c. If ventilation is according to California Title 24, in Occupied Mode only, parallel fan starts when primary airflow drops below Zone-Abs-OA-min minus one half of Pfan-z and shuts off when primary airflow rises above Zone-Abs-OA-min. Fan airflow rate setpoint is equal to Zone-Abs-OA-min minus the current primary airflow setpoint.

2. When the Zone State Is Deadband

   a. The active primary airflow setpoint shall be the minimum endpoint.

   b. Heating coil is off.

   c. If ventilation is according to California Title 24, in Occupied Mode only, parallel fan runs if the active primary airflow setpoint is below Zone-Abs-OA-min. Fan airflow rate setpoint is equal to Zone-Abs-OA-min minus the active primary airflow setpoint.

3. When Zone State is Heating

a. The active primary airflow setpoint shall be the minimum endpoint.

b. Parallel fan shall run.

c. From 0% to 50%, the Heating Loop output shall reset the discharge temperature from the current AHU SAT setpoint to a maximum of MaxΔT above space temperature setpoint.

d. From 50% to 100%, the Heating Loop output shall reset the parallel fan airflow setpoint from the airflow setpoint required in deadband (see above; this is Pfan-z if deadband setpoint is less than Pfan-z) proportionally up to the maximum heating-fan airflow setpoint (Pfan-htgmax).

4. The heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heating off zone temperature control loop is not acceptable).

5. The VAV damper shall be modulated to maintain the measured primary airflow at the primary airflow setpoint.

F. Alarms

1. Low Primary Airflow

a. If the measured airflow is less than 70% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 4 alarm.

b. If the measured airflow is less than 50% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

2. Low-Discharge Air Temperature

a. If heating hot-water plant is proven on, and the DAT is 8.3°C (15°F) less than setpoint for 10 minutes, generate a Level 4 alarm.

b. If heating hot-water plant is proven on, and the DAT is 17°C (30°F) less than setpoint for 10 minutes, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

3. Fan alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

a. Commanded on, status off Level 2

b. Commanded off, status on: Level 4

4. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5. Leaking Damper. If the damper position is 0%, and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 10 minutes while fan serving the zone is proven on, generate a Level 4 alarm.

6. Leaking Valve. If the valve position is 0% for 15 minutes, and DAT is above AHU SAT by 3°C (5°F), generate a Level 4 alarm.

G. Testing/Commissioning Overrides. Provide software switches that interlock to a system level point to

a. force zone airflow setpoint to zero,

b. force zone airflow setpoint to Vcool-max,

c. force zone airflow setpoint to Vmin,

d. force damper full closed/open,

e. force heating to off/closed,

f. turn fan on/off, and

g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

H. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone’s cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 3 requests.

b. Else if the zone temperature exceeds the zone’s cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 2 requests.

c. Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.

d. Else if the Cooling Loop is less than 95%, send 0 requests.

2. Static Pressure Reset Requests

a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.

b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.

c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.

d. Else if the damper position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the DAT is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

b. Else if the DAT is 8.3°C (15°F) less than setpoint for 5 minutes, send 2 requests.

c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil and a Heating Hot-Water Plant, Heating-Hot Water Plant Requests. Send the heating hot-water plant that serves the zone a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.9 SERIES FAN-POWERED TERMINAL UNIT – CONSTANT-VOLUME FAN

A. See “Generic Thermal Zones” (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See “Generic Ventilation Zones” (Section 3.3) for calculation of zone minimum outdoor airflow.

C. See Section 1.2C.5 for zone minimum airflow setpoints Vmin, zone maximum cooling airflow setpoint Vcool-max, and the maximum DAT rise above heating setpoint MaxΔT.

D. Active endpoints used in the control logic depicted in Figure 5.9.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.9.4).

Table 5.9.4 Endpoints as a Function of Zone Group Mode

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Minimum	Vmin*	0	0	0	0	0

E. Control logic is depicted schematically in Figure 5.9.5 and described in the following subsections.

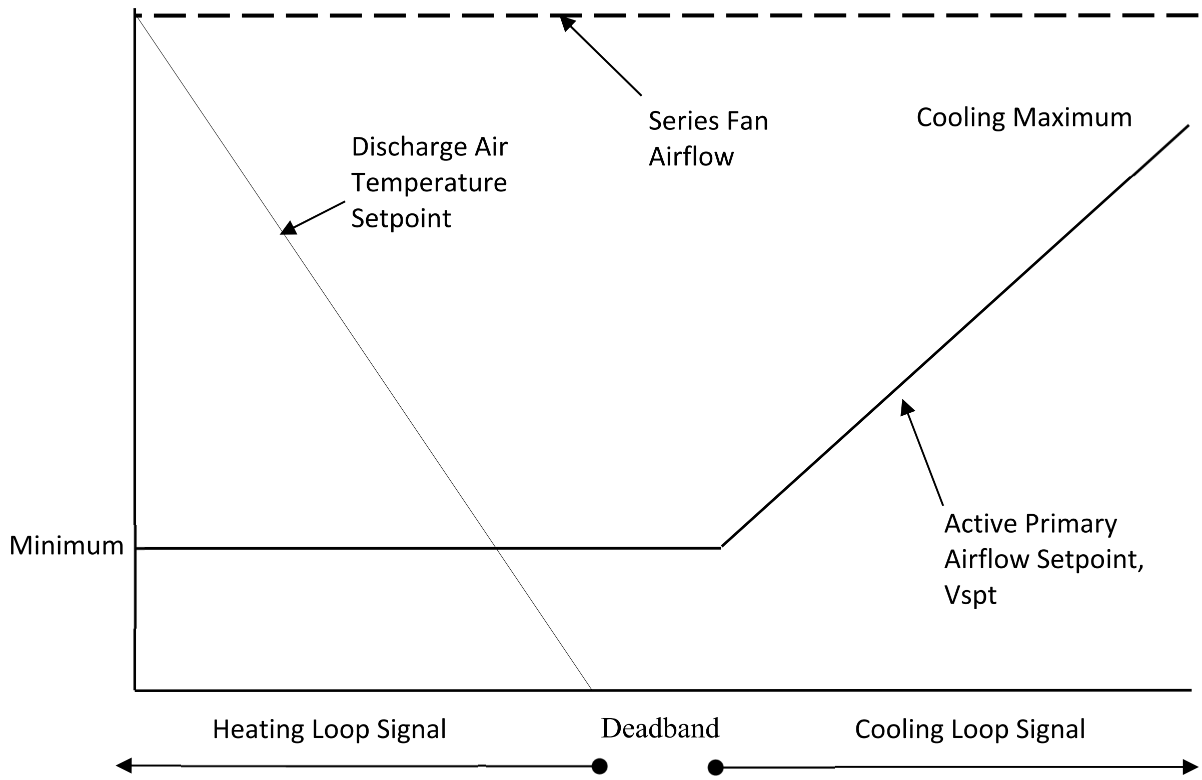


Figure 5.9.5 Control logic for constant-volume series fan-powered VAV zone.

1. When the Zone State Is Cooling
   a. The cooling-loop output shall be mapped to the active primary airflow setpoint from the minimum endpoint to the cooling maximum endpoint.
      1) If supply air temperature from the air handler is greater than room temperature, the active primary airflow setpoint shall be no higher than the minimum endpoint.
   b. Heating coil is off.
2. When the Zone State Is Deadband
   a. The active primary airflow setpoint shall be the minimum endpoint.
   b. Heating coil is off.
3. When Zone State Is Heating
   a. The active primary airflow setpoint shall be the minimum endpoint.
   b. The heating-loop shall reset the discharge temperature from the current AHU SAT setpoint to a maximum of MaxΔT above space temperature setpoint.

c. The heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heating off zone temperature control loop is not acceptable).

4. The VAV damper shall be modulated to maintain the measured airflow at setpoint.

5. Fan Control. Fan shall run whenever zone is in heating or cooling Zone State, or if the associated Zone Group is in Occupied Mode. Prior to starting the fan, the damper is first driven fully closed to ensure that the fan is not rotating backward. Once the fan is proven on for a fixed time delay (15 seconds), the damper override is released.

F. Alarms

1. Low Primary Airflow

a. If the measured airflow is less than 70% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 4 alarm.

b. If the measured airflow is less than 50% of setpoint for 10 minutes while setpoint is greater than zero, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

2. Low-Discharge Air Temperature

a. If heating hot-water plant is proven on, and the DAT is 8.3°C (15°F) less than setpoint for 10 minutes, generate a Level 4 alarm.

b. If heating hot-water plant is proven on, and the DAT is 17°C (30°F) less than setpoint for 10 minutes, generate a Level 3 alarm.

c. If a zone has an Importance-Multiplier of 0 (see Section 3.1O.2.a.1)) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

3. Fan alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

a. Commanded on, status off: Level 2

b. Commanded off, status on: Level 4

4. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5. Leaking Damper. If the damper position is 0%, and airflow sensor reading is above the larger of 10% of the cooling maximum airflow setpoint or 50 cfm for 10 minutes while the fan serving the zone is proven on, generate a Level 4 alarm.

6. Leaking Valve. If the valve position is 0% for 15 minutes, and DAT is above AHU SAT by 3°C (5°F), generate a Level 4 alarm.

G. Testing/Commissioning Overrides. Provide software switches that interlock to a system level point to

a. force zone airflow setpoint to zero,

b. force zone airflow setpoint to Vcool-max,

c. force zone airflow setpoint to Vmin,

d. force damper full closed/open,

e. force heating to on/closed,

f. turn fan on/off, and

g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

H. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone's cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 3 requests.

b. Else if the zone temperature exceeds the zone's cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 3.1S, send 2 requests.

c. Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.

d. Else if the Cooling Loop is less than 95%, send 0 requests.

2. Static Pressure Reset Requests

a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.

b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.

c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.

d. Else if the damper position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the DAT is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

b. Else if the DAT is 8.3°C (15°F) less than setpoint for 5 minutes, send 2 requests.

c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil and a Heating Hot-Water Plant, Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the zone a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.10 LABORATORY FOUR-PIPE VAV ZONE (FAST AND SLOW)

A. See "Generic Thermal Zones" (Section 3.4) for setpoints, loops, control modes, alarms, etc.

B. See Section 1.2D for airflow and discharge air temperature setpoints.

C. Lab air terminal controllable minimum

1. Supply air terminal controllable minimum (Vctrl-min) and general exhaust air valve controllable minimum (Vgex-ctrl-min) shall be determined in accordance with Paragraph 1.4B.

2. Where there is more than one terminal, rates shall be added together for control logic below.

D. Pressurization control

1. Sign conventions: All airflows have a positive sign, except for the room offset airflow which may be positive (for positively pressurized lab) or negative (for negatively pressurized lab.

2. The active supply air minimum Vmin* shall be equal to the larger of the following but no larger than Vmax:

a. Exhaust makeup air rate, Vmu

b. Minimum ventilation rate (Vvent) equal to

1) If the zone is unoccupied as indicated by its occupancy sensor <u>and</u> the lab is scheduled to be unoccupied, Vmin-unocc.

2) Otherwise, Vmin-occ

c. Vctrl-min

3. Vgex-step shall be equal to Vgex-ctrl-minimum

a. Exception: Vgex-step shall equal 0 if

1) The active airflow setpoint Vstp for temperature control is equal to Vmin*, and

2) The larger of Vvent and Vctrl-min has been less than or equal to the sum of the following for 30 seconds or more:

a) Sum of fume hood exhaust valve(s) airflow feedback

b) Vother

c) Voffset

4. The make-up airflow demand (Vmu) is equal to the sum of:

a. Sum of fume hood exhaust valve(s) airflow feedback

b. Vgex-step

c. Vother

d. Voffset

5. The active general exhaust valve setpoint Vgex-spt shall equal 0 when Vgex-step is equal 0; otherwise it shall equal the sum of the following but no larger than Vgex-max:

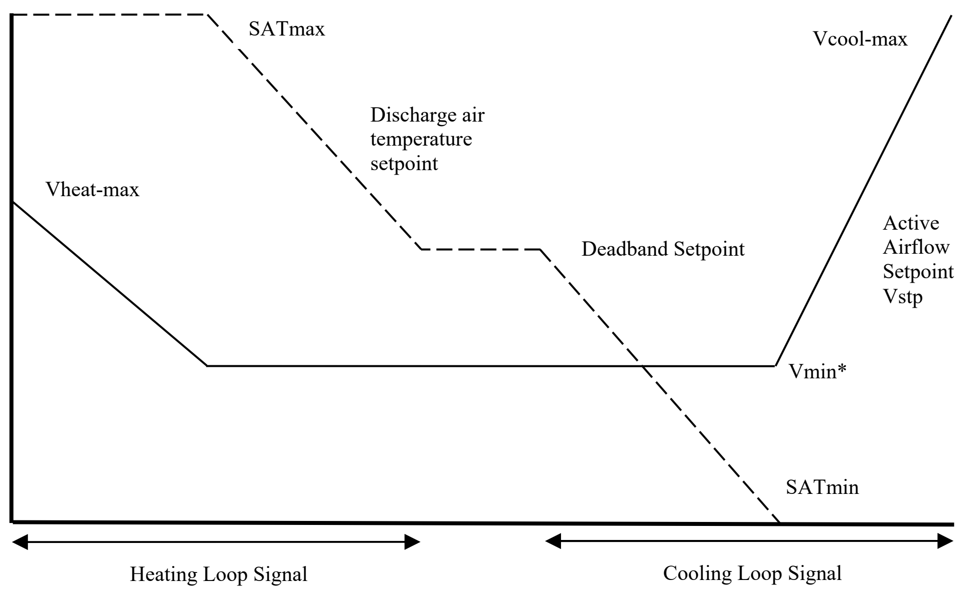
a. Supply valve feedback airflow minus Vmu

b. The general exhaust valve controllable minimum airflow, Vgex-ctrl-min

E. Supply air

1. Active endpoints used in the control logic depicted in the figure below shall not vary regardless of the Mode of the Zone Group the zone is a part of.

2. Control logic is depicted schematically in the figure below and described in the following sections.



3. When the Zone State is Cooling

    a. From 0-50%, the Cooling Loop output shall reset the discharge temperature setpoint from Deadband SAT Setpoint to SATmin. The active airflow setpoint shall be Vmin*.

    b. From 51%-100%, if the discharge air temperature is less than room temperature minus 0.5°C (1°F), the Cooling Loop output shall reset the active airflow setpoint from the Vmin* to Vcool-max, but no lower than Vmin*.

4. When the Zone State is Deadband

    a. The discharge temperature setpoint shall be the Deadband SAT Setpoint equal to the average of current cooling and heating space temperature setpoints.

    b. The active airflow setpoint shall be Vmin*.

5. When the Zone State is Heating

    a. From 0-50%, the Heating Loop output shall reset the discharge temperature setpoint from Deadband SAT Setpoint to SATmax. SATmin shall be 55ºF unless otherwise indicated on Drawings. The active airflow setpoint shall be Vmin*.

    b. From 51%-100%, if the discharge air temperature is greater than room temperature plus 3°C (5°F), the Heating Loop output shall reset the active airflow setpoint from the Vmin* to Vheat-max.

6. The hot water and chilled water valves shall be modulated in sequence using P+I loop to maintain the discharge temperature at setpoint. (Directly controlling valves off zone temperature PID loop is not acceptable.)

7. Where drawings indicate supply air valves have on-board controllers, the airflow setpoint is sent to the controller and the controller modulates the VAV damper to maintain the measured airflow at setpoint.

8. Where drawings indicate supply air valves are controlled by the BAS, the VAV damper shall be modulated to maintain the measured airflow at setpoint.

F. General exhaust

1. Where drawings indicate general exhaust air valves have on-board controllers, the active airflow setpoint Vgex-spt is sent to the controller and the controller modulates the VAV damper to maintain the measured airflow at setpoint.

2. Where drawings indicate general exhaust air valves are controlled by the BAS, the VAV damper shall be modulated to maintain the measured airflow at the active airflow setpoint Vgex-spt.

G. Alarms

1. Airflow alarm (except hoods for which setpoint is not known)

a. If the airflow feedback from any valve is 15% above or below setpoint for 5 minutes, generate a Level 3 alarm.

b. If the airflow feedback from any valve is 30% above or below setpoint for 5 minutes, generate a Level 2 alarm.

2. Room pressurization polarity alarm

a. Generate a Level 2 alarm if the airflow offset has incorrect polarity for 5 minutes based on sum of exhaust feedback signals and supply feedback signal:

1) For a room with negative offset, if exhaust minus supply < 0

2) For a room with positive offset, if exhaust minus supply > 0

3. Room low supply rate alarm

a. If the sum of exhaust feedback signals exceeds supply feedback signal by more than 4 times (adjustable) the offset for 1 minute:

1) Generate a Level 1 alarm (high level due to problems exiting)

2) All fume hood sashes in room shall be commanded closed.

3) All fume hood exhaust setpoints shall be reduced to a fixed percentage of the maximum hood rates, %hood-reduction.

4. Low supply air temperature

a. If boiler plant is proven on and the supply air temperature is 15°F less than setpoint for 10 minutes, generate a Level 3 alarm.

b. If boiler plant is proven on and the supply air temperature is 30°F less than setpoint for 10 minutes, generate a Level 2 alarm.

5. High supply air temperature

a. If chiller plant is proven on and the supply air temperature is 10°F more than setpoint for 10 minutes, generate a Level 3 alarm.

b. If chiller plant is proven on and the supply air temperature is 20°F more than setpoint for 10 minutes, generate a Level 2 alarm.

6. Fume hood

a. Fume hood alarm: Level 2

b. If average sash height (interpolated based on average cfm feedback through the hood and design maximum and minimum setpoints) during the last 24 hours is greater than 50% (adjustable), generate a Level 4 alarm

H. Testing/Commissioning Overrides: Provide software points that interlock to a system level point to

1. Force supply airflow setpoint to zero

2. Force supply airflow setpoint to Vmax

3. Force supply airflow setpoint to Vmin

4. Force supply damper full closed/open

5. Force heating valve to closed/open

6. Force cooling valve to closed/open

7. Force hood exhaust airflow setpoint to Vhex-max

8. Force hood exhaust airflow setpoint to Vhex-min

9. Force general exhaust airflow setpoint to Vgex-max

10. Force general exhaust airflow setpoint to Vgex-ctrl-min

11. Reset request-hours accumulator point to zero (provide one point for each reset type listed below)

I. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone's cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change, send 3 Requests,

b. Else if the zone temperature exceeds the zone's cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change, send 2 Requests,

c. Else if the Cooling Loop is greater than 95%, send 1 Request until the Cooling Loop is less than 85%,

d. Else if the Cooling Loop is less than 95%, send 0 Requests

2. Exhaust or Supply Static Pressure Reset Requests (Venturi type valves; separately include all exhaust and supply air valves in zone)

    a. If the air valve differential pressure is less than 0.25" for 30 seconds, send 3 request,

    b. Else if the air valve differential pressure is less than 0.3" for 30 seconds, send 1 request,

    c. Else if the air valve differential pressure is greater than 0.35", send 0 requests.

3. Exhaust or Supply Static Pressure Reset Requests (Feedback loop type valves; separately include all exhaust and supply air valves in zone)

    a. If the measured airflow is less than 85% of setpoint for 30 seconds, send 3 requests,

    b. Else if the Damper Loop is greater than 95%, send 1 request,

    c. Else if the Damper Loop is less than 85%, send 0 requests.

4. Hot Water Reset Requests

    a. If the discharge air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 Requests,

    b. Else if the discharge air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 Requests,

    c. Else if HW valve position is greater than 95%, send 1 Request until the HW valve position is less than 85%,

    d. Else if the HW valve position is less than 95%, send 0 Requests

5. Heating Hot Water Plant Requests. Send the heating hot water plant that serves the zone a Heating Hot Water Plant Request as follows:

    a. If the HW valve position is greater than 95%, send 1 Request until the HW valve position is less than 10%

    b. Else if the HW valve position is less than 95%, send 0 Requests.

6. Chilled Water Reset Requests

    a. If the supply air temperature is 10°F greater than setpoint for 5 minutes, send 3 requests,

b. Else if the supply air temperature is 5°F greater than setpoint for 5 minutes, send 2 requests,

c. Else if the CHW valve is greater than 95%, send 1 request,

d. Else if the CHW valve is less than 85%, send 0 requests.

7. Chiller Plant Requests. Send the chiller plant that serves the zone a Chiller Plant Request as follows:

a. If the CHW valve position is greater than 95%, send 1 Request until the CHW valve position is less than 10%

b. Else if the CHW valve position is less than 95%, send 0 Requests.

3.11 LABORATORY VAV REHEAT ZONE (FAST AND SLOW)

A. See “Generic Thermal Zones” (Section 3.4) for setpoints, loops, control modes, alarms, etc.

B. See Section 1.2D for airflow and discharge air temperature setpoints.

C. Lab air terminal controllable minimum

1. Supply air terminal controllable minimum (Vctrl-min) and general exhaust air valve controllable minimum (Vgex-ctrl-min) shall be determined in accordance with Paragraph 1.4B.

2. Where there is more than one terminal, rates shall be added together for control logic below.

D. Pressurization control

1. Sign conventions: All airflows have a positive sign, except for the room offset airflow which may be positive (for positively pressurized lab) or negative (for negatively pressurized lab.

2. The active supply air minimum Vmin* shall be equal to the larger of the following but no larger than Vmax:

a. Exhaust makeup air rate, Vmu

b. Minimum ventilation rate (Vvent) equal to

1) If the zone is unoccupied as indicated by its occupancy sensor <u>and</u> the lab is scheduled to be unoccupied, Vmin-unocc.

2) Otherwise, Vmin-occ

c. Vctrl-min

3. Vgex-step shall be equal to Vgex-ctrl-minimum

a. Exception: Vgex-step shall equal 0 if

1) The active airflow setpoint Vstp for temperature control is equal to Vmin*, and

2) The larger of Vvent and Vctrl-min has been less than or equal to the sum of the following for 30 seconds or more:

a) Sum of fume hood exhaust valve(s) airflow feedback

b) Vother

c) Voffset

4. The make-up airflow demand (Vmu) is equal to the sum of:

a. Sum of fume hood exhaust valve(s) airflow feedback

b. Vgex-step

c. Vother

d. Voffset

5. The active general exhaust valve setpoint Vgex-spt shall equal 0 when Vgex-step is equal 0; otherwise it shall equal the sum of the following but no larger than Vgex-max:

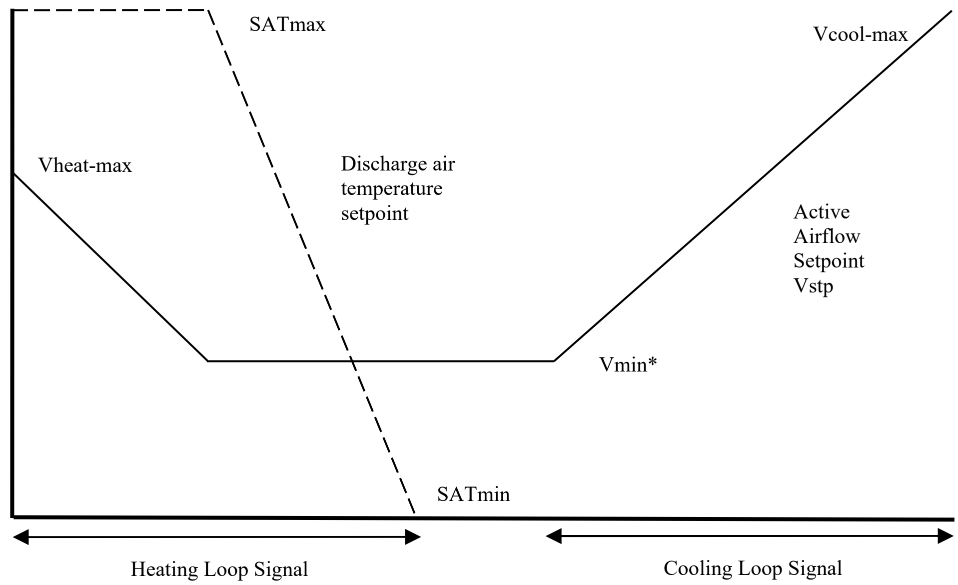
a. Supply valve feedback airflow minus Vmu

b. The general exhaust valve controllable minimum airflow, Vgex-ctrl-min

E. Supply air

1. Active endpoints used in the control logic depicted in the figure below shall not vary regardless of the Mode of the Zone Group the zone is a part of.

2. Control logic is depicted schematically in the figure below and described in the following sections.



3. When the Zone State is Cooling, the Cooling Loop output shall be mapped to the active airflow setpoint from the Vmin* to Vcool-max, but no lower than Vmin*..

   a. If supply air temperature from the air handler is greater than room temperature, the active airflow setpoint shall be no higher than Vmin*

4. When the Zone State is Deadband, the active airflow setpoint shall be Vmin*.

5. When the Zone State is Heating:

   a. From 0-50%, the Heating Loop output shall reset the discharge temperature setpoint from SATmin to SATmax. SATmin shall be 55ºF unless otherwise indicated on Drawings. The active airflow setpoint shall be Vmin*.

   b. From 51%-100%, if the discharge air temperature is greater than room temperature plus 3°C (5°F), the Heating Loop output shall reset the active airflow setpoint from the Vmin* to Vheat-max.

6. If the current supply air temperature from the AHU is less than the current heating coil discharge air setpoint, the heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heating off the zone temperature control loop is not acceptable).

7. Where drawings indicate supply air valves have on-board controllers, the airflow setpoint is sent to the controller and the controller modulates the VAV damper to maintain the measured airflow at setpoint.

8. Where drawings indicate supply air valves are controlled by the BAS, the VAV damper shall be modulated to maintain the measured airflow at setpoint.

F. General exhaust

1. Where drawings indicate general exhaust air valves have on-board controllers, the active airflow setpoint Vgex-spt is sent to the controller and the controller modulates the VAV damper to maintain the measured airflow at setpoint.

2. Where drawings indicate general exhaust air valves are controlled by the BAS, the VAV damper shall be modulated to maintain the measured airflow at the active airflow setpoint Vgex-spt.

G. Alarms

1. Airflow alarm

   a. If the airflow feedback from any valve is 15% above or below setpoint for 5 minutes, generate a Level 3 alarm.

   b. If the airflow feedback from any valve is 30% above or below setpoint for 5 minutes, generate a Level 2 alarm.

2. Room pressurization polarity alarm

   a. Generate a Level 2 alarm if the airflow offset has incorrect polarity for 5 minutes based on sum of exhaust feedback signals and supply feedback signal:

      1) For a room with negative offset, if exhaust minus supply < 0

      2) For a room with positive offset, if exhaust minus supply > 0

3. Room low supply rate alarm

   a. If the sum of exhaust feedback signals exceeds supply feedback signal by more than 4 times (adjustable) the offset for 1 minute:

      1) Generate a Level 1 alarm (high level due to problems exiting)

      2) All fume hood sashes in room shall be commanded closed.

      3) All fume hood exhaust setpoints shall be reduced to a fixed percentage of the maximum hood rates; this percentage shall be determined as specified in Section 230593 Testing, Adjusting and Balancing.

4. Low supply air temperature

   a. If boiler plant is proven on and the supply air temperature is 15°F less than setpoint for 10 minutes, generate a Level 3 alarm.

   b. If boiler plant is proven on and the supply air temperature is 30°F less than setpoint for 10 minutes, generate a Level 2 alarm.

5. High supply air temperature

   a. If chiller plant is proven on and the supply air temperature is 10°F more than setpoint for 10 minutes, generate a Level 3 alarm.

b. If chiller plant is proven on and the supply air temperature is 20°F more than setpoint for 10 minutes, generate a Level 2 alarm.

6. Fume hood

a. Fume hood alarm: Level 2

b. If average sash height (interpolated based on average cfm feedback through the hood and design maximum and minimum setpoints) during the last 24 hours is greater than 50% (adjustable), generate a Level 4 alarm

H. Testing/Commissioning Overrides: Provide software points that interlock to a system level point to

1. Force supply airflow setpoint to zero

2. Force supply airflow setpoint to Vmax

3. Force supply airflow setpoint to Vmin

4. Force supply damper full closed/open

5. Force heating valve to closed/open

6. Force hood exhaust airflow setpoint to Vhex-max

7. Force hood exhaust airflow setpoint to Vhex-min

8. Force general exhaust airflow setpoint to Vgex-max

9. Force general exhaust airflow setpoint to Vgex-ctrl-min

10. Reset request-hours accumulator point to zero (provide one point for each reset type listed below)

I. System Requests

1. Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone’s cooling setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change, send 3 Requests,

b. Else if the zone temperature exceeds the zone’s cooling setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change, send 2 Requests,

c. Else if the Cooling Loop is greater than 95%, send 1 Request until the Cooling Loop is less than 85%,

d. Else if the Cooling Loop is less than 95%, send 0 Requests

2. Exhaust or Supply Static Pressure Reset Requests (Venturi type valves; separately include all exhaust and supply air valves in zone)

a. If the air valve differential pressure is less than 0.25” for 30 seconds, send 3 request,

b. Else if the air valve differential pressure is less than 0.3” for 30 seconds, send 1 request,

c. Else if the air valve differential pressure is greater than 0.35”, send 0 requests.

3. Exhaust or Supply Static Pressure Reset Requests (Feedback loop type valves; separately include all exhaust and supply air valves in zone)

a. If the measured airflow is less than 85% of setpoint for 30 seconds, send 3 requests,

b. Else if the Damper Loop is greater than 95%, send 1 request,

c. Else if the Damper Loop is less than 85%, send 0 requests.

4. If there is a hot water coil, Hot Water Reset Requests

a. If the discharge air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 Requests,

b. Else if the discharge air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 Requests,

c. Else if HW valve position is greater than 95%, send 1 Request until the HW valve position is less than 85%,

d. Else if the HW valve position is less than 95%, send 0 Requests

5. If there is a hot water coil, Heating Hot Water Plant Requests. Send the heating hot water plant that serves the zone a Heating Hot Water Plant Request as follows:

a. If the HW valve position is greater than 95%, send 1 Request until the HW valve position is less than 10%

b. Else if the HW valve position is less than 95%, send 0 Requests.

3.12 VENTILATION OUTDOOR AIR VALVES (FROM DOAS)

A. See “Generic Thermal Zones” (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See “Generic Ventilation Zones” (Section 3.3) for calculation of zone minimum outdoor airflow and Vmin*.

C. Active endpoints used in the control logic shall vary depending on the mode of the Zone Group the zone is a part of the Table below:

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	0	0	0	0	0

Minimum	Vmin*	0	0	0	0	0

D. Control logic is as described in the following subsections.

1. Airflow setpoint shall be the Minimum endpoint with the following exception:

a. If the zone the air valve is serving is in Cooling State and DOAS supply air temperature is less than the zone's space temperature, and window switches indicate windows are closed, the airflow setpoint shall be equal to the Cooling Maximum (to provide free cooling).

E. Alarms

1. See Paragraph 3.6G.

F. Testing/Commissioning Overrides

1. See Paragraph 3.6H.

G. System Requests

1. See Paragraph 3.6I.

3.13 CEILING FANS

A. Zone mode, zone state, cooling setpoint, and heating loop output shall be that of the associated VAV zone.

B. Setpoints (adjustable)

1. Cfan-min = the minimum speed signal that causes the fan to visibly rotate

2. Cfan-max = 60%

3. Tfan-min = current cooling setpoint temperature minus 3°F

4. Tfan-max = current cooling setpoint temperature

C. Ceiling fan shall be off except as follows:

1. In Occupied or Warmup Modes, if the VAV zone heating loop output is greater than 30% and the heating fan supply air temperature is greater than the room temperature by at least 5°F, the ceiling fan shall operate for destratification at Cfan-min.

2. In Occupied Mode, if the VAV zone heating loop output is 0 (Zone State is not Heating), the ceiling fan shall operate when the space temperature is above Tfan-min with speed varying proportionally from Cfan-min at Tfan-min up to Cfan-max at Tfan-max.

D. User override controls:

1. Local fan control includes a 0-2 hour windup timer and speed potentiometer.

2. While timer is on, and the VAV Zone Group is in Occupied Mode, fan shall run at the speed indicated by the potentiometer overriding other logic.

E. Alarms

1. Generate a Level 4 maintenance alarm when fan has operated for more than 3000 hours. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status input being different from the output command for 15 seconds.

a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

F. Testing/Commissioning Overrides: Provide software points that interlock to a system level point to

1. Force ceiling fan to any user defined speed

3.14 AIR-HANDLING UNIT SYSTEM MODES

A. AHU system modes are the same as the mode of the Zone Group served by the system. When Zone Group served by an air-handling system are in different modes, the following hierarchy applies (highest one sets AHU mode):

a. Occupied Mode

b. Cooldown Mode

c. Setup Mode

d. Warmup Mode

e. Setback Mode

f. Unoccupied Mode

3.15 MULTIPLE ZONE VAV AIR HANDLERS

A. Supply Fan Control

1. Supply Fan Start/Stop

a. Supply fan shall run when system is in the Cooldown Mode, Setup Mode, or Occupied Mode.

b. If there are any VAV-reheat boxes on perimeter zones, supply fan shall also run when system is in Setback Mode or Warmup Mode (i.e., all modes except unoccupied).

c. Staged supply fan controls

1) VFD Fan groups shall be lead/lag controlled per Paragraph 3.1P.

2) When fans are enabled, start the lead supply fan. When %-supply airflow (totalized enabled VAV box setpoints (not readings) divided by design AHU airflow) exceeds stage-up setpoint (below) for 15 minutes (adjustable) then the next lag supply fan shall run. All VFDs receive the same speed signal. When %-airflow falls below the stage-up setpoint for 15 (adjustable) minutes then last lag fan shall be staged off. Each stage shall have its own PID gains, separately tuned.

VFD Stage	Stage up Flow
1	0%
2	45%

VFD Stage	Stage up Flow
1	0%
2	30%
3	60%

VFD Stage	Stage up Flow
1	0%
2	25%
3	40%
4	75%

VFD Stage	Stage up Flow
1	0%
2	10%
3	25%
4	35%
5	55%
6	75%

d. Totalize current airflow rate from VAV boxes to a software point Vps.

VAV box airflow rates are summed to obtain overall supply air rate without the need for an airflow measuring station (AFMS) at the air-handler discharge. This is used for ventilation rate calculations and may also be used for display and diagnostics.

2. Static Pressure Set-Point Reset

a. Static pressure setpoint. Setpoint shall be reset using T&R logic (see Section 3.1O) using the parameters shown in Table 5.16.1.2.

Table 5.16.1.2 Trim & Respond Variables

Variable	Value

Device	Supply fan
SP0	120 Pa (0.5 in. of water)
SPmin	25 Pa (0.1 in. of water)
SPmax	Max_DSP (see Section 1.3B.1)
Td	10 minutes
T	2 minutes
I	2
R	Zone static pressure reset requests
SPtrim	–12 Pa (–0.05 in. of water)
SPres	15 Pa (+0.06 in. of water)
SPres-max	32 Pa (+0.13 in. of water)

The T&R reset parameters in Table 5.16.1.2 are suggested as a starting point; they will most likely require adjustment during the commissioning/tuning phase.

3. Static Pressure Control

   a. Supply fan speed is controlled to maintain DSP at setpoint when the fan is proven on. Where the Zone Groups served by the system are small, provide multiple sets of gains that are used in the control loop as a function of a load indicator (such as supply-fan airflow rate, the area of the Zone Groups that are occupied, etc.).

High-pressure trips may occur if all VAV boxes are closed (as in Unoccupied Mode) or if fire/smoke dampers are closed (in some fire/smoke damper (FSD) designs, the dampers are interlocked to the fan status rather than being controlled by smoke detectors). Multiple sets of gains are used to provide control loop stability as system characteristics change.

B. Supply Air Temperature Control

1. Control loop is enabled when the supply air fan is proven on, and disabled and output set to deadband (no heating, minimum economizer) otherwise.

2. Supply Air Temperature Setpoint

The default range of outdoor air temperatures [21°C (70°F) –16°C (60°F)] used to reset the Occupied Mode SAT setpoint was chosen to maximize economizer hours. It may be preferable to use a lower range of OATs (e.g., 18°C [65°F] – 13°C [55°F]) to minimize fan energy if there is a 24/7 chiller plant that is running anyway; reheat is minimized, as in a VAV dual-fan dual-duct system, or the climate severely limits the number of available economizer hours.
If using this logic, the engineer should oversize interior zones and rooms with high cooling loads (design them to be satisfied by the warmest SAT) so these zones do not drive the T&R block to the minimum SAT setpoint.

   a. See Section 1.2F.1 for Min_ClgSAT, Max_ClgSAT, OAT_Min, and OAT_Max setpoints.

b. During Occupied Mode and Setup Mode, setpoint shall be reset from Min_ClgSAT when the outdoor air temperature is OAT_Max and above, proportionally up to T-max when the outdoor air temperature is OAT_Min and below.

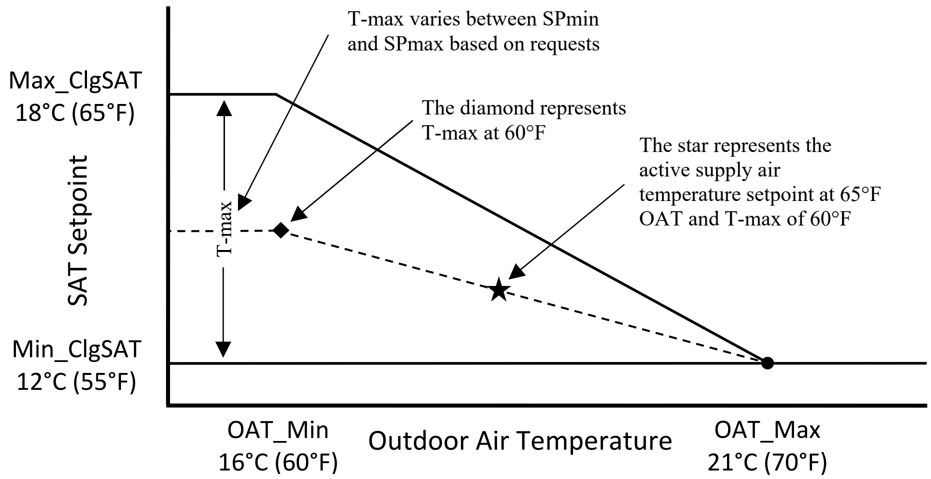
1) T-max shall be reset using T&R logic (see Section 3.1O) between Min_ClgSAT and Max_ClgSAT. The parameters shown in Table 5.16.2.2 are suggested as a starting place, but they will require adjustment during the commissioning/tuning phase.

The T&R reset parameters in Table 5.16.2.2 are suggested as a starting place; they will most likely require adjustment during the commissioning/tuning phase.

Table 5.16.2.2 Trim & Respond Variables

Variable	Value
Device	Supply fan
SP0	SPmax
SPmin	Min_ClgSAT
SPmax	Max_ClgSAT
Td	10 minutes
T	2 minutes
I	2
R	Zone cooling SAT requests
SPtrim	+0.1°C (+0.2°F)
SPres	–0.2°C (–0.3°F)
SPres-max	–0.6°C (–1.0°F)

The net result of this SAT reset strategy is depicted in the Figure 5.16.2.2 for Min_ClgSAT = 12°C (55°F), Max_ClgSAT = 18°C (65°F), OAT_Max = 21°C (70°F), and OAT_Min = 16°C (60°F).



Informative Figure 5.16.2.2 Example supply air temperature reset diagram.

c. During Cooldown Mode, setpoint shall be Min_ClgSAT.

d. During Warmup Mode and Setback Mode, setpoint shall be 35°C (95°F).

Raising the SAT setpoint in warmup will effectively lock out the economizer and cooling coil, which is desirable for warmup even if there is no heating coil at the AHU to meet the higher SAT.
This does not apply in the case of a DFDD AHU or if all the zones are equipped with fan-powered boxes such that the AHU is off in warmup and setback.

3. Supply air temperature shall be controlled to setpoint using a control loop whose output is mapped to sequence the heating coil (if applicable), outdoor air damper, return air damper, and cooling coil as shown in Figure 5.16.2.3.

   a. For units with return fans

      1) Return air damper maximum position MaxRA-P is modulated to control minimum outdoor air volume (see Sections 3.15D.3, 3.15E.3 and 3.15F.2).

   b. For units with relief dampers or relief fans

      1) Economizer damper minimum position MinOA-P and/or return air damper maximum position MaxRA-P are modulated to control minimum outdoor air volume (see Sections 3.15D.3, 3.15E.3 and 3.15F.2).

      2) For units with a separate minimum outdoor air damper, economizer damper minimum position MinOA-P is 0%, and return air damper maximum position MaxRA-P is modulated to control minimum outdoor air volume (see Sections 3.15D and 3.15E).

      3) For units with a single common minimum outdoor air and economizer damper, return air damper maximum position MaxRA-P and economizer damper minimum position MinOA-P are modulated to control minimum outdoor air volume (see Section 3.15F). Economizer damper maximum position MaxOA-P is

limited during minimum outdoor air control (e.g., economizer lockout due to high OAT).

c. The points of transition along the x-axis shown and described in Figure 5.16.2.3 are representative. Separate gains shall be provided for each section of the control map (heating coil, economizer, cooling coil) that is determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.16.2.3 to provide stable control. Damper control depends on the type of building pressure control system.

For AHUs with relief fans, outdoor air and return air dampers are sequenced rather than complementary (as per traditional sequences) to reduce fan power at part loads.

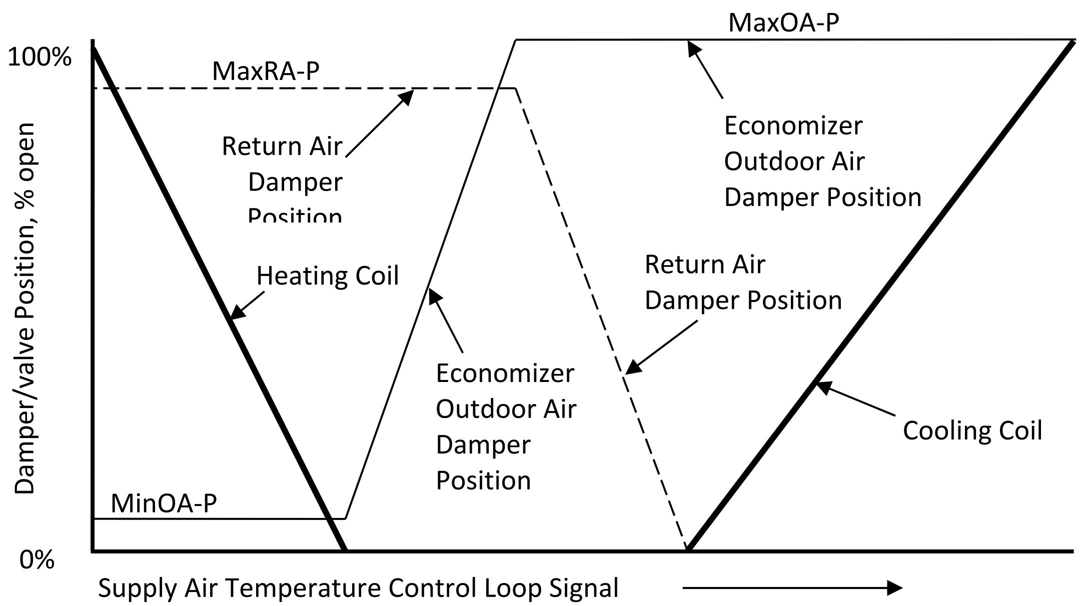


Figure 5.16.2.3-1 SAT loop mapping with relief damper or relief fan.

For AHUs with return fans and airflow tracking control, the SAT control loop makes the economizer outdoor air damper open fully whenever the AHU is on, while the return air damper modulates to maintain supply air temperature as shown below. Relief/exhaust damper position tracks inversely with the return damper position.
Outdoor air dampers on air handlers with return fans have no impact on the outdoor airflow rate into the mixing plenum. Instead, the return-fan and return-damper controls dictate outdoor air flow. See ASHRAE Guideline 16.
Note that the economizer damper will close (if there is a separate minimum outdoor air damper) or modulate to minimum position (if there is a single outdoor air damper) whenever minimum outdoor air control is active. See logic for Minimum Outdoor Air Control below.

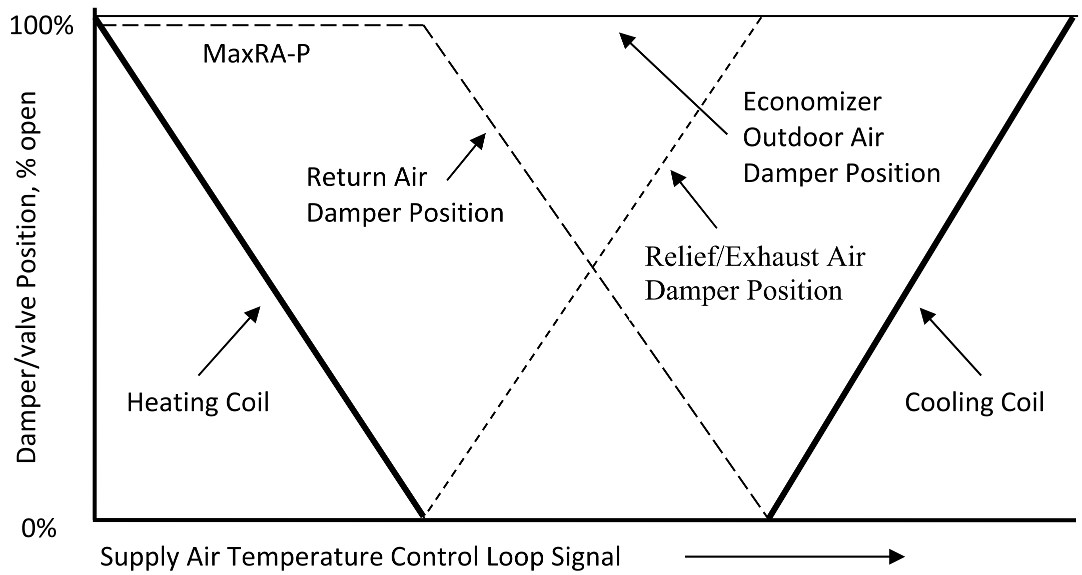


Figure 5.16.2.3-2 SAT loop mapping with return-fan control with airflow tracking.

For AHUs with return fans and direct building pressure controls, the SAT control loop makes the economizer outdoor air damper open fully whenever the AHU is on, while the return air damper modulates to maintain supply air temperature as shown below. Relief/exhaust damper position tracks inversely with the return damper position.
Outdoor air dampers on air handlers with return fans have no impact on the outdoor airflow rate into the mixing plenum. Instead, the return-fan and return-damper controls dictate outdoor air flow. See ASHRAE Guideline 16.
Note that the economizer damper will close (if there is a separate minimum outdoor air damper) or modulate to minimum position (if there is a single outdoor air damper) whenever minimum outdoor air control is active. See logic for Minimum Outdoor Air Control below.

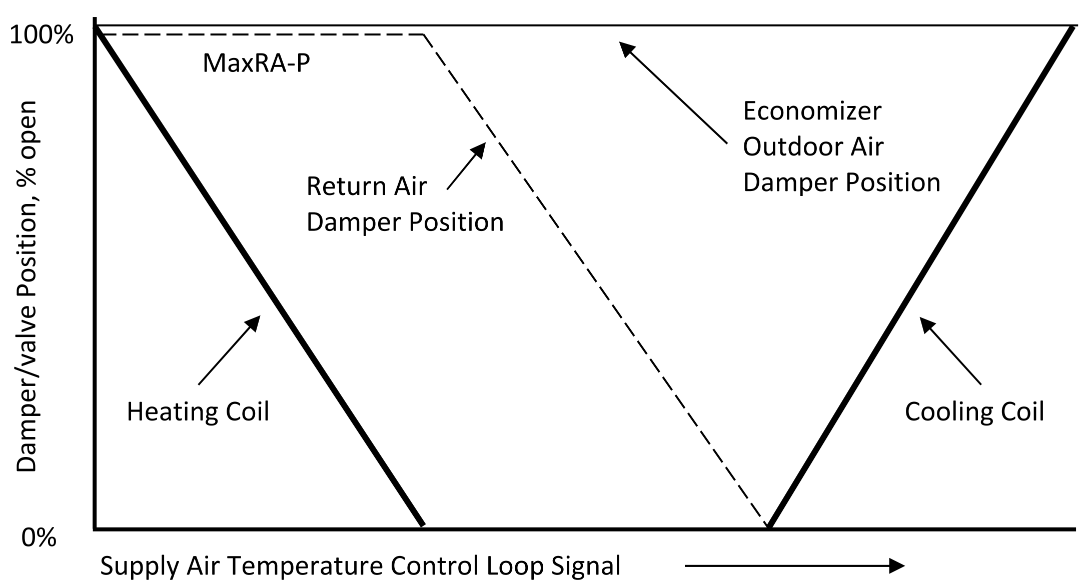


Figure 5.16.2.3-3 SAT loop mapping with return-fan control with direct building pressure controls.

C. Minimum Outdoor Airflow Setpoints

1. Outdoor Airflow Setpoint for California Title 24 Ventilation

a. See Section 3.3A.3 for zone outdoor air rates Zone-Abs-OA-min and Zone-Des-OA-min.

b. See Section 1.2F.2.a for setpoints AbsMinOA and DesMinOA.

c. Effective outdoor air absolute minimum and design minimum setpoints are recalculated continuously based on the mode of the zones being served.

1) AbsMinOA* is the sum of Zone-Abs-OA-min for all zones in all Zone Groups that are in Occupied Mode but shall be no larger than the absolute minimum outdoor airflow AbsMinOA.

2) DesMinOA* is the sum of Zone-Des-OA-min for all zones in all Zone Groups that are in Occupied Mode but shall be no larger than the design minimum outdoor airflow DesMinOA.

D. Minimum Outdoor Air Control with a Separate Minimum Outdoor Air Damper and Differential Pressure Control

1. DP setpoint for California Title 24 Ventilation

a. See Section 1.1.1.1.a for design OA DP setpoints.

b. See Section 3.15C.1 for calculation of current setpoints AbsMinOA* and DesMinOA*.

c. See zone CO2 control logic under terminal unit sequences.

d. The active minimum DP setpoints AbsDPsp* and DesDPsp* shall be determined by the following equations:

$$\text{AbsDPsp*} = \text{AbsMinDP}\left[\frac{\text{AbsMinOA*}}{\text{AbsMinOA}}\right]^2$$

$$\text{DesDPsp*} = \text{DesMinDP}\left[\frac{\text{DesMinOA*}}{\text{DesMinOA}}\right]^2$$

This equation prevents excess outdoor air from being supplied during periods of partial occupancy.

e. The minimum outdoor air DP setpoint MinDPsp shall be reset based on the highest zone CO2 control-loop signal from AbsDPsp* at 50% signal to DesDPsp* at 100% signal.

f. The minimum outdoor air setpoint MinOAsp shall be reset based on the highest zone CO2 control-loop signal from AbsMinOA* at 50% signal to DesMinOA* at 100% signal.

2. Open minimum outdoor air damper when the supply air fan is proven on and the system is in Occupied Mode and MinDPsp is greater than zero. Damper shall be closed otherwise.

3. Outdoor Air and Return Air Dampers

   a. For units with return fans

Minimum outdoor air control is enabled when return damper position exceeds MRA-P because it cannot be assumed that the combination of the minimum and the economizer outdoor air dampers are providing sufficient outdoor air under these conditions.
The 20% threshold can be increased to ensure minimum outdoor airflow will be maintained but at the expense of fan energy. This threshold could be determined empirically during TAB work as well.

1) When the supply air fan is proven on and the system is in Occupied Mode and MinDPsp is greater than zero, the system shall calculate MRA-P. The value of MRA-P shall scale from 95% when supply fan speed is at 100% design speed proportionally down to 20% when the fan is at minimum speed. When MRA-P is not being calculated for any reason, it shall be set to 100%.

2) Minimum outdoor air control shall be enabled when the unit is in Occupied Mode and either of the following conditions are true for 10 minutes:

   a) The economizer high limit conditions in Section 3.1Qare exceeded.

   b) When the minimum outdoor air damper is open and the return air damper position is greater than MRA-P.

3) When minimum outdoor air control is enabled, the normal sequencing of economizer outdoor air and return air dampers per Section 3.15Bshall be suspended per the following sequence:

   a) Fully open return air damper; and

Economizer outdoor air damper is closed when minimum outdoor air control is enabled to ensure a good signal across the minimum outdoor air damper.

   b) Wait 15 seconds, then close the economizer outdoor air damper; and

   c) Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 3.15B. Economizer outdoor air damper remains closed.

   d) The maximum return air damper position endpoint MaxRA-P shall be modulated from 100% to 0% to maintain DP across the minimum outdoor air damper at setpoint MinDPsp.

4) Minimum outdoor air control shall be disabled when the unit is no longer in Occupied Mode, or both of the following conditions are true for 10 minutes:

   a) The economizer high limit conditions in Section 3.1Q are not exceeded.

b) The minimum outdoor air damper is closed or the return air damper position is 10% below MRA-P.

5) When minimum outdoor air control is disabled:

a) Economizer outdoor air damper shall be fully opened.

b) MaxRA-P shall be set to 100%.

c) Economizer and return air damper positions shall be controlled by the SAT control loop per Section 3.15B.

b. For units with relief dampers or relief fans

> *Minimum outdoor air control is enabled when economizer damper position is less than MOA-P because it cannot be assumed that the combination of the minimum and the economizer outdoor air dampers are providing sufficient outdoor air under these conditions.*
> *Minimum outdoor air control is disabled when return damper position is less than MRA-P, because the economizer damper has been closed to enable an accurate airflow measurement through the minimum outdoor air damper.*
> *The 20% and 80% thresholds can be increased/decreased to ensure minimum outdoor airflow will be maintained but at the expense of fan energy. This threshold could be determined empirically during TAB work as well.*

1) When the supply air fan is proven on and the system is in Occupied Mode and MinDPsp is greater than zero, the system shall calculate MOA-P. The value of MOA-P shall scale from 5% when supply-fan speed is at 100% design speed proportionally up to 80% when the fan is at minimum speed. When MOA-P is not being calculated for any reason, it shall be set to 0%.

2) When the supply air fan is proven on and the system is in Occupied Mode and MinDPsp is greater than zero, the system shall calculate MRA-P. The value of MRA-P shall scale from 95% when supply fan speed is at 100% design speed proportionally down to 20% when the fan is at minimum speed. When MRA-P is not being calculated for any reason, it shall be set to 100%.

3) Minimum outdoor air control shall be enabled when the unit is in Occupied Mode and either of the following conditions are true for 10 minutes:

a) The economizer high limit conditions in Section 3.1Q are exceeded.

b) When the minimum outdoor air damper is open and the economizer outdoor air damper position is less than MOA-P.

4) When minimum outdoor air control is enabled, the normal sequencing of economizer outdoor air and return air dampers per Section 3.15B shall be suspended per the following sequence:

a) Fully open return air damper; and

> *Economizer outdoor air damper is closed when minimum outdoor air control is enabled to ensure a good signal across the minimum outdoor air damper.*

b) Wait 15 seconds, then close the economizer outdoor air damper; and

c) Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 3.15B. Economizer outdoor air damper remains closed.

d) The maximum return air damper position endpoint MaxRA-P shall be modulated from 100% to 0% to maintain DP across the minimum outdoor air damper at setpoint MinDPsp.

5) Minimum outdoor air control shall be disabled when the unit is no longer in Occupied Mode, or both of the following conditions are true for 10 minutes:

a) The economizer high limit conditions in Section 3.1Q are not exceeded.

b) The minimum outdoor air damper is closed or the return air damper position is 10% below MRA-P.

6) When minimum outdoor air control is disabled:

a) MaxRA-P shall be set to 100%.

b) Economizer and return air damper positions shall be controlled by the SAT control loop per Section 3.15B.

E. Minimum Outdoor Air Control with a Separate Minimum Outdoor Air Damper and Airflow Measurement

1. Outdoor Airflow Setpoint for California Title 24 Ventilation

a. See Section 3.15C.1 for calculation of current setpoints AbsMinOA* and DesMinOA*.

b. See zone CO2 control logic under terminal unit sequences.

c. The minimum outdoor air setpoint MinOAsp shall be reset based on the highest zone CO2 control-loop signal from AbsMinOA* at 50% signal to DesMinOA* at 100% signal.

2. Open the minimum outdoor air damper when the supply fan is proven ON, the AHU is in Occupied Mode and MinOAsp is greater than zero. Minimum outdoor air damper shall be closed otherwise.

3. Outdoor Air and Return Air Dampers

a. For units with return fans

Minimum outdoor air control is enabled when return damper position exceeds MRA-P because it cannot be assumed that the combination of the minimum and the economizer outdoor air dampers are providing sufficient outdoor air under these conditions.
The 20% threshold can be increased to ensure minimum outdoor airflow will be maintained but at the expense of fan energy. This threshold could be determined empirically during TAB work as well.

1) When the supply air fan is proven on and the system is in Occupied Mode and MinOAsp is greater than zero, the system shall calculate MRA-P. The value of MRA-P shall scale from 95% when supply fan speed is at 100% design speed proportionally down to 20% when the fan is at minimum speed. When MRA-P is not being calculated for any reason, it shall be set to 100%.

2) Minimum outdoor air control shall be enabled when the unit is in Occupied Mode and either of the following conditions are true for 10 minutes:

   a) The economizer high limit conditions in Section 3.1Q are exceeded.

   b) When the minimum outdoor air damper is open and the return air damper position is greater than MRA-P.

3) When minimum outdoor air control is enabled, the normal sequencing of economizer outdoor air and return air dampers per Section B shall be suspended per the following sequence:

   a) Fully open return air damper; and

Economizer outdoor air damper is closed when minimum outdoor air control is enabled to ensure a good signal across the minimum outdoor air damper.

   b) Wait 15 seconds, then close the economizer outdoor air damper; and

   c) Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section B. Economizer outdoor air damper remains closed.

   d) The maximum return air damper position endpoint MaxRA-P shall be modulated from 100% to 0% to maintain airflow across the minimum outdoor air damper at setpoint MinOAsp.

4) Minimum outdoor air control shall be disabled when the unit is no longer in Occupied Mode, or both of the following conditions are true for 10 minutes:

   a) The economizer high limit conditions in Section 3.1Q are exceeded.

   b) The minimum outdoor air damper is closed or the return air damper position is 10% below MRA-P.

5) When minimum outdoor air control is disabled:

   a) Economizer outdoor air damper shall be fully opened.

   b) MaxRA-P shall be set to 100%.

   c) Economizer and return air damper positions shall be controlled by the SAT control loop per Section B.

b. For units with relief dampers or relief fans

Minimum outdoor air control is enabled when economizer damper position is less than MOA-P because it cannot be assumed that the combination of the minimum and the economizer outdoor air dampers are providing sufficient outdoor air under these conditions.
Minimum outdoor air control is disabled when return damper position is less than MRA-P, because the economizer damper has been closed to enable an accurate airflow measurement through the minimum outdoor air damper.
The 20% and 80% thresholds can be increased/decreased to ensure minimum outdoor airflow will be maintained but at the expense of fan energy. This threshold could be determined empirically during TAB work as well.

1) When the supply air fan is proven on and the system is in occupied mode and MinOAsp is greater than zero, the system shall calculate MOA-P. The value of MOA-P shall scale from 5% when supply-fan speed is at 100% design speed proportionally up to 80% when the fan is at minimum speed. When MOA-P is not being calculated for any reason, it shall be set to 0%.

2) When the supply air fan is proven on and the system is in occupied mode and MinOAsp is greater than zero, the system shall calculate MRA-P. The value of MRA-P shall scale from 95% when supply fan speed is at 100% design speed proportionally down to 20% when the fan is at minimum speed. When MRA-P is not being calculated for any reason, it shall be set to 100%.

3) Minimum outdoor air control shall be enabled when the unit is in Occupied Mode and either of the following conditions are true for 10 minutes:

    a) The economizer high limit conditions in Section 3.1Q are exceeded.

    b) When the minimum outdoor air damper is open and the economizer outdoor air damper position is less than MOA-P.

4) When minimum outdoor air control is enabled, the normal sequencing of economizer outdoor air and return air dampers per Section B shall be superseded per the following:

    a) Fully open return air damper; and

Economizer outdoor air damper is closed when minimum outdoor air control is enabled to ensure a good signal across the minimum outdoor air damper.

    b) Wait 15 seconds, then close the economizer outdoor air damper; and

    c) Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section B. Economizer outdoor air damper remains closed.

    d) The maximum return air damper position endpoint MaxRA-P shall be modulated from 100% to 0% to maintain airflow across the minimum outdoor air damper at setpoint MinOAsp.

5) Minimum outdoor air control shall be disabled when the unit is no longer in Occupied Mode, or both of the following conditions are true for 10 minutes:

a) The economizer high limit conditions in Section 3.1Q are not exceeded.

b) The minimum outdoor air damper is closed or the return air damper position is 10% below MRA-P.

6) When minimum outdoor air control is disabled:

a) MaxRA-P shall be set to 100%.

b) Economizer and return air damper positions shall be controlled by the SAT control loop per Section B.

F. Minimum Outdoor Air Control with a Single Common Damper for Minimum Outdoor Air and Economizer Functions and Airflow Measurement

1. Outdoor Airflow Setpoint for California Title 24 Ventilation

a. See Section 3.15C.1 for calculation of current setpoints AbsMinOA* and DesMinOA*.

b. See zone CO2 control logic under terminal unit sequences.

c. The minimum outdoor air setpoint MinOAsp shall be reset based on the highest zone CO2 control-loop signal from AbsMinOA* at 50% signal to DesMinOA* at 100% signal.

2. Minimum Outdoor Air Control Loop

a. Minimum outdoor air control loop is enabled when the supply fan is proven on and the AHU is in Occupied Mode, and disabled and output set to zero otherwise.

b. For units with return fans:

The following logic limits the return damper position to ensure that minimum outdoor air is maintained at all times, while the actual return damper position is modulated by the SAT control loop.

1) The outdoor airflow rate shall be maintained at the minimum outdoor damper outdoor airflow setpoint MinOAsp by a direct-acting control loop whose output is mapped to the return air damper maximum position endpoint MaxRA-P.

The following logic directly controls the return damper position to ensure that exactly the minimum outdoor air – and no more – is provided when economizer lockout conditions are exceeded. When economizer lockout no longer applies, return damper control reverts to the SAT control loop.

2) While the unit is in Occupied Mode, if the economizer high limit conditions in Section 3.1Q are exceeded for 10 minutes, outdoor air shall be controlled to the minimum outdoor airflow. When this occurs, the normal sequencing of the return air damper by the SAT control loop is suspended, and the return air damper position shall be modulated directly to maintain measured airflow at MinOAsp (i.e. return damper position shall equal MaxRA-P). The economizer damper shall remain open.

3) If the economizer high limit conditions in Section 3.1Q are not exceeded for 10 minutes, or the unit is no longer in Occupied Mode, release return damper to control by the SAT control loop (i.e. return damper position is limited by MaxRA-P endpoint, but is not directly controlled to equal MaxRA-P).

c. For units with relief dampers or relief fans:

The following logic limits the return and economizer damper positions to ensure that minimum outdoor air is maintained at all times, while the actual damper positions are modulated by the SAT control loop.

1) The outdoor airflow rate shall be maintained at the minimum outdoor air setpoint MinOAsp by a reverse-acting control loop whose output is mapped to economizer damper minimum position MinOA-P and return air damper maximum position MaxRA-P as indicated in Figure 5.16.6.3.

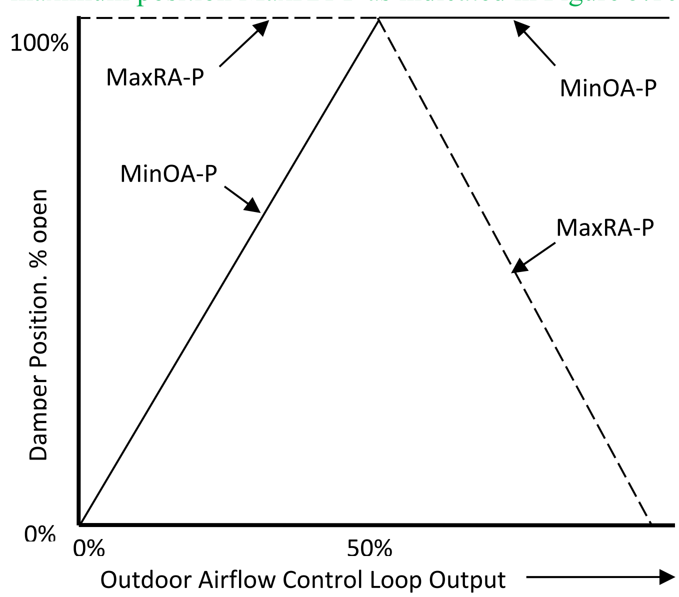


Figure 5.16.6.3 Minimum outdoor airflow control mapping with single damper.

The following logic directly controls the return and economizer damper positions to ensure that exactly the minimum outdoor air – and no more – is provided when economizer lockout conditions are exceeded. When economizer lockout no longer applies, return damper control reverts to the SAT control loop.

2) While the unit is in Occupied Mode, if the economizer high limit conditions in Section 3.1Q are exceeded for 10 minutes, outdoor airflow shall be controlled to the minimum outdoor airflow setpoint, MinOAsp. When this occurs, the normal sequencing of the return air damper by the SAT control loop is suspended as follows:

a) Fully open the return air damper

b) Wait 15 seconds, then set MaxOA-P equal to MinOA-P

c) Wait 3 minutes, then modulate the return air damper to maintain the measured airflow at MinOAsp (i.e. return air damper position shall equal MaxRA-P).

3) If the economizer high limit conditions in Section 3.1Q are not exceeded for 10 minutes, or the unit is no longer in Occupied Mode, set MaxOA-P = 100% and release the return air damper to control by the SAT control loop (i.e. return air damper position is limited by the MaxRA-P endpoint, but is not directly controlled to equal MaxRA-P).

G. Control of Actuated Relief Dampers without Fans

1. Relief dampers shall be enabled when the associated supply fan is proven on, and disabled otherwise.

2. When enabled, use a P-only control loop to modulate relief dampers to maintain 12 Pa (0.05 in. of water) building static pressure. Close damper when disabled.

H. Relief-Fan Control

A pressure zone is defined as an enclosed area with interconnected return paths. The appropriate boundaries for pressure zones, establishing which relief fans run together and which building pressure sensors are used, will need to be determined by the engineer based on building geometry.

Relief fans are enabled and disabled with their associated supply fans, but all relief fans that are running and serve a pressure zone run at the same speed. All operating relief fans that serve a pressure zone shall be controlled as if they were one system, running at the same speed and using the same control loop, even if they are associated with different AHUs. For example, if two AHUs share a pressure zone, their relief fans should be controlled together as one system, while both AHUs are operating.

This prevents relief fans from fighting each other, which can lead to flow reversal or unstable fan speed control and space pressurization problems.

The appropriate boundaries between relief systems, establishing which relief fans run together, will need to be determined by the engineer based on building geometry.

1. See Section 1.2F.5 for pressure Zone Group assignments.

2. Relief fans or relief fan VFD Fan groups shall be lead/lag controlled per Paragraph 3.1P.

3. All operating relief fans that serve a pressure zone shall be grouped and controlled as if they were one system, running at the same speed when enabled and using the same control loop, even if they are associated with different AHUs.

4. A relief fan shall be enabled when its associated supply fan is proven on, and shall be disabled otherwise.

5. Building static pressure shall be time averaged with a sliding 5-minute window and 15 second sampling rate (to dampen fluctuations). The averaged value shall be that displayed and used for control.

a. Where multiple building pressure sensors are used, each shall be time-averaged and the highest of the averaged values for sensors within a pressure zone shall be used for control.

6. A single P-only control loop for each pressure zone shall maintains the building pressure at a setpoint of 12 Pa (0.05 in. of water) with an output ranging from 0% to 100%. The loop shall be enabled when any supply fan within the pressure zone is proven ON. The loop is disabled with output set to zero otherwise.

The following is intended to use barometric relief as the first stage and then maintain many fans on at low speed to minimize noise and reduce losses through discharge dampers and louvers. Fans are staged off only when running at minimum speed.
For best results, fan speed minimums should be set as low as possible.

7. Fan speed signal to all operating fans in the relief system group shall be the same and shall be equal to the PID signal but no less than the minimum speed. Except for Stage 0, discharge dampers of all relief fans shall be open only when fan is commanded on.

In some installations, the relief fan inlet plenum may also be the return plenum to the AHU mixed air plenum, in which case the pressure in this plenum may be drawn negative relative to the outdoors by the supply air fan drawing return air from this plenum. This can occur when the return path has a fairly high pressure drop. If the engineer is concerned that this may occur, Stage 0 and references to it should be deleted.

a. Stage 0 (barometric relief). When relief system is enabled, and the control loop output is above 5%, open the motorized dampers to all relief fans serving the relief system group that are enabled; close the dampers when the loop output drops to 0% for 5 minutes.

b. Stage Up. When control loop is above minimum speed plus 15%, start stage-up timer. Each time the timer reaches 7 minutes, start the next relief fan (and open the associated damper) in the relief system group, per staging order, and reset the timer to 0. The timer is reset to 0 and frozen if control loop is below minimum speed plus 15%.

1) For systems where relief fans share a common relief fan inlet plenum: When staging from Stage 0 (no relief fans) to Stage 1 (one relief fan), the relief dampers of all nonoperating relief fans must be closed.

2) For systems where relief fans do not share a common relief fan inlet plenum: When staging from Stage 0 (no relief fans) to Stage 1 (one relief fan), the discharge dampers of all nonoperating relief fans shall remain open when the associated supply fan is proven ON.

c. Stage Down. When PID loop is below minimum speed, start stage-down timer. Each time the timer reaches 5 minutes, shut off lag fan per staging order and reset the timer to 0. The timer is reset to 0 and frozen if PID loop rises above minimum speed or all fans are off. If all fans are off, go to Stage 0 (all dampers open and all fans off).

8. For fans in a Level 2 alarm and status is off, discharge damper shall be closed when stage is above Stage 0.

I. Return-Fan Control − Direct Building Pressure

1. See Section 1.2F.5 for pressure Zone Group assignments.

2. Return fan or return fan VFD Fan groups shall be lead/lag controlled per Paragraph 3.1P.

3. Return fan operates whenever the associated supply fan is proven on and shall be off otherwise.

4. Return fans shall be controlled to maintain return-fan discharge static pressure at setpoint (Section 3.15I.6).

5. Building static pressure shall be time averaged with a sliding 5-minute window and 15 second sampling rate (to dampen fluctuations). The averaged value shall be that displayed and used for control.

   a. Where multiple building pressure sensors are used, the highest of the averaged values for sensors within a pressure zone shall be used for control.

Due to the potential for interaction between the building pressurization and return-fan control loops, extra care must be taken in selecting the control loop gains. To prevent excessive control-loop interaction, the closed-loop response time of the building pressurization loop should not exceed 1/5 the closed-loop response time of the return-fan control loop. This can be accomplished by decreasing the gain of the building pressurization control loop.

6. A single P-only control loop for each pressure zone shall modulate to maintain the building pressure at a setpoint of 12 Pa (0.05 in. of water) with an output ranging from 0% to 100%. The loop shall be enabled when the supply and return fans for any unit within the pressure zone are proven ON and the minimum outdoor air damper is open. The exhaust dampers shall be closed with loop output set to zero otherwise. All exhaust damper and return fan static pressure setpoints for units in an associated pressure zone shall be sequenced based on building pressure control loop output signal, as shown in Figure 5.16.10.5.

A pressure zone is defined as an enclosed area with interconnected return air paths. All operating relief dampers and return fans that serve a pressure zone shall be controlled as if they were one system, using the same control loop, even if they are associated with different AHUs.
The appropriate boundaries for pressure zones, establishing which return fans run together, will need to be determined by the engineer based on building geometry.

   a. From 0% to 50%, the building pressure control loop shall modulate the exhaust dampers from 0% to 100% open.

   b. From 51% to 100%, the building pressure control loop shall reset the return-fan discharge static pressure setpoint from RFDSPmin at 50% loop output to RFDSPmax at 100% of loop output. See Section 1.3B.3 for RFDSPmin and RFDSPmax.

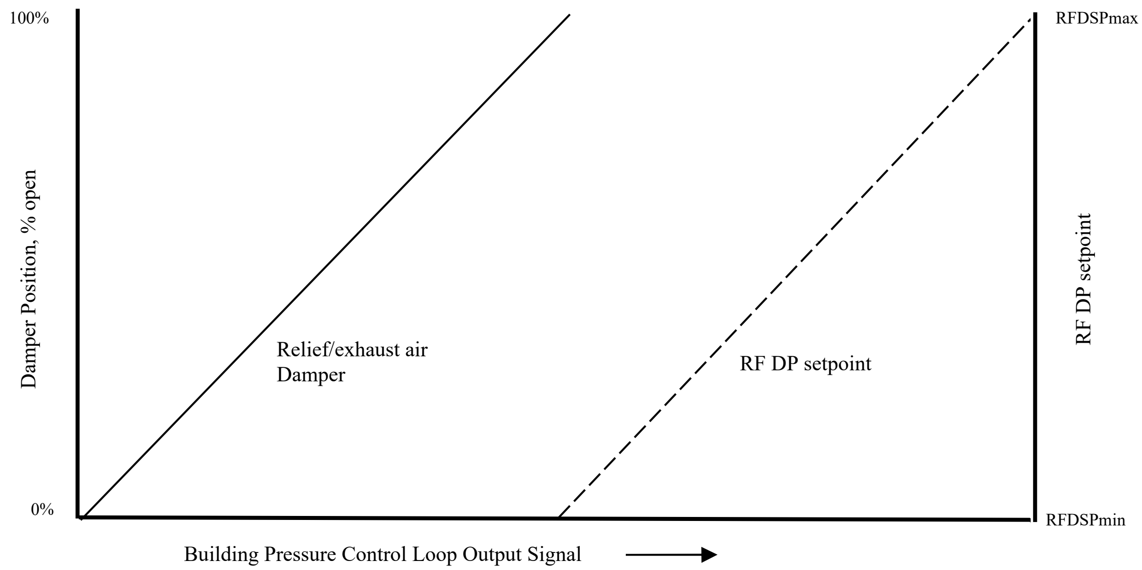


Figure 5.16.10.5 Exhaust damper position and return-fan DP reset

J. Return-Fan Control − Airflow Tracking

1. Return fan operates whenever associated supply fan is proven on.

2. The active differential airflow setpoint S-R-DIFF* shall be S-R-DIFF for the entire system (see Section 1.3B.5) adjusted by the sum of the area component of the breathing zone outdoor air flow rate of zones in Zone Groups that are in Occupied Mode relative to that in all zones served by the system.

The equations below will result in S-R-DIFF set to zero if no zones are in Occupied Mode, e.g., during Warmup, Cooldown, Setback, and Setup Modes.

a. $S-R-DIFF^{*} = S-R-DIFF\frac{\sum_{all\ Occupied\ Zones} V_{area-min}}{\sum_{all\ Zones} V_{area-min}}$

3. Return-fan speed shall be controlled to maintain return airflow equal to supply airflow less differential S-R-DIFF*. Where multiple air handling units share a common return fan (i.e. dual fan dual duct), return fan speed shall be controlled to maintain return airflow equal to total supply airflow of all associated units less differential S-R-DIFF*.

The following logic will keep supply airflow from exceeding the capability of the return fan, which is often designed to be smaller than the supply fan, which can result in excess outdoor air intake. This becomes an issue when S-R-DIFF is zero during Warmup, Cooldown, Setback, and Setup Modes because the supply air fan can be at full speed due to VAV boxes operating at Vcool-max during these modes.*

4. Supply fan airflow shall be limited by a reverse-acting P-only loop whose setpoint is (Vrf-max + S-R-DIFF*) and whose output is maximum supply fan speed ranging from 0% to 100%.

5. Relief/exhaust dampers shall be enabled when the associated supply and return fans are proven on and closed otherwise. Exhaust dampers shall modulate as the inverse of the return air damper per Section 3.15B.3.

Airflow tracking requires a measurement of supply airflow and return airflow. Appendix A-9shows AFMS at both fans. These are actually not mandatory, although they may improve accuracy if properly installed. The supply airflow can be calculated by summing VAV box airflow rates. Return airflow can be approximated by return-fan speed if there are no dampers in the return air path (the geometry of the return air system must be static for speed to track airflow.)

S-R-DIFF is determined empirically during the TAB phase. If there are intermittent or variable-flow exhaust fans, this setpoint should be dynamically adjusted based on exhaust fan status or airflow/speed.

Freeze protection logic was deleted since it is buggy and not needed in Bay Area. .

K. Alarms

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval count when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

3. Filter pressure drop exceeds the larger of the alarm limit or 12.5 Pa (0.05") for 10 minutes when airflow (expressed as a percentage of design airflow or design speed if total airflow is not known) exceeds 20%: Level 4. The alarm limit shall vary with total airflow (if available; use fan speed if total airflow is not known) as follows:

$$DP_x = DP_{100}(x)^{1.4}$$

where DP100 is the high-limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high limit at the current airflow rate x (expressed as a fraction). For instance, the setpoint at 50% of design airflow would be (0.5)1.4, or 38% of the design high-limit pressure drop. See Section 1.2F.4 for DP100.

The constant value threshold for the filter pressure drop alarm is a function of the transducer and A/D converter used to measure filter differential pressure. The value used shall be determined as the minimum accuracy of the transducer and A/D converter combination.

4. High building pressure (more than 25 Pa [0.10 in. of water]) for 5 minutes: Level 3.

5. Low building pressure (less than 0 Pa [0.0 in. of water], i.e., negative) for 5 minutes: Level 4.

Automatic fault detection and diagnostics (AFDD) is a sophisticated system for detecting and diagnosing air-handler faults.

To function correctly, AFDD requires specific sensors and data be available, as detailed in the sequences below. If this information is not available, AFDD tests that do not apply should be deleted.

L. Automatic Fault Detection and Diagnostics

The AFDD routines for AHUs continually assess AHU performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the operating state (OS) of the AHU, as *determined by the position of the cooling and heating valves and the economizer damper. Time delays are applied to the evaluation and reporting of fault conditions to suppress false alarms. Fault conditions that pass these filters are reported to the building operator along with a series of possible causes.*

These equations assume that the air handler is equipped with hydronic heating and cooling coils, as well as a fully integrated economizer. If any of these components are not present, the associated tests and variables should be omitted from the programming.

Note that these alarms rely on reasonably accurate measurement of mixed air temperature. An MAT sensor is required for many of these alarms to work, and an averaging sensor is strongly recommended for best accuracy.

1. AFDD conditions are evaluated continuously and separately for each operating AHU.

2. For units with return fans:

   a. The OS of each Ahu shall be defined by the commanded positions of the heating coil control valve, cooling coil control valve and the return air damper in accordance with Table 2.

Table 2 VAV AHU Operating States

Operating State	Heating Valve Position	Cooling Valve Position	Return Air Damper Position
#1: Heating	> 0	= 0	= MaxRA-P
#2: Free cooling, modulating OA	= 0	= 0	MaxRA-P > x > 0%
#3: Mechanical + economizer cooling	= 0	> 0	= 0%
#4: Mechanical cooling, minimum OA	= 0	> 0	= MaxRA-P
#5: Unknown or dehumidification	No other OS applies		

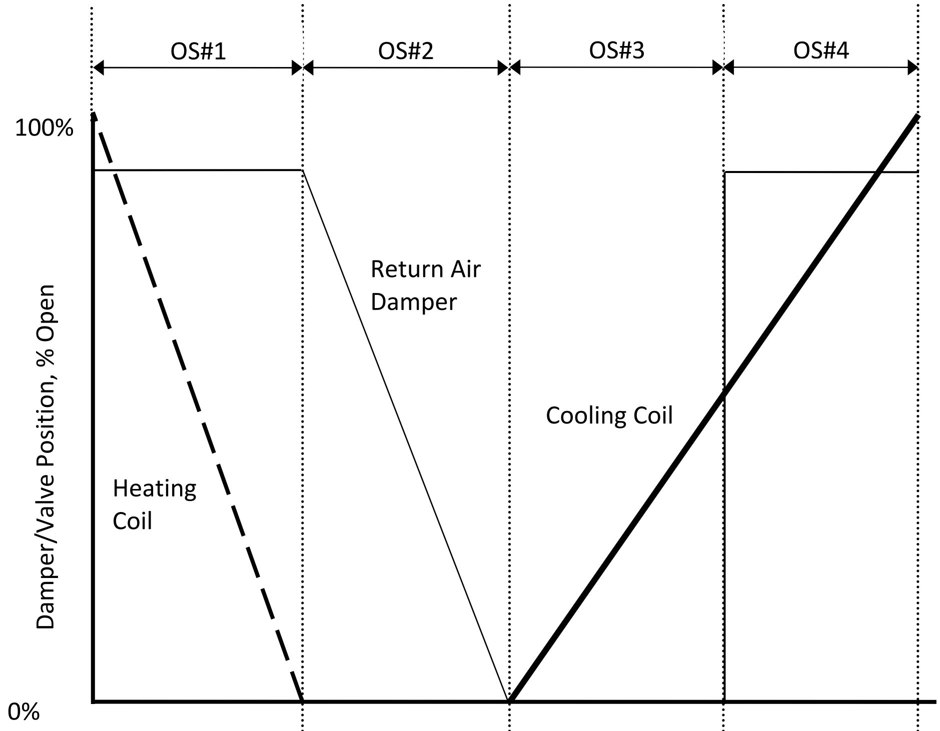


Figure 2 VAV AHU operating states.

3. For units with relief dampers or relief fans and a separate minimum outdoor air damper:

   a. The OS of each AHU shall be defined by the commanded positions of the heating-coil control valve, cooling-coil control valve, and economizer damper in accordance with Table 3 and Figure 3.

Table 3 VAV AHU Operating States

Operating State	Heating Valve Position	Cooling Valve Position	Economizer Outdoor Air Damper Position
#1: Heating	> 0	= 0	= 0%
#2: Free cooling, modulating OA	= 0	= 0	0% < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= 0%
#5: Unknown or dehumidification	No other OS applies		

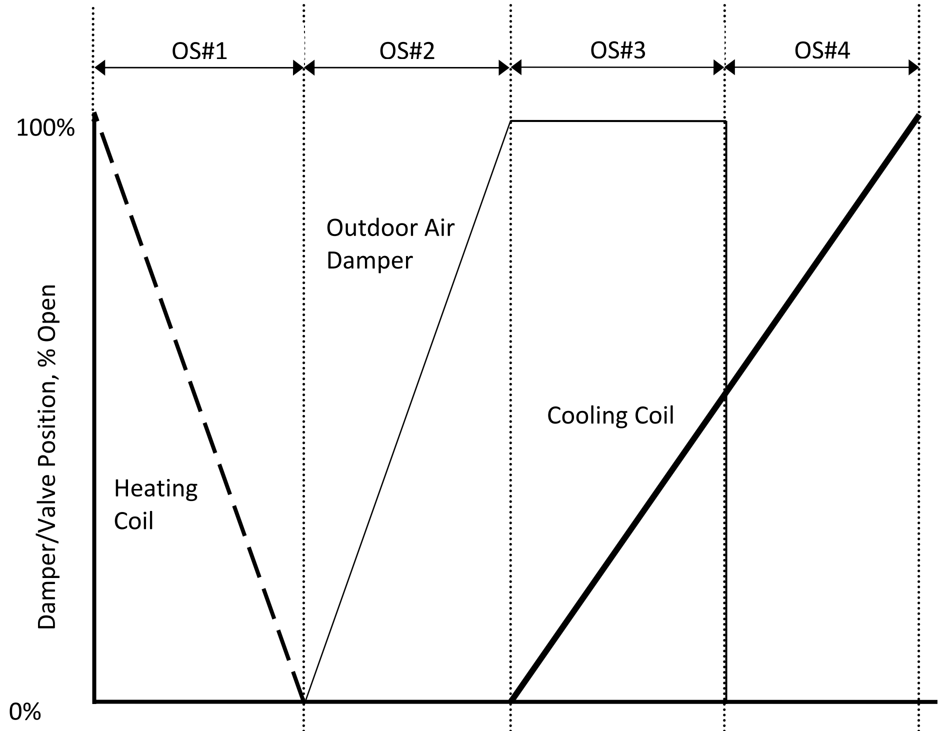


Figure 3 VAV AHU operating states.

4. For units with relief dampers or relief fans and a single common damper of minimum outdoor air and economizer functions.

   a. The OS of each AHU shall be defined by the commanded positions of the heating-coil control valve, cooling-coil control valve, and economizer damper in accordance with Table 4 and Figure 4.

Table 4 VAV AHU Operating States

Operating State	Heating Valve Position	Cooling Valve Position	Outdoor Air Damper Position
#1: Heating	> 0	= 0	= MinOA-P
#2: Free cooling, modulating OA	= 0	= 0	MinOA-P < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= MinOA-P
#5: Unknown or dehumidification	No other OS applies		

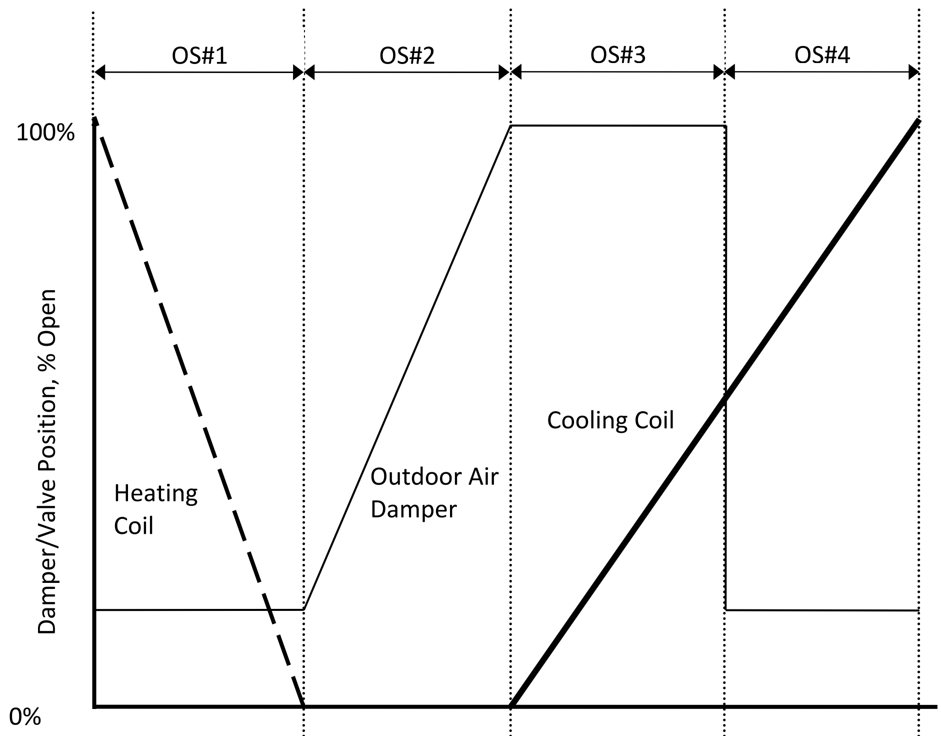


Figure 4 VAV AHU operating states.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or Zone Group mode (occupied, warmup, etc.).
OS#1 through OS#4 (see Tables 2 through 4) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 8. By contrast, OS#5 may represent an abnormal or incorrect condition (such as simultaneous heating and cooling) arising from a controller failure or programming error, but it may also occur normally, e.g., when dehumidification is active or during warmup.

5. The following points must be available to the AFDD routines for each AHU:

For the AFDD routines to be effective, an averaging sensor is recommended for SAT. An averaging sensor is essential for MAT, as the environment of the mixing box will be subject to nonuniform and fluctuating air temperatures. It is recommended that the OAT sensor be located at the AHU so that it accurately represents the temperature of the incoming air.

a. SAT = supply air temperature

b. MAT = mixed air temperature

c. RAT = return air temperature

d. OAT = outdoor air temperature

e. DSP = duct static pressure

f. SATSP = supply air temperature setpoint

g. DSPSP = duct static pressure setpoint

h. HC = heating-coil valve position command; 0% □ HC □ 100%

i. CC = cooling-coil valve position command; 0% □ CC □ 100%

j. FS = fan speed command; 0% □ FS □ 100%

k. CCET = cooling-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)

l. CCLT = cooling-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

m. HCET = heating-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)

n. HCLT = heating-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

6. The following values must be continuously calculated by the AFDD routines for each AHU:

a. Five-minute rolling averages with 1-minute sampling time of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently.

1) SATavg = rolling average of supply air temperature

2) MATavg = rolling average of mixed air temperature

3) RATavg = rolling average of return air temperature

4) OATavg = rolling average of outdoor air temperature

5) DSPavg = rolling average of duct static pressure

6) CCETavg = rolling average of cooling-coil entering temperature

7) CCLTavg = rolling average of cooling-coil leaving temperature

8) HCETavg = rolling average of heating-coil entering temperature

9) HCLTavg = rolling average of heating-coil leaving temperature

b. %OA = actual outdoor air fraction as a percentage = (MAT – RAT)/(OAT – RAT), or per airflow measurement station if available.

c. %OAmin = active minimum OA setpoint (MinOAsp) divided by actual total airflow (from sum of VAV box flows or by airflow measurement station) as a percentage.

d. OS = number of changes in operating state during the previous 60 minutes (moving window)

7. The internal variables shown in Table 5.16.14.5 shall be defined for each AHU. All parameters are adjustable by the operator, with initial values as shown.

Default values are derived from NISTIR 7365 and have been validated in field trials. They are expected to be appropriate for most circumstances, but individual installations may benefit from tuning to improve sensitivity and reduce false alarms.

The default values have been intentionally biased toward minimizing false alarms—if necessary, at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.

Values for physical factors, such as fan heat, duct heat gain, and sensor error, can be measured in the field or derived from trend logs. Likewise, the occupancy delay and switch delays can be refined by observing in trend data the time required to achieve quasi steady-state operation.

Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false errors, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the heating coil, cooling coil, temperature, or flow thresholds.

Table 7 VAV AHU AFDD Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	1°C (2°F)
ΔTMIN	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10° F)
ƐSAT	Temperature error threshold for SAT sensor	1°C (2°F)
ƐRAT	Temperature error threshold for RAT sensor	1°C (2°F)
ƐMAT	Temperature error threshold for MAT sensor	3°C (5°F)
ƐOAT	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
ƐF	Airflow error threshold	30%
ƐVFDSPD	VFD speed error threshold	5%
ƐDSP	Duct static pressure error threshold	25 Pa (0.1”)
ƐCCET	Cooling coil entering temperature sensor error. Equal to ƐMAT or dedicated sensor error	Varies, see Description
ƐCCLT	Cooling coil leaving temperature sensor error. Equal to ƐSAT or dedicated sensor error	
ƐHCET	Heating coil entering temperature sensor error; equal to ƐMAT or dedicated sensor error	
ƐHCLT	Heating coil leaving temperature sensor error. Equal to ƐSAT or dedicated sensor error	

Variable Name	Description	Default Value
ΔOSMAX	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	7
ModeDelay	Time in minutes to suspend Fault Condition evaluation after a change in Mode	30
AlarmDelay	Time in minutes to that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

The purpose of ΔTmin is to ensure that the mixing box/economizer damper tests are meaningful. These tests are based on the relationship between supply, return, and outdoor air. If RAT ~ MAT, these tests will not be accurate and will produce false alarms.
The purpose of TestModeDelay is to ensure that normal fault reporting occurs after the testing and commissioning process is completed as prescribed in Section 14.

8. Table 8 shows potential fault conditions that can be evaluated by the AFDD routines. If the equation statement is true, then the specified fault condition exists. The fault conditions to be evaluated at any given time will depend on the OS of the AHU.

The equations in Table 8 assume that the SAT sensor is located downstream of the supply fan and the RAT sensor is located downstream of the return fan. If actual sensor locations differ from these assumptions, it may be necessary to add or delete fan heat correction factors.
To detect the required economizer faults in California Title 24 section 120.2(i)7, use FC#2, #3, and #5 through #13 at a minimum. Other Title 24 AFDD requirements, including acceptance tests, are not met through these fault conditions.

Table 8 VAV AHU Fault Conditions

FC#1	Equation	DSPAVG < DSPSP - ƐDSP and VFDSPD ≥ 99% - ƐVFDSPD	Applies to OS #1 – #5
	Description	Duct static pressure is too low with fan at full speed	
	Possible Diagnosis	Problem with VFD Mechanical problem with fan Fan undersized SAT Setpoint too high (too much zone demand)	
FC#2 (omit if no MAT sensor)	Equation	MATAVG + ƐMAT < min[(RATAVG - ƐRAT), (OATAVG - ƐOAT)]	Applies to OS #1 – #5
	Description	MAT too low; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error	

FC#3 (omit if no MAT sensor)	Equation	MATAVG - ƐMAT > max[(RATAVG + ƐRAT), (OATAVG + ƐOAT)]	Applies to OS #1 – #5
	Description	MAT too high; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error	
FC#4	Equation	ΔOS > ΔOSMAX	Applies to OS #1 – #5
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#5 (omit if no MAT sensor)	Equation	SATAVG + ƐSAT ≤ MATAVG - ƐMAT + ΔTSF	Applies to OS #1
	Description	SAT too low; should be higher than MAT	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve leaking or stuck open Heating coil valve stuck closed or actuator failure Fouled or undersized heating coil HW temperature too low or HW unavailable Gas or electric heat unavailable DX cooling stuck on	
FC#6	Equation	| RATAVG - OATAVG | ≥ ΔTMIN and | %OA - %OAMIN | > ƐF	Applies to OS #1, #4
	Description	OA fraction is too low or too high; should equal %OAMIN	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error Leaking or stuck economizer damper or actuator	
FC#7 (omit if no heating coil)	Equation	SATAVG < SATSP - ƐSAT and HC ≥ 99%	Applies to OS #1
	Description	SAT too low in full heating	
	Possible Diagnosis	SAT sensor error Cooling coil valve leaking or stuck open Heating coil valve stuck closed or actuator failure Fouled or undersized heating coil HW temperature too low or HW unavailable Gas or electric heat unavailable DX cooling stuck on Leaking or stuck economizer damper or actuator	

FC#8 (omit if no MAT sensor)	Equation	$\lvert SATAVG - \Delta TSF - MATAVG \rvert > \sqrt{\varepsilon_{SAT}^{2} + \varepsilon_{MAT}^{2}}$	Applies to OS #2
	Description	SAT and MAT should be approximately equal	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve leaking or stuck open Heating coil valve leaking or stuck open	
FC#9	Equation	$OATAVG - \varepsilon OAT > SATSP - \Delta TSF + \varepsilon SAT$	Applies to OS #2
	Description	OAT is too high for free cooling without additional mechanical cooling	
	Possible Diagnosis	SAT sensor error OAT sensor error Cooling coil valve leaking or stuck open	
FC#10 (omit if no MAT sensor)	Equation	$\lvert MATAVG - OATAVG \rvert > \sqrt{\varepsilon_{MAT}^{2} + \varepsilon_{OAT}^{2}}$	Applies to OS #3
	Description	OAT and MAT should be approximately equal	
	Possible Diagnosis	MAT sensor error OAT sensor error Leaking or stuck economizer damper or actuator	
FC#11	Equation	$OATAVG + \varepsilon OAT < SATSP - \Delta TSF - \varepsilon SAT$	Applies to OS #3
	Description	OAT is too low for mechanical cooling	
	Possible Diagnosis	SAT sensor error OAT sensor error Heating coil valve leaking or stuck open Leaking or stuck economizer damper or actuator	
FC#12 (omit if no MAT sensor)	Equation	$SATAVG - \varepsilon SAT - \Delta TSF \geq MATAVG + \varepsilon MAT$	Applies to OS #2 – #4
	Description	SAT too high; should be less than MAT	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve stuck closed or actuator failure Fouled or undersized cooling coil CHW temperature too high or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	

FC#13	Equation	$SATAVG > SATSP + \varepsilon SAT$ and $CC \geq 99\%$	Applies to OS #3, #4
	Description	SAT too high in full cooling	
	Possible Diagnosis	SAT sensor error Cooling coil valve stuck closed or actuator failure Fouled or undersized cooling coil CHW temperature too high or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	
FC#14	Equation	$CCETAVG - CCLTAVG \geq \sqrt{\varepsilon_{CCET}^2 + \varepsilon_{CCLT}^2 + \Delta TSF^*}$ *Fan heat factor included or not depending on location of sensors used for CCET and CCLT	Applies to OS #1, #2
	Description	Temperature drop across inactive cooling coil	
	Possible Diagnosis	CCET sensor error CCLT sensor error Cooling coil valve stuck open or leaking DX cooling stuck on	
FC#15	Equation	$HCLTAVG - HCETAVG \geq \sqrt{\varepsilon_{HCET}^2 + \varepsilon_{HCLT}^2 + \Delta TSF^*}$ *Fan heat factor included or not depending on location of sensors used for HCET and HCLT	Applies to OS #2 – #4
	Description	Temperature rise across inactive heating coil	
	Possible Diagnosis	HCET sensor error HCLT sensor error Heating coil valve stuck open or leaking.	

9. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the OS of the AHU:

   a. In OS#1 (heating), the following fault conditions shall be evaluated:

      1) FC#1: DSP too low with fan at full speed

      2) FC#2: MAT too low; should be between RAT and OAT

      3) FC#3: MAT too high; should be between RAT and OAT

      4) FC#4: Too many changes in OS

      5) FC#5: SAT too low; should be higher than MAT

      6) FC#6: OA fraction too low or too high; should equal %OAmin

7) FC#7: SAT too low in full heating

8) FC#14: Temperature drop across inactive cooling coil

b. In OS#2 (modulating economizer), the following fault conditions shall be evaluated:

1) FC#1: DSP too low with fan at full speed

2) FC#2: MAT too low; should be between RAT and OAT

3) FC#3: MAT too high; should be between RAT and OAT

4) FC#4: Too many changes in OS

5) FC#8: SAT and MAT should be approximately equal

6) FC#9: OAT too high for free cooling without mechanical cooling

7) FC#12: SAT too high; should be less than MAT

8) FC#14: Temperature drop across inactive cooling coil

9) FC#15: Temperature rise across inactive heating coil

c. In OS#3 (mechanical + 100% economizer cooling), the following fault conditions shall be evaluated:

1) FC#1: DSP too low with fan at full speed

2) FC#2: MAT too low; should be between RAT and OAT

3) FC#3: MAT too high; should be between RAT and OAT

4) FC#4: Too many changes in OS

5) FC#10: OAT and MAT should be approximately equal

6) FC#11: OAT too low for mechanical cooling

7) FC#12: SAT too high; should be less than MAT

8) FC#13: SAT too high in full cooling

9) FC#15: Temperature rise across inactive heating coil

d. In OS#4 (mechanical Cooling, minimum OA), the following fault conditions shall be evaluated:

1) FC#1: DSP too low with fan at full speed

2) FC#2: MAT too low; should be between RAT and OAT

3) FC#3: MAT too high; should be between RAT and OAT

4) FC#4: Too many changes in OS

5) FC#6: OA fraction too low or too high; should equal %OAmin

6) FC#12: SAT too high; should be less than MAT

7) FC#13: SAT too high in full cooling

8) FC#15: Temperature rise across inactive heating coil

e. In OS#5 (other), the following fault conditions shall be evaluated:

1) FC#1: DSP too low with fan at full speed

2) FC#2: MAT too low; should be between RAT and OAT

3) FC#3: MAT too high; should be between RAT and OAT

4) FC#4: Too many changes in OS

10. For each air handler, the operator shall be able to suppress the alarm for any fault condition.

11. Evaluation of fault conditions shall be suspended under the following conditions:

a. When AHU is not operating

b. For a period of ModeDelay minutes following a change in mode (e.g., from Warmup Mode to Occupied Mode) of any Zone Group served by the AHU

12. Fault conditions that are not applicable to the current OS shall not be evaluated.

13. A fault condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

14. Test mode shall temporarily set ModeDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system, and ensure normal fault detection occurs after testing is complete.

15. When a fault condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from the table in Section 8.

M. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to

a. force HW valve full open if there is a hot-water coil,

b. force HW valve full closed if there is a hot-water coil,

c. force CHW valve full open, and

d. force CHW valve full closed.

Per Section 3.1L, all hardware points can be overridden through the BAS. Each of the following points is interlocked so that they can be overridden together at a zone-group level, per Section 3.5E.
For example, the CxA can check for leaking dampers by forcing all VAV boxes in a Zone Group closed and then recording airflow at the AHU.

N. Plant Requests

1. Chilled-Water Reset Requests

   a. If the supply air temperature exceeds the supply air temperature setpoint by 3°C (5°F) for 2 minutes, send 3 requests.

   b. Else if the supply air temperature exceeds the supply air temperature setpoint by 2°C (3°F) for 2 minutes, send 2 requests.

   c. Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.

   d. Else if the CHW valve position is less than 95%, send 0 requests.

2. Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

   a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.

   b. Else if the CHW valve position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

   a. If the supply air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

   b. Else if the supply air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.

   c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

   d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil, Heating Hot Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

   a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

   b. Else if the HW valve position is less than 95%, send 0 requests.

3.16 SINGLE-ZONE VAV AIR-HANDLING UNIT

A. See “Generic Thermal Zones” (Section 3.3C) for setpoints, loops, control modes, alarms, etc.

B. See Section 1.2G.1 for Cool_SAT, Heat_SAT, and MaxDPT.

C. See Section 1.3C for MinSpeed, MaxHeatSpeed, MaxCoolSpeed, MinPosMin, MinPosMax, DesPosMin, DesPosMax, MinRelief, MaxRelief, and S-R-DIFF.

D. Supply Fan Speed Control and Supply Air Temperature Set-Point Reset

These sequences use two supply air temperature setpoints SATsp and SATsp-C that are reset at different rates but are controlled using the same sensor and control loop, as well as a supply-fan speed reset that varies depending on outdoor air temperature. The goal of this scheme is to maximize free cooling and avoid chiller use when the outdoor air is cool, while avoiding excessive fan energy use and using the cooling coil when outdoor air is warm.
For this to work, it is essential that both SATsp and SATsp-C are controlled off the same physical SAT sensor.
It is also critical that the minimum value of the setpoint that controls the economizer SATsp is lower than the minimum value of the setpoint that controls the CHW valve SATsp-C. Otherwise, a brief temperature excursion due to the cooling coil will lead to short cycling of the economizer and subsequent unnecessary energy use by the cooling coil.

1. The supply fan shall run whenever the unit is in any mode other than Unoccupied Mode.

2. Provide a ramp function to prevent changes in fan speed of more than 10% per minute.

3. Minimum, medium, and maximum fan speeds shall be as follows:

    a. Minimum speed MinSpeed, maximum cooling speed MaxCoolSpeed, and maximum heating speed MaxHeatSpeed shall be determined per Section 1.3A.

    b. Medium fan speed MedSpeed shall be reset linearly based on outdoor air temperature from MinSpeed when outdoor air temperature is greater or equal to Endpoint #1 to MaxCoolSpeed when outdoor air temperature is less than or equal to Endpoint #2.

        1) Endpoint #1: the lesser of zone temperature +0.5°C (1°F) and maximum supply air dew point MaxDPT.

        2) Endpoint #2: the lesser of zone temperature minus 6°C (10°F) and the maximum supply air dew point MaxDPT minus 1°C (2°F).

When outdoor air temperature is high, there is a potential for a high humidity ratio, and thus high space humidity, which can increase the risk of mold/mildew. Because dew point sensors are expensive and can quickly drift out of calibration, this sequence uses outdoor air dry-bulb temperature as a proxy for supply air dew point. When outdoor air temperature is above the maximum limit MaxDPT, the medium speed setpoint is kept at the minimum, which will reduce supply air temperature and thus lower supply air temperature setpoint.

4. Minimum and maximum supply air temperature setpoints shall be as follows:

    a. The Deadband values of SATsp and SATsp-C shall be the average of the zone heating setpoint and the zone cooling setpoint but shall be no lower than 21°C (70°F) and no higher than 24°C (75°F).

The deadband setpoint is intended to provide neutral temperature air when the Zone State is deadband. The values of this setpoint are limited to avoid the situation where an extreme value for zone temperature setpoint forces unnecessary heating or cooling, e.g., a cold-aisle setpoint of 32°C (90°F) in a datacenter could cause unnecessary heating if this limit were not in place.

5. When the supply fan is proven on, fan speed and supply air temperature setpoints are controlled as shown in Figures 5.18.4.5-1 through 5.18.4.5-3. The points of transition along the x-axis shown and described are representative. Separate gains shall be provided for each section of the control map, that are determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.18.4.5-1 to provide stable control.

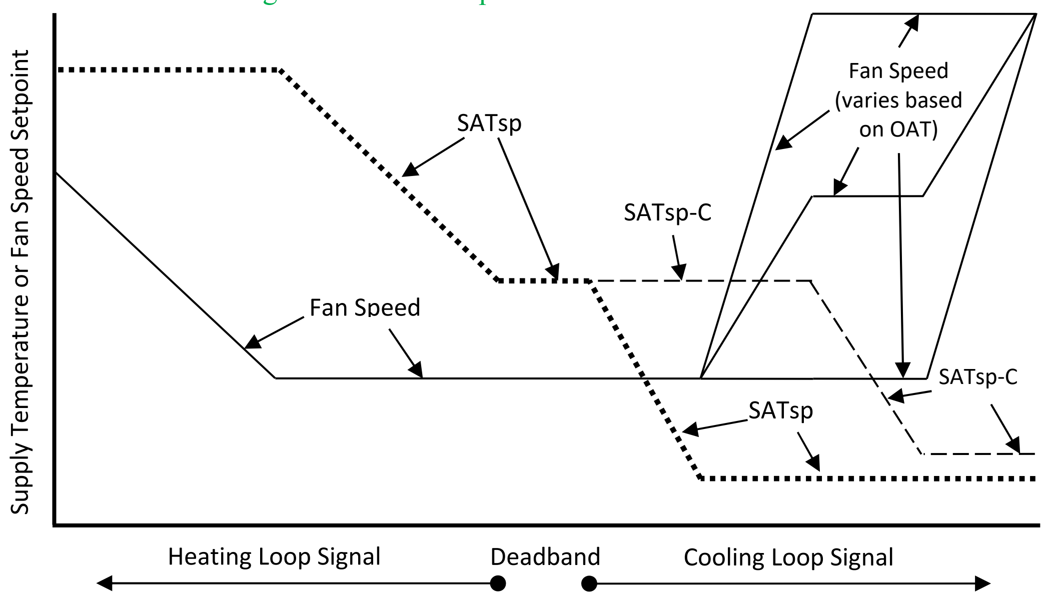


Figure 5.18.4.5-1 Control diagram for SZVAV AHU.

6. Figure 5.18.4.5-2 separates Figure 5.18.4.5-1 in two for clarity and to illustrate the relative setpoints. However, both fan speed and supply air temperature setpoints are reset simultaneously and by the same signal: the value of the Heating Loop or Cooling Loop.

   a. For a heating-loop signal of 100% to 50%, fan speed is reset from MaxHeatSpeed to MinSpeed.

   b. For a heating-loop signal of 50% to 0%, fan speed setpoint is MinSpeed.

   c. In deadband, fan speed setpoint is MinSpeed.

   d. For a cooling-loop signal of 0% to 25%, fan speed is MinSpeed.

   e. For a cooling-loop signal of 25% to 50%, fan speed is reset from MinSpeed to MedSpeed.

   f. For a cooling-loop signal of 50% to 75%, fan speed is MedSpeed.

   g. For a cooling-loop signal of 75% to 100%, fan speed is reset from MedSpeed to MaxCoolSpeed.

h. For a heating-loop signal of 100% to 50%, SATsp is Heat_SAT.

i. For a heating-loop signal of 50% to 0%, SATsp is reset from Heat_SAT to the deadband value.

j. In deadband, SATsp is the deadband value.

k. For a cooling-loop signal of 0% to 25%, SATsp is reset from the deadband value to Cool_SAT minus 1°C (2°F), while SATsp-C is the deadband value.

l. For a cooling-loop signal of 25% to 50%, SATsp and SATsp-C are unchanged.

m. For a cooling-loop signal of 50% to 75%, SATsp remains at Cool_SAT minus 1°C (2°F), SATsp-C is reset from the deadband value to Cool_SAT.

n. For a cooling-loop signal of 75% to 100%, SATsp and SATsp-C are unchanged.

In cooling, the economizer is controlled to a lower setpoint than the cooling coil (i.e., SATsp < SATsp-C) so that a low-temperature excursion does not cause the economizer to close inadvertently while cooling with mechanical cooling.

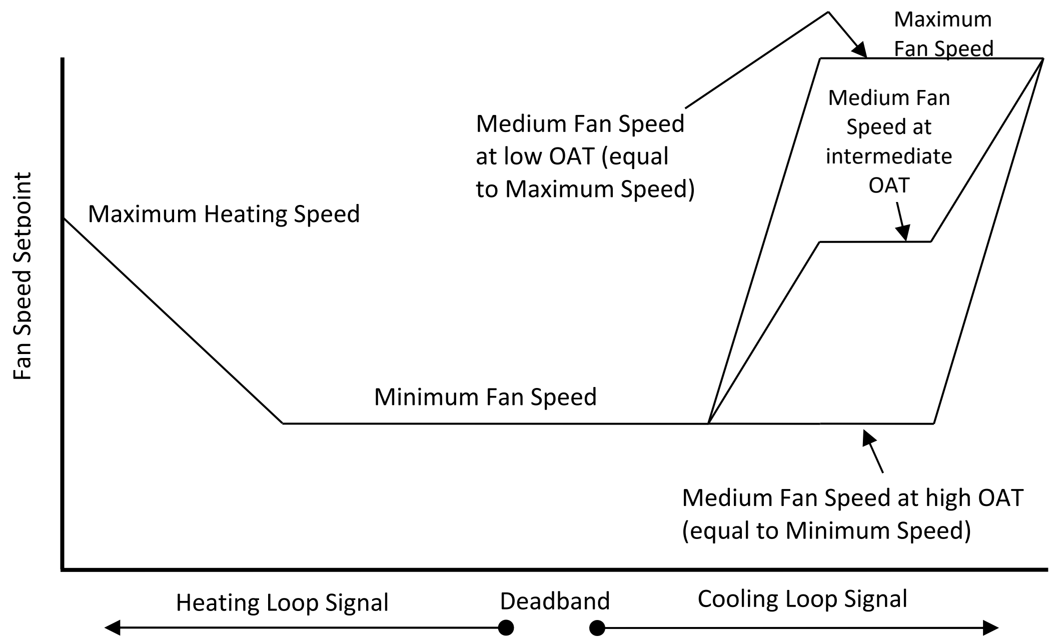


Figure 5.18.4.5-2 Control diagram for SZVAV AHU—fan speed.

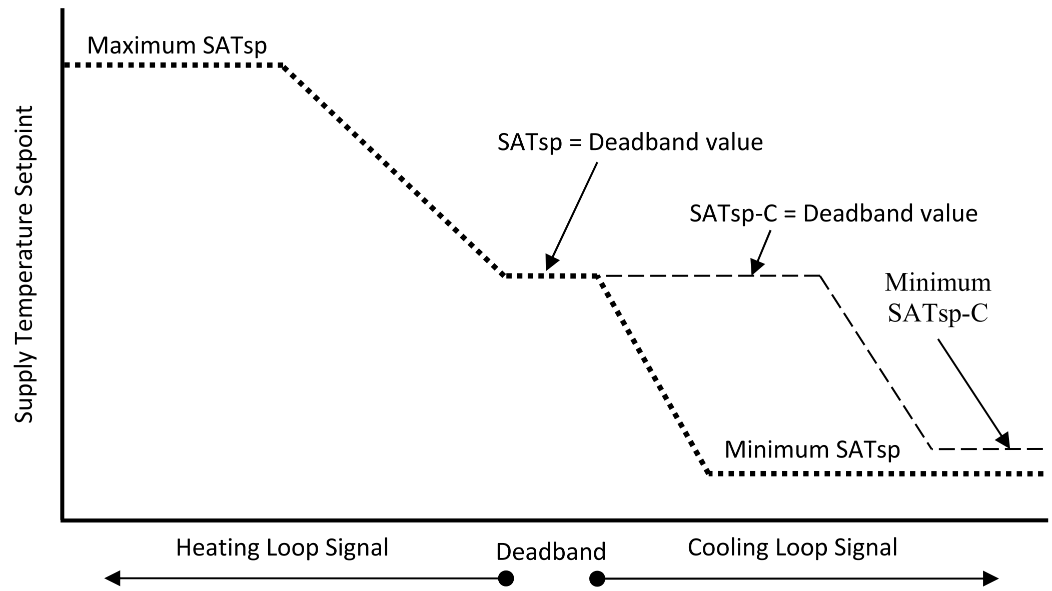


Figure 5.18.4.5-3 Control diagram for SZVAV AHU—supply air temperature.

E. Supply Air Temperature Control

1. There are two supply air temperature setpoints, SATsp and SATsp-C. Each setpoint is maintained by a separate control loop, but both loops use the same supply air temperature sensor.

2. The control loop for SATsp is enabled when the supply air fan is proven on and disabled and set to neutral otherwise.

   a. Supply air temperature shall be controlled to SATsp by a control loop whose output is mapped to sequence the heating coil (if applicable) and economizer dampers as shown in the Figure 5.18.5.2. Outdoor air damper minimum MinOA-P and maximum MaxOA-P positions are limited for economizer lockout and to maintain minimum outdoor airflow rate as described in Sections 3.16Fand 3.16F.3.

These sequences assume that the heat source can be modulated and thus control SAT to a setpoint in heating. If this is not the case (e.g., because heating is by multistage furnace or electric coil), then the following will need to be modified to add appropriate staging logic.

   b. The points of transition along the x-axis shown in Figure 5.18.5.2 are representative. Separate gains shall be provided for each section of the control map (heating coil, economizer) that are determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.18.5.2 to provide stable control.

Dampers are complementary (rather than sequenced, as they are for multiple-zone VAV AHUs) to reduce equipment costs (avoiding multiple actuators) and to maintain a more-linear relationship between fan speed and outdoor air volume.
In order to make this relationship as linear as possible, the economizer should use parallel blade dampers.

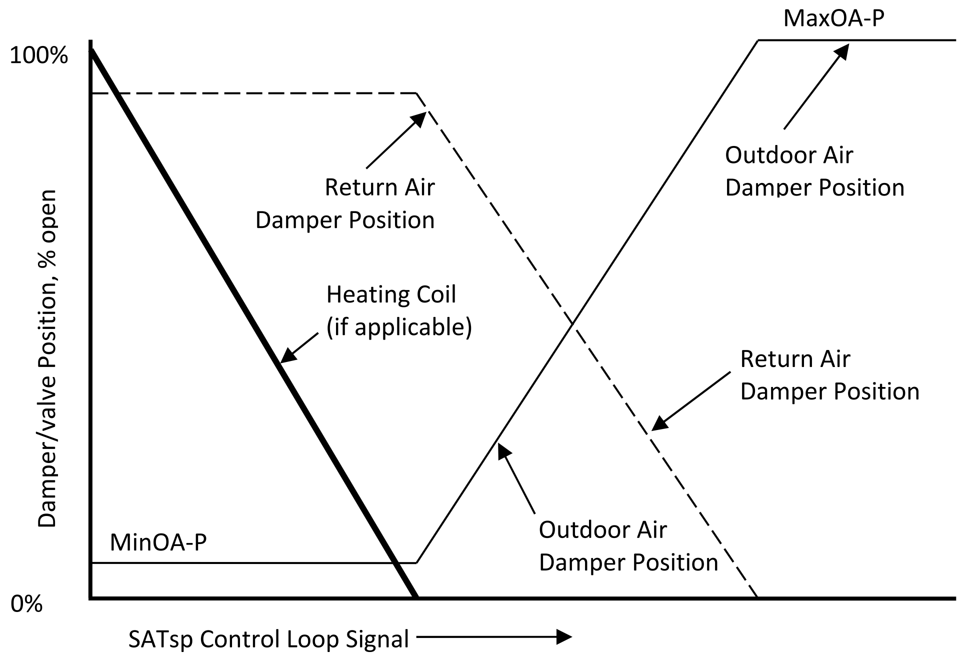


Figure 5.18.5.2 SZVAV AHU supply air temperature loop mapping.

3. The control loop for SATsp-C is enabled when the supply fan is proven on and the Zone State is cooling and disabled and set to neutral otherwise. When enabled, supply air temperature shall be controlled to SATsp-C by modulating the cooling coil.

F. Minimum Outdoor Air Control

1. See Section 3.3 for calculation of zone minimum outdoor airflow setpoint.

2. Outdoor Air Damper Control for Units without an Outdoor Airflow Measurement Station

This section describes minimum outdoor air control logic for a unit with a single common minimum OA and economizer damper (i.e., no separate minimum OA damper) and Demand Control Ventilation.
This logic assumes that there is no airflow measurement station across the outdoor air intake and controls OA volume indirectly via damper position setpoints. This works for a single zone unit because there are no downstream dampers that would change the relationship between OA damper position and OA airflow. This logic is not appropriate for a system with actuated dampers downstream of the AHU.
Other configurations are possible and would require modifications to the points list (above) and the control logic below.

a. See Section 1.3C.2 for minimum damper position setpoints.

b. At least once per minute while the zone is in Occupied Mode, the BAS shall calculate MinPos* as a linear interpolation between MinPosMin and MinPosMax based on the current fan speed.

c. At least once per minute while the zone is in Occupied Mode, the BAS shall calculate DesPos* as a linear interpolation between DesPosMin and DesPosMax based on the current fan speed.

d. If MinOAsp is zero, MinOA-P shall be zero (i.e., outdoor air damper fully closed).

e. If MinOAsp is nonzero, then the outdoor air damper minimum position MinOA-P shall be the value between MinPos* and DesPos* that is proportional to the value of MinOAsp between MinOA and DesOA. Figure 5.18.6.2 illustrates this (points are chosen arbitrarily and are not meant to be representative).

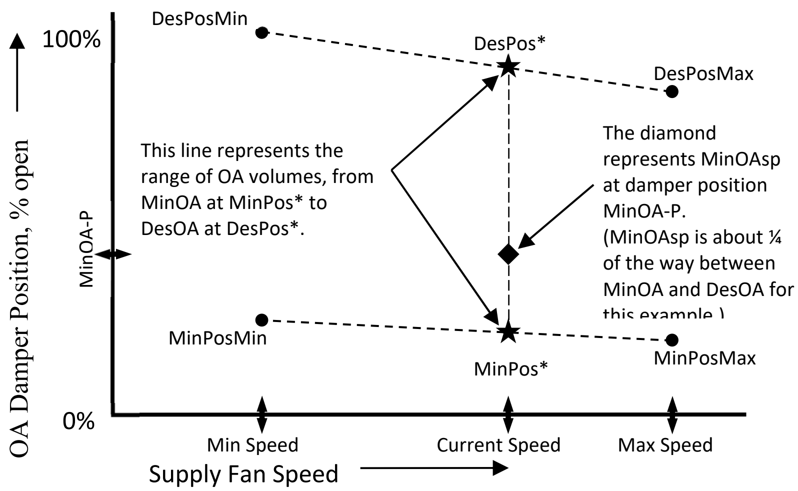


Figure 5.18.6.2 SZVAV AHU minimum outdoor air control.

3. Outdoor Air Damper Control for Units with an Outdoor Airflow Measurement Station

This section describes minimum outdoor air control logic for a unit with a single common minimum OA and economizer damper (i.e., no separate minimum OA damper) and Demand Control Ventilation.
This logic assumes that there is an airflow measurement station across the outdoor air intake and controls OA volume directly via control over the minimum OA damper position.
Other configurations are possible and would require modifications to the points list (above) and the control logic below.

a. Minimum outdoor air control loop is enabled when the supply fan is proven on and in Occupied Mode and disabled and output set to zero otherwise.

b. The minimum outdoor airflow rate shall be maintained at the minimum outdoor air setpoint MinOAsp by a reverse-acting control loop whose output is mapped to MinOA-P.

G. Economizer Lockout

This section describes economizer lockout logic for a unit with a common minimum OA and economizer damper (i.e., no separate minimum OA damper). Other configurations are possible, and would require modifications to the points list (above) and the control logic below.

1. The normal sequencing of the economizer dampers shall be disabled in accordance with Section 3.1Q.

2. Once the economizer is disabled, it shall not be reenabled within 10 minutes and vice versa.

3. When economizer is enabled, MaxOA-P = 100%. When economizer is disabled, set MaxOA-P equal to MinOA-P. See Section 3.15E, “Supply Air Temperature Control,” and Section 3.16F, “Minimum Outdoor Air Control,” for outdoor air damper minimum setpoint.

H. Control of Actuated Relief Dampers without Fans

1. Direct Building Pressure Control

a. Relief dampers shall be enabled when the associated supply fan is proven on, and disabled otherwise.

b. When enabled, use a P-only control loop to modulate relief dampers to maintain 12 Pa (0.05 in. of water) building static pressure. Close damper when disabled.

2. Passive Building Pressure Control

a. See Section **Error! Reference source not found.** for relief-damper position setpoints.

b. Relief dampers shall be enabled when the associated supply fan is proven on and any outdoor air damper is open, and disabled and closed otherwise.

c. Relief-damper position shall be reset linearly from MinRelief to MaxRelief as the minimum outdoor airflow setpoint, MinOAsp, is reset from MinOA to DesOA.

I. Relief-Fan Control

1. Refer to Section 3.15H, “Relief-Fan Control” for multiple-zone air handlers.

J. Return-Fan Control

1. Return-Fan Control – Speed Tracking

a. Exhaust damper shall open whenever associated supply fan and return fan are proven on and shall be closed otherwise.

b. Return fan shall run whenever associated supply fan is proven on.

c. The active differential airflow setpoint S-R-SPD-DIFF* shall be S-R-SPD-DIFF (see Section 1.3C.4) adjusted by the active minimum outdoor airflow setpoint, MinOAsp relative to the design outdoor airflow setpoint, DesOA.

$$S-R-SPD-DIFF^{*} = S-R-SPD-DIFF\frac{MinOAsp}{DesOA}$$

d. Return-fan speed shall be the controlled to maintain return fan speed equal to supply fan speed less differential S-R-SPD-DIFF*.

2. Return Fan Control – Direct Building Pressure

a. Refer to Section 3.15I Return Fan Control – Direct Building Pressure for multiple-zone air handlers.

K. Alarms

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

a. Commanded on, status off: Level 2

b. Commanded off, status on: Level 4

3. Filter pressure drop exceeds the larger of the alarm limit or 12.5 Pa (0.05”) for 10 minutes when fan speed exceeds 20% of MaxCoolSpeed: Level 4. The alarm limit shall vary with fan speed as follows:

$$DP_x = DP_{100}(x)^{1.4}$$

where DP100 is the high limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high limit at the current fan speed x (expressed as a fraction). For instance, the setpoint at 50% of design speed would be (0.5)1.4 or 38% of the design high limit pressure drop. See Section 1.3C.1 for MaxCoolSpeed and Section 0 for DP100.

The constant value threshold for the filter pressure drop alarm is a function of the transducer and A/D converter used to measure filter differential pressure. The value used shall be determined as the minimum accuracy of the transducer and A/D converter combination.

L. Automatic Fault Detection and Diagnostics

The AFDD routines for AHUs continually assess AHU performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the OS of the AHU, as determined by the position of the cooling and heating valves and the economizer damper. Time delays are applied to the evaluation and reporting of fault conditions to suppress false alarms. Fault conditions that pass these filters are reported to the building operator along with a series of possible causes.

These equations assume that the air handler is equipped with hydronic heating and cooling coils, as well as a fully integrated economizer. If any of these components are not present, the associated tests and variables should be omitted from the programming.

Note that these alarms rely on reasonably accurate measurement of mixed air temperature. An MAT sensor is required for many of these alarms to work, and an averaging sensor is strongly recommended for best accuracy. If an MAT sensor is not installed, omit Fault Conditions #2, #3, #5, #8, #10, and #12. If a heating coil is not installed, omit Fault Condition #7.

1. AFDD conditions are evaluated continuously and separately for each operating AHU.

2. The OS of each AHU shall be defined by the commanded positions of the heating-coil control valve, cooling-coil control valve, and economizer damper in accordance with Table 5.18.13.2 and Figure 5.18.13.2.

Table 5.18.13.2 SZVAV AHU Operating States

Operating State	Heating Valve Position	Cooling Valve Position	Outdoor Air Damper Position
#1: Heating	> 0	= 0	= MinOA-P
#2: Free cooling, modulating OA	= 0	= 0	MinOA-P < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= MinOA-P
#5: Unknown or dehumidification	No other OS applies		

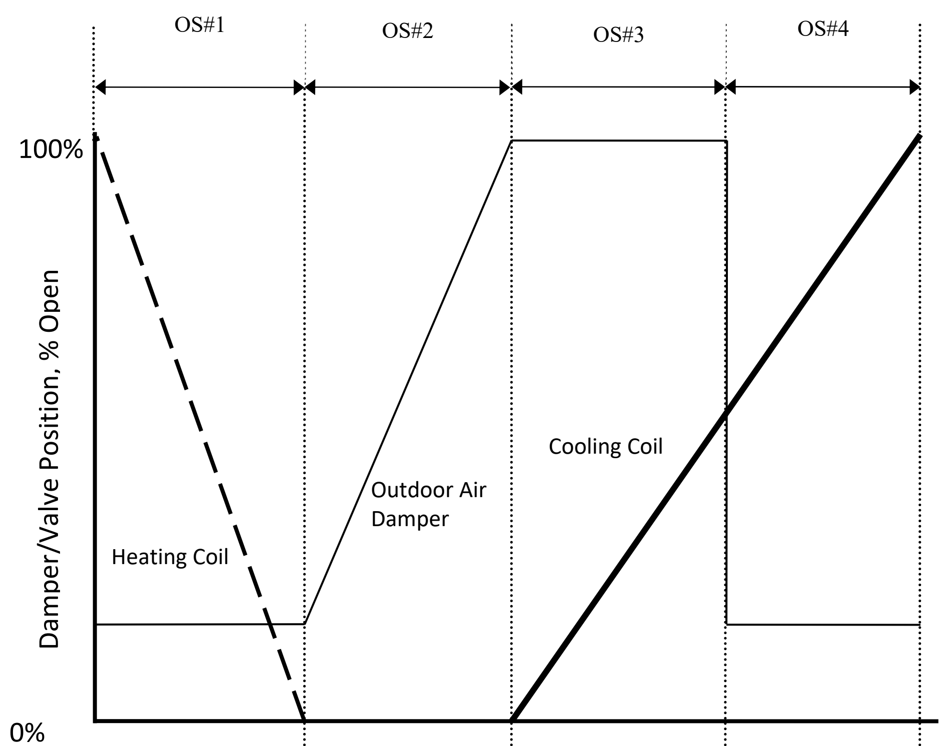


Figure 5.18.13.2 SZVAV AHU operating states.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or Zone Group mode (occupied, warmup, etc.).
OS#1 through OS#4 (see Table 5.18.13.2) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 3.16L.6. By contrast, OS#5 may represent an abnormal or incorrect condition (such as simultaneous heating and cooling) arising from a controller failure or programming error, but it may also occur normally, e.g., when dehumidification is active or during warmup.

3. The following points must be available to the AFDD routines for each AHU:

For the AFDD routines to be effective, an averaging sensor is recommended for supply air temperature. An averaging sensor is essential for mixed air temperature, as the environment of the mixing box will be subject to nonuniform and fluctuating air temperatures. It is recommended that the OAT sensor be located at the AHU so that it accurately represents the temperature of the incoming air.

a. SAT = supply air temperature

b. MAT = mixed air temperature

c. RAT = return air temperature

d. OAT = outdoor air temperature

e. DSP = duct static pressure

f. SATsp = supply air temperature setpoint for heating coil and economizer control

g. SATsp-C = supply air temperature setpoint for cooling coil control

h. HC = heating-coil valve position command; 0% □ HC □ 100%

i. CC = cooling-coil valve position command; 0% □ CC □ 100%

j. FS = fan-speed command; 0% □ FS □ 100%

k. CCET = cooling-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose).

l. CCLT = cooling-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

m. HCET = heating-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)

n. HCLT = heating-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

4. The following values must be continuously calculated by the AFDD routines for each AHU:

   a. Five-minute rolling averages with 1-minute sampling of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently.

      1) SATavg = rolling average of supply air temperature

      2) MATavg = rolling average of mixed air temperature

      3) RATavg = rolling average of return air temperature

      4) OATavg = rolling average of outdoor air temperature

5) CCETavg = rolling average of cooling-coil entering temperature

6) CCLTavg = rolling average of cooling-coil leaving temperature

7) HCETavg = rolling average of heating-coil entering temperature

8) HCLTavg = rolling average of heating-coil leaving temperature

9) □OS = number of changes in OS during the previous 60 minutes (moving window)

5. The internal variables shown in Table 5.18.13.5 shall be defined for each AHU. All parameters are adjustable by the operator, with initial values as given below.

Default values are derived from NISTIR 7365 and have been validated in field trials. They are expected to be appropriate for most circumstances, but individual installations may benefit from tuning to improve sensitivity and reduce false alarms.
The default values have been intentionally biased toward minimizing false alarms, if necessary at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.
Values for physical factors such as fan heat, duct heat gain, and sensor error can be measured in the field or derived from trend logs. Likewise, the occupancy delay and switch delays can be refined by observing in trend data the time required to achieve quasi steady state operation.
Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false errors, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the heating coil, cooling coil, temperature, or flow thresholds.

Table 5.18.13.5 SZVAV AHU Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	0.5°C (1°F)
ΔTMIN	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10°F)
□SAT	Temperature error threshold for SAT sensor	1°C (2°F)
□RAT	Temperature error threshold for RAT sensor	1°C (2°F)
□MAT	Temperature error threshold for MAT sensor	3°C (5°F)
□OAT	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.

□CCET	Cooling coil entering temperature sensor error. Equal to □MAT or dedicated sensor error	Varies; see description.
□CCLT	Cooling coil leaving temperature sensor error. Equal to □SAT or dedicated sensor error	
□HCET	Heating coil entering temperature sensor error; equal to □MAT or dedicated sensor error	
□HCLT	Heating coil leaving temperature sensor error. Equal to □SAT or dedicated sensor error	
□OSmax	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	7
ModeDelay	Time in minutes to suspend Fault Condition evaluation after a change in mode	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

The purpose of □Tmin is to ensure that the mixing box/economizer damper tests are meaningful. These tests are based on the relationship between supply, return, and outdoor air. If RAT □ MAT, these tests will not be accurate and will produce false alarms.
The purpose of TestModeDelay is to ensure that normal fault reporting occurs after the testing and commissioning process is completed as described in Section 3.16L.12.

6. Table 5.18.13.6 shows potential fault conditions that can be evaluated by the AFDD routines. (At most, 14 of the 15 fault conditions are actively evaluated, but numbering was carried over from multiple-zone AHUs for consistency.) If the equation statement is true, then the specified fault condition exists. The fault conditions to be evaluated at any given time will depend on the OS of the AHU.

The equations in Table 5.18.13.6 assume that the SAT sensor is located downstream of the supply fan and the RAT sensor is located downstream of the return fan. If actual sensor locations differ from these assumptions, it may be necessary to add or delete fan heat correction factors.
To detect the required economizer faults in California Title 24 section 120.2(i)7, use FC#2, #3, and #5 through #13 at a minimum. Other Title 24 AFDD requirements, including acceptance tests, are not met through these fault conditions.

Table 5.18.13.6 SZVAV AHU Fault Conditions

FC #1	This fault condition is not used in single zone units, as it requires a static pressure setpoint.		Applies to OS #1 – #5
FC #2 (omit if no MAT sensor)	Equation	$MATAVG + \varepsilon MAT < \min[(RATAVG - \varepsilon RAT), (OATAVG - \varepsilon OAT)]$	Applies to OS #1 – #5
	Description	MAT too low; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error	
FC #3 (omit if no MAT sensor)	Equation	$MATAVG - \varepsilon MAT > \min[(RATAVG + \varepsilon RAT), (OATAVG + \varepsilon OAT)]$	Applies to OS #1 – #5
	Description	MAT too high; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error	
FC #4	Equation	$\Delta OS > \Delta OSMAX$	Applies to OS #1 – #5
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC #5 (omit if no MAT sensor)	Equation	$SATAVG + \varepsilon SAT \leq MATAVG - \varepsilon MAT + \Delta TSF$	Applies to OS #1
	Description	SAT too low; should be higher than MAT	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve leaking or stuck open Heating coil valve stuck closed or actuator failure Fouled or undersized heating coil HW temperature too low or HW unavailable Gas or electric heat unavailable	

FC #6	Equation	$\lvert RATAVG - OATAVG \rvert \geq \Delta TMIN$ and $\lvert RATAVG - MATAVG \rvert > \lvert OATAVG - MATAVG \rvert$	Applies to OS #1, #4
	Description	OA fraction is too high; MAT should be closer to RAT than to OAT	
	Possible Diagnosis	RAT sensor error MAT sensor error OAT sensor error Leaking or stuck economizer damper or actuator	
FC #7 (omit if no heating coil)	Equation	$SATAVG < SATSP - \varepsilon SAT$ and $HC \geq 99\%$	Applies to OS #1
	Description	SAT too low in full heating	
	Possible Diagnosis	SAT sensor error Cooling coil valve leaking or stuck open Heating coil valve stuck closed or actuator failure Fouled or undersized heating coil HW temperature too low or HW unavailable Gas or electric heat is unavailable DX cooling is stuck on Leaking or stuck economizer damper or actuator	
FC #8 (omit if no MAT sensor)	Equation	$\lvert SATAVG - \Delta TSF - MATAVG \rvert > \sqrt{\varepsilon_{SAT}^2 + \varepsilon_{MAT}^2}$	Applies to OS #2
	Description	SAT and MAT should be approximately equal	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve leaking or stuck open DX cooling stuck on Heating coil valve leaking or stuck open Gas or electric heat stuck on	

FC #9	Equation	OATAVG + ƐOAT > SATSP - ΔTSF + ƐSAT	Applies to OS #2
	Description	OAT is too high for free cooling without additional mechanical cooling	
	Possible Diagnosis	SAT sensor error OAT sensor error Cooling coil valve leaking or stuck open DX cooling stuck on	
FC #10 (omit if no MAT sensor)	Equation	$\lvert MATAVG - OATAVG \rvert > \sqrt{\varepsilon_{MAT}^2 + \varepsilon_{OAT}^2}$	Applies to OS #3
	Description	OAT and MAT should be approximately equal	
	Possible Diagnosis	MAT sensor error OAT sensor error Leaking or stuck economizer damper or actuator	
FC #11	Equation	OATAVG + ƐOAT < SATSP - ΔTSF - ƐSAT	Applies to OS #3
	Description	OAT is too low for mechanical cooling	
	Possible Diagnosis	SAT sensor error OAT sensor error Heating coil valve leaking or stuck open Gas or electric heat stuck on Leaking or stuck economizer damper or actuator	
FC #12 (omit if no MAT sensor)	Equation	SATAVG - ƐSAT - ΔTSF ≥ MATAVG + ƐMAT	Applies to OS #2 – #4
	Description	SAT too high; should be less than MAT	
	Possible Diagnosis	SAT sensor error MAT sensor error Cooling coil valve stuck closed or actuator failure Fouled or undersized cooling coil CHW temperature too high or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	

FC #13	Equation	SATAVG > SATSP-C + ƐSAT and CC ≥ 99%	Applies to OS #3, #4
	Description	SAT too high in full cooling	
	Possible Diagnosis	SAT sensor error Cooling coil valve stuck closed or actuator failure Fouled or undersized cooling coil CHW temperature too low or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	
FC#14	Equation	CCETAVG - CCLTAVG ≥ $\sqrt{\varepsilon_{CCET}{}^{2} + \varepsilon_{CCLT}{}^{2}} + \Delta TSF^{*}$ *Fan heat factor included or not depending on location of sensors used for CCET and CCLT	Applies to OS #1, #2
	Description	Temperature drop across inactive cooling coil	
	Possible Diagnosis	CCET sensor error CCLT sensor error Cooling coil valve stuck open or leaking DX cooling stuck on	
FC#15	Equation	HCLTAVG - HCETAVG ≥ $\sqrt{\varepsilon_{HCET}{}^{2} + \varepsilon_{HCLT}{}^{2}} + \Delta TSF^{*}$ *Fan heat factor included or not depending on location of sensors used for HCET and HCLT	Applies to OS #2 – #4
	Description	Temperature rise across inactive heating coil	
	Possible Diagnosis	HCET sensor error HCLT sensor error Heating coil valve stuck open or leaking Gas or electric heat stuck on	

7. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the OS of the AHU. If an MAT sensor is not installed, omit FCs #2, #3, #5, #8, #10, and #12. If there is no heating coil, omit FC#7:

   a. In OS#1 (Heating), the following fault conditions shall be evaluated:

1) FC#2: MAT too low; should be between RAT and OAT

2) FC#3: MAT too high; should be between RAT and OAT

3) FC#4: Too many changes in OS

4) FC#5: SAT too low; should be higher than MAT

5) FC#6: OA fraction too high; MAT should be closer to RAT than to OAT

6) FC#7: SAT too low in full heating

7) FC#14: Temperature drop across inactive cooling coil

b. In OS#2 (modulating economizer), the following fault conditions shall be evaluated:

1) FC#2: MAT too low; should be between RAT and OAT

2) FC#3: MAT too high; should be between RAT and OAT

3) FC#4: Too many changes in OS

4) FC#8: SAT and MAT should be approximately equal

5) FC#9: OAT too high for free cooling without mechanical cooling

6) FC#12: SAT too high; should be less than MAT

7) FC#14: Temperature drop across inactive cooling coil

8) FC#15: Temperature rise across inactive heating coil

c. In OS#3 (mechanical + 100% economizer cooling), the following fault conditions shall be evaluated:

1) FC#2: MAT too low; should be between RAT and OAT

2) FC#3: MAT too high; should be between RAT and OAT

3) FC#4: Too many changes in OS

4) FC#10: OAT and MAT should be approximately equal

5) FC#11: OAT too low for mechanical cooling

6) FC#12: SAT too high; should be less than MAT

7) FC#13: SAT too high in full cooling

8) FC#15: Temperature rise across inactive heating coil

d. In OS#4 (mechanical cooling, minimum OA), the following fault conditions shall be evaluated:

1) FC#2: MAT too low; should be between RAT and OAT

2) FC#3: MAT too high; should be between RAT and OAT

3) FC#4: Too many changes in OS

4) FC#6: OA fraction too high; MAT should be closer to RAT than to OAT

5) FC#12: SAT too high; should be less than MAT

6) FC#13: SAT too high in full cooling

7) FC#15: Temperature rise across inactive heating coil

e. In OS#5 (other), the following fault conditions shall be evaluated:

1) FC#2: MAT too low; should be between RAT and OAT

2) FC#3: MAT too high; should be between RAT and OAT

3) FC#4: Too many changes in OS

8. For each air handler, the operator shall be able to suppress the alarm for any fault condition.

9. Evaluation of fault conditions shall be suspended under the following conditions:

a. When AHU is not operating

b. For a period of ModeDelay minutes following a change in mode (e.g., from Warmup Mode to Occupied Mode) of any Zone Group served by the AHU

10. Fault conditions that are not applicable to the current OS shall not be evaluated.

11. A fault condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

12. Test mode shall temporarily set ModeDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system and ensure normal fault detection occurs after testing is complete.

13. When a fault condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from Table 5.18.13.6.

M. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to

a. force HW valve full open if there is a hot-water coil,

b. force HW valve full closed if there is a hot-water coil,

c. force CHW valve full open if there is a CHW coil, and

d. force CHW valve full closed if there is a CHW coil.

Per Section 3.1K, all hardware points can be overridden through the BAS. Each of the following points is interlocked so that they can be overridden as a group on a plant level. For example, the CxA can check for valve leakage by simultaneously forcing closed all CHW valves at all AHUs served by the chiller plant and then recording flow at the chiller.

N. Plant Requests

1. Chilled-Water Reset Requests

a. If the supply air temperature exceeds SATsp-C by 3°C (5°F) for 2 minutes, send 3 requests.

b. Else if the supply air temperature exceeds SATsp-C by 2°C (3°F) for 2 minutes, send 2 requests.

c. Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.

d. Else if the CHW valve position is less than 95%, send 0 requests.

2. Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.

b. Else if the CHW valve position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the supply air temperature is 17°C (30°F) less than SATsp for 5 minutes, send 3 requests.

b. Else if the supply air temperature is 8°C (15°F) less than SATsp for 5 minutes, send 2 requests.

c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil, Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.17 DEDICATED OUTDOOR AIR VAV AIR HANDLERS

A. See Section **Error! Reference source not found.** for Cool_SAT, Heat_SAT, and MaxDSP.

B. See Section 1.3D for MinSpeed.

C. Supply Fan Control

1. Supply Fan Start/Stop

a. Supply fan shall run when system is in Occupied Mode only.

b. Staged supply fan controls

1) VFD Fan groups shall be lead/lag controlled per Paragraph 3.1P.

2) When fans are enabled, start the lead supply fan. When %-supply airflow (totalized enabled VAV box setpoints (not readings) divided by design AHU airflow) exceeds stage-up setpoint (below) for 15 minutes (adjustable) then the next lag supply fan shall run. All VFDs receive the same speed signal. When %-airflow falls below the stage-up setpoint for 15 (adjustable) minutes then last lag fan shall be staged off. Each stage shall have its own PID gains, separately tuned.

VFD Stage	Stage up Flow
1	0%
2	45%

VFD Stage	Stage up Flow
1	0%
2	30%
3	60%

VFD Stage	Stage up Flow
1	0%
2	25%
3	40%
4	75%

VFD Stage	Stage up Flow
1	0%
2	10%
3	25%
4	35%
5	55%
6	75%

c. Totalize current airflow rate from ventilation CAV/VAV boxes to a software point Vps.

VAV box airflow rates are summed to obtain overall supply air rate without the need for an airflow measuring station (AFMS) at the air-handler discharge. This is used for ventilation rate calculations and may also be used for display and diagnostics.

2. Static Pressure Set-Point Reset

   a. Static pressure setpoint. Setpoint shall be reset using T&R logic (see Section 3.1O) using the parameters shown in Table 5.16.1.2.

Table 5.16.1.2 Trim & Respond Variables

Variable	Value
Device	Supply fan
SP0	120 Pa (0.5 in. of water)
SPmin	25 Pa (0.1 in. of water)
SPmax	Max_DSP (see Section 1.3B.1)
Td	10 minutes
T	2 minutes
I	2
R	Zone static pressure reset requests
SPtrim	–12 Pa (–0.05 in. of water)
SPres	15 Pa (+0.06 in. of water)
SPres-max	32 Pa (+0.13 in. of water)

The T&R reset parameters in Table 5.16.1.2 are suggested as a starting point; they will most likely require adjustment during the commissioning/tuning phase.

3. Static Pressure Control

   a. Supply fan speed is controlled to maintain DSP at setpoint when the fan is proven on. Where the Zone Groups served by the system are small, provide multiple sets of gains that are used in the control loop as a function of a load indicator (such as supply-fan airflow rate, the area of the Zone Groups that are occupied, etc.).

High-pressure trips may occur if all VAV boxes are closed (as in Unoccupied Mode) or if fire/smoke dampers are closed (in some fire/smoke damper (FSD) designs, the dampers are interlocked to the fan status rather than being controlled by smoke detectors). Multiple sets of gains are used to provide control loop stability as system characteristics change.

D. Supply Air Temperature Control

1. Control loop is enabled when the supply air fan is proven on, and disabled and output set to deadband otherwise.

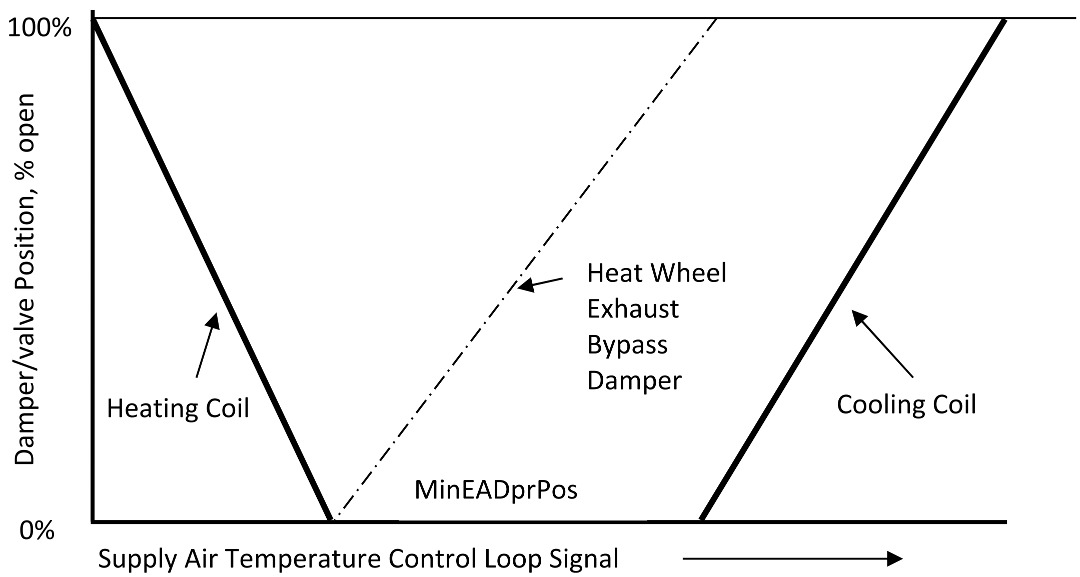
2. Supply Air Temperature Setpoint

a. When the outdoor air temperature is below Heat_SAT, the supply air temperature setpoint shall be Heat_SAT

b. When the outdoor air temperature is above Cool_SAT, the supply air temperature setpoint shall be Cool_SAT

c. When the outdoor air temperature is between Heat_SAT and Cool_SAT, heating and cooling systems shall be locked off.

3. Supply air temperature shall be controlled to setpoint using a control loop whose output is mapped to sequence the heating coil, heat recovery bypass damper, and cooling coil as shown in the Figure below:



a. The heat wheel shall run, supply air bypass damper shall close, and bypass damper enabled to modulate per Figure above from MinEADprPos to 100% open when

1) Supply fan is proven on, and

2) Heat wheel exhaust fan is proven on, and

3) Either

a) Outdoor air temperature is below the supply air temperature setpoint. In this mode, MinEADprPos = 0%.

b) Or the outdoor air temperature is above the economizer high limit temperature per Paragraph 3.1Q. In this mode, MinEADprPos = 100%.

The HR coils will save some heating or cooling energy any time the economizer (if there were one) is off.

b. The heat wheel shall shut off after minimum 5 minutes runtime if all of the above is false. When the heat wheel is off, the wheel supply and exhaust bypass dampers shall fully open.

E. Relief Air Control

F. Alarms

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval count when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

3. Filter pressure drop exceeds the larger of the alarm limit or 12.5 Pa (0.05”) for 10 minutes when airflow (expressed as a percentage of design airflow or design speed if total airflow is not known) exceeds 20%: Level 4. The alarm limit shall vary with total airflow (if available; use fan speed if total airflow is not known) as follows:

$$DP_x = DP_{100}(x)^{1.4}$$

where DP100 is the high-limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high limit at the current airflow rate x (expressed as a fraction). For instance, the setpoint at 50% of design airflow would be (0.5)1.4, or 38% of the design high-limit pressure drop. See Section 1.2F.4 for DP100.

The constant value threshold for the filter pressure drop alarm is a function of the transducer and A/D converter used to measure filter differential pressure. The value used shall be determined as the minimum accuracy of the transducer and A/D converter combination.

4. High building pressure (more than 25 Pa [0.10 in. of water]) for 5 minutes: Level 3.

5. Low building pressure (less than 0 Pa [0.0 in. of water], i.e., negative) for 5 minutes: Level 4.

G. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to

   a. force HW valve full open if there is a hot-water coil,

   b. force HW valve full closed if there is a hot-water coil,

   c. force CHW valve full open, and

   d. force CHW valve full closed.

Per Section 3.1L, all hardware points can be overridden through the BAS. Each of the following points is interlocked so that they can be overridden together at a zone-group level, per Section 3.5E.
For example, the CxA can check for leaking dampers by forcing all VAV boxes in a Zone Group closed and then recording airflow at the AHU.

H. Plant Requests

1. If There Is a Chilled-Water Coil, Chilled-Water Reset Requests

a. If the supply air temperature exceeds the supply air temperature setpoint by 3°C (5°F) for 2 minutes, send 3 requests.

b. Else if the supply air temperature exceeds the supply air temperature setpoint by 2°C (3°F) for 2 minutes, send 2 requests.

c. Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.

d. Else if the CHW valve position is less than 95%, send 0 requests.

2. If There Is a Chilled-Water Coil, Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.

b. Else if the CHW valve position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the supply air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

b. Else if the supply air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.

c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

d. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil, Heating Hot Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.18 GENERAL CONSTANT SPEED EXHAUST FAN

A. Exhaust Fan Control

1. Exhaust Fan Start/Stop

a. Scheduled fans

1) Exhaust fan shall operate when any of the associated system supply fans is proven on and any associated Zone Group is in the Occupied Mode. See Section 1.2D for Zone Group assignments.

b. Fans controlled by space temperature

1) Exhaust fan shall run when zone temperature rises above the active cooling setpoint until zone temperature falls more than 1°C (2°F) below the active cooling setpoint for 2 minutes.

The room temperature control method should only be used in non-occupied spaces where ventilation is not required (e.g., equipment rooms).

B. Alarms

1. Maintenance interval alarm when fan has operated for more than 3,000 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

a. Commanded on, status off: Level 2

b. Commanded off, status off: Level 4

3.19 FAN COIL UNIT

A. See "Generic Thermal Zones" (Section 3.4) for setpoints, loops, control modes, alarms, etc.

B. See Section 1.2H for Cool_SAT, Heat_SAT, and DP100.

C. See Section 1.3D for MinSpeed, DeadbandSpeed, MaxHeatSpeed, and MaxCoolSpeed.

D. Supply Fan Speed and Supply Air Temperature Control

1. The supply fan shall run whenever the unit is in any mode other than Unoccupied Mode.

2. Provide a ramp function to prevent changes in fan speed of more than 10% per minute.

3. When the supply fan is proven on, fan speed and supply air temperature setpoints are controlled as shown in Figures 5.20.4.3. The points of transition along the x-axis shown and described are representative. Separate gains shall be provided for each section of the control map, that are determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.20.4.3 to provide stable control.

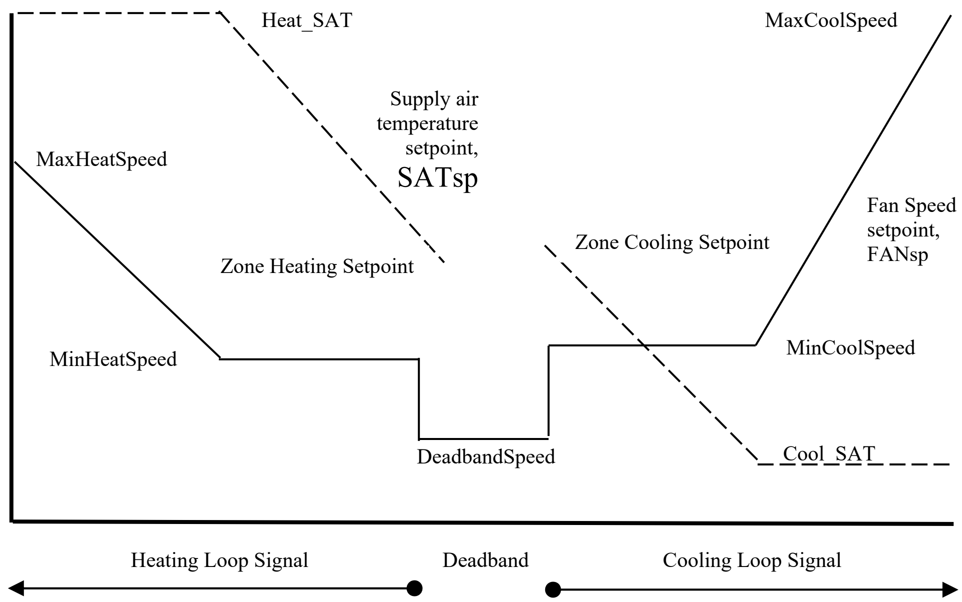


Figure 5.20.4.3 Control diagram for FCU.

a. If there is a heating coil, when Zone State is Heating

1) For a heating-loop signal of 100% to 50%, FANsp is reset from MaxHeatSpeed to MinHeatSpeed.

2) For a heating-loop signal of 50% to 0%, FANsp is MinHeatSpeed.

3) For a heating-loop signal of 100% to 50%, SATsp is Heat_SAT.

4) For a heating-loop signal of 50% to 0%, SATsp is reset from Heat_SAT to the active zone heating setpoint.

5) The heating coil shall be modulated with a PID loop to maintain the discharge temperature at SATsp.

6) Cooling coil off

b. When Zone State is Deadband

1) FANsp shall be DeadbandSpeed. If DeadbandSpeed is zero, shut the fan off.

2) Cooling coil off

3) Heating coil off

c. If there is a cooling coil, when Zone State is Cooling

1) For a cooling-loop signal of 0% to 50%, FANsp is MinCoolSpeed.

2) For a cooling-loop signal of 50% to 100%, FANsp is reset from MinCoolSpeed to MaxCoolSpeed.

3) For a cooling-loop signal of 0% to 50%, SATsp is reset from the active zone cooling setpoint to Cool_SAT.

4) For a cooling-loop signal of 50% to 100%, SATsp is Cool_SAT.

5) The cooling coil shall be modulated with a PID loop to maintain the discharge temperature at SATsp.

6) Heating coil off

E. Alarms

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

3. Filter pressure drop exceeds the larger of the alarm limit or 12.5 Pa (0.05") for 10 minutes when fan speed exceeds 20% of MaxCoolSpeed: Level 4. The alarm limit shall vary with fan speed as follows:

$$DP_x = DP_{100}(x)^{1.4}$$

where DP100 is the high limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high limit at the current fan speed x (expressed as a fraction). For instance, the setpoint at 50% of design speed would be (0.5)1.4 or 38% of the design high limit pressure drop. See Section 1.3D for MaxCoolSpeed and Section 1.2H for DP100.

The constant value threshold for the filter pressure drop alarm is a function of the transducer and A/D converter used to measure filter differential pressure. The value used shall be determined as the minimum accuracy of the transducer and A/D converter combination.

F. Automatic Fault Detection and Diagnostics

The AFDD routines for FCUs continually assess FCU performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the OS of the AHU, as determined by the position of the cooling and heating valves. Time delays are applied to the evaluation and reporting of fault conditions to suppress false alarms. Fault conditions that pass these filters are reported to the building operator along with a series of possible causes.
These equations assume that the FCU is equipped with heating and cooling coils. If any of these components are not present, the associated tests and variables should be omitted from the programming.

1. AFDD conditions are evaluated continuously and separately for each operating FCU.

2. The OS of each FCU shall be defined by the commanded positions of the heating-coil control valve and cooling-coil control valve in accordance with Table 5.20.6.2 and Figure 5.20.6.2.

Table 5.20.6.2 FCU Operating States

Operating State	Heating Valve Position	Cooling Valve Position
#1: Heating	> 0	= 0
#2 No Heating or Cooling	= 0	= 0
#3: Cooling	= 0	> 0
#4 Unknown	No other OS applies	

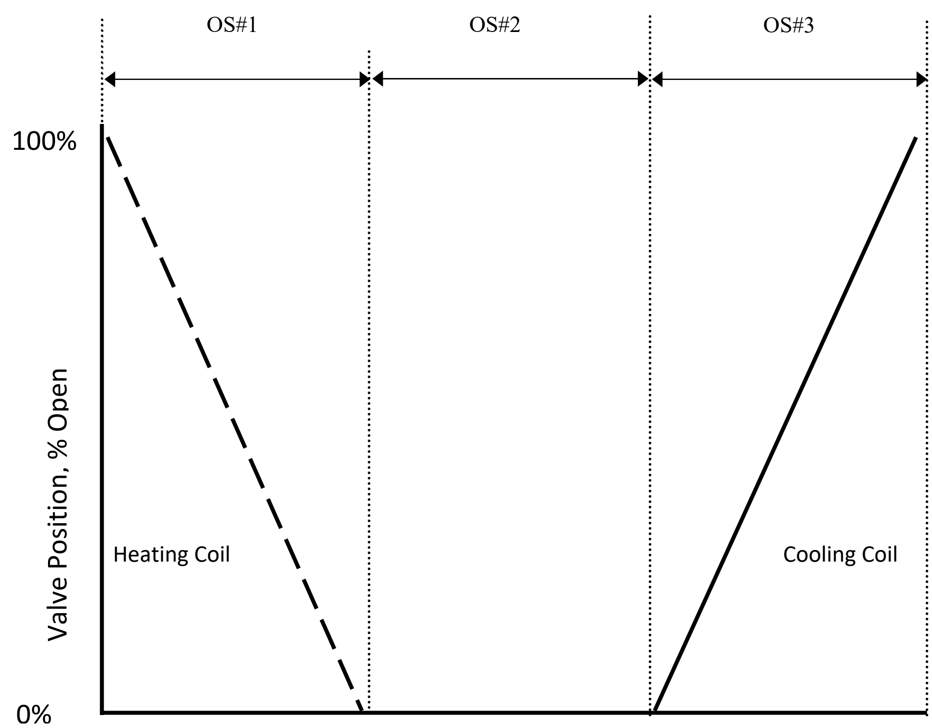


Figure 5.20.6.2 FCU operating states.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband).
OS#1 through OS#3 (see Table 5.20.6.2) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 3.16L.6. By contrast, OS#4 may represent an abnormal or incorrect condition (such as simultaneous heating and cooling) arising from a controller failure or programming error.

3. The following points must be available to the AFDD routines for each FCU:

For the AFDD routines to be effective, an averaging sensor is recommended for the supply air temperature but it is noted that in most cases a single point sensor will be provided with the FCU.

   a. SAT = supply air temperature

b. RAT = return air temperature (if present)

c. SATsp = supply air temperature setpoint

d. HC = heating-coil valve position command; 0% ≤ HC ≤ 100%

e. CC = cooling-coil valve position command; 0% ≤ CC ≤ 100%

f. FS = fan-speed command; 0% ≤ FS ≤ 100%

4. The following values must be continuously calculated by the AFDD routines for each FCU:

a. Five-minute rolling averages with 1-minute sampling of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently.

1) SATavg = rolling average of supply air temperature

2) RATavg = rolling average of return air temperature (if fitted)

3) □OS = number of changes in OS during the previous 60 minutes (moving window)

5. The internal variables shown in Table 5.20.6.5 shall be defined for each FCU. All parameters are adjustable by the operator, with initial values as given below.

Default values are derived from NISTIR 7365 and have been validated in field trials. They are expected to be appropriate for most circumstances, but individual installations may benefit from tuning to improve sensitivity and reduce false alarms.
The default values have been intentionally biased toward minimizing false alarms, if necessary at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.
Values for physical factors such as fan heat, duct heat gain, and sensor error can be measured in the field or derived from trend logs. Likewise, the occupancy delay and switch delays can be refined by observing in trend data the time required to achieve quasi steady state operation.
Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false errors, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the heating coil, cooling coil, temperature, or flow thresholds.

Table 5.20.6.5 FCU Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	0.5°C (1°F)
□SAT	Temperature error threshold for SAT sensor	1°C (2°F)
□RAT	Temperature error threshold for RAT sensor	1°C (2°F)

□OSmax	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	7
ModeDelay	Time in minutes to suspend Fault Condition evaluation after a change in mode	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

The purpose of TestModeDelay is to ensure that normal fault reporting occurs after the testing and commissioning process is completed as described in Section 3.16L.12.

6. Table 5.20.6.6 shows potential fault conditions that can be evaluated by the AFDD routines. If the equation statement is true, then the specified fault condition exists. The fault conditions to be evaluated at any given time will depend on the OS of the AHU.

The equations in Table 5.20.6.6 assume that the SAT sensor is located downstream of the supply fan and the RAT sensor is located upstream of the supply fan. If actual sensor locations differ from these assumptions, it may be necessary to add or delete fan heat correction factors.

Table 5.20.6.6 FCU Fault Conditions

FC #1	Equation	$\Delta OS > \Delta OSMAX$	Applies to OS #1 – #4
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC #2	Equation	$SATAVG < SATSP - \varepsilon SAT$ and $HC \geq 99\%$	Applies to OS #1
	Description	SAT too low in full heating	
	Possible Diagnosis	SAT sensor error Cooling coil valve leaking or stuck open Heating coil valve stuck closed or actuator failure Fouled or undersized heating coil HW temperature too low or HW unavailable Gas or electric heat is unavailable DX cooling is stuck on	

FC #3	Equation	$SATAVG > SATSP + \varepsilon SAT$ and $CC \geq 99\%$	Applies to OS #3
	Description	SAT too high in full cooling	
	Possible Diagnosis	SAT sensor error Cooling coil valve stuck closed or actuator failure Fouled or undersized cooling coil CHW temperature too high or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	
FC#4	Equation	$SATAVG - RAT \geq \sqrt{\varepsilon_{RAT}{}^2 + \varepsilon_{SAT}{}^2} + \Delta TSF$	Applies to OS #2 (cooling only FCU with RAT)
	Description	Temperature drop across inactive cooling coil	
	Possible Diagnosis	RAT sensor error SAT sensor error Cooling coil valve stuck open or leaking DX cooling stuck on	
FC#5	Equation	$SATAVG - RAT \leq \sqrt{\varepsilon_{RAT}{}^2 + \varepsilon_{SAT}{}^2} + \Delta TSF$	Applies to OS #2 (heating only FCU with RAT)
	Description	Temperature rise across inactive heating coil	
	Possible Diagnosis	RAT sensor error SAT sensor error Heating coil valve stuck open or leaking Gas or electric heat stuck on	

7. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the OS of the FCU.

   a. In OS#1 (Heating), the following fault conditions shall be evaluated:

      1) FC#1: Too many changes in OS

      2) FC#2: SAT too low in full heating

   b. In OS#2 (Deadband), the following fault conditions shall be evaluated:

      1) FC#5: Temperature drop across inactive heating coil (heating only FCU

      2) FC#4: Temperature drop across inactive cooling coil (cooling only FCU

   c. In OS#3 (Cooling), the following fault conditions shall be evaluated:

      1) FC#1: Too many changes in OS

      2) FC#3: SAT too high in full cooling

d. In OS#4 (other), the following fault conditions shall be evaluated:

1) FC#1: Too many changes in OS

8. For each FCU, the operator shall be able to suppress the alarm for any fault condition.

9. Evaluation of fault conditions shall be suspended under the following conditions:

a. When FCU is not operating

b. For a period of ModeDelay minutes following a change in mode (e.g., from Warmup Mode or Cooldown Mode to Occupied Mode) of any Zone Group served by the FCU.

10. Fault conditions that are not applicable to the current OS shall not be evaluated.

11. A fault condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

12. Test mode shall temporarily set ModeDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system and ensure normal fault detection occurs after testing is complete.

13. When a fault condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from Table 5.20.6.6.

G. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to

a. force HW valve full open if there is a hot-water coil,

b. force HW valve full closed if there is a hot-water coil,

c. force CHW valve full open if there is a CHW coil, and

d. force CHW valve full closed if there is a CHW coil.

Per Section 5.1.10, all hardware points can be overridden through the BAS. Each of the following points is interlocked so that they can be overridden as a group on a plant level. For example, the CxA can check for valve leakage by simultaneously forcing closed all CHW valves at all coils served by the chiller plant and then recording flow at the chiller.

H. Plant Requests

1. If There Is a Chilled-Water Coil, Chilled-Water Reset Requests

a. All requests shall be suppressed (send 0 requests) if fan is not at MaxCoolSpeed.

The previous sequence is to prevent CHWST reset until fan is at full speed since chiller plant energy is much larger than FC fan energy.

b. If the supply air temperature is 10°F greater than setpoint for 5 minutes, send 3 requests,

c. Else if the supply air temperature is 5°F greater than setpoint for 5 minutes, send 2 requests,

d. Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.

e. Else if the CHW valve position is less than 95%, send 0 requests.

2. If There Is a Chilled-Water Coil, Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.

b. Else if the CHW valve position is less than 95%, send 0 requests.

3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. All requests shall be suppressed (send 0 requests) if fan is not at MaxHeatSpeed.

The previous sequence is to prevent HWST reset until fan is at full speed since heating plant energy is much larger than FC fan energy.

b. If the supply air temperature is 17°C (30°F) less than SATsp for 5 minutes, send 3 requests.

c. Else if the supply air temperature is 8°C (15°F) less than SATsp for 5 minutes, send 2 requests.

d. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

e. Else if the HW valve position is less than 95%, send 0 requests.

4. If There Is a Hot-Water Coil, Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the FCU a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.20 VRF FAN COIL

A. See “Generic Thermal Zones” (Section 3.4) for setpoints, alarms, etc.

B. All fan-coils are controlled by built-in factory controls, not the BAS.

C. Fan coil factory logic shall be configured to stage fan speed as well as supply air temperature to achieve room temperature setpoint, and configured to go to minimum speed when in deadband.

D. All setpoints and scheduling shall be written from the BAS to the fan-coil controller via the BACnet interface.

1. Enable

a. Fan coils served by ventilation air valves shall be commanded to run in Occupied Mode by the BAS when the air valve is in Occupied Mode.

b. Otherwise, fan coils shall be enabled/disabled by internal logic based on difference between zone cooling and heating temperature setpoints and zone temperature.

3.21 RADIANT MANIFOLD

A. Radiant manifold serve one or more space temperature sensors if the radiant zone overlaps with several VAV zones. See Drawings. If more than one:

1. The control heating loop output shall be the highest heating loop output from the radiant zones served by the manifold.

2. The control cooling loop output shall be the highest cooling loop output from the radiant zones served by the manifold.

B. Slab Temperature Setpoints

1. Maximum Slab Temperature Setpoint, STSPmax, shall equal 85°F (adj.).

2. Minimum Slab Temperature Setpoint, STSPmin, shall equal the greater of 65°F (adj.) and 1°F (adj.) more than the present outdoor air dew point temperature.

3. Neutral Temperature Setpoint, STSPneut, shall equal the average of the active radiant zone heating and cooling setpoints for the zone served by the manifold.

C. Slab Temperature Setpoint Reset

1. Upper and lower limits of the reset range shall be STSPmax and STSPmin.

2. When the Radiant Water Loop serving the manifold is indexed to Heating Mode, Slab Temperature Setpoint shall be reset from STSPmin at 0% control heating loop output to STSPmax at 100% control heating loop output.

3. When the Radiant Water Loop serving the manifold is indexed to Cooling Mode, Slab Temperature Setpoint shall be reset from STSPmax at 0% control cooling loop output to STSPmin at 100% control cooling loop output.

D. Slab Temperature Control

1. When in Heating Mode, the 2-position manifold valve shall open when slab temperature falls 1°F below setpoint and close when slab temperature exceeds setpoint.

2. When in Cooling Mode, the 2-position manifold valve shall open when the slab temperature is 1°F above setpoint and close when slab temperature falls below setpoint.

3. Valve Lockout: When valve lockout logic is triggered, it shall override all preceding valve control logic.

   a. When in Heating Mode and all radiant zones served by the manifold are above zone heating setpoint for 5 minutes continuously, manifold valve shall be closed. Valve shall remain locked out until any radiant zone served by the manifold falls below its heating setpoint.

   b. When in Cooling Mode and all radiant zones served by the manifold are below cooling setpoint for 5 minutes continuously, manifold valve shall be closed. Valve shall remain locked out until any radiant zone served by the manifold rises above its cooling setpoint.

   c. When the radiant loop changes modes, the manifold valve shall not be allowed to open until it has been closed for at least 3 hours (e.g. if the manifold valve were last open in Heating Mode 120 minutes prior to the loop switching to Cooling Mode, the valve would remain shut for another 60 minutes before being unlocked for cooling control).

E. Alarms

1. Slab temperature drops to 62°F for 15 minutes (adj.) continuously. Level 2.

2. Slab temperature rises above 90°F for 15 minutes (adj.) continuously. Level 2.

F. Testing/Commissioning Overrides: Provide software points that interlock to a physical IO point to

1. Force manifold control valve full open

2. Force manifold control valve full closed

G. Radiant Water Loop Requests

1. If the manifold control valve is open for 1 minute continuously, send 1 request.

2. If the manifold control valve is closed, send 0 requests.

3.22 RADIANT WATER PUMPING LOOPS

A. Radiant Water Loop Mode

1. Definitions

   a. CoolAvg = The average Radiant Zone Cooling Loop output from all radiant zones served by the loop.

   b. HeatAvg = The average Radiant Zone Heating Loop output from all radiant zones served by the loop.

2. When the system is first enabled (e.g. following a control system shutdown), index the loop to Heating Mode.

3. Thereafter, index the Radiant Water Loop to Cooling Mode if all of the following are true:

   a. CoolAvg > HeatAvg for 20 minutes (adj.) continuously.

   b. CoolAvg > 10% for 20 minutes (adj.) continuously.

   c. There are no active Radiant Heating Mode Requests.

   d. The zone generating the highest cooling loop output is not being set from occupied mode to unoccupied mode within the next 120 minutes (adj.).

The goal is to avoid cooling the floor in the afternoon if the zone is about to go unoccupied.

4. Index the Radiant Water Loop to Heating Mode if:

   a. Either:

      1) Both of the following are true:

         a) HeatAvg > CoolAvg for 20 minutes (adj.) continuously.

         b) HeatAvg > 10% for 20 minutes (adj.) continuously.

      2) There is at least 1 active Radiant Heating Mode Request.

   b. AND the zone generating the highest heating loop output is not being set from occupied mode to unoccupied mode within the next 60 minutes (adj.).

The goal is to avoid heating the floor in the evening if the zone is about to go unoccupied. A less aggressive delay is appropriate for heating than cooling since some zones only have radiant heating.

B. Loop Changeover Control

1. When changing over from heating to cooling,

   a. First command the heating control valve shut.

   b. Wait 15 minutes to allow heat from water loop to dissipate in the slab, then command the changeover valves from open to the hot water loop to open to the chilled water loop.

   c. After 2 minutes, release the tempered chilled water control valve to control Radiant Loop Supply Water Temperature.

2. When changing over from cooling to heating, logic shall operate identically to heating to cooling switchover, but in reverse.

C. Radiant Loop Supply Water Temperature Control

1. Loop Supply Water Temperature Setpoint

a. When the loop is in Cooling Mode, supply water temperature setpoint shall be the greater of:

1) 10°F below the lowest Slab Temperature Setpoint for a manifold served by the loop; and

2) The plant tempered chilled water supply temperature plus 1°F.

b. When the loop is in Heating Mode, supply water temperature shall be the lesser of:

1) 15°F above the highest Slab Temperature Setpoint for a manifold served by the loop; and

2) The plant hot water minus 2°F.

2. Loop supply water temperature shall be controlled to setpoint by a PID loop that modulates the enabled (heating or cooling) 2-way control valve. In Heating Mode, loop shall be reverse acting; in Cooling Mode, loop shall be direct acting.

3. 2-way control valve for enabled mode shall be shut whenever Radiant Water Pump status is off.

D. Radiant Water Pump (RWP) Control

1. Enable pump whenever there is 1 or more Radiant Water Loop requests from manifolds served by the loop.

2. Disable pump whenever there are 0 Radiant Water Loop requests from manifolds served by the loop for 1 minute (adj.) continuously.

E. Alarms

1. Maintenance interval alarm when pump has operated for more than 1500 hours: Level 5. Reset interval counter when alarm is acknowledged.

2. Pump alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

a. Commanded on, status off: Level 2

b. Commanded off, status on: Level 4

3. Loop supply water temperature alarm if supply temperature is more than 3°F off setpoint for 15 minutes continuously: Level 3. Suppress alarm if RWP is off.

F. Testing/Commissioning Overrides: Provide software points that interlock to a physical IO point to

1. Force hot water valve full open

2. Force hot water valve full closed

3. Force changeover valves from one position to the other

4. Force tempered chilled water valve full open

5. Force tempered chilled water valve full closed

G. Plant Requests

1. Cooling TCHWST Reset Requests

a. Whenever Loop Supply Water Temperature Setpoint is equal to TCHWST plus 1°F:

1) Send 0 requests when the TCHW valve is closed.

2) Send 1 request for each manifold control valve open for 30 minutes continuously when the TCHW valve is greater than 10% open, up to a maximum of 2.

3) Requests from a given manifold control valve shall clear when that manifold valve is closed.

b. Otherwise:

1) If the TCHW valve is greater than 85%, send 0 requests.

2) If the TCHW valve is greater than 95%, send 1 request.

3) If the loop supply water temperature is 3°F greater than set point for 5 minutes, send 2 requests.

2. Tempered Chilled Water Loop Requests. Send the chiller plant that serves the system a Tempered Chilled Water Loop Request as follows:

a. If the TCHW valve is less than 10%, send 0 requests.

b. If the TCHW valve is greater than 95%, send 1 request.

3. Heating HWST Reset Requests

a. Whenever Loop Supply Water Temperature Setpoint is equal to HWST minus 2°F:

1) Send 0 requests when the HW valve is closed.

2) Send 1 request for each manifold control valve open for 30 minutes continuously when the HW valve is greater than 10% open, up to a maximum of 2.

3) Requests from a given manifold control valve shall clear when that manifold valve is closed.

b. Otherwise:

1) If the HW valve is greater than 85%, send 0 requests.

2) If the HW valve is greater than 95%, send 1 request.

3) If the loop supply water temperature is 3°F less than set point for 5 minutes, send 2 requests.

4. Heating Hot-Water Plant Requests. Send the boiler plant that serves the system a Heating Hot-Water Plant Request as follows:

   a. If the HW valve is less than 10%, send 0 requests.

   b. If the HW valve is greater than 95%, send 1 request.

3.23 PACKAGED SINGLE ZONE HEAT PUMP OR GAS/ELECTRIC AC UNIT WITH BACNET

A. See “Generic Thermal Zones” (Section 3.4) for setpoints, alarms, etc.

B. Each of the AC units operates independently through its factory installed controller.

C. All setpoints and scheduling shall be written from the BAS to the AC unit controller via the BACnet interface.

D. Alarms

   1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 5. Reset interval counter when alarm is acknowledged.

   2. AC unit alarm: Level 2 to 4 based on severity.

3.24 PACKAGED SINGLE ZONE HEAT PUMP OR GAS/ELECTRIC AC UNIT WITH DDC

A. See “Generic Thermal Zones” (Section 3.4) for setpoints, loops, control modes, alarms, etc.

B. Supply fan control

   1. For occupied areas: The unit fan shall run when system is in any mode other than Unoccupied Mode.

   2. For IDF rooms and other unoccupied areas: The unit fan shall run only when zone is in Cooling State or Heating State and off in Deadband State.

C. Cooling control

   1. Cooling is enabled when the zone is in Cooling State.

   2. The zone Cooling Loop output shall be mapped to stage the two stages of cooling as follows. Each stage shall have a 5 minute minimum on time and a 5 minute minimum off-time:

      a. Stage 1 of cooling shall be enabled when the loop output is at 50 and staged off when the loop output is at 0. Note the economizer (where applicable) is enabled by the unit controls whenever the first stage of cooling is engaged.

      b. Stage 2 of cooling shall be enabled when the loop output is at 100 and staged off when the loop output is at 50.

c. Each stage shall have a 5 minute minimum on time and a 5 minute minimum off-time

D. Heating control

1. Heating is enabled when the zone is in Heating Mode.

2. The zone Heating Loop output shall be mapped to stage the two stages of heating as follows. Each stage shall have a 5 minute minimum on time and a 5 minute minimum off-time:

   a. Stage 1 of heating shall be enabled when the loop output is at 40 and staged off when the loop output is at 0.

   b. Stage 2 of heating shall be enabled when the loop output is at 70 and staged off when the loop output is at 30.

   c. The electric auxiliary heat shall be enabled when the outdoor air temperature is below 40°F and the loop output is at 100, and staged off when the loop output is below 60 or the outdoor air rises above 45°F.

E. Outdoor air and return air damper control.

1. Outdoor air and return air dampers are controlled internally by the AC unit.

2. Set minimum outdoor air damper position using the potentiometer on the packaged economizer, or two-position actuator if no economizer. Minimum outdoor air is enabled by the outdoor air enable contact from the DDC system only when the system is in the Occupied Mode.

3. Set economizer high limit in AC unit to disable economizer when outdoor air temperature is above the high limit per Paragraph 3.1Q for this climate zone.

F. Alarms

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status input being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

3. Generate a Level 3 alarm if:

   a. Heating outputs are on and supply air fan is proven on and supply air temperature is below 80°F for more than 3 minutes indicating heating system failure.

b. Cooling outputs are on and supply air fan is proven on and supply air temperature is above 65°F for more than 3 minutes indicating cooling system failure.

4. Filter pressure drop exceeds adjustable alarm limit. Level 4

3.25 PACKAGED MULTIPLE ZONE VAV AC UNIT

A. AC Unit shall be configured to disable any internal scheduling, start/stop, and mode control. All operating modes and setpoints shall be determined by the BAS as described herein. The AC unit shall be configured to operate only when enabled by BAS commands and to maintain the setpoints determined by the BAS below. All commands and setpoints shall be passed from the BAS to the to the AC unit's internal controls via the gateway.

B. AC System Modes. See Paragraph **Error! Reference source not found.** for Modes which are generated by Zone Group Requests.

C. Supply Fan Control

1. Supply Fan Start/Stop

a. Supply fan shall run when system is in the Cooldown Mode, Setup Mode, or Occupied Mode.

b. If there are any VAV-reheat boxes on perimeter zones, supply fan shall also run when system is in Setback Mode or Warmup Mode (i.e., all modes except unoccupied).

c. Totalize current airflow rate from VAV boxes to a software point Vps.

VAV box airflow rates are summed to obtain overall supply air rate without the need for an airflow measuring station (AFMS) at the air-handler discharge. This is used for ventilation rate calculations and may also be used for display and diagnostics.

2. Static Pressure Set-Point Reset

a. Static pressure setpoint. Setpoint shall be reset using T&R logic (see Section 3.1O) using the parameters shown in Table 5.16.1.2.

Table 5.16.1.2 Trim & Respond Variables

Variable	Value
Device	Supply fan
SP0	120 Pa (0.5 in. of water)
SPmin	25 Pa (0.1 in. of water)
SPmax	Max_DSP (see Section 1.3B.1)
Td	10 minutes
T	2 minutes
I	2
R	Zone static pressure reset requests

SPtrim	–12 Pa (–0.05 in. of water)
SPres	15 Pa (+0.06 in. of water)
SPres-max	32 Pa (+0.13 in. of water)

The T&R reset parameters in Table 5.16.1.2 are suggested as a starting point; they will most likely require adjustment during the commissioning/tuning phase.

3. Static Pressure Control

a. Static pressure tip shall be extended in field to location shown on plans.

b. Supply fan shall be controlled by AC unit internal controls to maintain supply duct static pressure setpoint.

c. VFD ramp rate shall be configured to rise very slowly to prevent high pressure trips in case all VAV boxes are closed (they should close during unoccupied periods) or in case fire/smoke dampers are closed (in some FSD designs, the dampers are interlocked to the fan status rather than being controlled by smoke detectors).

D. Supply Air Temperature Control

1. Control loop is enabled when the supply air fan is proven on, and disabled and output set to deadband (no heating, minimum economizer) otherwise.

2. Supply Air Temperature Setpoint

The default range of outdoor air temperatures [21°C (70°F) –16°C (60°F)] used to reset the Occupied Mode SAT setpoint was chosen to maximize economizer hours. It may be preferable to use a lower range of OATs (e.g., 18°C [65°F] – 13°C [55°F]) to minimize fan energy if there is a 24/7 chiller plant that is running anyway; reheat is minimized, as in a VAV dual-fan dual-duct system, or the climate severely limits the number of available economizer hours.
If using this logic, the engineer should oversize interior zones and rooms with high cooling loads (design them to be satisfied by the warmest SAT) so these zones do not drive the T&R block to the minimum SAT setpoint.

a. See Section 1.2F.1 for Min_ClgSAT, Max_ClgSAT, OAT_Min, and OAT_Max setpoints.

b. During Occupied Mode and Setup Mode, setpoint shall be reset from Min_ClgSAT when the outdoor air temperature is OAT_Max and above, proportionally up to T-max when the outdoor air temperature is OAT_Min and below.

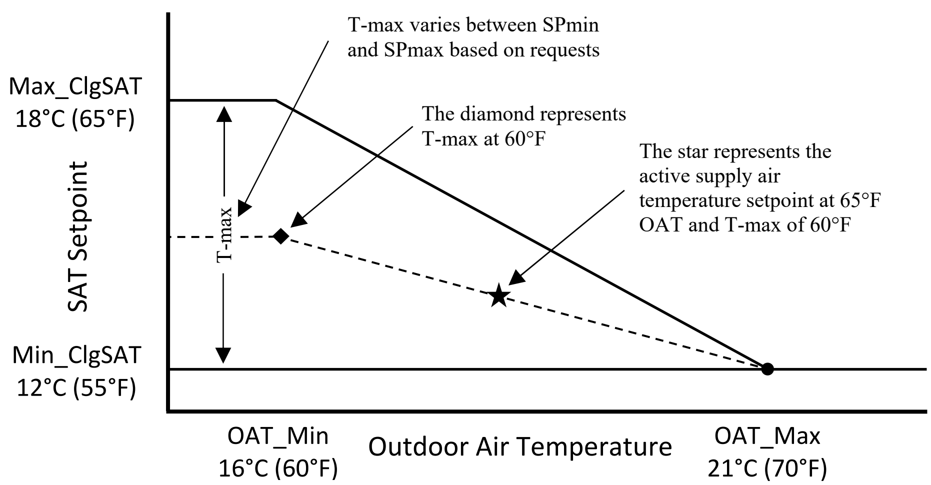
1) T-max shall be reset using T&R logic (see Section 3.1O) between Min_ClgSAT and Max_ClgSAT. The parameters shown in Table 5.16.2.2 are suggested as a starting place, but they will require adjustment during the commissioning/tuning phase.

The T&R reset parameters in Table 5.16.2.2 are suggested as a starting place; they will most likely require adjustment during the commissioning/tuning phase.

Table 5.16.2.2 Trim & Respond Variables

Variable	Value
Device	Supply fan
SP0	SPmax
SPmin	Min_ClgSAT
SPmax	Max_ClgSAT
Td	10 minutes
T	2 minutes
I	2
R	Zone cooling SAT requests
SPtrim	+0.1°C (+0.2°F)
SPres	–0.2°C (–0.3°F)
SPres-max	–0.6°C (–1.0°F)

The net result of this SAT reset strategy is depicted in the Figure 5.16.2.2 for Min_ClgSAT = 12°C (55°F), Max_ClgSAT = 18°C (65°F), OAT_Max = 21°C (70°F), and OAT_Min = 16°C (60°F).



Informative Figure 5.16.2.2 Example supply air temperature reset diagram.

c. During Cooldown Mode, setpoint shall be Min_ClgSAT.

d. During Warmup Mode and Setback Mode, setpoint shall be 35°C (95°F).

Raising the SAT setpoint in warmup will effectively lock out the economizer and cooling coil, which is desirable for warmup even if there is no heating coil at the AHU to meet the higher SAT.

This does not apply in the case of a DFDD AHU or if all the zones are equipped with fan-powered boxes such that the AHU is off in warmup and setback.

3. Supply air temperature shall be controlled by the AC unit internal controls to sequence the ***heating***, economizer, and compressors.

    a. Adjust the damper actuators so that dampers sequence rather than overlap, e.g. from 0 Vdc to 5 Vdc, the outdoor air damper goes from full closed to full open and from 5 Vdc to 10 Vdc the return air damper goes from full open to full closed.

    b. Set economizer high limit in AC unit to disable economizer when outdoor air temperature is above the high limit per Paragraph 3.1Q for this climate zone.

E. Minimum Outdoor Air Control

1. Outdoor Airflow Setpoint for California Title 24 Ventilation

    a. See Section 3.15C.1 for calculation of current setpoints AbsMinOA* and DesMinOA*.

    b. See zone CO2 control logic under terminal unit sequences.

    c. The minimum outdoor air setpoint MinOAsp shall be reset based on the highest zone CO2 control-loop signal from AbsMinOA* at 50% signal to DesMinOA* at 100% signal.

    d. Minimum outdoor air control shall be controlled by the AC unit internal controls to maintain minimum outdoor air at setpoint. Setpoint shall be set to MinOAsp when the AC unit is in Occupied Mode and set to zero otherwise.

    e. Minimum Outdoor Air Control Loop

        1) Minimum outdoor air control loop is enabled when the AC unit is in Occupied Mode and disabled and output set to zero otherwise.

        2) The measured outdoor airflow rate shall be maintained at the minimum outdoor air setpoint MinOAsp by a PID loop whose output is written to the AC unit internally controlled minimum damper position input.

F. Relief Fans

1. Building pressure sensor shall be field installed in location indicated on Drawings.

2. Relief fans shall be controlled by AC unit internal controls to maintain building pressure at setpoint (0.05” adjustable).

G. Return Fans

1. Building pressure sensor shall be field installed in location indicated on Drawings.

2. Return fans shall be controlled by AC unit internal controls to track supply air fans to maintain building pressure at approximately 0.05”.

H. Alarms:

1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval count when alarm is acknowledged.

2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

3. Filter pressure drop exceeds the larger of the alarm limit or 12.5 Pa (0.05”) for 10 minutes when airflow (expressed as a percentage of design airflow or design speed if total airflow is not known) exceeds 20%: Level 4. The alarm limit shall vary with total airflow (if available; use fan speed if total airflow is not known) as follows:

$$DP_x = DP_{100}(x)^{1.4}$$

where DP100 is the high-limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high limit at the current airflow rate x (expressed as a fraction). For instance, the setpoint at 50% of design airflow would be (0.5)1.4, or 38% of the design high-limit pressure drop. See Section 1.2F.4 for DP100.

The constant value threshold for the filter pressure drop alarm is a function of the transducer and A/D converter used to measure filter differential pressure. The value used shall be determined as the minimum accuracy of the transducer and A/D converter combination.

4. High building pressure (more than 25 Pa [0.10 in. of water]) for 5 minutes: Level 3.

5. Low building pressure (less than 0 Pa [0.0 in. of water], i.e., negative) for 5 minutes: Level 4.

6. AC unit failure alarm: Level 2

7. Cooling compressors operate when the outdoor air is below 55°F. Level 4.

I. Plant Requests

1. If There Is a Hot-Water Coil, Hot-Water Reset Requests

   a. If the supply air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.

   b. Else if the supply air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.

   c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.

   d. Else if the HW valve position is less than 95%, send 0 requests.

2. If There Is a Hot-Water Coil, Heating Hot Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

a. If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.

b. Else if the HW valve position is less than 95%, send 0 requests.

3.26 CHILLED WATER PLANT

A. See Section 1.2H for CHWSTminX, CWRTdesX, CWSTdesX, CH-LOT, CHW-MinFlowX, CHW-DesFlowX, LIFTminX, LIFTmaxX, QchX, PCHWFdesign, SCHWFdesign, MinUnloadCapX, DAHX, DTWB, DACT, HXFdesign, and HXDP-Design. See Section 1.3D for CHW-DPmax, LocalCHW-DPmax, Cw-DesPumpSpdStage, MinCWVlvPos, MinCWPspeed, HxPumpDesSpd, Ch-MaxPriPumpSpdStage, and CH-MinPriPumpSpdStage.

B. Plant Enable/Disable

1. The chiller plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, holidays, or any other scheduled event, e.g., to allow off-hour operation of HVAC systems except the chiller plant. The default schedule shall be 24/7 (adjustable).

2. Enable the plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

a. Number of Chiller Plant Requests > I (I = Ignores shall default to 0, adjustable), and

b. OAT>CH-LOT, and

c. The chiller plant enable schedule is active.

3. Disable the plant when it has been enabled for at least 15 minutes and:

a. Number of Chiller Plant Requests ≤ I for 3 minutes, or

b. OAT<CH-LOT – 1°F, or

c. The chiller plant enable schedule is inactive.

Chiller Plant Requests are generated by coil control valves. If the plant serves critical valves whose positions are not known to the plant controller, e.g., pneumatic controls, the Chiller Plant Request variable can be set to 1 manually by the operator such that the plant is enabled strictly based on OAT lockout and schedule per subsequent logic.
At a future date, Importance multipliers (IM) shall be added to Chiller Plant Requests in AHU and fan coils sequences to ensure that critical coils can independently cause the plant to start. For example, setting the importance multiplier of a large air handler's Chiller Plant Requests to 4 will cause 4 requests so that air handler alone can start the plant even if I=4. Unimportant coils can be assigned an IM of zero so that they cannot cause the plant to start. Small coils can be assigned IM values less than one so that several are required to be active before the plant will start.

4. When the plant is enabled:

a. If the plant is enabled in WSE Mode (see Section 3.26D.15):

1) Open the CW isolation valve of the waterside economizer.

2) Stage on lead primary CHW pump, CW pump, and cooling tower(s) per Sections 3.26F, 3.26I, and 3.26L respectively.

3) Stage on lead secondary CHW pump, CW pump, and cooling towers per Sections 3.26G, 3.26I, and 3.26L respectively.

b. If the plant is enabled in Chiller Mode (see Section 3.26D.15):

1) Open the CHW isolation valve of the lead chiller.

2) Open the CW isolation valve of the lead chiller.

3) Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per Sections 3.26F, 3.26G, 3.26I, and 3.26L and respectively.

4) Stage on lead primary CHW pump, CW pump, and cooling towers per Sections 3.26F, 3.26I, and 3.26L respectively.

5) Once the lead pumps are proven on, enable the lead chiller.

5. When the plant is disabled:

a. Shut off all enabled chillers, if any.

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

b. For each enabled chiller, close the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Where chillers have a CW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

c. For each enabled chiller, close the CW isolation valve after 3 minutes or the chiller is not requesting CW flow.

d. Disable the operating primary CHW pump(s) (if enabled), secondary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 3.26F, 3.26I, 3.26G, and 3.26L respectively.

e. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 3.26F, 3.26I, and 3.26L respectively.

6. When the plant is enabled:

a. Open the CHW isolation valve of the lead chiller.

b. Close the CHW isolation valve of the lead chiller.

c. Open the CW isolation valve of the lead chiller.

d. Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per Sections 3.26F, 3.26G, 3.26I, and 3.26L respectively.

e. Stage on lead primary CHW pump and secondary CHW pump per Sections 3.26F, and 3.26G respectively.

f. Stage on lead primary CHW pump, CW pump, and cooling towers per Sections 3.26F, 3.26I, and 3.26L respectively.

g. Stage on lead primary CHW pump per Section 3.26F.

h. Once the lead pumps are proven on, enable the lead chiller.

7. When the plant is disabled:

a. Shut off the enabled chiller(s).

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

b. For each enabled chiller, close the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Where chillers have a CHW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

c. For each enabled chiller, open the CHW isolation valve after 3 minutes or the chiller is not requesting CHW flow.

Where chillers have a CW request network point, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

d. For each enabled chiller, close the CW isolation valve after 3 minutes or the chiller is not requesting CW flow.

e. Disable the operating primary CHW pump(s), secondary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 3.26F, 3.26G, 3.26I, and 3.26L respectively.

f. Disable the operating primary CHW pump(s) and secondary CHW pump(s) per Sections 3.26F and 3.26G respectively.

g. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 3.26F, 3.26I, and 3.26L respectively.

h. Disable the operating primary CHW pump(s) per Section 3.26F.

C. Waterside Economizer Control

1. Enable waterside economizer (WSE) if it has been disabled for at least 20 minutes and CHWRT upstream of HX is greater than the predicted heat exchanger leaving water temperature (PHXLWT) plus 2°F. PHXLWT is:

$$PHXLWT = T_{WB} + PA_{HX} + PA_{CT}$$
$$PA_{HX} = DA_{HX} * PLR_{HX}$$
$$PA_{CT} = m * (DT_{WB} - T_{WB}) + DA_{CT}$$

   where
   T_{WB}= current wetbulb temperature
   PA_{HX}= predicted heat exchanger approach
   PA_{CT} = predicted cooling tower approach
   DA_{HX} = design heat exchanger approach
   PLR_{HX}= the lesser of 1 and predicted heat exchanger part load ratio (current chilled water flow rate divided by design HX chilled water flow rate)
   PLR_{HX}= the lesser of 1 and predicted heat exchanger part load ratio (current secondary chilled water flow rate divided by design HX chilled water flow rate)
   DT_{WB}= design wetbulb temperature
   DA_{CT} = design cooling tower approach
   m = output of logic in Section 3.26C.3 below.

This algorithm predicts the achievable HXLWT based on current plant load conditions, as estimated by PLRHX, and ambient wet bulb relative to design conditions. The logic is tuned based on the "m" parameter, which accounts for whether cooling tower approach tends to worsen or improve with decreasing ambient wet bulb. Tower psychrometrics are such that for a given condenser water flow rate and range, approach will worsen as wetbulb temperature decreases, which drives "m" positive. However, for most plant, plant load (and thus either range or flowrate) tends to decrease as ambient wetbulb decreases, so closer approaches are achievable at lower wetbulb temperatures, which drives "m" negative. "m" is therefore tuned on a plant specific basis per subsequent logic.

2. Disable WSE when it has run for at least 20 minutes and CHW temp downstream of HX is greater than CHWRT upstream of HX less 1ºF for 2 minutes (i.e., if the HX is not reducing the CHW temp by at least 1°F).

3. PHXLWT Tuning

   a. Decrease "m" by 0.02 when the economizer is disabled if the economizer remained enabled for greater than 60 minutes.

   b. Increase "m" by 0.02 when the economizer is disabled if the economizer remained enabled for less than 30 minutes and WseTower-MaxSpeed did not decrease below 100% speed while the WSE was enabled. See Section 3.26L.2.c.1)b) for definition and use of WseTower-MaxSpeed.

   c. "m" shall be limited to the range of -0.2 to 0.5.

   d. "m" shall initialize at 0 upon first plant start up and shall not be reinitialized every time the plant is disabled/enabled. Rather, "m" holds its value when the plant is disabled and tuning resumes from that value when the plant is re-enabled.

4. When economizer is enabled, start next CW pump and/or adjust CW pump speed per Section I.6, open CW isolation valve to the HX, and enable the WSE in-line CHW return line valve.

5. When the WSE in-line CHW return line valve is enabled, it shall be modulated by a direct-acting PID loop to maintain the DP across the CHW side of the HX at HXDP-Design. Map the loop output from 0% open at 0% output to 100% open at 100% output. Bias the loop to launch from 100% output. The valve shall be fully open when loop is disabled.

This loop ensures that flow through the heat exchanger does not exceed design, which has the potential to cause chilled water loop DP to rise above design and starve loads of flow. Biasing the loop output to 100% when the loop is enabled ensures that the valve does not immediately modulate closed upon WSE startup.

6. When economizer is disabled, WSE in-line CHW return line valve shall be disabled (opened), HX CW isolation valve fully closed, and the last lag CW pump disabled and/or CW pump speed changed per Section I.6.

7. When economizer is enabled, start next CW pump and/or adjust CW pump speed per Section I.6, open CW isolation valve to the HX and enable the CHW HX Pump.

8. WSE HX Pump Speed Reset Requests shall be generated based on the difference (ΔT) between chilled water return temperature upstream of the WSE and WSE HX entering CHW temperature.

   a. If ΔT exceeds 2°F, send 2 requests until ΔT is less than 1.2°F.

   b. Else if ΔT exceeds 1°F, send 1 request until ΔT is less than 0.2°F.

   c. Else send 0 requests.

9. When the WSE HX pump is proven on, WSE HX pump speed shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	WSE HX pump proven on
SP0	HxPumpDesSpd
SPmin	Minimum Speed
SPmax	HxPumpDesSpd
Td	15 minutes
T	2 minutes
I	0
R	WSE HX Pump Speed Reset Requests
SPtrim	+2%
SPres	-3%
SPres-max	-6%

This trim and respond loop resets pump speed to avoid wasting pump energy by recirculating water through the heat exchanger. Recirculating water also decreases heat transfer by degrading heat exchanger log mean temperature difference (LMTD), reducing economizer capacity.

10. When economizer is disabled, CHW HX Pump shall be disabled, HX CW isolation valve fully closed, and the last lag CW pump disabled and/or CW pump speed changed per Section I.6.

11. When economizer is enabled and all chiller isolation valves are commanded closed, open the economizer-only CHW bypass valve. Close bypass valve when any chiller isolation valve is commanded open and exceeds 25% open (as determined by valve position (if provided), or either nominal valve timing or valve ramp rate, whichever is slower).

In atypical primary-only applications where waterside economizer flow exceeds the design flow of one chiller, it may prove necessary to modify sequences to utilize this bypass for trim capacity control. As an example, suppose a plant has (3) 500 tons chillers and a waterside economizer sized for the whole load; this is typical of some data centers. Suppose the waterside economizer is meeting the whole plant load of 1200 tons at some point. If ambient wet bulb temperature increases such that the waterside economizer can only meet 1150 tons of plant load, then a chiller needs to start. But 1200 tons of flow cannot be sent through one 500 ton chiller, so either (2) chillers need to start and will cycle under low load, or one chiller needs to start with the remaining plant flow sent through the bypass. In such a case, the chiller supplies water at a temperature below plant supply temperature setpoint, which is then blended with the remaining WSE flow not sent through the chiller to achieve plant setpoint. Sequences for this application, which is typical of a data center, are outside the purview of the RP.

D. Chiller Staging

1. Chiller stages shall be defined as follows:

Chiller Stage	Enabled Chillers	Waterside Economizer Status
0	None	Off
0+WSE	None	On
1	CH-1	On or Off
2	CH-2 or CH-3	On or Off
3	CH-1 and (CH-2 or CH-3)	On or Off
4	CH-2 and CH-3	On or Off
5	CH-1, CH-2, and CH-3	On or Off

Interchangeable chillers are generally those considered to be equal in capacity and type (positive displacement, constant speed or variable speed centrifugal), or are otherwise deemed equally suitable to meet the same load by the Designer.

2. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per Section 3.1P.3. If a chiller is in alarm per Section 3.1P.5.b, its CHW and CW isolation valves shall be closed.

3. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per Section 3.1P.3. If a chiller is in alarm per Section 3.1P.5.b, its CHW valve shall be opened and CW isolation valve shall be closed.

4. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per Section 3.1P.3. If a chiller is in alarm per Section 3.1P.5.b, its CHW isolation valve shall be closed.

5. Interchangeable chillers indicated with "or" in the table above shall be lead/lag controlled per Section 3.1P.3. If a chiller is in alarm per Section 3.1P.5.b, its CHW valve shall be opened.

6. Chillers are staged in part based on required capacity, Qrequired, relative to design capacity of a given stage, which is the sum of the design capacity of each chiller active in each stage. This ratio is the operative part load ratio, OPLR.

7. Qrequired is calculated based on chilled water return temperature (CHWRT) entering the chillers, active chilled water supply temperature setpoint (CHWSTSP), and measured flow through the primary circuit flow meter (FLOWP), as shown in the equation below. Qrequired used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = \frac{FLOW_P(CHWRT - CHWST_{SP})}{24}\ [tons]$$

Required capacity, as opposed to actual load, is used to provide more stable staging since chilled water supply temperature setpoint changes less dynamically than actual chilled water supply temperature. Note that using entering return temperature, as opposed to temperature upstream of waterside economizers or chilled water minimum flow bypasses as applicable, is critical for calculations to be executed properly.

8. Qrequired is calculated based on secondary chilled water return temperature (SCHWRT), active chilled water supply temperature setpoint (CHWSTSP), and measured flow through the secondary circuit flow meter (FLOWS), as shown in the equation below.

Qrequired used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = \frac{FLOW_S(SCHWRT - CHWST_{SP})}{24}\ [tons]$$

9. When a stage up or stage down transition is initiated, hold Qrequired fixed at its last value until the longer of the successful completion of the stage change (e.g., lag chiller proven on) and 15 minutes.

As staging occurs, flowrate and return temperature may fluctuate, so Qrequired may be unstable. As detailed subsequently, Qrequired impacts plant part load ratio, which drives condenser water return temperature setpoint and tower control. As such, if Qrequired is unstable, so too would be condenser water return temperature, and thus chiller lift.

10. OPLR shall be calculated as follows:

$$OPLR = \frac{Q_{required}[tons]}{Sum\ of\ QchX\ for\ Chillers\ in\ stage}$$

11. Minimum cycling part load ratio, OPLRMIN, shall be calculated as:

$$OPLR_{MIN,stage} = \frac{Sum\ of\ MinUnloadTonsX\ for\ Chillers\ in\ stage}{Sum\ of\ QchX\ for\ Chillers\ in\ stage}$$

12. Stage up events are initiated in part based on current stage OPLR exceeding a stage up part load ratio, SPLRUP; stage down events are initiated in part based on OPLR for the next lower stage falling below a stage down part load ratio, SPLRDN.

13. Staging events require that a chiller stage be available. A stage shall be deemed unavailable if the stage cannot be achieved because a chiller required to operate in the stage is faulted per Section 3.1P.5.b.1)b) or a chilled water or condenser water pump dedicated to that chiller is faulted per Section 3.1P.5.b.1)a); otherwise, the stage shall be deemed available.

14. SPLRUP and SPLRDN reset based on the types of chillers operating in the current stage and the types of chillers operating in the next higher and lower available stages per the subsequent logic. The rules below are organized in order of precedence from most important to least important; more important rules supersede less important rules.

The above section effectively means the rules for staging constant speed centrifugal chillers supersede the rules for staging positive displacement chillers, and the rules for staging positive displacement chillers supersede the rules for staging variable speed centrifugal chillers. These rules assume the following staging hierarchy applies globally across chiller plants based on current industry best practice:

(1) If the plant has any positive displacement machines, those are staged on first since they are generally sized to handle low load conditions.

(2) Variable speed centrifugal machines are staged on next.

(3) Constant speed centrifugal machines are staged on last.

a. Set SPLRUP as follows:

1) When any chillers in the next higher stage are constant speed centrifugal, SPLRUP shall be 90%.

Fixed speed chillers are only able to unload using throttling devices, e.g., inlet guide vanes. As a result, chiller efficiency worsens significantly at low loads. Efficiency is optimized by staging once the operating chillers are fully loaded. The staging point is therefore selected to be just slightly less than full load to avoid losing CHWST setpoint briefly as would occur if staging were delayed until full load for the current stage were achieved.

Where used, constant speed centrifugal machines are typically the largest (and last stage) chillers in the plant and their efficiency is most sensitive to load. Therefore, the rules for staging these machines takes precedence.

2) When all chillers operating in the current stage are positive displacement, SPLRUP shall be 80%.

Positive displacement chillers utilize a fixed staging PLR because screw and scroll compressors have a fixed compression ratio (most commercial screw chillers typically do not employ variable volume ratio technology, though some are coming to market). Positive displacement chiller efficiency at a given load is therefore not as sensitive to changes in lift as centrifugal chiller efficiency, and the relative efficiencies at different chiller load percentages (e.g., 30% for two chiller operation vs. 60% for one chiller operation) hold reasonably constant as lift changes. As such, resetting staging PLR with lift is not necessary to optimize screw chiller plant performance. This is in contrast to variable speed centrifugal chiller reset logic described below.

Positive displacement machines are typically used as low load chillers in larger plants. It therefore makes sense to load them nearly fully prior to staging on larger variable speed centrifugal machines (where used). As such, positive displacement machine staging criteria take precedence over variable speed centrifugal machine staging criteria.

3) When any chillers in the current operating stage are variable speed centrifugal, SPLRUP shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{UP} = Min(Max(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

a) LIFTmin and LIFTmax shall be calculated as the averages of LIFTminX and LIFTmaxX for all variable speed centrifugal chillers operating in the current stage respectively.

Centrifugal chiller efficiency varies significantly with lift. As lift increases for a given load, centrifugal compressors must run faster to avoid surge. Capacity trimming under such conditions is accomplished using inlet guide vanes or variable geometry diffusers, which reduces chiller efficiency. The above equation resets the centrifugal staging point up when lift is high to minimize throttling of surge control devices and keep chillers operating near to their optimal efficiency. Engineers should consult with the chiller manufacturer to obtain part load efficiency data and adjust the optimal staging bounds for each application. See the ASHRAE Fundamentals of Design and Control of Central Chilled-Water Plants Self-Directed Learning Course for how E and F can be optimally determined. The E and F values above are the

simplified coefficients from this SDL, Appendix A normalized for a plant with any number of chillers.
Upper and lower limits of 0.45 and 0.9 are placed on SPLR to ensure stable plant staging irrespective of the optimal staging point indicated by the lift reset curve. Using a two chiller plant with equally sized machines as the simplest example, bounding SPLR to a minimum of 0.45 ensures that the logic does not stage on the second machine if doing so would cause the chillers to be less than 22.5% loaded (0.45 OPLR divided by 2). Bounding SPLR to a maximum of 0.9 ensures that the logic does not delay staging once the operating chiller is more than 90% loaded (OPLR > 0.9) since doing so could risk losing the load.

b. Set SPLRDN as follows:

In the sections below, the stage down SPLR values appear identical to the stage up values. It is important to remember, per Section 3.26D.12, that these values are applied against the OPLR values of different plant stages, so they yield different tonnage thresholds.
Note also that the stage down conditions below do not yield a hysteresis band. I.e., if the positive displacement chiller rules were applied to a plant with only two screw chillers sized at 200 tons each, the plant stage up and stage down points would both be 160 tons. This is acceptable because the stages have minimum run times to prevent cycling. Furthermore, plant load for most applications generally trends in one direction for multiple hours before beginning to trend the opposite direction. As such, there is little risk of repeated stage cycling.

1) When any chillers in the current stage are constant speed centrifugal, SPLRDN shall be 90%.

2) When all chillers operating in the next lower stage are positive displacement, SPLRDN shall be 80%.

3) When a variable speed centrifugal chiller operates in the next lower stage, SPLRDN shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{DN} = Min(Max(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

a) LIFTmin and LIFTmax shall be calculated as the averages of LIFTminX and LIFTmaxX for all variable speed centrifugal chillers operating in the next lower stage respectively.

15. Staging shall be executed per the conditions below subject to the following requirements.

a. Each stage shall have a minimum runtime of 15 minutes.

b. Timers shall reset to zero at the completion of every stage change.

c. Any unavailable stage (see Section 13) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

1) Exception: If Stage 1 is unavailable, then the stage down conditionals used while the next higher available Stage is operating shall be those normally applied to Stage 1.

This exception is necessary because the Stage down conditionals for Stage 1 are unique relative to the other stages. They evaluate whether the waterside economizer can run alone without any chillers. If Stage 1 is unavailable, the same evaluation must be conducted for the next higher available stage.

d. Chilled water supply and return temperatures used in staging logic shall be those located in common supply and return mains hardwired to plant controllers.

e. Where a primary CHW supply temperature sensor is not provided, primary CHW supply temperature used in staging logic shall be the weighted average supply temperature of all chillers with open CHW isolation valves. Temperatures shall be weighted by design chiller flowrates.

f. Where a primary CHW supply temperature sensor is not provided, primary CHW supply temperature used in staging logic shall be the weighted average supply temperature of all chillers with dedicated CHW pumps proven on. Temperatures shall be weighted by design chiller flowrates.

The above section assumes that flows through the chillers are balanced proportional to design.

g. Stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Current stage OPLR > SPLRUP for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

3) Failsafe Condition:

a) CHW DP is 2 psi < setpoint for 15 minutes; or

b) CHW supply temperature is 2°F > setpoint for 15 minutes.

h. Stage down if both of the following are true:

1) Next available lower stage OPLR < SPLRDN for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and

2) The failsafe stage up condition is not true.

The first stage up condition stages the chillers at the optimum load point, SPLR, to maximize chiller efficiency. The second stage up condition acts as a failsafe bringing on the lag chiller if one or more coils is starved because chilled water differential pressure is below setpoint or chilled water supply temperature is above setpoint for an extended period. The former may occur if chilled water delta-T is degraded from design or one pump is down for maintenance *and the pump(s) are unable to drive additional flow through the operating chiller; the latter may occur if the lead chiller has an active fault condition that is not generating a failure alarm. It is also possible that the OPLR calculation could go out of calibration due to a failed flow meter and/or return temperature sensor, thus necessitating fallback on the failsafe conditions. Note that the DP failsafe condition does not apply to series chiller plants since bringing on an additional chiller would only increase pressure drop in a series chiller plant.*

i. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLRHX set equal to 1 is not 1°F < CHWST setpoint.

j. When only the Waterside Economizer is enabled, stage up if either of the following is true:

   1) CHW supply temperature is 2°F > setpoint for 20 minutes; or

   2) CHW supply temperature is 4°F > setpoint for 10 minutes.

k. In all other stages, stage up if any of the following is true:

   1) Availability Condition: The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

   2) Efficiency Condition: Current stage OPLR > SPLRUP for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

   3) Failsafe Condition:

      a) CHW DP is 2 psi < setpoint for 15 minutes; or

      b) CHW supply temperature is 2°F > setpoint for 15 minutes.

l. When only the Waterside Economizer is enabled in the next lower stage, stage down if all of the following are true:

   1) WseTower-MaxSpeed is less than 100%; and

   2) WSE is enabled; and

   3) PHXLWT is 1°F < CHW supply temp setpoint.

m. In all other stages, stage down if both of the following are true:

   1) Next available lower stage OPLR < SPLRDN for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and

   2) The failsafe stage up condition is not true.

Chiller staging for a Primary-only plant with a WSE mirrors staging for a standard Primary-only plant with the only complications being deciding (1) whether the plant can start with just the waterside economizer and (2) when chillers can be staged off leaving the WSE to meet the *load alone. For (1), the logic conservatively estimates the CHWST that the WSE will be able to achieve assuming the WSE HX is fully loaded at startup. If the WSE is projected to be able to provide water at least 1°F colder than the CHWST setpoint, then the plant starts in WSE mode. For (2), the logic similarly verifies that the WSE is predicted to be able to provide water at least 1°F colder than the CHWST setpoint and cross-validates that prediction by ensuring that WseTower-MaxSpeed, which is reset to false load the chillers to prevent cycling with the WSE on, is less than 100%. In other words, the logic checks that the WSE is currently throttling its capacity at current plant conditions with a chiller on; if it is not, then clearly the WSE cannot meet the CHWST setpoint alone.*

n. Stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Current stage OPLR > SPLRUP for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

3) Failsafe Condition:

a) Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or

b) Primary CHW supply temperature is 2°F > setpoint for 15 minutes.

o. Stage down if both of the following are true:

1) Next available lower stage OPLR < SPLRDN for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and

2) The failsafe stage up condition is not true.

Primary-secondary staging needs to ensure that secondary flow does not exceed primary flow. When secondary flow exceeds primary flow, the secondary CHWST degrades (elevates), in turn causing lower secondary CHWRT. This in turn decreases the load on the chillers while causing the secondary flowrate to only increase further. Staging logic avoids this positive feedback scenario by staging up when the presence of secondary recirculation has been confirmed by secondary CHWST exceeding primary by 2°F. The conditional also requires that primary pumps be at maximum speed to ensure that, for variable primary flow applications, the primary pumps are already providing maximum primary flow before staging.
The high primary CHW supply temperature conditional ensures that the plant will stage up in the event that secondary recirculation is not occurring (e.g., because the primary pumps have sufficient head to deliver in excess of design chiller flow), the operating chiller(s) cannot make supply temperature setpoint, and the efficiency condition is not being triggered due to a failed sensor(s).

p. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLRHX set equal to 1 is not 1°F < CHWST setpoint.

q. When only the Waterside Economizer is operating, stage up if either of the following is true:

1) Secondary CHW supply temperature is 2°F > setpoint for 20 minutes; or

2) Secondary CHW supply temperature is 4°F > setpoint for 10 minutes.

r. In all other stages, stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Current stage OPLR > SPLRUP for 15 minutes and current stage OPLR is not decreasing at a rate greater than 2.5% per minute averaged over 5 minutes; or

3) Failsafe Condition:

a) Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or

b) Primary CHW supply temperature is 2°F > setpoint for 15 minutes.

s. When only the Waterside Economizer is enabled in the next lower stage, stage down if all of the following are true:

1) WseTower-MaxSpeed is less than 100%; and

2) WSE is enabled; and

3) PHXLWT is 1°F < CHW supply temp setpoint.

t. In all other stages, stage down if both of the following are true:

1) Next available lower stage OPLR < SPLRDN for 15 minutes and next lower stage OPLR is not increasing at a rate greater than 2.5% per minute averaged over 5 minutes; and

2) The failsafe stage up condition is not true.

The added complications for staging with a WSE are the same for a primary-secondary plant as they are for a primary only plant, so the necessary additional staging logic is identical.

At various points in all of the staging sequences, there is a requirement to wait for requests for CHW and CW flow to clear, or 3 minutes to elapse, before moving on to the next step in staging. Where chillers have CHW and CW request network points, consider increasing the delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have these points (e.g., older chillers without network interfaces), the default delay is appropriate.

16. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section H.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.
For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

d. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

e. Slowly open CHW isolation valve of the chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

Slowly opening the chilled water isolation valve prevents a sudden disruption in flow through the active chiller.

f. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

4) Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in 3.26H.1.

h. Release the demand limit.

17. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage OPLRMIN, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2) Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.26H.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

3) Enable head pressure control for the chiller being enabled. Wait 30 seconds.

4) Slowly open CHW isolation valve of the smaller chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

5) Start the smaller chiller after its CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

6) Wait 5 minutes for the newly enabled chiller to prove that it is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller being enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller’s CHW isolation valve to avoid a sudden change in flow through other operating chillers.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I.

e. Change the chilled water minimum flow bypass control setpoint to that appropriate for the new stage as indicated in Section 3.26H.1.

18. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.
For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

d. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

e. Slowly open CHW isolation valve of the chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

Slowly opening the chilled water isolation valve prevents a sudden disruption in flow through the active chiller.

f. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller's CHW isolation valve to avoid a sudden change in flow through other operating chillers.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

4) Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H below.

h. Release the demand limit.

19. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage OPLRMIN, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2) Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.26H.3. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

3) Enable the CW pump of smaller chiller being enabled. Wait 30 seconds.

4) Slowly open CHW isolation valve of the smaller chiller being enabled. Determine valve timing in the field as that required to prevent nuisance trips.

5) Start the smaller chiller after its CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

6) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly close the chiller’s CHW isolation valve to avoid a sudden change in flow through other operating chillers.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller’s CW pump.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1.

20. Whenever there is a stage-up command:

    a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

    b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

    c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.
For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

    d. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

    e. Enable and slowly ramp up the CHW pump of the chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

Slowly ramping the CHW pump prevents a sudden disruption in flow through the active chiller(s).

    f. Start the next stage chiller after all operating CHW pumps are at the same speed.

    g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

        1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

        2) When the controller of the smaller chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller’s CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

4) Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1 below.

h. Release the demand limit.

21. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage OPLRMIN, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2) Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.26H.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

3) Enable head pressure control for the chiller being enabled. Wait 30 seconds.

4) Enable and slowly ramp up the CHW pump of the smaller chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

5) Start the smaller chiller after all operating CHW pumps are at the same speed.

6) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1.

22. Whenever there is a stage-up command:

a. Command operating chillers to reduce demand to 75% of their current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

b. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in 5.2.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

c. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

If the bypass valve opens quickly, then the chiller load will suddenly drop and the chiller(s) could trip. Suddenly opening a chilled water isolation valve will also destabilize the chilled water DP control loop.
For stage up transitions during which one chiller is enabled while another is disabled, it is necessary to temporarily set the minimum flow bypass setpoint to that necessary to satisfy both the chiller to be enabled and the chiller to be disabled because the newly enabled chiller is brought online prior to disabling a currently operating chiller to avoid dropping the load.

d. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

e. Enable and slowly ramp up the CHW pump of the chiller to be enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

Slowly ramping the CHW pump prevents a sudden disruption in flow through the active chiller(s).

f. Start the next stage chiller after all operating CHW pumps are at the same speed.

g. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the smaller chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

4) Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H below.

h. Release the demand limit.

23. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Command operating chillers to reduce demand to 75% of their current load or a percentage equal to current stage OPLRMIN, whichever is greater. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

The above section is recommended for applications where a sudden change in load may induce a chiller trip. This was commonly true of older chillers but has often proven unnecessary for modern machines with more robust capacity controls. Leave it if unsure.

2) Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.26H.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

3) Enable the CW pump of smaller chiller being enabled. Wait 30 seconds.

4) Enable and slowly ramp up the CHW pump of the smaller chiller being enabled to match the other operating CHW pump(s). Determine ramp rate in the field as that required to prevent nuisance trips.

5) Start the smaller chiller after all operating CHW pumps are at the same speed.

6) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller and release the demand limit.

Stage down transitions during which one chiller is enabled while another is disabled require similar logic to stage up events since the chiller to be enabled is brought online prior to disabling a currently operating chiller. This avoids dropping the load during staging transitions.

b. If staging down from any other stage, shut off the last stage chiller.

c. When the controller of the chiller being disabled indicates no request for chilled water flow or 3 minutes has elapsed, slowly ramp down the chiller's CHW pump to avoid a sudden change in flow through other operating chillers. Turn off the CHW pump once it reaches 25% speed.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

e. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1.

24. Whenever there is a stage-up command:

a. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

b. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

c. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

25. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Enable head pressure control of the chiller being enabled. Wait 30 seconds.

2) Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

3) Start the smaller stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

4) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I.

26. Whenever there is a stage-up command:

a. Start the CW pump of the chiller being enabled. Wait 30 seconds.

b. Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

c. Start the next stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the smaller chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

27. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Enable the CW pump of the smaller chiller being enabled. Wait 30 seconds.

2) Start the next primary CHW pump and after 10 seconds open the CHW isolation valve of the chiller being enabled.

3) Start the smaller stage chiller after the CHW isolation valve is fully open (as determined by end switch status, or nominal valve timing if end switches are not provided).

4) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, close the chiller's CHW isolation valve. Wait 15 seconds then shut off the last stage primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

28. Whenever there is a stage-up command:

a. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

b. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

c. Start the next stage chiller.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller's primary CHW pump.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop.

29. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Enable head pressure control of the chiller being enabled. Wait 30 seconds.

2) Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

3) Start the smaller chiller.

4) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller’s primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I.

30. Whenever there is a stage-up command:

a. Start the CW pump of the chiller being enabled. Wait 30 seconds.

b. Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

c. Start the next stage chiller.

d. For any stage change during which a smaller chiller is disabled and a larger chiller is enabled:

1) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the smaller chiller.

2) When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller’s primary CHW pump.

3) When the controller of the smaller chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller’s CW pump.

31. Whenever there is a stage-down command:

a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

1) Enable the CW pump of the smaller chiller being enabled. Wait 30 seconds.

2) Start the primary CHW pump of the chiller being enabled. Wait 30 seconds.

3) Start the smaller chiller.

4) Wait 5 minutes for the newly enabled chiller to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)b)), then shut off the larger chiller.

b. For any other stage change, shut off the last stage chiller.

c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, shut off the chiller’s primary CHW pump.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller’s CW pump.

32. Whenever there is a stage-up command:

    a. If the chiller to be started is the upstream chiller, command the operating chiller to reduce demand to 75% of its current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

    b. If the chiller to be started is the downstream chiller, ramp the CHWST setpoint of the operating chiller from the current plant CHWST setpoint to the average of the current plant CHWST setpoint and the current CHW return temperature over 5 minutes.

    c. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I and after 10 seconds enable head pressure control for the chiller being enabled. Wait 30 seconds.

    d. Slowly close CHW bypass valve of the chiller that is to be started. Determine valve timing in the field as that required to prevent nuisance trips.

    e. Start the next stage chiller after the CHW bypass valve is fully shut (as determined by end switch status, or nominal valve timing if end switches are not provided).

        1) If the newly enabled chiller is the upstream chiller, set its CHWST setpoint to the average of the current plant CHWST setpoint and current CHW return temperature.

        2) If the newly enabled chiller is the downstream chiller, set its CHWST setpoint equal to the plant CHWST setpoint.

    f. Release the demand limit on the lead chiller (if enabled).

33. Whenever there is a stage-down command:

    a. Shut off the last stage chiller.

    b. If the disabled chiller is the downstream chiller, reset the upstream chiller's CHWST setpoint to the current plant CHWST setpoint (do not ramp).

    c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly open the chiller's CHW bypass valve to avoid a sudden change in flow through the other operating chiller.

    d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, disable the chiller's head pressure control loop. When the CW isolation/head pressure control valve is fully closed (as determined by end switch status, or nominal valve timing if end switches are not provided), shut off the last lag CW pump and/or change CW pump speed to that required of the new stage per Section 3.26I.

34. Whenever there is a stage-up command:

a. If the chiller to be started is the upstream chiller, command the operating chiller to reduce demand to 75% of its current load. Wait until actual demand <80% of current load up to a maximum of 5 minutes before proceeding.

b. If the chiller to be started is the downstream chiller, ramp the CHWST setpoint of the operating chiller from the current plant CHWST setpoint to the average of the current plant CHWST setpoint and the current CHW return temperature over 5 minutes.

c. Start the CW pump of the chiller to be enabled. Wait 30 seconds.

d. Slowly close CHW bypass valve of the chiller that is to be started. Determine valve timing in the field as that required to prevent nuisance trips.

e. Start the next stage chiller after the CHW bypass valve is fully shut (as determined by end switch status, or nominal valve timing if end switches are not provided).

    1) If the newly enabled chiller is the upstream chiller, set its CHWST setpoint to the average of the current plant CHWST setpoint and current CHW return temperature per Section 3.26E.7.

    2) If the newly enabled chiller is the downstream chiller, set its CHWST setpoint equal to the plant CHWST setpoint.

f. Release the demand limit on the lead chiller (if enabled).

35. Whenever there is a stage-down command:

a. Shut of the last stage chiller.

b. If the disabled chiller is the downstream chiller, reset the upstream chiller's CHWST setpoint to the current plant CHWST setpoint (do not ramp).

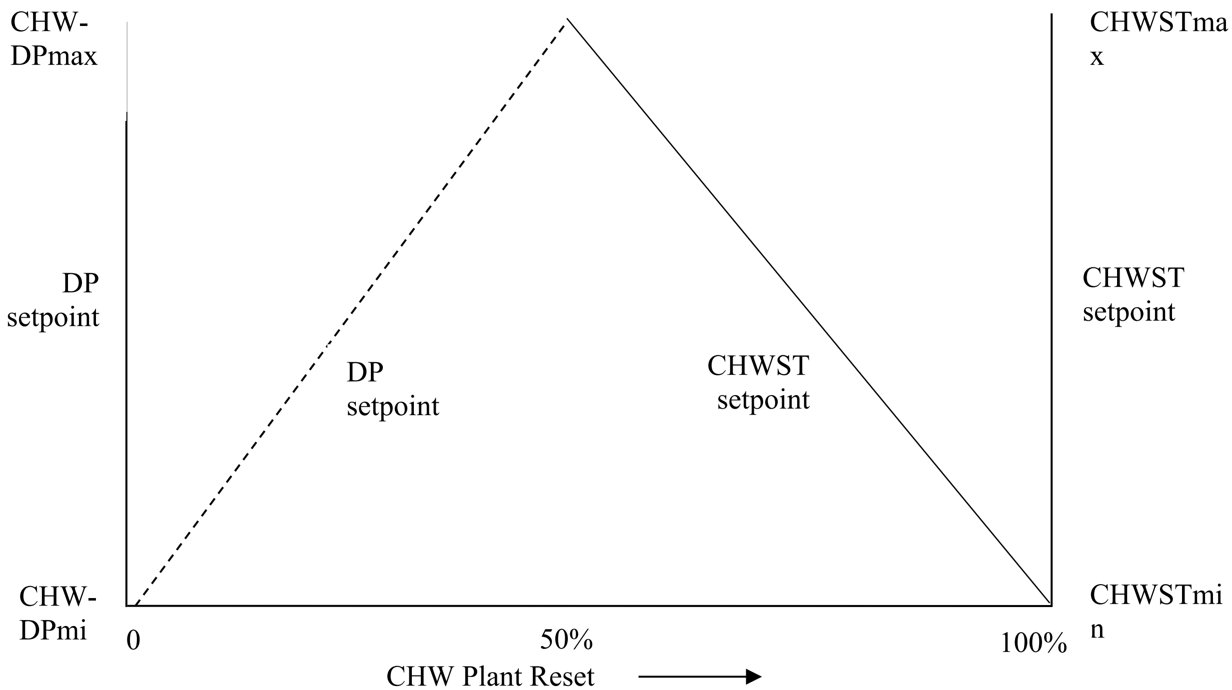
c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly open the chiller's CHW bypass valve to avoid a sudden change in flow through the other operating chiller.

d. When the controller of the chiller being shut off indicates no request for condenser water flow or 3 minutes has elapsed, shut off the chiller's CW pump.

E. Chilled Water Plant Reset

1. CHWSTmin in the following logic shall be the lowest CHWSTminX of chillers in the plant.

2. Differential Pressure Controlled Loops: Chilled water supply temperature setpoint CHWSTsp and pump differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called "CHW Plant Reset" as shown below and described subsequently.



The recommended logic first resets differential pressure setpoint to maximum before resetting chilled water supply temperature setpoint down towards design. Parametric plant analysis performed in a variety of climate zones during the development of ASHRAE's "Fundamentals of Design and Control of Central Chilled-Water Plants" Self-Directed Learning Course showed that the pump energy penalty incurred with this approach is more than offset by chiller energy savings resulting from keeping the chilled water supply temperature setpoint as high as possible.

Engineers may nonetheless adjust the CHW Plant Reset loop mapping based on unique project constraints. For plants with very low design CHW delta-Ts (<12°F) and high pump heads (>120 ft) it may be advisable to overlap the resets—e.g., reset DP setpoint from 0% to 75% loop output and CHWST setpoint from 25% to 100% loop output—instead of fully resetting CHWST setpoint up before beginning to lower resetting pump DP setpoint down.

a. From 0% loop output to 50% loop output, reset DP setpoint from CHW-DPmin to CHWP-DPmax.

b. From 50% loop output to 100% loop output, reset CHWST setpoint from CHWSTmax to CHWSTmin.

c. CHW Plant Reset variable shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any CHW Pump Distribution Loop
SP0	100%
SPmin	0%
SPmax	100%

Td	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SPtrim	-2%
SPres	+3%
SPres-max	+7%

The reset starts at CHWSTmin because starting at a high temperature often causes the chiller to bring down CHWST too quickly and pass the CHWST setpoint, leading the chiller to cycle off. Additionally, if the loop reset starts at a CHWST that cannot satisfy the load at startup (e.g., CHWST setpoint = 60°F, but an AHU requires 55°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before CHWST setpoint resets down.

d. CHWST Plant Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

e. When a plant stage change is initiated, CHW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

Locking out continued reset during a staging event prevents CHW loop instability resulting from staging from driving the plant reset.

f. A unique instance of the above reset shall be used for each set of differential pressure controlled secondary pumps.

1) Chilled Water Reset Requests from all loads served by a set of pumps shall be directed to those pumps' reset loop only.

2) The DP setpoint output from each reset shall be used in the DP control loop for the associated set of pumps only (i.e., the DP setpoint will not change for any other DP control loops).

g. Where more than one remote DP sensor serves a given set of primary or secondary pumps, remote DP setpoints for all remote sensors serving those pumps shall increase in unison. Note: if remote sensors have different CHW-DPmax values, then the amount each DP setpoint changes per percent loop output will differ.

3. CHWST setpoint shall be reset as a function of the air handler SAT control loop output. Refer to air handler sequences.

When a chilled water plant serves a single very large load, such as a massive custom air handler, SAT is often controlled by directly resetting CHWST setpoint. No DP reset is needed since there are no control valves in the system.

4. Coil Pumped Loops: Chilled water supply temperature setpoint, CHWSTsp, shall be reset using Trim & Respond logic with the following parameters:

Variable	Value

Device	Any CHW Pump
SP0	CHWSTmin
SPmin	CHWSTmin
SPmax	60°F
Td	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SPtrim	+0.75°F
SPres	-1°F
SPres-max	-2.5°F

The reset starts at CHWSTmin because starting at a high temperature often causes the chiller to bring down CHWST too quickly and pass the CHWST setpoint, leading the chiller to cycle off. Additionally, if the loop reset starts at a CHWST that cannot satisfy the load at startup (e.g., CHWST setpoint = 60°F, but an AHU requires 55°F supply air), there is a resultant delay in satisfying the load as the reset loop winds up before CHWST setpoint resets down.

5. A unique instance of the above reset shall be used for each set of coil pumps.

6. The CHWST setpoint used at the plant shall be the lowest value output from each of the active reset loops.

7. When only one chiller is enabled, CHWST setpoint shall be the setpoint resulting from the plant reset loop(s).

8. When the upstream and downstream machines are enabled:

   a. Downstream chiller CHWST setpoint shall be the setpoint resulting from the plant reset loop(s).

   b. Upstream chiller CHWST setpoint shall be the 5-minute rolling average of the following calculation:

$$\mathrm{CWHST}_{\mathrm{upstream}} = CHWRT - (CHWRT - CHWSTsp_{downstream}) * \frac{QchX_{upstream}}{QchX_{upstream} + QchX_{downstream}}$$

Using a rolling average avoids sudden fluctuations in chiller setpoint that may induce plant instability. Weighting the setpoint by the design capacity ratio of the series chillers improves efficiency when the upstream chiller is selected to provide more of the load. The efficiency of even identical chillers in series can be optimized by shifting load to the upstream chiller which is more efficient due to the warmer CHWST. This is usually determined by iteratively varying this setpoint to minimize combined chiller power using chiller selection software.

F. Primary Chilled Water Pumps

1. Primary CHW pumps shall be lead/lag controlled per Section 3.1P.3.

2. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded open. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded closed.

3. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded open or WSE is enabled. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded closed and WSE is disabled.

4. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded closed. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded open.

5. Enable lead primary CHW pump when any chiller CHW isolation valve is commanded closed or WSE is enabled. Disable the lead primary CHW pump when all chiller CHW isolation valves are commanded open and WSE is disabled.

Where chillers have a CHW request network point, consider increasing the pump disable delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

6. Enable lead primary CHW pump when the lead chiller is required to run, but prior to the chiller being enabled. Disable the lead CHW pump when the lead chiller is disabled and either the lead chiller has been proven off for 3 minutes or is not requesting chilled water flow.

7. CHW pumps shall be staged as a function of CHWFR, the ratio of current chilled water flow, FLOWP, to design primary pump flow, PCHWFdesign. and the number of pumps, N-PCHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{CHWFR} = \frac{FLOW_P}{PCHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operating near their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their curves). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

   a. Start the next lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} > \frac{Number\ of\ Operating\ Pumps}{N} - .03$$

   b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} \leq \frac{Number\ of\ Operating\ Pumps - 1}{N} - .03$$

8. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal.

9. Where multiple DP sensors exist, a PID loop shall run for each sensor. CHW pumps shall be controlled to the high signal output of all DP sensor loops.

10. Remote DP shall be maintained at a setpoint of CHW-DPsp determined by the reset scheme described herein. CHW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local primary loop DP sensor hardwired to the plant controller. Reset local DP from CHW-DPmin psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

11. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local primary DP signal at the DP setpoint output from the remote sensor control loop. All pumps receive the same speed signal.

12. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of the remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the remote DP sensor all the way back to the CHW plant.

The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

13. The number of operating primary chilled water pumps shall match the number of operating chillers.

14. See Section 3.26D for primary chilled water pump staging sequence relative to chiller stage-up and stage-down events.

15. Pump speed shall be Ch-MaxPriPumpSpdStage as determined by the balancer as that necessary to provide design flow, CHW-DesFlowX through all chillers operating in the stage.

The above scenario—variable speed pumps operated at a constant speed—most commonly applies to constant flow primary-only plants. For example, a plant serving only one or two very large air handlers may use this scheme.

16. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler, as measured by the primary flowrate less secondary flowrate, at 5% of PCHWFdesign. Loop output shall be mapped from CH-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

Maintaining slightly more than 0 gpm through the bypass avoids the risk of secondary recirculation caused by any control loop instability.

17. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler flow meter at 5% of PCHWFdesign, where positive flow indicates flow from the supply to the return. Loop output shall be mapped from CH-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

Maintaining slightly more than 0 gpm through the bypass avoids the risk of secondary recirculation caused by any control loop instability.

18. Primary Pump Speed Reset Requests shall be generated based on the difference (ΔT) between secondary CHW supply temperature and primary CHW supply temperature upstream of the decoupler.

    a. If ΔT exceeds 2°F, send 2 requests until ΔT is less than 1.2°F.

    b. Else if ΔT exceeds 1°F, send 1 request until ΔT is less than 0.2°F.

    c. Else send 0 requests.

Using supply temperature sensors to generate requests is preferable to using return temperature sensors because it allows for a quick response to a sudden change in secondary flow (i.e., secondary supply temperature exceeding primary supply temperature by a large margin). If return temperature sensors are used, it is only possible to know that secondary recirculation is occurring when primary and secondary return temperatures match, but the degree of recirculation is unknown.
Where dynamic changes in secondary flow are expected, e.g., for plants with only a few large coils or pumped coils, then more request levels can be defined as needed, but control using one of the preceding flow matching strategies is preferred.

    d. Primary CHW supply temperature used in the request logic shall be the weighted average supply temperature of all chillers proven on. Temperatures shall be weighted by design chiller flowrates.

The above section assumes that flows through the chillers are balanced proportional to design.

19. Pump speed of all primary CHW pumps proven on shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any primary pump proven on
SP0	100%
SPmin	CH-MinPriPumpSpdStage
SPmax	100%
Td	15 minutes
T	2 minutes
I	0
R	Primary Pump Speed Reset Requests
SPtrim	-2%
SPres	+3%
SPres-max	+6%

G. Secondary Chilled Water Pumps

1. Secondary CHW pumps shall be lead/lag controlled per Section 3.1P.3.

2. Enable lead secondary CHW pump when plant is enabled and any load served by the pump(s) is generating a Chiller Plant Request. Disable the lead pump otherwise.

3. Pumps serving multiple coils

a. Secondary CHW pumps shall be staged as a function of SCHWFR, the ratio of current chilled water flow, FLOWS, to design flow, and the number of pumps, N-SCHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{SCHWFR} = \frac{FLOW_S}{SCHWF_{design}}$$

Flow is used, as opposed to speed, to keep the chilled water pumps operating near to their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

1) Start the next lag pump whenever the following is true for 10 minutes:

$$\text{SCHWFR} > \frac{Number\ of\ Operating\ Pumps}{N} - .03$$

2) Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{SCHWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{N} - .03$$

b. When any secondary CHW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal.

c. Where multiple DP sensors exist, a PID loop shall run for each sensor. Secondary CHW pumps shall be controlled to the high signal output of all DP sensor loops.

d. Remote secondary loop DP shall be maintained at a setpoint of CHW-DPsp determined by the reset scheme described herein. CHW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

e. When any secondary CHW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal.

f. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the DP sensor all the way back to the CHW plant.
The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all

the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

4. Coil Pumps

a. Enable the coil pump(s) when plant is enabled and the coil pump speed command exceeds 30% for 5 minutes continuously. Disable the pump(s) when either the plant is disabled or the pump speed command drops to minimum speed for 5 minutes continuously.

b. Enable the lead coil pump when plant is enabled and the coil pump speed command exceeds 30% for 5 minutes continuously. Disable the lead pump when either the plant is disabled or the pump speed command drops to minimum speed for 5 minutes continuously.

c. Coil pumps shall be staged based on minimum speed, PumpSpeedMin, and the number of pumps that operate at design coil flow, N.

1) Enable the next lag pump if less than N pumps are operating and pump speed exceeds the following for 1 minute:

$$PumpSpeedMin * \frac{(Number\ of\ operating\ pumps + 1)}{Number\ of\ operating\ pumps} + 10\%$$

2) Disable the last lag pump if pump speed falls below PumpSpeedMin for 1 minute.

Coil pumps with good turndown are not staged since coil pumps operate on a nearly fixed system curve (ignoring variations in differential pressure across the primary loop points of connection). As such, coil pump speed generally tracks linearly with flow and pump efficiency varies minimally along the fixed system curve. This means efficiency is optimized by running the design quantity of pumps at all times if the pumps are selected near their best efficiency point at design. This approach also avoids running pumps to the right of their choke line.
In rare applications, typically limited to those involving smaller coils served by ECM driven pumps, speed turndown may be insufficient with multiple pumps running for stable supply air temperature control. In such cases, pumps should instead be staged. The above logic stages additional pumps on as soon as possible to maximize efficiency and minimize operation to the right of the choke line.

d. Refer to air handler system control sequence for pump speed control logic.

Coil pumps are generally controlled to maintain supply air temperature setpoint as part of a control loop running on an air handler controller, e.g., increase pump speed via a direct acting control loop to maintain supply air temperature at setpoint. Coil pump speed control sequences therefore cannot be generalized as part of the plant logic.

When the request logic below is inserted in Guideline 36, it will live in the Air Handler sequences.

e. Chilled Water Reset Requests

1) If any coil pump is proven on, pump speed exceeds 99% for 2 minutes, and the supply air temperature exceeds the supply air temperature setpoint by 5°F for 2 minutes, send 3 Requests,

2) Else if any coil pump is proven on, pump speed exceeds 99% for 2 minutes, and the supply air temperature exceeds the supply air temperature setpoint by 3°F for 2 minutes, send 2 Requests,

3) Else if any coil pump is proven on and pump speed exceeds 95%, send 1 Request until pump speed is less than 85% or no coil pumps serving the coil are proven on.

4) Else if the coil pump speed is less than 95%, send 0 Requests.

f. Chiller Plant Requests. Send the chiller plant that serves the coil pump a Chiller Plant Request as follows:

1) If the pump speed command is greater than 95%, send 1 Request until the speed command is minimum for 5 minutes.

2) Else if the pump speed command is less than 95%, send 0 Requests.

H. Chilled Water Minimum Flow Bypass Valve

1. Bypass valve shall modulate to maintain minimum flow as measured by the chilled water flow meter at a setpoint that provides minimum flow through all operating chillers, determined as follows:

a. For the chillers operating in the stage, identify the chiller with the highest ratio, MinFlowRatio, of CHW-MinFlowX to CHW-DesFlowX.

b. Calculate the minimum flow setpoint as MinFlowRatio multiplied by the sum of CHW-DesFlowX for the operating chillers.

If the chillers have different minimum flow to design flow ratios, just maintaining the sum of the minimum flows will not satisfy the chiller(s) with the highest relative minimum flows. Note that this also requires that chillers be balanced to distribute flow proportional to their design flow.

2. Bypass valve shall modulate to maintain minimum flow as measured by the chilled water flow meter at a setpoint equal to the largest CHW-MinFlowX of the operating series chillers.

3. During stage changes that require one chiller to be enabled while another is disabled, the minimum flow setpoint shall temporarily change to account for the CHW-MinFlowX of both the chiller to be enabled and to be disabled prior to starting the newly enabled chiller. See staging events in Section 3.26D for timing of setpoint change to this transitionary value.

4. When any CHW pump is proven on, the bypass valve PID loop shall be enabled. The valve shall be opened 100% otherwise. When enabled, the bypass valve loop shall be biased to start with the valve 100% open.

Biasing the loop to 100% upon start up ensures that the valve does not slam shut upon enabling the loop. Starting with the valve fully open is appropriate because flows are often very low when the plant is first turned on.

I. Condenser Water Pumps

1. Condenser water pumps shall be lead/lag controlled per Section 3.1P.3.

2. Enable lead CW pump when any chiller or WSE CW isolation valve is commanded open. Disable the lead CW pump when all chiller and WSE CW isolation valves are commanded closed.

3. Enable lead CW pump when any chiller CW isolation valve is commanded open. Disable the lead CW pump when all chiller CW isolation valves are commanded closed.

Where chillers have a CW request network point, consider increasing the pump disable delay to 10 minutes to ensure that flow is not cut off too soon. Where chillers do not have this point (e.g., older chillers without network interfaces), the default delay is appropriate.

4. Enable lead CW pump when the lead chiller is required to run, but prior to the chiller being enabled. Disable the lead CW pump when the lead chiller is disabled and either the lead chiller has been proven off for 3 minutes or is not requesting CW flow.

5. The number of operating condenser water pumps shall match the number of operating chillers.

6. The number of operating condenser water pumps and design condenser water pump speed for the stage, Cw-DesPumpSpdStage, shall be set per the table below.

Chiller Stage	CWPs On	Cw-DesPumpSpdStage
0	0	N/A, Off
0+WSE	1	Per TAB to provide design flow through HX
1	1	Per TAB to provide design flow through chiller
1+WSE	2	Per TAB to provide at least design flow through both chiller and WSE
2	2	Per TAB to provide at least design flow through both chillers
2+WSE	2	Per TAB to provide at least design flow through both chillers and WSE, or 100% speed if design flow cannot be achieved.

The above table would be expanded with additional stages if the plant includes more chiller stages. Note that for plants with more chillers, it is unlikely that the WSE will be enabled with >2 chillers enabled, so defining unique pump quantity and speed combinations to account for WSE operation is typically unnecessary. I.e., for a 3 chiller plant, the same CWP quantity and speed would be applicable to Chiller Stage 3 and Chiller Stage 3 + WSE.
Note that unless chillers and the WSE HX are dynamically balanced with head pressure control valves based on chiller stage (complexity not recommended), design balance will only be achieved in one stage (typically all chillers operating and WSE HX disabled). The staging table therefore calls for determining speeds in all stages such that at least design flow is achieved through all operating equipment, which means all but one piece of equipment will exceed design flow.

7. Condenser water pump speed setpoint for a given stage shall be Cw-DesPumpSpdStage unless reset per Head Pressure Control logic in Section 3.26J.

8. See Section 3.26D for lag condenser water pump on/off staging timing.

Most water-cooled chillers require a minimum refrigerant head (lift) between the evaporator and condenser to ensure trouble-free chiller starts and to maintain oil circulation. However, centrifugal chillers serving air handlers with air-side economizers (and without waterside economizers) often are not provided with head pressure control, and some oil-free chillers with magnetic or ceramic bearings, can operate with zero or even negative lift (as measured by water temperatures).

J. Head Pressure Control

1. Head pressure control signal shall be that output from the chiller controller whenever available. Otherwise, if a head pressure control signal is not available from the chiller controller, a reverse acting PID loop shall maintain the temperature differential between the chiller's condenser water return temperature and chilled water supply temperature at LIFTminX.

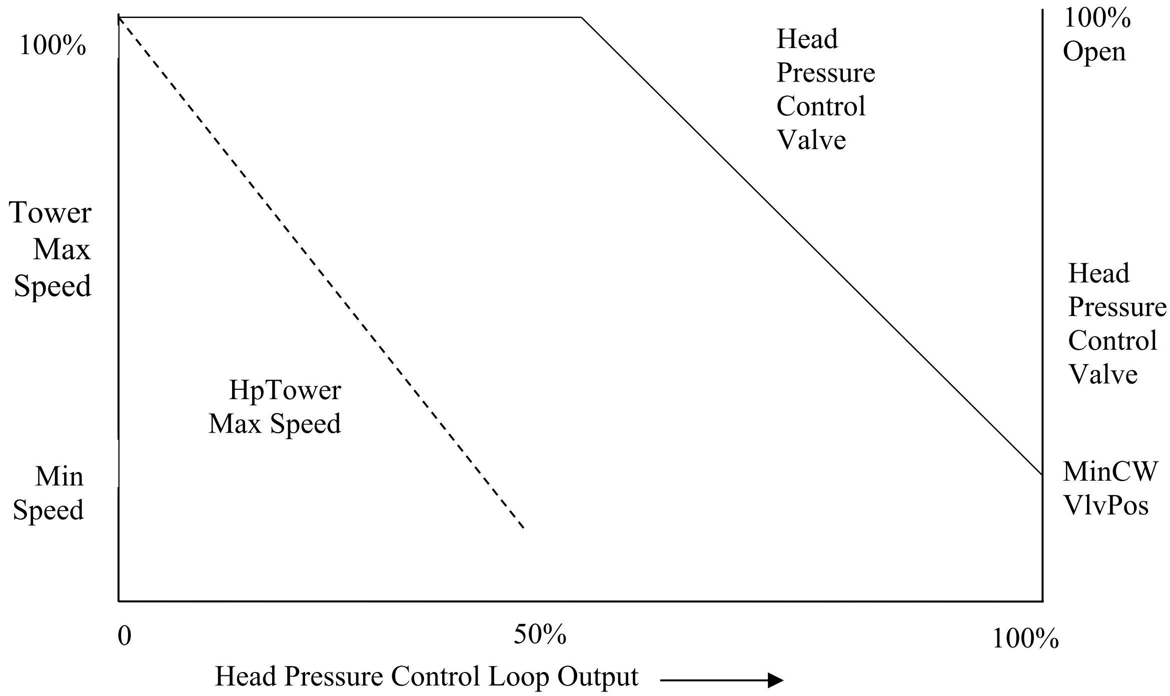
Subsequent sequences assume that the head pressure control signal, where output from the chiller controller is not wired directly to the head pressure control valve, but rather hardwired to an AI on the plant BAS controller. This allows monitoring of the head pressure control signal for stability, as well as remapping the signal as specified herein to avoid fighting between the head pressure control and tower speed control loops.
Note that the above BAS loop maintaining LIFTminX, if required, relies on the chiller's sensors, not common loop sensors. If hardwired sensors are available, they should be used; otherwise use network points through the chiller interface.

2. Each operating chiller shall have its own head pressure control loop. Head pressure control loop is enabled and disabled per chiller staging logic in Section 3.26D.

3. For each chiller, map loop output as follows:

   a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

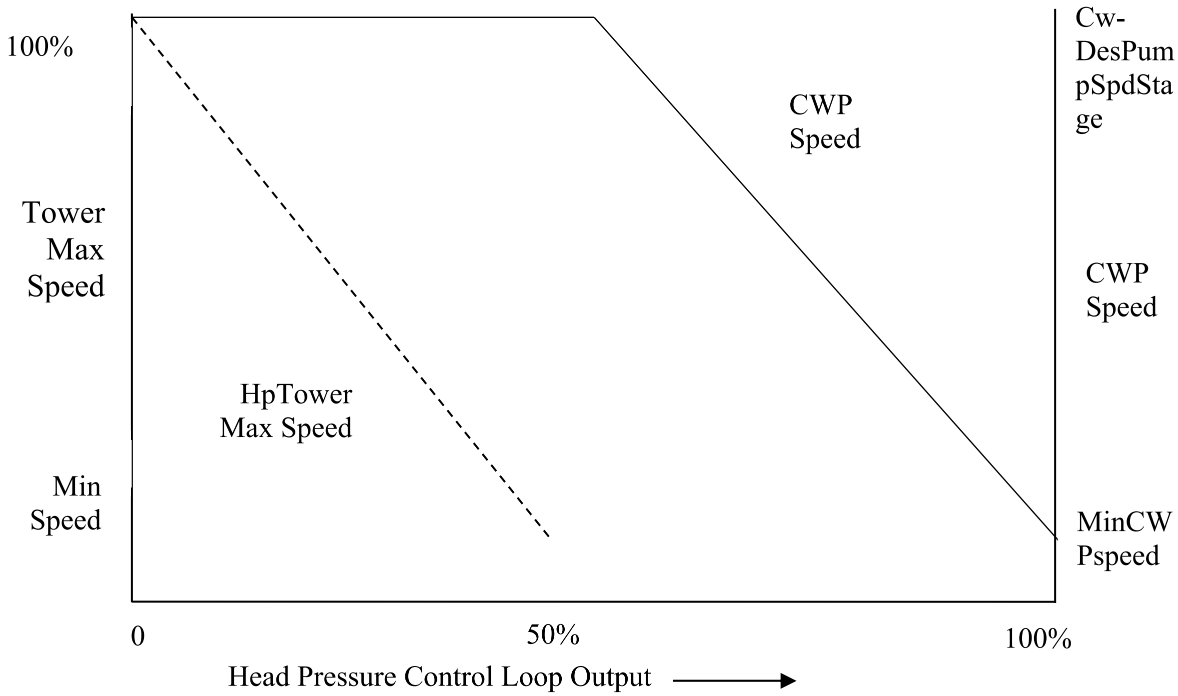
   b. From 50-100%, the loop output shall reset head pressure control valve position from 100% open to MinCWVlvPos.



4. For each chiller, map loop output as follows:

   a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

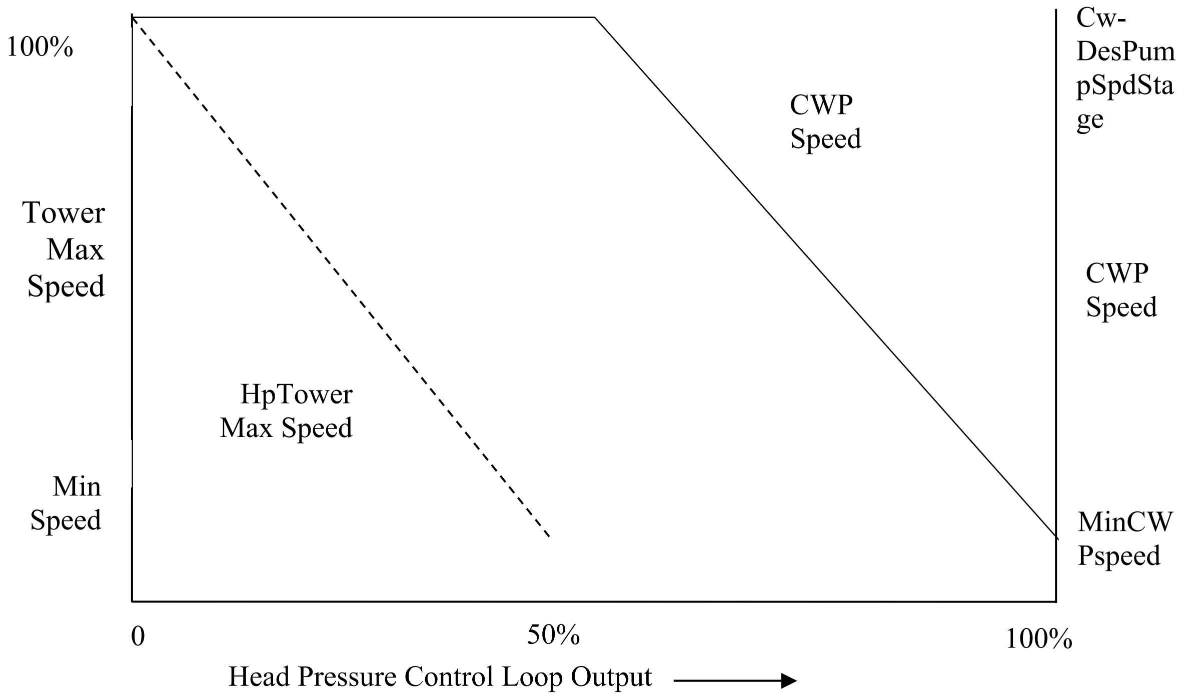
   b. From 50-100%, the loop output shall reset condenser water pump speed from Cw-DesPumpSpdStage to MinCWPspeed. Where condenser water pumps are dedicated, speed reset shall be independent for each chiller.



5. For each chiller, when the WSE is disabled, map loop output as follows:

    a. From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.

    b. From 50-100%, the loop output shall reset condenser water pump speed from Cw-DesPumpSpdStage to MinCWPspeed.



c. Note: Each enabled chiller's head pressure control valve shall be 100% open irrespective of loop output.

6. When the WSE is enabled, map loop outputs as follows:

   a. Maximum cooling tower speed point, HpTowerMaxSpeed, shall be 100% irrespective of loop output.

   b. Condenser water pump speed shall be equal to the design speed for the stage irrespective of loop output.

   c. Each enabled chiller's head pressure control loop output shall reset head pressure control valve position from 100% open at 0% loop output to MinCWVlvPos at 100% loop output.

7. When the head pressure control loop is disabled per Section 3.26D.17, the CW isolation/head pressure control valve shall be closed.

K. Water Treatment Override

1. Every night at 1:00 am, if all condenser water pumps are off and the condenser water pumps have not accumulated at least 20 minutes of runtime in the last 36 hours then:

   a. Open all chiller condenser isolation valves.

   b. Open all tower isolation valves.

   c. Start lead condenser water pump.

d. After 20 minutes, or if the plant is enabled, release back to normal control.

L. Cooling Towers

For a two chiller/two tower plant, ASHRAE Standard 90.1 requires that the tower minimum flow on each tower be above 50% so tower isolation valves are neither needed nor desired. The sequences below are configured to allow for plants with 3 or more CW pumps and towers where staging is needed to maintain minimum flow. The tower isolation valves can be on the tower inlet only provided the equalizer (or flume gate) is large enough to allow water to flow from the enabled cell to the disabled cell(s) with the small head between the high-water-level point of the enabled cell to the low-water-level point of the disabled cells. If not, valves are required on both inlet and outlet.

1. Tower Staging

a. Tower cells shall be lead/lag controlled per Section 3.1P.3.

b. Quantity of enabled cooling tower cells shall map to Plant Stage.

Plant Stage	Enabled Tower Cells
0	0
0 + WSE	2
1	2
1 + WSE	4
2	4
2 + WSE	4

Quantity of enabled cells per pump stage should be the maximum that provides at least minimum tower flow through each cell as required by the tower manufacturer. Maximizing the quantity of operating towers minimizes fan power because fans have variable speed drives. For instance, one tower at full speed uses approximately four times as much power as two towers at half speed.

c. Lead cell(s) shall be enabled when the lead CW pump is enabled. Lead cell(s) shall be disabled when all CW pumps are proven off.

d. Tower stage changes shall be initiated concurrently with condenser water pump stage and/or condenser water pump speed changes per plant staging logic in Section 3.26D.

e. When enabling a tower cell, open its supply isolation valve, and outlet isolation valve if provided. Once proven open as determined by end switch status, or nominal valve timing if end switches are not provided, enable tower fan.

f. When disabling a tower cell, command the fan off and shut its supply isolation valve, and outlet isolation valves if provided.

2. Fan Control

a. Condenser Water Return Temperature (CWRT) Control

1) Tower fan control is in part dictated by plant part load ratio, PLRplant, which is the ratio of current plant required capacity, Qrequired, to plant design capacity:

$$PLR_{plant} = \frac{Q_{required}}{Q_{design}}$$

2) CWRTdes in the subsequent logic shall be the lowest CWRTdesX of all chillers.

3) When any chillers are enabled and the waterside economizer is disabled, the following logic shall apply.

This sequence controls condenser water return temperature, as opposed to supply, since CWRT more closely correlates to chiller lift, which drives chiller efficiency and surge conditions.

4) Maximum tower speed shall be limited based on OPLR. Reset the variable PlrTowerMaxSpd linearly from 100% at 50% OPLR down to 70% at 0% OPLR.

Maximum tower speed is limited at low plant part load ratios to prevent tower energy waste when either (1) CHWST is reset low at low PLRs or (2) wet bulb is elevated at low PLRs. Both conditions can cause the CWRT setpoint output from the following equation to be unachievable.

5) CWRT setpoint, CWRTsp, shall be the output of the following equation.

$$CWRTsp = CHWSTsp + LIFTtarget$$

$$LIFTtarget = Max\left(LIFTmin, Min(LIFTmax, A * PLR_{Plant} + B)\right)$$

$$A = 1.1 * (LIFTmax - LIFTmin)$$

$$B = LIFTmax - A$$

a) Where chillers have different LIFTminX values, LIFTmin in the above equation shall reset dynamically to equal the highest LIFTminX of enabled chillers.

b) Where chillers have different LIFTmaxX values, LIFTmax in the above equations shall reset dynamically to equal the lowest LIFTmaxX of enabled chillers.

c) LIFTmax shall be calculated based on the downstream chiller(s) on the chilled water side. Where downstream chillers have different LIFTmaxX values, LIFTmax shall be calculated for each downstream machine and the lowest value used in the above logic.

The above equation resets desired chiller lift (as approximated by CWRT and CHWST setpoint) as a function of load. This heuristic relationship is based on modeling indicating that, for plants with constant condenser water flow, optimal combined chiller and tower efficiency is most closely approximated with such a reset. See the ASHRAE Fundamentals of Design and Control of Central Chilled-Water Plants Self-Directed Learning Course for more information. The values of A and B are the simplified values from the SDL, Appendix A.
This implementation puts an upper bound on lift to prevent the setpoint from resetting too high (and causing surge for centrifugal machines).

6) When any condenser water pump is proven on, CWRT shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the

variable CWRTTowerSpd. Map CWRTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

7) Tower speed command signal shall be the lowest value of CWRTTowerSpd, HpTowerMaxSpd from each chiller head pressure control loop, and PlrTowerMaxSpd. All operating fans shall receive the same speed signal.

8) When any condenser water pump is proven on, CWRT shall be controlled to CWRTsp by setting CWST setpoint, CWSTsp, equal to CWRTsp minus CWdt, where CWdt is the 5 minute rolling average of common condenser water return temperature less condenser water supply temperature, sampled at minimum once every 30 seconds. When the plant is first enabled CWdt shall be held fixed equal to 50% of CWRTdesX less CWSTdesX of the enabled chiller for 5 minutes to populate the rolling average queue before populating with actual data.

9) When any condenser water pump is proven on, CWST shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWSTTowerSpd. Reset CWSTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

10) Tower speed command signal shall be the lowest value of CWSTTowerSpd, HpTowerMaxSpd from each chiller head pressure control loop, and PlrTowerMaxSpd. All operating fans shall receive the same speed signal.

The above cascading loop logic improves control stability when there is significant thermal mass in the loop. Thermal mass slows the response of CWRT to changes in setpoint.

11) Disable the tower fans if either

    a) Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or

    b) Tower fans have been at minimum speed for 5 minutes and CWRT drops below setpoint minus 1°F.

    c) Tower fans have been at minimum speed for 5 minutes and CWST drops below setpoint minus 1°F.

12) Enable the tower fans if

    a) They have been off for at least 1 minute, and

    b) CWRT rises above setpoint by 1°F, and

    c) CWST rises above setpoint by 1°F, and

    d) All enabled chillers' HpTowerMaxSpd are greater than tower minimum speed.

13) When all condenser water pumps are commanded off, disable the PID loop and stop all tower fans.

14) Upon plant startup, hold CWRTsp at 10°F degrees less than CWRTdes for 10 minutes before ramping the setpoint to the calculated value above over 10 minutes.

This logic gives plant load an opportunity to stabilize prior to releasing control to the reset logic.

b. Condenser Water Supply Temperature (CWST) Control

1) CWSTdes in the subsequent logic shall be the lowest CWSTdesX of all chillers.

2) When any chillers are enabled and the waterside economizer is disabled, the following logic shall apply.

3) When the plant is first enabled, initialize CWST setpoint, CWSTsp, to 10°F less than CWSTdes.

4) Instantaneous plant output, Qactual, is calculated based on chilled water return temperature (CHWRT) entering the chillers, current chilled water supply temperature leaving the plant, and measured flow through the primary circuit flow meter (FLOWP), as shown in the equation below.

$$Q_{actual} = \frac{FLOW_P(CHWRT - CHWST)}{24}\ [tons]$$

5) Combined chiller and tower fan efficiency, EffCh+T, is calculated based on the combined power draw of all tower fans as read from tower VFD interfaces (kWTowers), the combined power draw of all chillers as read from the chiller interfaces or power meters (kWCh), and instantaneous plant output (Qactual). EffCh+T used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Eff_{Ch+T} = \frac{kW_{Towers} + kW_{Ch}}{Q_{actual}}$$

6) At the end of every time interval, equal in length to the Chilled Water Plant Reset time step (see Section 3.26E) plus 5 minutes, execute the following reset:

a) After the initial time interval, reset CWSTsp down 1°F.

There is no history when the plant is first enabled, so a direction to reset must be picked arbitrarily.

b) For each subsequent time interval, reset CWSTsp down by 1°F if CWST is no more than 0.5°F above present setpoint, tower fan speed command is less than 95%, CHWST setpoint has not increased relative to the setpoint at the end of the previous interval, and either:

1. CWSTsp had reset down in the previous time interval and EffCh+T is now less than at the previous setpoint change.

2. CWSTsp had reset up in the previous time interval and EffCh+T is now greater than at the previous setpoint change.

c) Else, if CWST is no more than 0.5°F below present setpoint, reset CWSTsp up by 1°F.

d) Else, do not change CWSTsp.

This logic attempts to optimize total chiller and tower efficiency. Since CW pump speed is fixed except when modulated for head pressure control (as applicable), CW pump power is not included in the optimization logic.
Two varying parameters can cofound this stepwise efficiency optimization routine: (1) varying plant load and (2) chilled water supply temperature setpoint reset. Both factors independently impact chiller efficiency and tower efficiency, making attribution of increases and decreases in efficiency to CWST setpoint reset alone impossible. As such, this approach is not recommended for plants with dynamic load profiles. Additionally, note that CWST setpoint is not allowed to reset down concurrently with CHWST setpoint resetting up since the latter typically outweighs the impact of the former making it impossible to tell whether the CWST reset did any good. A similar restriction is not placed on the CWST reset when CHWST setpoint is resetting down since chiller efficiency should continuously get worse in such a scenario, meaning the CWST setpoint will be self-correcting by repeatedly alternating setpoints within a 1°F range as efficiency continues to worsen until CHWST setpoint stabilizes.

7) Maximum CWST-setpoint shall be limited to CWSTdes from contract documents.

8) Minimum CWST-setpoint shall reset dynamically and equal the active chilled water supply temperature setpoint plus LIFTminX – 2°F. Where chillers have different LIFTminX values, LIFTminX in the above equation shall reset dynamically to equal the highest LIFTminX of enabled chillers.

Set the temperature offset (2°F) in the above sentence equal to the minimum temperature rise across a single chiller's condenser when operating at minimum load and design condenser water flow.

9) When any condenser water pump is proven on, CWST shall be maintained at setpoint by a direct acting PID loop. The loop output shall be mapped to the variable CWSTTowerSpd. Reset CWSTTowerSpd from minimum tower speed at 0% loop output to 100% speed at 100% loop output.

10) Tower speed command signal shall be the lower value of CWSTTowerSpd and HpTowerMaxSpd from each chiller head pressure control loop. All operating fans shall receive the same speed signal.

11) Disable the tower fans if either

a) Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or

b) Tower fans have been at minimum speed for 5 minutes and the CWST drops below setpoint minus 1°F.

12) Enable the tower fans if

a) They have been off for at least 1 minute, and

b) CWST rises above setpoint by 1°F, and

c) All enabled chillers' HpTowerMaxSpd are greater than tower minimum speed.

13) When all condenser water pumps are commanded off, disable the PID loop and stop all tower fans.

c. WSE Mode

1) When the WSE is enabled and chiller(s) are running (i.e., integrated operation):

a) Fan speed shall be equal to WseTower-MaxSpeed.

b) WseTower-MaxSpeed shall be reset by a direct acting PID loop maintaining the chiller load at 110% of the sum of MinUnloadCapX values for the operating chillers. Map WseTower-MaxSpeed from minimum speed at 0% loop output to 100% speed at 100% loop output. Bias the loop to launch from 100% output.

c) When starting integrated operation after previously operating with only the WSE, hold WseTower-MaxSpeed at 100% for 10 minutes to give the chiller time to get up to speed and produce at least MinUnloadCapX, then enable the loop.

2) When the WSE is running alone:

Waterside economizer only mode sequences herein presume a plant where the WSE flowrate is does not exceed the design flow of one chiller in WSE only mode as is typical of most commercial applications. For applications where WSE only mode CHW flow is likely to exceed the design flow of one chiller, e.g., a data center, additional logic is warranted for tower and CWP staging not included within the scope of this RP. For such plants, tower speed is typically controlled to maintain a leaving temperature setpoint and CWP speed is modulated to maintain CHWST at setpoint.

a) Fan speed shall be modulated to maintain CHWST at setpoint by a direct acting PID loop that resets fan speed from minimum at 0% loop output to maximum at 100% loop output.

b) If CHWST drops below setpoint and fans have been at minimum fan speed for 5 minutes, fans shall cycle off for at least 3 minutes and until CHWST rises above setpoint by 1°F.

3. Cooling Tower Bypass Valves

a. If any condenser water pump is on, all tower fans are off, and CWST from the tower falls below 40F for 5 minutes, fully open the tower bypass valve to the tower basins.

Modulating a tower bypass valve in freezing weather runs the risk of icing towers. Manufacturer guidance is either to run in full bypass, or no bypass.

b. Close the valve to the tower basins when any of the following are true:

1) The WSE is disabled, the valve has been open for at least 5 minutes, and CWST rises LIFTminX – 2°F above CHWST setpoint. Where chillers have different LIFTminX values, LIFTminX in the above equation shall reset dynamically to equal the highest LIFTminX of enabled chillers.

2) The WSE is enabled, the valve has been open for at least 5 minutes, and CHWST rises to within 1°F of CHWST setpoint.

3) Tower fans are commanded on (valve shall never be open when fans are on).

M. Tower Make-up Water

1. Make-up water valve shall cycle based on tower water fill level sensor. The valve shall be modulated with a P-only loop from 0% open when water level is at T-level-max-fill and 100% when tower level is at T-level-min-fill.

N. Cooling tower filtration system

1. Each tower filter supply isolation valve shall be enabled within a 5-hour window between 10 PM to 3 AM (adjustable) if its tower pumps had operated during the previous 24 hours. After the valve has been commanded open for 1 hour (adjustable), the valve shall be disabled and closed until the next day.

2. The cooling tower filtration pump shall run when any tower supply isolation valve is enabled and open.

3. While the pump is commanded on, the isolation valves on each cell shall open (while the others close) every 1 hour (as listed above), rotating so that each enabled valve is open 1 hour (as listed above).

4. When the pump is ready to shut off after all cells have been filtered, open the purge valve for 25 seconds, then stop pump.

O. Emergency Chiller Off

1. Chillers shall be locked off (start/stop points overridden to off at highest protocol priority) upon closing of emergency chiller off switch located at chiller room entry. Remaining equipment shall remain enabled and be indexed to Stage 0 + WSE until the plant is either disabled or the emergency power off switch is released, at which point staging shall resume from Stage 0 + WSE.

2. Chillers shall be locked off (start/stop points overridden to off at highest protocol priority) upon closing of emergency chiller off switch located at chiller room entry. After 5 minutes, shut off all pumps and towers.

P. Freeze Protection

1. Tower Basin Heaters

a. Enable basin heater whenever basin temperature drops below 38°F.

b. Disable basin heater whenever basin temperature rises above 40°F.

2. Piping Heat Trace

   a. Enable heat trace whenever outdoor air temperature drops below 34°F.

   b. Disable heat trace whenever outdoor air temperature rises above 40°F.

Q. Performance Monitoring

1. All calculations listed below shall be performed at least once every 30 seconds. Time averaged values shall be recorded at least once every 5 minutes. The averaging period shall equal the trending interval.

2. Total plant power. Calculate total plant power as the sum of chiller power, pump power, and cooling tower fan power. For motors with VFDs, power shall be actual power as read through the VFD network interface. For fixed speed motors (e.g., CW pumps without VFDs), power shall be assumed to be fixed at BHP (from equipment schedule) * 0.746 / 0.93 (approximate motor efficiency).

3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, FLOWP; chilled water return temperature upstream of the first HX or chiller, CHWRT; and primary loop chilled water supply temperature leaving the plant, CHWST.

$$Q_{Plant} = \frac{FLOW_P\ (CHWRT - CHWST)}{24}[tons]$$

4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, FLOWS; secondary chilled water return temperature, SCHWRT; and secondary chilled water supply temperature, SCHWST.

$$Q_{Plant} = \frac{FLOW_S\ (SCHWRT - SCHWST)}{24}[tons]$$

5. Equipment Load. Calculate load for each operating chiller and WSE heat exchanger (as applicable) using flowrate through the equipment, FLOWD; chilled water return temperature entering the equipment, CHWRTD; and chilled water supply temperature leaving the equipment, CHWSTD. Inputs to the below equation shall be determined per the following rules.

$$Q_D = \frac{FLOW_D\ (CHWRT_D - CHWST_D)}{24}[tons]$$

   1) Where flow through each chiller is individually measured using a flow meter, FLOWD shall be the flow measured by the chiller’s associated flow meter.

   2) For parallel chillers where flowrate through each chiller is not measured, but flowrate through the primary circuit is measured, FLOWD shall be assumed proportional to design flow through all operating chillers in the circuit.

   3) For constant flow primary loops where neither flowrate through the chillers nor flowrate through the primary loop is measured, FLOWD shall be assumed equal to the design flowrate through the chiller for the current stage as determined during balancing.

4) For variable flow primary loops without flow meters, use chiller evaporator barrel differential pressure if available through the network interface to determine FLOWD per manufacturer's pressure versus flow curves; otherwise, do not execute the above calculation for individual chillers.

5) For WSE heat exchangers controlled to differential pressure, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, HXFdesign; design heat exchanger pressure drop, HXDP-Design, and current HX pressure drop, HXDP-D:

$$GPM_D = HXFdesign\left(\frac{HX_{DP-D}}{HX_{DP-Design}}\right)^{0.5}$$

6) For WSE heat exchangers with side stream CHW pumps, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, HXFdesign; design heat exchanger pump speed, HxPumpDesSpd; and current HX pump speed, HXSp-D.

$$GPM_D = HXFdesign\left(\frac{HX_{Sp-D}}{HxPumpDesSpd}\right)$$

7) CHWRTD shall be the return temperature entering the equipment as read by a hardwired sensor if available. If a hardwired sensor is unavailable for a chiller, temperature shall be read from a sensor internal to the chiller through its network interface.

8) CHWSTD shall be a hardwired temperature sensor at the outlet of the equipment if available. If a hardwired sensor is unavailable for a chiller, temperature shall be read from a sensor internal to the chiller through its network interface. Only if neither of the above is available shall a common supply temperature sensor (i.e., one measuring the output from multiple chillers), be used.

6. Calculate plant efficiency as total plant power divided by plant load. Calculate efficiency for each chiller as chiller power divided by chiller load.

7. Summary Data. For each chiller, and for the total plant, statistics shall be calculated for runtime, kWh, average actual efficiency (kW/ton), peak demand (tons), average demand (tons) and average load (ton-hours), all on an instantaneous, year-to-date, and previous-year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

	Instantaneous				Year-to-date						Previous Year					
	Lifetime Runtime (hours)	*Electrical Demand (kW)*	*CHW Demand (ton)*	*Efficiency (kW/ton)*	*Runtime (hours)*	*Avg Daily Energy Use (kWh)*	*Avg Daily CHW Load (ton-hr)*	*Avg CHW Demand (ton)*	*Peak CHW Demand (ton)*	*Avg Efficiency (kW/ton)*	*Runtime (hours)*	*Avg Daily Energy Use (kWh)*	*Avg Daily CHW Load (ton-hr)*	*Avg CHW Demand (ton)*	*Peak CHW Demand (ton)*	*A Effic (kW*
CH-1																
CH-2																
Total Plant																

R. Alarms

1. Maintenance interval alarm when pump has operated for more than 3000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

2. Maintenance interval alarm when chiller has operated for more than 1000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

3. Chiller alarm: level 2

4. Emergency off switch: Level 1

5. Tower level

   a. If tower water level sensor indicates water level below T-level-low-alarm, generate a Level 2 alarm.

   b. If tower water level sensor indicates water level above T-level-high-alarm, generate a Level 3 alarm.

6. Pump or tower fan alarm is indicated by the status input being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the equipment has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate the alarm until the equipment has been commanded off for 60 seconds.

7. Tower basin heater alarm is indicated by the status being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the equipment has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate alarm until the equipment has been commanded off for 15 seconds.

8. Piping heat trace alarm indicated by the status being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the equipment has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate alarm until the equipment has been commanded off for 15 seconds.

9. Valve alarm is indicated by the end switch status being different from the output command for 90 seconds.

   a. Commanded open, status not open: Level 2. Do not evaluate alarm until the equipment has been commanded open for 90 seconds.

b. Commanded closed, status not closed: Level 4. Do not evaluate alarm until the equipment has been commanded closed for 90 seconds.

10. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2

11. Tower basin temperature alarm

a. Basin temperature is below 38°F for 5 minutes continuously: Level 3

b. Basin temperature is below 36°F for 5 minutes continuously: Level 2

12. Sensor Failure:

a. Sensor shall be deemed outside of its widest possible operating range if any of the following are true:

1) Feedback less than 2 mA from any 4 to 20 mA transducer; or

2) Temperature reading less than 0°F from any temperature sensor.

b. Any sensor that goes outside of its widest possible operating range.

1) If the sensor is used for monitoring only: Level 3.

2) If the sensor is used for control: Level 2.

S. Automatic Fault Detection and Diagnostics

The Automatic Fault Detection and Diagnostics (AFDD) routines for chilled water plants continually assess plant performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the Operating State of the plant, as determined by the positions of the isolation valves and statuses of pumps. Time delays are applied to the evaluation and reporting of fault conditions, to suppress false alarms. Fault conditions that pass these filters are reported to the building operator as alarms along with a series of possible causes.
These equations assume that the plant is equipped with isolation valves, as well as a pump status monitoring. If any of these components are not present, the associated tests, and variables should be omitted from the programming.
Note that these faults rely on reasonably accurate measurement of water temperature. Extra precision sensors installed in thermowells with thermal paste are strongly recommended for best accuracy.

1. AFDD conditions are evaluated continuously for the plant.

2. The Operating State (OS) of the plant shall be defined by the commanded positions of the valves and status feedback from the pumps in accordance with the following table.

The Operating State is distinct from and should not be confused with the chilled water plant stage.
OS#1 – OS#5 represent normal operating states during which a fault may nevertheless occur if so determined by the fault condition tests below.

Operating State	Chiller CHW Isolation Valves (if Series Chillers)	Chiller CHW Isolation Valves or Dedicated PCHWPs (if Parallel Chillers)	Chiller CW Isolation Valves or Dedicated CWPs (if water-cooled)	CHW Pump Status	CW Pump Status (if water-cooled and headered)	WSE CHW Pump Status (if WSE with HX Pump)	WSE CHW Diverting Valve (if WSE with HX diverting valve)	WSE CW Isolation Valve (if WSE)	Chiller Bypass Valve (if primary-only and WSE)
#1: Disabled	All Open	All Closed/Off	All Closed/Off	All Off	All Off	Off	Open	Closed	Closed
#2: One Chiller Enabled	One Closed, All Others Open	One Open/On, All Others Closed/Off	One Modulating, All Others Closed/Off	Any On	Any On	Off	100% Open	Closed	Closed
#3: More than one Chiller Enabled	Both Closed	More than one Open/On	More than one modulating	Any On	Any On	Off	100% Open	Closed	Closed
#4: Waterside Economizer-only	All Open	All Closed/Off	All Closed/Off	Any On	Any On	On	< 100% Open	Open	Open
#5: Integrated Waterside Economizer	Any Open or Any Closed	Any Open/On or Any Closed/Off	Any Modulating or Any Closed/Off	Any On	Any On	On	< 100% Open	Open	Closed

3. The following points must be available to the AFDD routines for the chilled water plant:

   a. DP = Chilled water loop differential pressure (each loop, where applicable)

   b. DPSP = Chilled water loop differential pressure setpoint (each loop, where applicable)

   c. FLOWP = Primary chilled water flow

   d. FLOWS = Secondary chilled water flow

   e. MFBPV = Chilled water minimum flow bypass valve command; 0% ≤ MFBPV ≤ 100%

   f. CHW-MinFlowSP = Effective minimum chilled water flow setpoint (MinFlowRatio multiplied by the sum of CHW-DesFlowX of enabled chillers).

   g. SpeedCT = Cooling tower speed command; 0% ≤ SpeedCT ≤ 100%

h. StatusCWP = Lead condenser water pump status

i. StatusPCHWP = Lead primary chilled water pump status

j. StatusSCHWP = Lead secondary chilled water pump status

k. StatusWSEHXP = Waterside economizer heat exchanger pump status

l. CHWST = Common chilled water supply temperature leaving the chillers

m. CHWSTSP = Chilled water supply temperature setpoint

n. CHWRT = Common chilled water return temperature entering the chillers

o. CWST = Condenser water supply temperature

p. CWSTdes = Lowest condenser water supply temperature at chiller selection conditions for chillers; CWSTdes shall be the lowest CWSTdesX of all chillers

q. CHWRTBeforeWSE = Chilled water return temperature before the waterside economizer

r. CHWRTAfterWSE = Chilled water return temperature after the waterside economizer

s. CHWSTCH-x = CH-x chilled water supply temperature (each chiller)

t. CHWRTCH-x = CH-x chilled water return temperature (each chiller)

u. CWSTCH-x = CH-x condenser water supply temperature (each chiller)

v. CWRTCH-x = CH-x condenser water return temperature (each chiller)

w. CWRTHX = Waterside economizer condenser water return temperature

x. DAHX = Design heat exchanger approach

y. RefrigEvapTempCH-x = CH-x refrigerant evaporating temperature (each chiller)

z. RefrigCondTempCH-x = CH-x refrigerant condensing temperature (each chiller)

aa. CHW-ISOCH-x = CH-x chilled water isolation valve commanded position (each chiller)

bb. CW-ISOCH-x = CH-x condenser water isolation valve commanded position; 0% ≤ CW-ISOCH-x ≤ 100% if modulating, open/closed if two-position (each chiller)

cc. WSE-HX-CHW-DIV = Waterside economizer chilled water diverting valve commanded position; 0% ≤ WSE-HX-CHW-DIV ≤ 100%

dd. WSE-HX-CW-ISO = Waterside economizer condenser water isolation valve commanded position; open/closed ee. PGAUGE = Chilled water system gauge pressure

4. The following values must be continuously calculated by the AFDD routines:

a. 5-minute rolling averages with 1-minute sampling time of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently

1) CHWSTAVG = rolling average of the common chilled water supply temperature

2) CHWRTAVG = rolling average of the common chilled water return temperature

3) CHWRTBEFOREWSE, AVG = rolling average of the chilled water return temperature before the waterside economizer

4) CHWRTAFTERWSE, AVG = rolling average of the chilled water return temperature after the waterside economizer

5) CWSTAVG = rolling average of the common condenser water supply temperature

6) CWRTAVG = rolling average of the common condenser water return temperature

7) CWSTCH-x, AVG = rolling average of CH-x condenser water supply temperature (each chiller)

8) CWRTCH-x, AVG = rolling average of CH-x condenser water return temperature (each chiller)

9) CHWSTCH-x, AVG = rolling average of CH-x chilled water supply temperature (each chiller)

10) CHWRTCH-x, AVG = rolling average of CH-x chilled water return temperature (each chiller)

11) CWRTHX, AVG = rolling average of the waterside economizer heat exchanger condenser water return temperature

12) PGAUGE, AVG = rolling average of chilled water system gauge pressure

13) DPAVG = rolling average of loop differential pressure (each loop, where applicable)

14) FLOWP, AVG = rolling average of primary chilled water flow

15) FLOWS, AVG = rolling average of secondary chilled water flow

16) RefrigCondTempCH-x, AVG = rolling average of CH-x refrigerant condensing temperature (each chiller)

17) RefrigEvapTempCH-x, AVG = rolling average of CH-x refrigerant evaporating temperature (each chiller)

b. CHW-FlowCH-X (each chiller)

1) For plants with parallel chillers and headered primary chilled water pumps: 1 if CHW-ISOCH-x > 0, 0 if CHW-ISOCH-X = 0

2) For plants with parallel chillers and dedicated primary chilled water pumps: 1 if StatusPCHWP = On, 0 if StatusPCHWP = Off.

3) For plants with series chillers: 1 if CHW-ISOCH-x <100, 0 if CHW-ISOCH-X = 100 (each chiller)

c. CW-FlowCH-X (each chiller)

1) For plants with headered condenser water pumps and if condenser water isolation valve is modulating: 1 if CW-ISOCH-x > 0% open, 0 if CW-ISOCH-X = 0% open (each chiller)

2) For plants with headered condenser water pumps and if condenser water isolation valve is two-position: 1 if CW-ISOCH-X = open, 0 if CW-ISOCH-X = closed (each chiller)

3) For plants with dedicated condenser pumps: 1 if StatusCWP = on, 0 if StatusCWP = off

d. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)

e. ΔStage = number of chilled water plant stage changes during the previous 60 minutes (moving window)

f. StartsCH-x = number of CH-x starts in the last 60 mins (each chiller)

5. The following internal variables shall be defined. All parameters are adjustable by the operator, with initial values as given below:

The default values have been intentionally biased towards minimizing false alarms at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.

Values for physical factors such as pump heat and sensor error can be measured in the field or derived from trend logs and hardware submittals. Likewise, the switch delays can be refined by observing the time required to achieve quasi steady state operation in trend data.

Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false alarms, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the temperature, pressure or flow thresholds.

Variable Name	Description	Default Value
ƐCHWT	Temperature error threshold for chilled water temperature sensors	2°F
Retain the following variable for water-cooled plants. Delete otherwise.		
ƐCWT	Temperature error threshold for condenser water temperature sensors	2°F
Retain the following variable for primary-secondary and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.		
ƐDP	Differential pressure error threshold for DP sensor	2 psi
Retain the following variable for plants with a flow meter. Delete otherwise.		
ƐFM	Flow error threshold for flow meter	20 gpm
ƐVFDSPD	VFD speed error threshold	5%
Retain the following variable for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
ƐMFBVP	Minimum flow bypass valve position error threshold	5%
Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.		
CHW-ETPreChargePress	Chilled water system expansion tank pre-charge pressure	See mechanical schedule (psig)
Retain the following variable for water-cooled plants. Delete otherwise.		
ApproachCOND	Condenser approach threshold	4°F
ApproachEVAP	Evaporator approach threshold	3°F
CHStartsMAX	Maximum number of chiller starts during the previous 60 minutes (moving window)	2
ΔOSMAX	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	2
ΔStageMAX	Maximum number of chilled water plant stage changes during the previous 60 minutes (moving window)	2
StageDelay	Time in minutes to suspend Fault Condition evaluation after a change in stage	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

TestModeDelay ensures that normal fault reporting occurs after the testing and commissioning process is completed as prescribed in Section 3.26S.12.

6. The following are potential Fault Conditions that can be evaluated by the AFDD routines. If the equation statement is true, then the specified fault condition exists. The Fault Conditions to be evaluated at any given time will depend on the Operating State of the chilled water plant.

Retain the following fault condition for plants with any chilled water pumps controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor.			
FC#1	Equation	DPAVG > ƐDSP and StatusCHWP = Off	Applies to OS #1
	Description	Differential pressure is too high with the chilled water pumps off	
	Possible Diagnosis	DP sensor error	
Retain the following fault condition if there is a flow meter in the primary loop. Delete otherwise.			
FC#2	Equation	FLOWP, AVG > ƐFM and StatusPCHWP = Off	Applies to OS #1
	Description	Primary chilled water flow is too high with the chilled water pumps off	
	Possible Diagnosis	Flow meter error	

<table>
<tr><td colspan="4">Retain the following fault condition for primary-secondary plants with a flow meter in the secondary loop. Delete otherwise. Duplicate the following fault condition for each secondary loop flow meter.</td></tr>
<tr><td rowspan="3">FC#3</td><td>Equation</td><td>FLOWS, AVG > ƐFM
and
StatusSCHWP = Off</td><td rowspan="3">Applies to OS #1</td></tr>
<tr><td>Description</td><td>Secondary chilled water flow is too high with the chilled water pumps off</td></tr>
<tr><td>Possible Diagnosis</td><td>Flow meter error</td></tr>
<tr><td colspan="4">Retain the following fault condition for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor and/or each secondary loop where pump speed is controlled to maintain differential pressure.</td></tr>
<tr><td rowspan="3">FC#4</td><td>Equation</td><td>DPAVG < DPSP – ƐDP
and
SpeedCHWP ≥ 99% - ƐVFDSPD</td><td rowspan="3">Applies to OS #2 – #5</td></tr>
<tr><td>Description</td><td>Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.</td></tr>
<tr><td>Possible Diagnosis</td><td>Problem with VFD
Mechanical problem with pump(s)
Pump(s) are undersized
Differential pressure setpoint is too high
CHWST is too high
Primary flow is higher than the design evaporator flow of the operating chillers</td></tr>
<tr><td colspan="4">Retain the following fault condition for primary-only plants with a minimum flow bypass valve. Delete otherwise.</td></tr>
<tr><td rowspan="3">FC#5</td><td>Equation</td><td>FLOWP, AVG < CHW-MinFlowSp – ƐFM
and
MFBPV ≥ 99% - ƐMFBPV</td><td rowspan="3">Applies to OS #2, #3, #5</td></tr>
<tr><td>Description</td><td>Primary chilled water flow is too low with the minimum flow bypass valve fully open.</td></tr>
<tr><td>Possible Diagnosis</td><td>Problem with minimum flow bypass valve
Problem with chiller CHW isolation valves
Minimum loop differential pressure setpoint too low</td></tr>
<tr><td rowspan="3">FC#6</td><td>Equation</td><td>CHWSTAVG - ƐCHWT ≥ CHWSTSP</td><td rowspan="3">Applies to OS #2 – #5</td></tr>
<tr><td>Description</td><td>Chilled water supply temperature is too high</td></tr>
<tr><td>Possible Diagnosis</td><td>Mechanical problem with chillers
Primary flow is higher than the design evaporator flow of the operating chillers</td></tr>
</table>

Retain the following fault condition for plants where system gauge pressure is monitored. Delete otherwise.			
FC#7	Equation	CHW-PGAUGE, AVG < 0.9 * CHW-ETPreChargePress	Applies to OS #1 – #5
	Description	Chilled water system gauge pressure is too low	
	Possible Diagnosis	Possible chilled water system leak	
Retain the following fault condition for water-cooled plants with chiller network interfaces. Delete otherwise.			
FC#8	Equation	ApproachCOND ≥ RefrigCondTempCH-x, AVG - CWRTCH-x, AVG	Applies to OS #2, #3, #5
	Description	Condenser approach is too high	
	Possible Diagnosis	Possible condenser fouling or blocked condenser tubes Low condenser water temperature Low condenser water flow	
Retain the following fault condition for plants with chiller network interfaces. Delete otherwise.			
FC#9	Equation	ApproachEVAP ≥ CHWSTCH-x, AVG - RefrigEvapTempCH-x, AVG	Applies to OS #2, #3, #5
	Description	Evaporator approach is too high	
	Possible Diagnosis	Possible evaporator fouling or blocked evaporator tubes Low refrigeration charge Contaminated refrigeration charge	

<table>
<tr><td colspan="4">Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.</td></tr>
<tr><td rowspan="3">FC#10</td><td>Equation</td><td>| (∑(CHW-FlowCH-X * CHWSTCH-X) / ∑CHW-FlowCH-X) - CHWSTAVG | > ƐCHWT
and
∑CHW-FlowCH-X = 1</td><td rowspan="3">Applies to OS #2, #5</td></tr>
<tr><td>Description</td><td>Deviation between the active chiller chilled water supply temperature and the common chilled water supply temperature is too high.</td></tr>
<tr><td>Possible Diagnosis</td><td>A chilled water supply temperature sensor is out of calibration</td></tr>
<tr><td colspan="4">Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.</td></tr>
<tr><td rowspan="3">FC#11</td><td>Equation</td><td>| (∑(CHW-FlowCH-X * CHWRTCH-X) / ∑CHW-FlowCH-X) - CHWRTAVG | > ƐCHWT
and
∑CHW-FlowCH-X = 1</td><td rowspan="3">Applies to OS #2, #5</td></tr>
<tr><td>Description</td><td>Deviation between the active chiller chilled water return temperature and the common chilled water return temperature is too high.</td></tr>
<tr><td>Possible Diagnosis</td><td>A chilled water return temperature sensor is out of calibration</td></tr>
<tr><td colspan="4">Retain the following two fault conditions for water-cooled plants with chiller network interfaces. Delete otherwise.</td></tr>
<tr><td rowspan="3">FC#12</td><td>Equation</td><td>| (∑(CW-FlowCH-X * CWSTCH-X) / ∑CW-FlowCH-X) - CWSTAVG | > ƐCWT
and
∑CW-FlowCH-X = 1</td><td rowspan="3">Applies to OS #2</td></tr>
<tr><td>Description</td><td>Deviation between the active chiller condenser water supply temperature and the common condenser water supply temperature is too high.</td></tr>
<tr><td>Possible Diagnosis</td><td>A condenser water supply temperature sensor is out of calibration</td></tr>
<tr><td>FC#13</td><td>Equation</td><td>| (∑(CW-FlowCH-X * CWRTCH-X) / ∑CW-FlowCH-X) - CWRTAVG | > ƐCWT
and
∑CW-FlowCH-X = 1</td><td>Applies to OS #2</td></tr>
</table>

	Description	Deviation between the active chiller condenser water return temperature and the common condenser water return temperature is too high.	
	Possible Diagnosis	A condenser water return temperature sensor is out of calibration	
Retain the following fault condition for water-cooled plants. Delete otherwise.			
FC#14	Equation	CWSTAVG - ƐCWT ≥ DesCWSTdes and SpeedCT ≥ 99% - ƐVFDSPD	Applies to OS #2, #3
	Description	Condenser water supply temperature is too high with cooling tower(s) at full speed.	
	Possible Diagnosis	Problem with cooling tower VFD Mechanical problem with cooling tower(s) Cooling tower(s) undersized	
Retain the following three fault conditions for plants with a waterside economizer. Delete otherwise.			
FC#15	Equation	| CWRTHX, AVG - CWRTAVG | > ƐCWT and ∑CW-FlowCH-X = 0 and WSE-HX-CW-ISO = 1	Applies to OS #4
	Description	Deviation between the active waterside economizer condenser water return temperature and the common condenser water return temperature is too high.	
	Possible Diagnosis	A condenser water return temperature sensor is out of calibration	
FC#16	Equation	CWSTAVG – CHWRTAFTERWSE, AVG > (1.5 * DAHX) + ƐCHWRT	Applies to OS #4, #5
	Description	Heat exchanger approach is high	
	Possible Diagnosis	Possible heat exchanger fouling or blocked heat exchanger tubes	
FC#17	Equation	| CHWRTBeforeWSE - CHWRTAfterWSE | > ƐCHWT and StatusWSE-HX-P = Off (if HX Pump) or WSE-HX-CHW-DIV = 100% (if diverting valve)	Applies to OS #4, #5
	Description	Deviation between the chilled water return temperature before and after the waterside economizer is too high.	
	Possible Diagnosis	A chilled water return temperature sensor is out of calibration	

FC#18	Equation	ΔOS > ΔOSMAX	Applies to OS #1 – #5
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#19	Equation	ΔStartsCH-x > ΔCHStartMAX	Applies to OS #2, #3, #5
	Description	Too many chiller starts	
	Possible Diagnosis	Chiller is cycling due to load loads. Chiller is oversized and/or has insufficient turndown capability. Chiller stage-up threshold may be set too low.	
FC#20	Equation	ΔStage > ΔStageMAX	Applies to OS #1 – #5
	Description	Too many stage changes	
	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	

7. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the Operating State of the plant:

   a. In OS #1 (Disabled), the following Fault Conditions shall be evaluated:

      1) FC#1: Differential pressure is too high with the chilled water pumps off

      2) FC#2: Primary chilled water flow is too high with the primary chilled water pumps off

      3) FC#3: Secondary chilled water flow is too high with the secondary chilled water pumps off

      4) FC#7: Chilled water system gauge pressure is too low

      5) FC#18: Too many changes in operating state

      6) FC#20: Too many stage changes

   b. In OS#2 (One chiller enabled without WSE), the following Fault Conditions shall be evaluated:

      1) FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.

      2) FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.

      3) FC#6: Chilled water supply temperature is too high

      4) FC#7: Chilled water system gauge pressure is too low

5) FC#8: Condenser approach is too high

6) FC#9: Evaporator approach is too high

7) FC#10: A chilled water supply temperature sensor is out of calibration

8) FC#11: A chilled water return temperature sensor is out of calibration

9) FC#12: A condenser water supply temperature sensor is out of calibration

10) FC#13: A condenser water return temperature sensor is out of calibration

11) FC#14: Condenser water supply temperature is too high with cooling tower(s) at full speed

12) FC#18: Too many changes in Operating State

13) FC#19: Too many chiller starts

14) FC#20: Too many stage changes

c. In OS#3 (More than one chiller enabled), the following Fault Conditions shall be evaluated:

1) FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.

2) FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.

3) FC#6: Chilled water supply temperature is too high

4) FC#7: Chilled water system gauge pressure is too low

5) FC#8: Condenser approach is too high

6) FC#9: Evaporator approach is too high

7) FC#14: Condenser water supply temperature is too high with cooling tower(s) at full speed

8) FC#18: Too many changes in Operating State

9) FC#19: Too many chiller starts

10) FC#20: Too many stage changes

d. In OS#4 (Waterside Economizer-only), the following Fault Conditions shall be evaluated:

1) FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.

2) FC#6: Chilled water supply temperature is too high

3) FC#7: Chilled water system gauge pressure is too low

4) FC#15: A condenser water return temperature sensor is out of calibration

5) FC#16: Heat exchanger approach is high

6) FC#17: Deviation between the chilled water return temperature before and after the waterside economizer is too high

7) FC#18: Too many changes in Operating State

8) FC#20: Too many stage changes

e. In OS#5 (Integrated waterside economizer), the following Fault Conditions shall be evaluated:

1) FC#4: Chilled water loop differential pressure is too low with chilled water pump(s) at full speed.

2) FC#5: Primary chilled water flow is too low with the minimum flow bypass valve fully open.

3) FC#6: Chilled water supply temperature is too high

4) FC#7: Chilled water system gauge pressure is too low

5) FC#8: Condenser approach is too high

6) FC#9: Evaporator approach is too high

7) FC#10: A chilled water supply temperature sensor is out of calibration

8) FC#11: A chilled water return temperature sensor is out of calibration

9) FC#16: Heat exchanger approach is high

10) FC#17: Deviation between the chilled water return temperature before and after the waterside economizer is too high

11) FC#18: Too many changes in Operating State

12) FC#19: Too many chiller starts

13) FC#20: Too many stage changes

8. For each chiller, the operator shall be able to suppress the alarm for any Fault Condition.

9. Evaluation of Fault Conditions shall be suspended under the following conditions:

a. When no pumps are operating.

b. For a period of StageDelay minutes following a change in plant stage.

10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.

11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

12. Test Mode shall temporarily set StageDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system and to ensure normal fault detection occurs after testing is complete.

13. When a Fault Condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from the table in Section 3.26S.6.

3.27 HOT WATER PLANT

A. See Section 1.2K for HWSTmax, HW-LOT, HW-MinFlowX, HW-DesFlowX, QbX, B-FiringMinX, PHWFdesign, and SHWFdesign. See Section 1.3G for HW-DPmax, LocalHW-DPmax, and B-MinPriPumpSpdStage.

B. Plant Enable/Disable

1. The Boiler plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the Boiler plant. The default schedule shall be 24/7 (adjustable).

2. Enable the plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

a. Number of Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

b. OAT<HW-LOT, and

c. The Boiler plant enable schedule is active.

3. Disable the plant when it has been enabled for at least 15 minutes and:

a. Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

b. OAT>HW-LOT + 1°F, or

c. The Boiler plant enable schedule is inactive.

Heating Hot-Water Plant Requests are generated by coil control valves. If the plant serves critical valves whose positions are not known to the plant controller, e.g. pneumatic controls, the Heating Hot-Water Plant Request variable can be set to 1 manually by the operator such that the plant is enabled strictly based on OAT lockout and schedule per subsequent logic.

Importance multipliers (IM) shall be added to Heating Hot-Water Plant Requests in a future addendum to Guideline 36 to ensure that critical coils can independently cause the plant to *start. For example, setting the importance multiplier of a large air handler's Heating Hot-Water Plant Requests to 4 will cause 4 requests so that air handler alone can start the plant even if I=4. Unimportant coils can be assigned an IM of zero so that they cannot cause the plant to start. Small coils can be assigned IM values less than one so that several are required to be active before the plant will start.*

4. When the plant is enabled:
    a. Open the HW isolation valve of the lead boiler.
    b. Stage on lead primary HW pump and secondary HW pump per Sections F and G respectively.
    c. Once the lead pumps have proven on, enable the lead boiler.
    d. Stage on lead primary HW pump per Section F.
    e. Once the lead pump has proven on, enable the lead boiler.
5. When the plant is disabled:
    a. Shut off the enabled boiler(s).
    b. For each enabled boiler with headered primary HW pumps, close the HW isolation valve(s) after 3 minutes and disable the operating HW pump(s) per Section F.
    c. For each enabled boiler with dedicated primary HW pumps, disable the operating primary HW pump(s) per Section F.
    d. Disable the operating secondary HW pump(s) per Section G.

C. Boiler Staging

1. Boiler stages shall be defined as follows:

Boiler Stage	Enabled Boilers
0	None
1	B-1
2	B-2 or B-3
3	B-1 and (B-2 or B-3)
4	B-2 and B-3
5	B-1, B-2, and B-3

2. Interchangeable boilers indicated with "or" in the table above shall be lead/lag controlled per Section 3.1P.3.
3. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its HW isolation valve shall be closed.
4. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its dedicated primary pump shall be disabled.

5. Boilers are staged in part based on required capacity, Qrequired. Qrequired is calculated based on hot water return temperature (HWRT), active hot water supply temperature setpoint (HWSTSP), and measured flow through the primary circuit flow meter (FLOWP), as shown in the equation below. Qrequired used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = 0.49 * FLOW_P(HWST_{SP} - HWRT)\ [\frac{\text{kbtu}}{\text{h}}]$$

6. Boilers are staged in part based on required capacity, Qrequired. Qrequired is calculated based on secondary hot water return temperature (SHWRT), active hot water supply temperature setpoint (HWSTSP), and measured flow through the secondary circuit flow meter (FLOWS), as shown in the equation below. Qrequired used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = 0.49 * FLOW_S(HWST_{SP} - SHWRT)\ [\frac{\text{kbtu}}{\text{h}}]$$

7. Boilers are staged in part based on the minimum output of a given stage, B-STAGEMIN. Calculate B-STAGEMIN as the largest B-FiringMinX of all boilers in the stage times design capacity of all boilers in the stage. Note that B-FiringMin and capacity may vary for each boiler, e.g. for unequally sized boilers with different minimum turndowns.

B-STAGEMIN defines the minimum load boilers can operate at in a given stage without any of them cycling. If minimum capacities of all boilers (e.g. B-FiringMinX for a given boiler times its design capacity) were summed directly instead of correcting for the highest B-FiringMinX among all enabled boilers in a stage, boilers with a higher B-FiringMinX would still cycle.

8. Staging events require that a boiler stage be available. A stage shall be deemed unavailable if the stage cannot be achieved because a boiler required to operate in the stage is faulted per Section 3.1P.5.b.1)c) or a hot water pump dedicated to that boiler is faulted per Section 3.1P.5.b.1)a); otherwise the stage shall be deemed available.

9. Staging shall be executed per the conditions below subject to the following requirements:

    a. Each stage shall have a minimum runtime of 10 minutes.

    b. Timers shall reset to zero at the completion of every stage change.

    c. Any unavailable stage (see Section 8) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

        1) Exceptions:

            a) If the highest condensing boiler stage is unavailable, the stage up conditionals in the next lower condensing boiler stage shall be those from the highest condensing boiler stage.

            b) If the lowest non-condensing boiler stage is unavailable, the stage down conditionals of the next higher non-condensing boiler stage shall be those from the lowest non-condensing boiler stage.

d. Hot water supply and return temperatures used in staging logic shall be those located in common supply and return mains hardwired to plant controllers.

e. Where a primary HW supply temperature sensor is not provided, primary HW supply temperature used in staging logic shall be the weighted average supply temperature of all boilers with open HW isolation valves. Temperatures shall be weighted by design boiler flowrates.

The above section assumes that flows through the boilers are balanced proportional to design.

f. Stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage are unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Both of the following are true:

a) Qrequired exceeds 200% of B-STAGEMIN of the next available stage for 10 minutes

b) Hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 3.27H).

3) Failsafe Condition: HW supply temperature is 10°F < setpoint for 15 minutes.

g. Stage down if all of the following are true:

1) Either:

a) Qrequired falls below 110% of B-STAGEMIN of the current stage for 5 minutes; or

b) The minimum flow bypass valve, if provided, is greater than 0% open for 5 minutes.

2) The failsafe stage up condition is not true.

3) Qrequired is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

Condensing boilers are generally more efficient at low load since the ratio of heat transfer surface area to thermal mass flowrate is maximized, increasing flue gas condensation. Staging on boilers at low load therefore maximizes plant efficiency. However, the energy penalty from cycling losses due to staging on lag equipment prematurely, only to have them cycle off, may more than offset the part load efficiency gains.

Staging is delayed until the current stage output exceeds the minimum output of the next stage by 100% to avoid boiler short cycling following stage up, which dramatically decreases plant efficiency. The default stage up threshold for the efficiency condition is set to ensure sufficient load to prevent boilers from short cycling and to create an adequate hysteresis to prevent unnecessary boiler staging, but the optimal threshold will depend in part on the boiler turndown. The designer should consider adjusting this threshold based on plant attributes: higher for boilers with more turndown, lower for boilers with less turndown.

Staging is also dependent on minimum flow requirements. If minimum flowrate of the next stage is not satisfied under current operating conditions, then supply water will need to be bypassed to the return following a stage up, which raises return temperature. Elevated return temperature decreases condensation and boiler efficiency as a result, so staging up is inhibited under these conditions. For the same reason, a stage down is triggered if the minimum flow bypass valve is opened with more than one boiler in operation.

h. Stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage is unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Both of the following are true:

a) Qrequired exceeds 150% of B-STAGEMIN of the next available stage for 10 minutes

b) Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 3.27H).

3) Failsafe Condition: HW supply temperature is 10°F < setpoint for 15 minutes.

i. Stage down if all of the following are true:

1) Either:

a) Qrequired falls below 110% of B-STAGEMIN of the current stage for 5 minutes; or

b) For 5 minutes, Primary HW pumps are at B-MinPriPumpSpdStage and primary HWRT exceeds secondary HWRT by 3°F.

2) The failsafe stage up condition is not true.

3) Qrequired is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

Staging conditions are identical for variable primary/variable secondary condensing boiler plants to those used for primary only condensing boiler plants, except that slightly different logic must be used for the minimum flow based stage down conditional since there is no minimum flow bypass valve. Primary hot water return temperature exceeding secondary hot water return temperature indicates primary recirculation, which limits condensing boiler plant efficiency as described previously. This conditional only applies when primary hot water pumps are at minimum speed since minimum speed indicates (1) low load for the stage and that (2) primary pump speed cannot be reduced further to mitigate return temperature degradation.

j. Stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage is unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Qrequired exceeds 90% of the design capacity, QbX, of the boilers in the current stage for 10 minutes; or

3) Failsafe Condition: HW supply temperature is 10°F < setpoint for 15 minutes.

k. Stage down if both of the following are true:

1) Qrequired is less than 80% of the design capacity of the next lower available stage for 10 minutes; and

2) The failsafe stage up condition is not true.

Non-condensing boilers do not benefit significantly from operating at low turndowns since the primary benefit of doing so is to maximize condensing, which is not permissible with non-condensing boiler heat exchangers. Logic is therefore simplified by running boilers to near full output prior to staging.

The following logic is written with the intent that the designer first enables all condensing boiler stages before any non-condensing boiler stages. The logic will still work if this rule is not followed, but some of the efficiency afforded by the condensing boilers may be lost in the process.

l. If all boilers enabled in the next higher stage are condensing, stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage is unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Both of the following are true:

a) Qrequired exceeds 150% of B-STAGEMIN of the next available stage for 10 minutes

b) Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 3.27H).

3) Failsafe Condition: HW supply temperature is 10°F < setpoint for 15 minutes.

m. If all boilers enabled in the current stage are condensing, stage down if all of the following are true:

1) Either:

a) Qrequired falls below 110% of B-STAGEMIN of the current stage for 5 minutes; or

b) For 5 minutes, Primary HW pumps are at B-MinPriPumpSpdStage and primary HWRT exceeds secondary HWRT by 3°F.

2) The failsafe stage up condition is not true.

3) Qrequired is less than 80% of the design capacity, QbX, of the boilers in the next available lower stage for 5 minutes.

n. If any boiler enabled in the next higher stage is non-condensing, stage up if any of the following is true:

1) Availability Condition: The equipment necessary to operate the current stage is unavailable. The availability condition is not subject to the minimum stage runtime requirement. Or

2) Efficiency Condition: Qrequired exceeds 90% of the design capacity, QbX, of the boilers in the current stage for 10 minutes; or

3) Failsafe Condition: HW supply temperature is 10°F < setpoint for 15 minutes.

o. If any boiler enabled in the current stage is non-condensing, stage down if all of the following are true:

1) Qrequired is less than 80% of the design capacity of the next available lower stage for 10 minutes.

2) The failsafe stage up condition is not true.

10. Whenever a lag boiler is enabled:

a. For any stage change during which a smaller boiler is disabled and a larger boiler is enabled, slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.27H.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

b. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.26H.1.

A stabilization delay does not apply in this case since flowrate will already be at least the stage minimum per staging logic.

c. Start the next lag boiler’s primary pump.

d. Open the next lag boiler’s isolation valve.

e. Start the next lag primary pump and simultaneously open the next lag boiler’s isolation valve.

f. After 30 seconds, enable the lag boiler.

g. For any stage change during which a smaller boiler is disabled and a larger boiler is enabled:

1) Wait 5 minutes for the newly enabled boiler to prove that is operating correctly (not faulted as defined in Section 3.1P.5.b.1)c), then shut off the smaller boiler.

2) After 3 minutes, turn off the smaller boiler's primary pump.

3) After 3 minutes, close the smaller boiler's isolation valve.

4) After 3 minutes, turn off the last lag primary pump and simultaneously close the smaller boiler's isolation valve.

5) Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.27H.1.

11. Whenever a lag boiler is disabled:

a. For any stage change during which a smaller boiler is enabled and a larger boiler is disabled:

1) Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 3.27H.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

2) Enable the smaller boiler's primary pump.

3) Open the smaller boiler's isolation valve.

4) Start the next lag primary pump and simultaneously open the smaller boiler's isolation valve.

5) After 30 seconds, enable the smaller boiler.

6) Wait 5 minutes for the newly enabled boiler to prove that it is operating correctly (not faulted as defined in Section 3.1P.5.b.1)c), then shut off the larger boiler.

b. If staging down from any other stage, disable the last stage boiler.

c. After 3 minutes, turn off the disabled boiler's primary pump.

d. After 3 minutes, close the disabled boiler's isolation valve.

e. After 3 minutes, turn off the last lag primary pump and simultaneously close the disabled boiler's isolation valve.

f. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 3.27H.1.

12. Whenever a lag condensing boiler is enabled:

a. Start the next lag condensing boiler's primary pump.

b. Start the next lag condensing loop primary pump and simultaneously open the next lag boiler's isolation valve.

c. After 30 seconds, enable the lag boiler.

13. Whenever the first non-condensing boiler is enabled:

    a. Reset the non-condensing boiler hot water supply temperature setpoint per Section 3.27D.3.

    b. Whenever the hot water supply temperature upstream of the non-condensing loop return pipe connection exceeds 140°F, or 5 minutes have elapsed, start the first non-condensing boiler’s primary pump.

    c. Whenever the hot water supply temperature upstream of the non-condensing loop return pipe connection exceeds 140°F, or 5 minutes have elapsed, start the first non-condensing loop primary pump and simultaneously open the first non-condensing boiler’s isolation valve.

    d. After 30 seconds, enable the lag boiler.

14. Whenever any other non-condensing boiler is enabled:

    a. Start the next lag non-condensing boiler’s primary pump.

    b. Start the next lag non-condensing loop primary pump and simultaneously open the next lag boiler’s isolation valve.

    c. After 30 seconds, enable the lag non-condensing boiler.

15. Whenever any non-condensing boiler other than the lead non-condensing boiler is disabled:

    a. Disable the non-condensing boiler.

    b. After 3 minutes, turn off the lag non-condensing boiler’s primary pump.

    c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler’s isolation valve.

16. Whenever the lead non-condensing boiler is disabled:

    a. Disable the non-condensing boiler and reset the condensing boiler hot water supply temperature setpoint per Section 3.27D.2.

    b. After 3 minutes, turn off the lag non-condensing boiler’s primary pump.

    c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler’s isolation valve.

17. Whenever a lag condensing boiler is disabled:

    a. Disable the condensing boiler.

    b. After 3 minutes, turn off the lag boiler’s primary pump.

c. After 3 minutes, turn off the last lag primary pump and simultaneously close the boiler's isolation valve.

D. Hot Water Supply Temperature Reset

1. Plant hot water supply temperature setpoint shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any HW Pump Distribution Loop
SP0	SPmax
SPmin	90ºF for condensing and hybrid boiler plants; 155°F for non-condensing plants
SPmax	HWSTmax
Td	10 minutes
T	5 minutes
I	2
R	Hot-Water Reset Requests
SPtrim	-2ºF
SPres	+3ºF
SPres-max	+7ºF

Hot water supply temperature is reset downwards under low load conditions to minimize piping heat losses, improve controllability, and maximize condensing operation.
SPmin must be higher for non-condensing boiler plants to avoid condensing operation. 155°F should be sufficient for most plants, though SPmin will vary as a function of coil selections and the nature of loads served. Engineers may therefore need to adjust this limit on a project specific basis.
Note that for hybrid boiler plants SPmin is reset from 90°F to 155°F based on whether non-condensing boilers are in operation or not in subsequent logic.

2. When only condensing boilers are enabled, condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.

3. Whenever any non-condensing boilers are enabled:

a. Non-condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.

b. SPmin in the Plant hot water supply temperature trim and respond loop shall be reset to 155°F while any non-condensing boilers are in operation.

c. Condensing boiler setpoint shall be the lesser of the design condensing boiler supply temperature, HWSTmax-cond, and current Plant hot water supply temperature setpoint less an offset of 10°F.

Maintaining the condensing boiler setpoint 10°F below the non-condensing boiler setpoint ensures the non-condensing boilers are sufficiently loaded to avoid cycling.
Note that leaving condensing boiler supply temperature must be at least 135°F to protect non-condensing boilers from condensing operation. Since SPmin is 155°F when any non-condensing boilers are enabled, the 10°F offset yields an effective minimum condensing boiler

supply temperature of 145°F. This provides a 10°F buffer between allowable non-condensing boiler entering temperature and condensing boiler setpoint, which allows for some instability in the condensing boiler HWST control loop and minimizes control loop interaction with the condensation control sequences below.

Note that if the design condensing boiler flow is less than the design plant flow (not recommended), the effective minimum condensing boiler temperature setpoint of 145°F may need to be elevated to protect the non-condensing boilers by raising SPmin. Reducing the 10°F offset instead would not be appropriate since it may lead to non-condensing boiler cycling under moderate load conditions when the condensing boiler flow can match secondary loop flow.

E. Non-Condensing Boiler Condensation Control

1. A reverse acting condensation control P-only loop shall reset a required minimum flow bypass valve position variable, MinCondVlvPos, from 0% at 140°F boiler entering temperature to 100% at 135°F boiler entering temperature.

2. Minimum bypass valve condensation control loop shall be enabled whenever any non-condensing boiler is enabled. Loop shall be disabled otherwise.

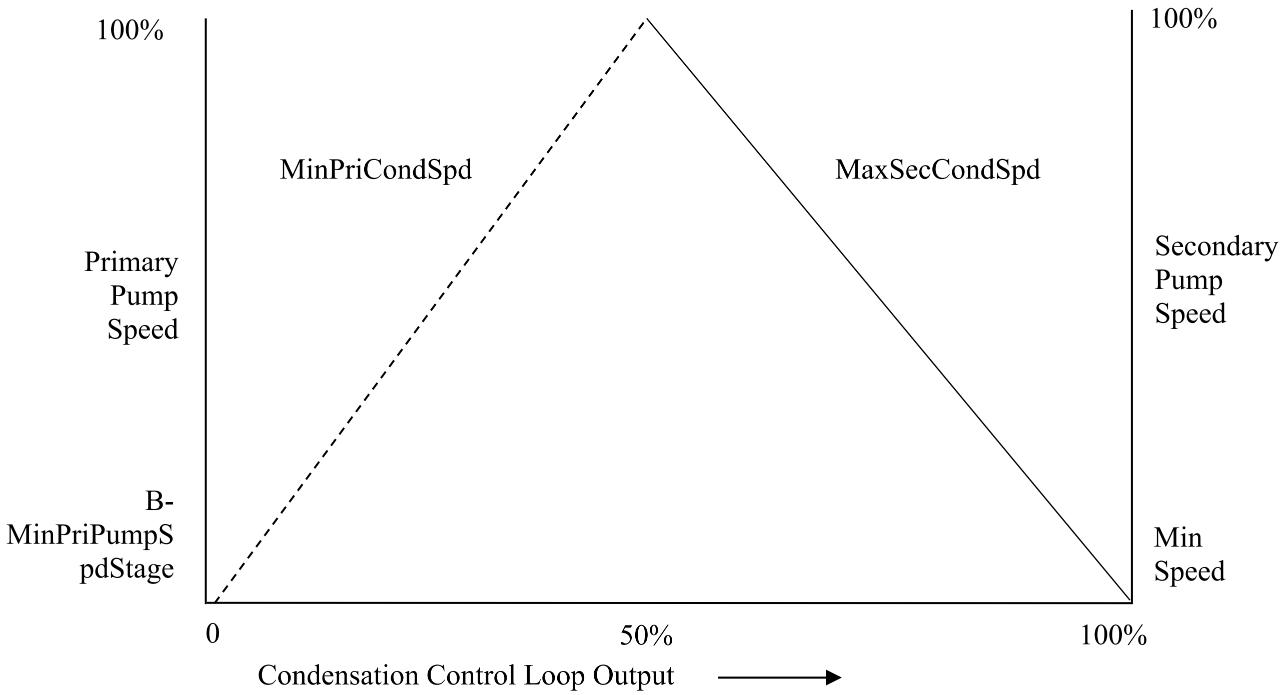
3. A reverse acting condensation control P-only loop shall reset an allowable maximum secondary pump speed variable, MaxSecCondSpd, from 100% at 140°F boiler entering temperature to minimum pump speed at 135°F boiler entering temperature.

4. Secondary pump speed condensation control loop shall be enabled whenever any secondary pump is enabled and any non-condensing boiler is enabled. Loop shall be disabled and MaxSecCondSpd set to 100% otherwise.

The above two sections assume that secondary pump VFDs are provided for condensation control instead of 3-way thermostatic mixing valves. Limiting secondary pump speed increases the ratio of primary recirculation to secondary return entering the boiler(s), which elevates boiler entering temperature much the same as a 3-way mixing valve does.

VFDs cost less than thermostatic mixing valves and the associated piping, reduce pump energy use, and allow for improved valve controllability via differential pressure pump speed control. A P-only limiting loop is specified to ensure that once boiler entering temperature dips to 135°F, maximum recirculation is provided to avoid condensation.

5. A reverse acting condensation control P-only loop shall maintain boiler entering temperature at 140°F. Loop output shall vary from 0% at 140°F boiler entering temperature to 100% at 135°F boiler entering temperature. Loop output shall be mapped as shown below and described subsequently.



a. From 0% to 50% loop output, reset an allowable minimum primary pump speed variable, MinPriCondSpd, from B-MinPriPumpSpdStage to 100%.

b. From 50% to 100% loop output, reset an allowable maximum secondary pump speed variable, MaxSecCondSpd, from 100% to minimum pump speed.

6. Condensation control loop shall be enabled whenever any non-condensing boiler is enabled. Loop shall be disabled, MinPriConSpd set to B-MinPriPumpSpd, and MaxSecCondSpd set to 100%, otherwise.

Where variable speed primary pumps are provided, they should be used first to provide condensation protection since increasing primary pump speed to increase boiler entering temperature does not starve loads like limiting secondary pump speed (or using thermostatic mixing valves for that matter) does. A slow PID loop is used for this purpose in the interest of minimizing control interaction with the secondary pump speed P-only limiting loop. The loop is biased to launch from 100% as a startup protection mechanism.

7. Refer to pump speed control logic for use of condensation control variables.

8. A thermostatic mixing valve shall maintain boiler entering temperature above 135°F.

F. Primary Hot Water Pumps

1. Primary hot water pumps shall be lead/lag controlled per Section 3.1P.3.

2. Enable lead primary hot water pump when any boiler isolation valve is commanded open. Disable the lead hot water pump when all boiler isolation valves are commanded closed.

3. Enable lead primary hot water pump when plant is enabled. Disable the lead primary hot water pump when the lead boiler is disabled and the lead boiler has been proven off for 3 minutes.

4. HW pumps shall be staged as a function of the ratio of current hot water flow, FLOWP, to design flow, PHWFdesign, and the number of pumps, N-PHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{HWFR} = \frac{FLOW_P}{PHWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot water pumps operating near their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

a. Start the next lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} > \frac{Number\ of\ Operating\ Pumps}{N} - .03$$

b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} < \frac{Number\ of\ Operating\ Pumps - 1}{N} - .03$$

Note: VFDs are not required on HW pumps by Title 24 and only required on large HW pumps used in fossil fuel boiler plants by Standard 90.1. These provisions exist because pump energy is converted to heat through friction losses at the pump and in pipe, coils, valves; reductions in HW pump energy are made up by the boilers. Energy costs are reduced because fossil fuel costs less per BTU than electricity, but savings are minor. However, constant speed pumps are not recommended on pumps with design head greater than about 50 feet due to increased noise from control valves, reduced controllability, and increased valve and pump wear.

5. When any pump is proven on, pump speed shall be controlled by a reverse acting PID loop maintaining differential pressure at HW-DPmax. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

6. Where multiple DP sensors exist, a PID loop shall run for each sensor. HW pumps shall be controlled to the high signal output of all DP sensor loops.

HW pump DP setpoint is not reset by valve position because valve position is already used to reset HWST, which saves much more energy than DP reset. As noted above, pump energy is ultimately turned into heat so reductions in HW pump energy are made up by the boilers.

7. Remote loop DP shall be maintained at a setpoint of HW-DPmax. HW-DPmax shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local primary loop DP sensor hardwired to the plant controller. Reset local DP from 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

8. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local primary DP signal at the DP setpoint output from the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

9. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of the remote loops.

The above situation arises in very large buildings where it may be impractical to homerun the remote DP sensor all the way back to the CHW plant.
The above cascading control logic prevents pump speed instability issues that would otherwise be caused by running the pump speed control loop over the BAS network. It also provides some fault tolerance should the network fail—instead of the loop either winding all the way up or all the way down, DP is controlled to the last known setpoint sent from the remote controller until network communication is restored.

10. Primary pumps shall be staged with the boilers, i.e. the number of pumps shall match the number of boilers.

11. See Section C for primary hot water pump staging sequence relative to boiler stage-up and stage-down events.

12. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler as measured by the primary flowrate less secondary flowrate at 0 gpm. Loop output shall be mapped from B-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

An offset of 0 gpm maximizes condensing operation for plants with condensing boilers at the risk of some secondary recirculation (and thus HWST degradation) due to control loop hunting. This risk is warranted to maximize condensing boiler efficiency. For non-condensing boiler plants, a small positive offset can be used to minimize the risk of secondary recirculation.

13. Primary pump speed shall be reset by a reverse acting PID loop maintaining flow through the decoupler flow meter at 0 gpm, where positive flow indicates flow from the supply to the return. Loop output shall be mapped from B-MinPriPumpSpdStage to 100% speed in proportion to loop output from 0% to 100%.

14. Primary Pump Speed Reset Requests shall be generated based on the difference (ΔT) between primary HW supply temperature and secondary loop temperature immediately downstream of the decoupler.

    a. If ΔT exceeds 2°F, send 2 requests until ΔT is less than 1.2°F.

    b. Else if ΔT exceeds 1°F, send 1 request until ΔT is less than 0.2°F.

    c. Else send 0 requests.

Using supply temperature sensors to generate requests is preferable to using return temperature sensors because it allows for a quick response to a sudden change in secondary flow (i.e. secondary supply temperature dropping below primary supply temperature by a large margin). If return temperature sensors are used, it is only possible to know that secondary recirculation is occurring when primary and secondary return temperatures match, but the degree of recirculation is unknown.

Where dynamic changes in secondary flow are expected, e.g. for plants with only a few large coils or pumped coils, then more request levels can be defined as needed, but control using one of the preceding flow matching strategies is preferred.

15. Primary HW supply temperature used in the request logic shall be the weighted average supply temperature of all boilers that are proven on. Temperatures shall be weighted by design boiler flowrates.

The above section assumes that flows through the boilers are balanced proportional to design.

16. Primary HW pump speed of all Primary HW pumps proven on shall be reset using Trim & Respond logic with the following parameters:

Variable	Value
Device	Any Primary pump proven on
SP0	100%
SPmin	B-MinPriPumpSpdStage
SPmax	100%
Td	15 minutes
T	2 minutes
I	0
R	Primary Pump Speed Reset Requests
SPtrim	-2%
SPres	+3%
SPres-max	+6%

17. Whenever MinPriCondSpd is greater than the current flow control loop speed command, the pump speed setpoint shall be MinPriCondSpd.

Condensation protection takes precedence over all other flow control logic to avoid damaging non-condensing boilers.

G. Secondary Hot Water Pumps

1. Secondary HW pumps shall be lead/lag controlled per Section 3.1P.3.

2. Enable lead secondary HW pump when plant is enabled and any load served by the pump(s) is generating a Heating Hot-Water Plant Request. Disable the lead pump otherwise.

3. Secondary HW pumps shall be staged as a function of SHWFR, the ratio of current hot water flow, FLOWS, to design flow, and the number of pumps, N-SHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{SHWFR} = \frac{FLOW_s}{SHWF_{design}}$$

Flow is used, as opposed to speed, to keep the hot water pumps operating near their best efficiency point. Staging at slightly less than design flowrate for operating pumps yields good results for most applications (note that when fewer than design pumps are enabled, pumps will be able to produce greater than design flow since they will be operating further out their pump curves). If desired, the stage down flow point can be offset slightly below the stage up point to prevent cycling between pump stages in applications with highly variable loads.

a. Start the next lag pump whenever the following is true for 10 minutes:

$$\text{SHWFR} > \frac{\textit{Number of Operating Pumps}}{N} - .03$$

b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{SHWFR} < \frac{\textit{Number of Operating Pumps} - 1}{N} - .03$$

4. Secondary HW pumps shall be staged as a function of speed.

   a. Stage up when speed exceeds 90% for 5 minutes or 99% for 1 minutes.

   b. Stage down when speed falls below 40% for 10 minutes.

When staging based on speed, the stage down point must be selected judiciously to minimize the possibility of repeat cycling (stage down point too high) and avoid getting "stuck" in a higher stage (stage down point too low). The stage up point must also be carefully selected to avoid running to the right of the operating pump's choke line before staging up, which can lead to excess vibration. For large systems with 3 or more secondary pumps, this is a particularly critical consideration and may warrant using a lower stage up speed for Stage 1 to Stage 2 than for higher stage transitions.
The above setpoints are general guidelines, but each project warrants inspection of the pump curve(s) relative to the estimated system curve to identify the proper staging points.
Note that none of these considerations are critical when staging on flow, which is preferred.

5. When any pump is proven on, pump speed shall be controlled by a reverse acting PID loop maintaining differential pressure at HW-DPmax. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

6. Where multiple DP sensors exist, a PID loop shall run for each sensor. HW pumps shall be controlled to the high signal output of all DP sensor loops.

HW pump DP setpoint is not reset by valve position because valve position is already used to reset HWST, which saves much more energy that DP reset. As noted above, pump energy is converted to heat so reductions in HW pump energy are made up by the boilers.

7. Remote loop DP shall be maintained at a setpoint of HW-DPmax. HW-DPmax shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local primary loop DP sensor hardwired to the plant controller. Reset local DP from 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

8. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local primary DP signal at the DP setpoint output from the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

9. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of the remote loops.

10. Whenever MaxSecCondSpd is less than the current DP loop speed command signal, the pump speed setpoint shall be MaxSecCondSpd.

Condensation protection takes precedence over DP control to avoid damaging non-condensing boilers.

11. Secondary HW pumps shall be staged with primary pumps.

Constant speed secondary pumps are generally not advisable on any boiler system. For non-condensing boiler systems, secondary pump VFDs are a more cost-effective means of providing condensation protection than 3-way thermostatic mixing valves and provide energy benefits as discussed in Section 3.27E.
For condensing boiler systems, constant speed secondary pumps could in theory be provided in conjunction with variable speed primary pumps to still allow for condensing operation at low loads, but a better option would be to simply provide a variable-primary system with either variable speed or constant speed pumps. The controls are simpler and as good or better energy performance will result.

H. Minimum Flow Bypass Valve

1. Bypass valve shall modulate to maintain minimum flow as measured by the hot water flow meter at a setpoint that provides minimum flow through all operating boilers, determined as follows:

    a. For the boilers operating in the stage, identify the boiler with the highest ratio, MinFlowRatio, of HW-MinFlowX to HW-DesFlowX.

    b. Calculate the minimum flow setpoint, HW-MinFlowSP as MinFlowRatio multiplied by the sum of HW-DesFlowX for the operating boilers.

If the boilers have different minimum flow to design flow ratios, just maintaining the sum of the minimum flows will not satisfy the boiler(s) with the highest relative minimum flows. Note that this also requires that boilers be balanced to distribute flow proportional to their design flow.

2. During stage changes that require one boiler to be enabled while another is disabled, the minimum flow setpoint, HW-MinFlowSP shall temporarily change to include the HW-MinFlowX of both the boiler to be enabled and the boiler to be disabled prior to starting the newly enabled boiler. See staging events in Section B.4 for timing of setpoint change to this transitionary value.

3. A reverse acting PID loop shall maintain minimum flow as measured by the hot water flow meter at setpoint. Reset valve position from 0% open at 0% loop output to 100% open at 100% loop output.

4. A reverse acting PID loop shall maintain minimum flow as measured by the hot water flow meter at setpoint. Reset the variable MinFlowVlvPos from 0% open at 0% loop output to 100% open at 100% loop output.

5. Minimum flow bypass valve position shall be the larger of MinFlowVlvPos and MinCondVlvPos defined in the Condensation Control Section.

6. When any HW pump is proven on, the bypass valve control loop shall be enabled. The valve shall be opened otherwise. When enabled, the bypass valve minimum flow PID loop shall be biased 100% (valve 100% open).

Biasing the minimum flow PID loop to 100% upon start up ensures that the valve does not slam shut upon enabling the loop. Starting with the valve fully open is appropriate because flows are often very low when the plant is first turned on.

I. Performance Monitoring

1. All calculations listed below shall be performed at least once every 30 seconds. Time averaged values shall be recorded at least once every 5 minutes. The averaging period shall equal the trending interval.

2. Total Plant Gas Use. Convert measured gas usage to Btu/h by a user adjustable conversion factor (default value = 1000 Btu/h per ft3 of gas; actual value set by user from utility bill).

3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, FLOWP; primary hot water return temperature, PHWRT; and primary hot water supply temperature, PHWST.

$$Q_{actual} = 0.49 * \ FLOW_P(PHWST - PHWRT) \ [\frac{\mathrm{kbtu}}{\mathrm{h}}]$$

4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, FLOWS; secondary hot water return temperature, SHWRT; and secondary hot water supply temperature leaving the plant, SHWST.

$$Q_{actual} = 0.49 * \ FLOW_S(SHWST - SHWRT)[\frac{\mathrm{kbtu}}{\mathrm{h}}]$$

5. Boiler Load. Calculate load for each operating boiler (as applicable) using flowrate through the boiler, FLOWB; hot water return temperature entering the boiler, HWRTB; and hot water supply temperature leaving the boiler, HWSTB. Inputs to the below equation shall be determined per the following rules.

$$Q_D = \ 0.49 * FLOW_B(HWST_B - HWRT_B)[\frac{kbtu}{h}]$$

Where flow through each boiler is individually measured using a flow meter, FLOWB shall be the flow measured by the boiler's associated flow meter.

a. FLOWB shall be assumed proportional to design flow through all operating boilers in the circuit.

b. FLOWB shall be assumed equal to the design flowrate through the boiler for the current stage as determined during balancing.

c. HWRTB shall be the return temperature entering the boiler as read by a hardwired BAS sensor if available. If a hardwired sensor is unavailable, temperature shall be read from a sensor internal to the boiler through its network interface. If multiple boilers are enabled, the temperature shall be the average return temperature read from the operating boilers through the network interface.

d. HWSTB shall be a hardwired temperature sensor at the outlet of the equipment if available. If a hardwired sensor is unavailable, temperature shall be read from a sensor internal to the boiler through its network interface. Only if neither of the above is available shall a common supply temperature sensor (i.e. one measuring the output from multiple boilers), be used.

6. Calculate plant thermal efficiency as equal to measured plant load divided by measured gas consumption.

7. Summary Data

a. For each boiler, statistics shall be calculated for runtime, cumulative load (btu), average demand (btu/h), and peak demand (btu/h). All statistics shall be presented on an instantaneous, year-to-date, and previous year basis.

b. For the total plant, statistics shall be calculated for runtime, energy use (btu), cumulative load (btu), average demand (btu/h), peak demand (btu/h), and actual efficiency (btu/btu). All statistics shall be presented on an instantaneous, year-to-date, and previous year basis.

Below is an example summary of the performance monitoring parameters. Summary table should be edited based on plant configuration, available statistics and desired units of measurement.

	Instantaneous				*Year-to-date*						*Previous Year*					
	Lifetime Runtime (hours)	*Gas Demand (kBtu/h)*	*HW Demand (kBtu/h)*	*Efficiency*	*Runtime (hours)*	*Gas Use (MMBtu)*	*HW Load (MMBtu)*	*Avg HW Demand (kBtu/h)*	*Peak HW Demand (kBtu/h)*	*Avg Efficiency*	*Runtime (hours)*	*Gas Use (MMBtu)*	*HW Load (MMBtu)*	*Avg HW Demand (kBtu/h)*	*Peak HW Demand (kBtu/h)*	*A Effic*
B-1																
B-2																
Total Plant																

J. Alarms

1. Maintenance interval alarm when pump has operated for more than 3000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

2. Maintenance interval alarm when boiler has operated for more than 2000 hours as indicated by the Staging Runtime: Level 4. Reset the Staging Runtime interval counter when alarm is acknowledged.

3. Boiler alarm: Level 2

4. Low boiler leaving hot water temperature (more than 15°F below setpoint) for more than 15 minutes when boiler has been enabled for longer than 15 minutes: Level 3

5. Pump alarm is indicated by the status input being different from the output command for 15 seconds.

a. Commanded on, status off: Level 2. Do not evaluate alarm until the equipment has been commanded on for 15 seconds.

b. Commanded off, status on: Level 4. Do not evaluate alarm until the equipment has been commanded off for 60 seconds.

6. Valve alarm is indicated by the end switch status being different from the output command for 90 seconds.

    a. Commanded open, status not open: Level 2. Do not evaluate alarm until the equipment has been commanded open for 90 seconds.

    b. Commanded closed, status not closed: Level 4. Do not evaluate alarm until the equipment has been commanded closed for 90 seconds.

7. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2

8. Sensor Failure:

    a. Sensor shall be deemed outside of its widest possible operating range if any of the following are true:

        1) Feedback less than 2 mA from any 4 to 20 mA transducer; or

        2) Temperature reading less than 0°F from any temperature sensor.

    b. Any sensor that goes outside of its widest possible operating range.

        1) If the sensor is used for monitoring only: Level 3.

        2) If the sensor is used for control: Level 2.

K. Automatic Fault Detection and Diagnostics

The Automatic Fault Detection and Diagnostics (AFDD) routines for hot water plants continually assess plant performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the Operating State of the plant, as determined by the positions of the isolation valves and statuses of pumps. Time delays are applied to the evaluation and reporting of fault conditions, to suppress false alarms. Fault conditions that pass these filters are reported to the building operator as alarms along with a series of possible causes.
These equations assume that the plant is equipped with isolation valves, as well as a pump status monitoring. If any of these components are not present, the associated tests, and variables should be omitted from the programming.
Note that these faults rely on reasonably accurate measurement of water temperature. Extra precision sensors installed in thermowells with thermal paste are recommended for best accuracy.

1. AFDD conditions are evaluated continuously for the plant.

2. The Operating State (OS) of the plant shall be defined by the commanded positions of the valves and status feedback from the pumps in accordance with the following table. For hybrid plants, determine the Operating State for each primary loop.

The Operating State is distinct from and should not be confused with the hot water plant stage. OS#1 – OS#3 represent normal operation during which a fault may nevertheless occur, if so determined by the fault condition tests below.

Operating State	Boiler Isolation Valve or Dedicated Primary HW Pump Status	PHW Pump Status (if primary-only) or SHW Pump Status (if primary-secondary)
#1: Disabled	All Closed/Off	All Off
#2: One boiler enabled	One Open/On, All Others Closed/Off	Any On
#3: More than one boiler enabled	Any Open/On	Any On

3. The following points must be available to the AFDD routines for the hot water plant:

   a. DP = Hot water loop differential pressure (each loop, where applicable)

   b. DPSP = Hot water loop differential pressure setpoint (each loop, where applicable)

   c. FLOWP = Primary hot water flow (each primary loop, where applicable)

   d. FLOWS = Secondary hot water flow (each secondary loop, where applicable)

   e. MFBPV = Hot water minimum flow bypass valve command; 0% ≤ MFBPV ≤ 100%

   f. HW-MinFlowSP = Effective minimum hot water flow setpoint (equal to MinFlowRatio multiplied by the sum of HW-MinFlowX of operating boilers)

   g. SpeedHWP = Secondary hot water pump speed command; 0% ≤ SpeedHWP ≤ 100%

   h. SpeedHWP = Hot water pump speed command; 0% ≤ SpeedHWP ≤ 100%

   i. StatusPHWP = Lead primary hot water pump status (each primary loop, where applicable)

   j. StatusSHWP = Lead secondary hot water pump status (each secondary loop, where applicable)

   k. HWST = Common hot water supply temperature

   l. HWSTSP = Hot water supply temperature setpoint

   m. HWRT = Average boiler entering water temperature (each loop)

   n. HWISOB-x = B-x hot water isolation valve commanded position (each boiler)

   o. PGAUGE = Hot water system gauge pressure

4. The following values must be continuously calculated by the AFDD routines:

   a. 5-minute rolling averages with 1-minute sampling time of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently

1) HWSTAVG = rolling average of the common hot water supply temperature (each primary loop, where applicable)

2) HWRTAVG = rolling average of the average boiler entering water return temperature.

3) PGAUGE, AVG = rolling average of hot water system gauge pressure

4) DPAVG = rolling average of loop differential pressure (each loop, where applicable)

5) FLOWP, AVG = rolling average of primary hot water flow (each loop, where applicable)

6) FLOWS, AVG = rolling average of secondary hot water flow (each loop, where applicable)

7) HWSTB-x = rolling average of B-x hot water supply temperature (each boiler)

8) HWRTB-x = rolling average of B-x hot water return temperature (each boiler)

b. HWFlowB-X (each boiler)

1) For plants with headered primary hot water pumps: 1 if HWISOB-X = open, 0 if HWISOB-X = closed

2) For plants with dedicated primary hot water pumps: 1 if StatusPHWP = on, 0 if StatusPHWP = off

c. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)

d. ΔStage = number of hot water plant stage changes during the previous 60 minutes (moving window)

e. StartsB-x = number of B-x starts in the last 60 mins (each boiler)

5. The following internal variables shall be defined. All parameters are adjustable by the operator, with initial values as given below:

The default values have been intentionally biased towards minimizing false alarms at the expense of missing real alarms. This avoids excessive false alarms that will erode user confidence and responsiveness. However, if the goal is to achieve the best possible energy performance and system operation, these values should be adjusted based on field measurement and operational experience.
Values for physical factors such as pump heat and sensor error can be measured in the field or derived from trend logs and hardware submittals. Likewise, the switch delays can be refined by observing the time required to achieve quasi steady state operation in trend data.
Other factors can be tuned by observing false positives and false negatives (i.e., unreported faults). If transient conditions or noise cause false alarms, increase the alarm delay. Likewise, failure to report real faults can be addressed by adjusting the temperature, pressure or flow thresholds.

Variable Name	Description	Default Value
ƐHWT	Temperature error threshold for hot water temperature sensors	5°F
Retain the following variable for primary-secondary and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.		
ƐDP	Differential pressure error threshold for DP sensor	2 psi
ƐFM	Flow error threshold for flow meter	20 gpm
Retain the following variable for plants with variable speed pumps. Delete otherwise.		
ƐVFDSPD	VFD speed error threshold	5%
Retain the following variable for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
ƐMFBVP	Minimum flow bypass valve position error threshold	5%
Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.		
ETPreChargePress	Hot water system expansion tank pre-charge pressure	See mechanical schedule (psig)
CondTemp	Boiler condensing temperature threshold	135°F
BStartsMAX	Maximum number of boiler starts during the previous 60 minutes (moving window)	2
ΔOSMAX	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	2
ΔStageMAX	Maximum number of hot water plant stage changes during the previous 60 minutes (moving window)	2
StageDelay	Time in minutes to suspend Fault Condition evaluation after a change in stage	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

TestModeDelay ensures that normal fault reporting occurs after the testing and commissioning process is completed as prescribed in Section 3.27K.12.

6. The following are potential Fault Conditions that can be evaluated by the AFDD routines. If the equation statement is true, then the specified fault condition exists. The Fault Conditions to be evaluated at any given time will depend on the Operating State of the hot water plant.

Retain the following fault condition for plants with any hot water pumps controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor.			
FC#1	Equation	DPAVG > ƐDSP and StatusHWP = Off	Applies to OS #1
	Description	Differential pressure is too high with the hot water pumps off	
	Possible Diagnosis	DP sensor error	
Retain the following fault condition if there is a flow meter in the primary loop. Delete otherwise. Duplicate the following fault condition for each primary loop with a flow meter.			
FC#2	Equation	FLOWP, AVG > ƐFM and StatusPHWP = Off	Applies to OS #1
	Description	Primary hot water flow is too high with the hot water pumps off	
	Possible Diagnosis	Flow meter error	
Retain the following fault condition for primary-secondary plants with a flow meter in the secondary loop. Delete otherwise. Duplicate the following fault condition for each secondary loop flow meter.			
FC#3	Equation	FLOWS, AVG > ƐFM and StatusSHWP = Off	Applies to OS #1
	Description	Secondary hot water flow is too high with the associated hot water pumps off	
	Possible Diagnosis	Flow meter error	
Retain the following fault condition for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise. Duplicate the following fault condition for each differential pressure sensor and/or each secondary loop where pump speed is controlled to maintain differential pressure.			
FC#4	Equation	DPAVG < DPSP – ƐDP and SpeedHWP ≥ 99% - ƐVFDSPD	Applies to OS #2, #3
	Description	Hot water loop differential pressure is too low with hot water pump(s) at full speed.	

	Possible Diagnosis	Problem with VFD Mechanical problem with pump(s) Pump(s) are undersized Differential pressure setpoint is too high HWST is too low Primary flow is higher than the design flow of the operating boilers	
	Retain the following fault condition for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
FC#5	Equation	FLOWP, AVG < HW-MinFlowSp – ƐFM and MFBPV ≥ 99% - ƐMFBPV	Applies to OS #2, #3
	Description	Primary hot water flow is too low with the minimum flow bypass valve fully open.	
	Possible Diagnosis	Problem with minimum flow bypass valve Problem with boiler isolation valves Minimum loop differential pressure setpoint too low	
	For hybrid plants, duplicate the following fault condition for each primary loop.		
FC#6	Equation	HWSTAVG + ƐHWT < HWSTSP	Applies to OS #2, #3
	Description	Hot water supply temperature is too low.	
	Possible Diagnosis	Mechanical problem with boilers Primary flow is higher than the design flow of the operating boilers Deviation between the internal boiler hot water supply temperature sensor and the plant hot water supply temperature is too high (i.e. boiler sensor is out of calibration).	
	Retain the following fault condition for plants where system gauge pressure is monitored. Delete otherwise.		
FC#7	Equation	PGAUGE, AVG < 0.9 * ETPreChargePress	Applies to OS #1 – #3
	Description	Hot water system gauge pressure is too low	
	Possible Diagnosis	Possible hot water system leak	
	Retain the following fault condition for plants with a condensing boiler. Delete otherwise.		
FC#8	Equation	HWRTAVG - ƐHWT > CondTemp	Applies to OS #2, #3
	Description	Hot water return temperature is too high for condensing to occur.	
	Possible Diagnosis	Hot water supply temperature setpoint is too high. Hot water load is too low. High bypass flow is raising the entering water temperature. Hot water coils are not designed for condensing at current loads.	

Retain the following fault condition for plants with a non-condensing boiler. Delete otherwise.			
FC#9	Equation	HWRTAVG + ƐHWT < CondTemp	Applies to OS #2, #3
	Description	Hot water return temperature is too low. Condensing is likely to occur.	
	Possible Diagnosis	Hot water supply temperature setpoint is too low.	
Retain the following fault condition if any boiler has a network interface and the plant has a common hot water supply temperature sensor at the discharge of the boiler(s). Delete otherwise. For hybrid plants, duplicate the following fault condition for each primary loop.			
FC#10	Equation	| (∑(HW-FlowB-X * HWSTB-X) / ∑HW-FlowB-X) - HWSTAVG | > ƐHWT	Applies to OS #2
	Description	Deviation between the active boiler hot water supply temperature and the common hot water supply temperature is too high.	
	Possible Diagnosis	A hot water supply temperature sensor is out of calibration	
Retain the following fault condition if any boiler has a network interface and the plant has a common hot water return temperature sensor at the inlet of the boiler(s). Delete otherwise. For hybrid plants, duplicate the following two fault condition for each primary loop.			
FC#11	Equation	| (∑(HW-FlowB-X * HWRTB-X) / ∑HW-FlowB-X) - HWRTAVG | > ƐHWT	Applies to OS #2
	Description	Deviation between the active boiler hot water return temperature and the common boiler entering water temperature is too high.	
	Possible Diagnosis	A hot water return temperature sensor is out of calibration	
FC#12	Equation	ΔOS > ΔOSMAX	Applies to OS #1 – #3
	Description	Too many changes in Operating State	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#13	Equation	ΔStartsB-x > ΔBStartMAX	Applies to OS #2, #3
	Description	Too many boiler starts	
	Possible Diagnosis	Boiler is cycling due to load loads Boiler is oversized and/or has insufficient turndown. Boiler stage-up threshold may be set too low.	
FC#14	Equation	ΔStage > ΔStageMAX	
	Description	Too many stage changes	

	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	Applies to OS #1 – #3

7. A subset of all potential fault conditions is evaluated by the AFDD routines. The set of applicable fault conditions depends on the Operating State of the plant:

   a. In OS #1 (Disabled), the following Fault Conditions shall be evaluated:

      1) FC#1: Differential pressure is too high with the hot water pumps off

      2) FC#2: Primary hot water flow is too high with the primary hot water pumps off

      3) FC#3: Secondary hot water flow is too high with the associated secondary hot water pumps off

      4) FC#7: Hot water system gauge pressure is too low

      5) FC#10: Too many changes in operating state

      6) FC#12: Too many stage changes

   b. In OS#2 (One boiler enabled), the following Fault Conditions shall be evaluated:

      1) FC#4: Hot water loop differential pressure is too low with hot water pump(s) at full speed.

      2) FC#5: Primary hot water flow is too low with the minimum flow bypass valve fully open.

      3) FC#6: Hot water supply temperature is too low

      4) FC#7: Hot water system gauge pressure is too low

      5) FC#8: Hot water return temperature is too high for condensing to occur

      6) FC#9: Hot water return temperature is too low. Condensing is likely to occur

      7) FC#10: Deviation between the active boiler hot water supply temperature and the common hot water supply temperature is too high.

      8) FC#11: Deviation between the active boiler hot water return temperature and the common boiler entering water temperature is too high.

      9) FC#12: Too many changes in Operating State

      10) FC#13: Too many boiler starts

      11) FC#14: Too many stage changes

c. In OS#3 (More than one boiler enabled), the following Fault Conditions shall be evaluated:

1) FC#4: Hot water loop differential pressure is too low with hot water pump(s) at full speed.

2) FC#5: Primary hot water flow is too low with the minimum flow bypass valve fully open.

3) FC#6: Hot water supply temperature is too low

4) FC#7: Hot water system gauge pressure is too low

5) FC#8: Hot water return temperature is too high for condensing to occur

6) FC#9: Hot water return temperature is too low. Condensing is likely to occur

7) FC#12: Too many changes in Operating State

8) FC#13: Too many boiler starts

9) FC#14: Too many stage changes

8. For each boiler, the operator shall be able to suppress the alarm for any Fault Condition.

9. Evaluation of Fault Conditions shall be suspended under the following conditions:

a. When no pumps are operating.

b. When all equipment associated with a fault condition in maintenance mode.

c. For a period of StageDelay minutes following a change in plant stage.

10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.

11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.

12. Test Mode shall temporarily set StageDelay and AlarmDelay to 0 minutes for a period of TestModeDelay minutes to allow instant testing of the AFDD system and to ensure normal fault detection occurs after testing is complete.

13. When a Fault Condition is reported to the operator, it shall be a Level 3 alarm and shall include the description of the fault and the list of possible diagnoses from the table in 3.27K.6.

3.28 AIR-TO-WATER HEAT PUMP/CHILLER PLANT

A. Heating Parameters

1. HWSTmax, the highest hot water supply temperature setpoint = 110°F

2. HW-LOT, the outdoor air lockout temperature above which the heating plant is prevented from operating = 70°F

3. HWFdesign, design primary loop flow = 320

4. HW-DPmax = as determine under 230593 Testing, Adjusting and Balancing.

5. QH, design capacity in KBtu/h for each AWHP = 800

B. Cooling Parameters:

1. CHWSTmin, the lowest chilled water supply temperature setpoint = 50°F

2. CH-LOT, the outdoor air lockout temperature below which the cooling plant is prevented from operating = 55°F.

3. CHWFdesign, design primary loop flow in gpm = 470 gpm

4. CHW-DPmax = as determine under 230593 Testing, Adjusting and Balancing.

5. QC, design capacity in tons for each AWHP = 81 tons

C. Lead/Lag Alternation

1. AWHPs shall be lead/lag controlled per Paragraph 3.1P (regardless of heating and cooling modes).

2. If an AWHP is manually overridden to heating mode, cooling mode or off, follow procedure in Paragraph 3.28E.4

D. Heat Pump Mode

1. The lead AWHP shall be the lead Heat Pump per lead/lag logic unless it is already operating in Chiller Mode in which case the lag AWHP shall operate in Heat Pump Mode.

2. Lead Heat Pump

a. The lead AWHP shall operate in Heat Pump Mode if

1) It has been disabled for at least 15 minutes and:

2) Number of Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

3) OAT<HW-LOT, and

4) The heating plant enable schedule is active. The enabling schedule allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the heating plant. The default schedule shall be 24/7 (adjustable).

b. Disable the lead AWHP from Heat Pump Mode if after a minimum of 10 minutes runtime:

1) Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

2) OAT>HW-LOT – 1°F, or

3) The heating enable schedule is inactive.

3. Lag Heat Pump

a. The lag AWHP shall operate in Heat Pump Mode if

1) Outdoor air temperature is less than the Cooling Lockout Temperature, and

2) The lead AWHP is operating in Heat Pump Mode and has been proven on for at least 15 minutes (adjustable), and

3) HW Plant Reset is at 100% for at least 10 minutes, and

4) Lag AWHP is not already running in Cooling mode.

b. Disable the lag AWHP from Heat Pump Mode if after a minimum of 10 minutes runtime:

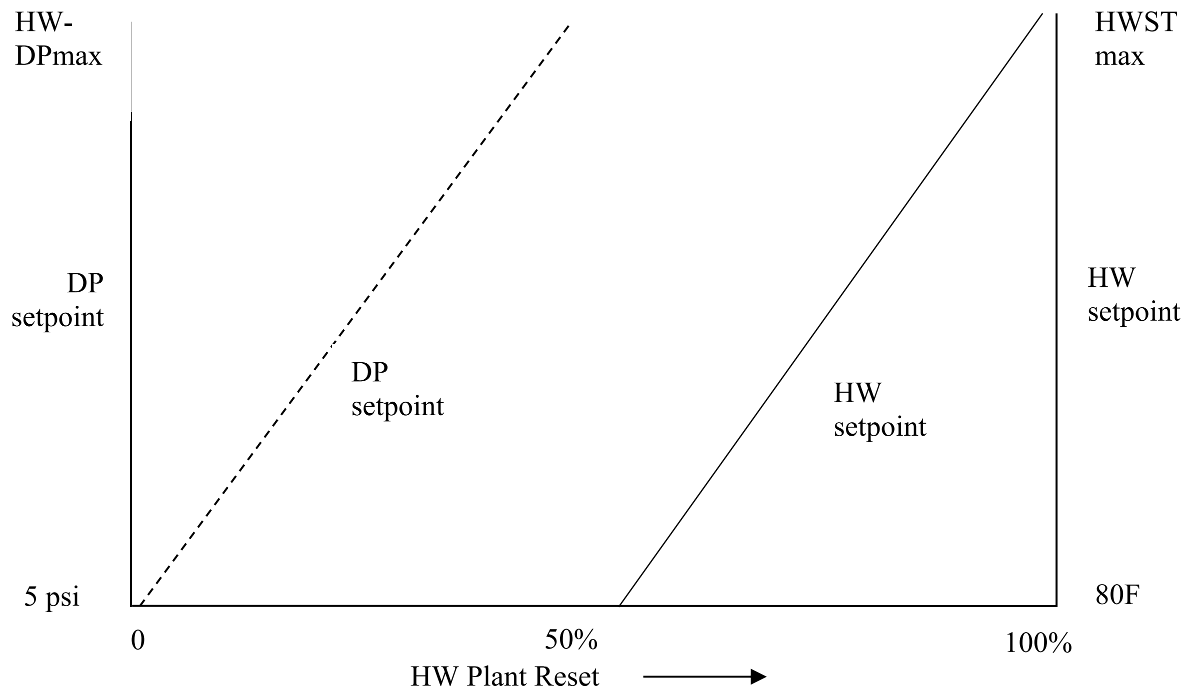
1) Outdoor air temperature is greater than the Cooling Lockout Temperature, or

2) The lead AWHP is disabled, or

3) The current load from BTU meter is less than QH * 0.9 and the HWS temperature is above setpoint minus 2°F

4. Hot Water Plant Reset

a. Hot water supply temperature setpoint HWSTsp and pump differential pressure setpoint HW-DPsp shall be reset based on the current value of the logic variable called "HW Plant Reset" as shown below and described subsequently.



b. HW Plant Reset shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters:

Variable	Value
Device	Any HW Pump
SP_0	100%
SP_{min}	0%
SP_{max}	100%
T_d	15 minutes
T	5 minutes
I	2
R	Hot Water Reset Request
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res-max}$	+7%

c. HWST Plant Reset loop shall be enabled when the heating plant is enabled, and disabled when the plant is disabled.

d. When a plant stage change is initiated, HW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

5. Secondary Hot Water Pumps

a. HW pumps shall be lead/lag controlled per Paragraph 3.1P.

b. Run lead HW pump when either AWHP is in Heating Mode is enabled and shut off otherwise.

c. HW pumps shall be staged as a function of HWFR, the ratio of current secondary water flow, GPM_{HW}, to design flow.

$$\text{HWFR} = \frac{GPM_{CHW}}{HWF_{design}}$$

1) Start the lag pump whenever the HWFR>0.47 for 10 minutes:

2) Shut off the lag pump whenever the HWFR≤0.47 for 10 minutes:

d. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint HW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed (10%) at 0% to maximum pump speed at 100%.

E. Chiller Mode

1. The lead AWHP shall be the lead Chiller per lead/lag logic unless it is already operating in Heat Pump Mode in which case the lag AWHP shall operate in Chiller Mode.

2. Lead Chiller

a. The lead AWHP shall operate in Chiller Mode if

1) It has been disabled for at least 15 minutes and

2) Number of Chiller Plant Requests > I (I= Ignores = 0, adjustable), and

3) OAT>CH-LOT, and

4) The cooling plant enable schedule is active. The enabling schedule allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the chiller plant. The default schedule shall be 24/7 (adjustable).

b. Disable the lead AWHP from Chiller Mode if it has run for a minimum of 10 minutes runtime and

1) Number of Chiller Plant Requests ≤ I for 3 minutes, or

2) OAT<CH-LOT – 1°F, or

3) The cooling plant enable schedule is inactive.

3. Lag Chiller

a. The lag AWHP shall operate in Chiller Mode if

1) Outdoor air temperature is greater than the Heating Lockout Temperature, and

2) The lead AWHP is operating in Chiller Mode and has been proven on for at least 15 minutes (adjustable), and

3) CHW Plant Reset is at 100% for at least 10 minutes, and

4) Lag AWHP is not already running in Heat Mode.

b. Disable the lag AWHP from Chiller Mode if after a minimum of 10 minutes runtime:

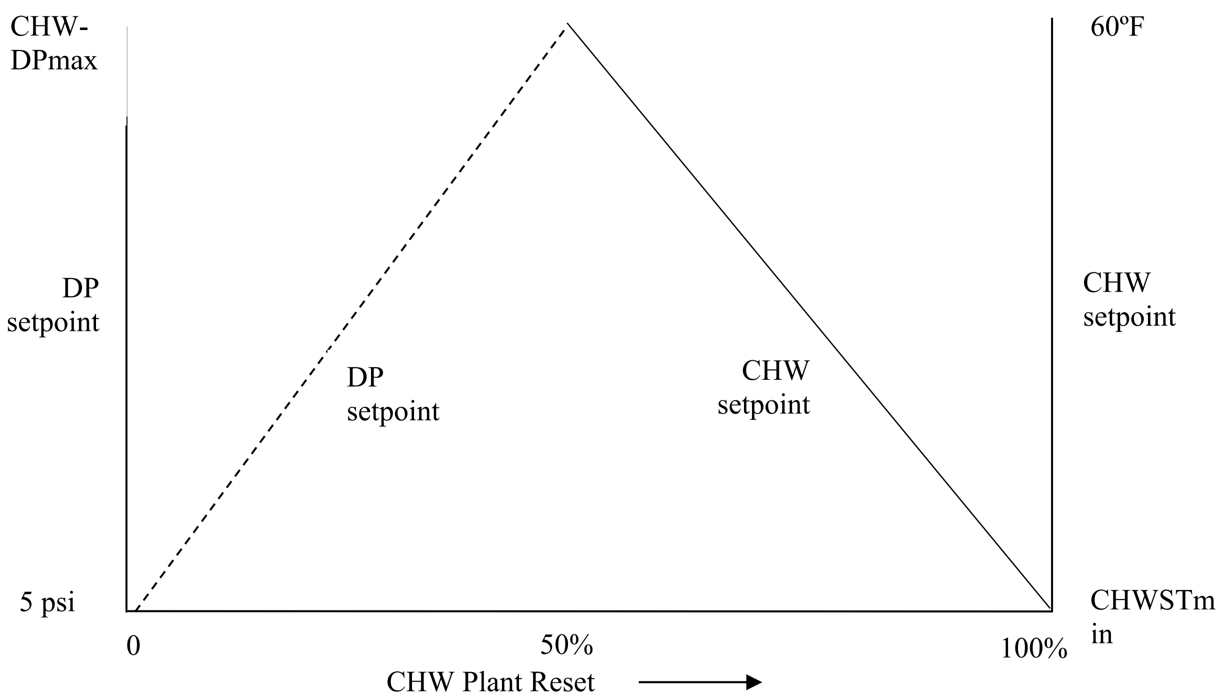
1) Outdoor air temperature is less than the Cooling Lockout Temperature, or

2) The lead AWHP is disabled, or

3) The current load from BTU meter is less than QC * 0.9 and the CHWS temperature is below setpoint plus 2°F

4. Chilled Water Plant Reset

a. Chilled water supply temperature setpoint CHWSTsp and pump differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called “CHW Plant Reset” as shown below and described subsequently.



b. CHW Plant Reset shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters:

Variable	Value
Device	Any CHW Pump
SP_0	100%
SP_{min}	0%

SP_{max}	100%
T_d	15 minutes
T	5 minutes
I	2
R	Chilled Water Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res-max}$	+7%

c. CHWST Plant Reset loop shall be enabled when the cooling plant is enabled, and disabled when the plant is disabled.

d. When a plant stage change is initiated, CHW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

5. Secondary Chilled Water Pumps

a. CHW pumps shall be lead/lag controlled per Paragraph 3.1P.

b. Run lead CHW pump when Cooling Plant is enabled and shut off otherwise.

c. CHW pumps shall be staged as a function of CHWFR, the ratio of current secondary water flow, GPM_{CHW}, to design flow.

$$\text{CHWFR} = \frac{GPM_{CHW}}{CHWF_{design}}$$

1) Start the lag pump whenever the CHWFR>0.47 for 10 minutes:

2) Shut off the lag pump whenever the CHWFR≤0.47 for 10 minutes:

d. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed (10%) at 0% to maximum pump speed at 100%.

F. AWHP Mode Changes

1. On a call for AWHP Heat Pump Mode:

a. Set changeover switch to hot water system.

b. Wait 75 seconds to allow valves to change position

c. Command AWHP to Heat Pump mode. Internal primary pump starts automatically via AWHP controller.

2. If AWHP is in Heat Pump Mode and it is to be disabled:

   a. Command AWHP to off

   b. Lock AWHP out of Chiller Mode for a minimum 15 minutes (to allow water to cool)

3. On a call for AWHP Chiller Mode:

   a. Set changeover switch to chilled water system.

   b. Wait 75 seconds to allow valves to change position

   c. Command AWHP to Chiller mode. Internal primary pump starts automatically via AWHP controller.

4. If AWHP is in Chiller Mode and it is to be disabled:

   a. Command AWHP to off

   b. Lock AWHP out of Heat Pump Mode for a minimum 15 minutes (to allow water to warm)

G. Performance Monitoring

1. Total plant power. Calculate total plant power as the sum of AWHP power and pump power.

2. Summary Data. For each AWHP and total plant, statistics shall be retained and displayed on graphic for runtime, average actual efficiency (kW/ton), and average demand (tons) and load (ton-hours). Show on AWHP plant graphic: instantaneous values, year-to-date totals/averages and previous-year totals/averages.

H. Alarms

1. Maintenance interval alarm when pump has operated for more than 1500 hours: Level 5. Reset interval counter when alarm is acknowledged.

2. Maintenance interval alarm when AWHP has operated for more than 1000 hours: Level 5. Reset interval counter when alarm is acknowledged.

3. AWHP alarm: level 2

4. Pump alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

5. High chiller leaving chilled water temperature (more than 5°F above setpoint) for more than 15 minutes when chiller has been enabled in cooling mode for longer than 15 minutes: Level 3

6. Low heat pump leaving hot water temperature (more than 5°F below setpoint) for more than 15 minutes when heat pump has been enabled in heating mode for longer than 15 minutes: Level 3

7. Pump alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

    a. Commanded on, status off: Level 2

    b. Commanded off, status on: Level 4

8. CHW System low gauge pressure

    a. if CHW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

    b. if CHW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

9. HW System low gauge pressure

    a. if HW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

    b. if HW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

3.29 2-PIPE AND 4-PIPE AIR-TO-WATER CHILLED WATER PLANT

A. Cooling Parameters:

1. Temperature Setpoints

    a. CHWSTmin, the lowest chilled water supply temperature setpoint = 54°F

    b. CH-LOT, the outdoor air lockout temperature below which the chiller plant is prevented from operating = 60°F.

2. Cooling Capacity

    a. QCdesign, design plant capacity in tons = 195 tons

    b. QCchiller, design capacity in tons for each chiller:

        1) Q1 = 65 tons

        2) Q2 = 65 tons

        3) Q3 = 65 tons

    c. CHWFdesign, design primary loop flow in gpm = 570 gpm

3. Minimum Cycling Load

   a. MinUnloadTons, the load below which the chiller will begin cycling

      1) MinUnloadTons1 = 16.3 tons

      2) MinUnloadTons2 = 16.3 tons

      3) MinUnloadTons3 = 16.3 tons

4. CHW Pump DP setpoint

   a. CHW-DPmax = as determine under 230593 Testing, Adjusting and Balancing.

B. Heating Parameters

1. Temperature Setpoints

   a. HWSTmax, the highest hot water supply temperature setpoint = 110°F

   b. HW-LOT, the outdoor air lockout temperature above which the boiler plant is prevented from operating = 70°F

2. Capacity

   a. QHdesign, design plant capacity = 2400 KBtu/h

   b. QHstage, design capacity in KBtu/h for each heat pump

      1) Q1 = 800

      2) Q2 = 800

      3) Q2 = 800

   c. HWFdesign, design primary loop flow = 320

3. Minimum Cycling Load

   a. MinUnloadMBH, the load below which the chiller will begin cycling

      1) MinUnloadMBH1 = 200

      2) MinUnloadMBH2 = 200

      3) MinUnloadMBH3 = 200

4. HW Pump DP setpoint

   a. HW-DPmax = as determine under 230593 Testing, Adjusting and Balancing.

C. Cooling Plant Enable/Disable

1. The Cooling Plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the chiller plant. The default schedule shall be 24/7 (adjustable).

2. Enable the Cooling Plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

    a. Number of Chiller Plant Requests > I (I= Ignores = 0, adjustable), and

    b. OAT>CH-LOT, and

    c. The cooling plant enable schedule is active.

3. Disable the Cooling Plant when it has been enabled for at least 15 minutes and:

    a. Number of Chiller Plant Requests ≤ I for 3 minutes, or

    b. OAT<CH-LOT – 1°F, or

    c. The cooling plant enable schedule is inactive.

D. Heating Plant Enable/Disable

1. The Heating Plant shall include an enabling schedule that allows operators to lock out the plant during off-hours, e.g. to allow off-hour operation of HVAC systems except the heating plant. The default schedule shall be 24/7 (adjustable).

2. Enable the Heating Plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

    a. Number of Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

    b. OAT<HW-LOT, and

    c. The heating plant enable schedule is active.

3. Disable the Heating Plant when it has been enabled for at least 15 minutes and:

    a. Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

    b. OAT>HW-LOT – 1°F, or

    c. The heating enable schedule is inactive.

E. Lead/Lag Alternation

1. 2-pipe heat pump/chillers (AWHP) shall be lead/lag controlled per Paragraph 3.1P, both in heating and cooling modes.

2. If the Heating Plant and Cooling Plant are both enabled, the 4-pipe air-to-water heat recovery (AWHR) heat pump/chiller shall operate in Stage 1 for both Plants. Else it shall

operate in Stage 3 and the 2-pipe AWHPs shall operate in Stages 1 and 2 based on lead/lag order.

3. 2-pipe AWHPs

a. If a AWHP is on in one heating/cooling mode, it is removed from the staging order of the opposite mode until it has been off for 15 minutes.

b. If a AWHP is commanded on in a desired heating/cooling mode:

1) Open changeover valves for desired cooling/heating mode.

2) Enable AWHP

c. If a AWHP is commanded off:

1) Disable AWHP and wait 3 minutes or as required for internal shutdown cycle to time out (determine empirically).

2) Close all four changeover valves.

F. Cooling Plant

1. Staging

a. Chillers are staged in part based on required capacity, $Q_{required}$, relative to nominal capacity of a given stage, Q_{stage}. This ratio is the operative part load ratio, *OPLR*.

b. If both primary and secondary chilled water temperatures and flow rates are available, use those in the primary for calculating $Q_{required}$.

c. All chillers are assumed to have integral primary pumps controlled by chiller controller.

d. $Q_{required}$ is calculated based on chilled water return temperature (*CHWRT*), active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the associated circuit flow meter (*GPM*), as shown in the equation below. $Q_{required}$ used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = \frac{GPM \quad (CHWRT - CHWST_{SP})}{24} \ [tons]$$

e. When a stage up or stage down transition is initiated, hold $Q_{required}$ fixed at its last value until the longer of the successful completion of the stage change (e.g. lag chiller proven on) and 15 minutes.

f. Q_{stage} is calculated as the sum of the design capacities of the chillers in a given stage.

g. *OPLR* shall be calculated as follows:

$$OPLR_{stage} = \frac{Q_{required}[tons]}{Q_{stage}[tons]}$$

h. Staging part load ratio, *SPLR,* shall be 90%:

i. Staging shall be executed per the table below subject to the following requirements.

1) Each stage shall have a minimum runtime of 15 minutes.

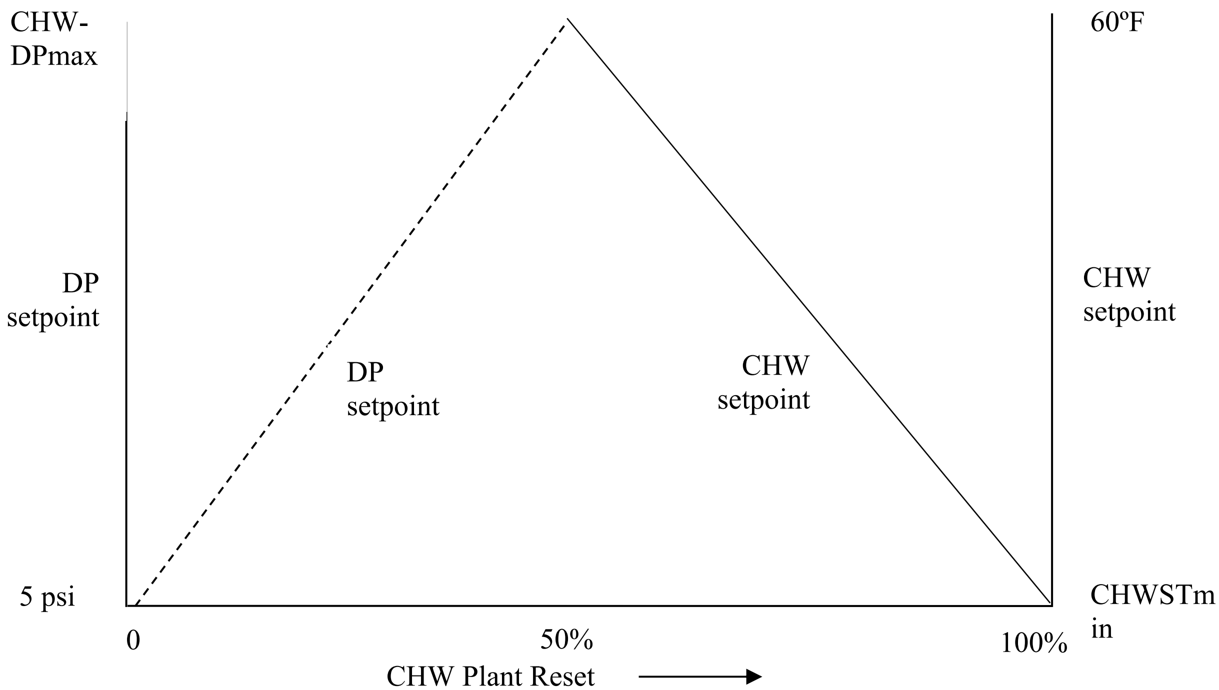
2) Timers shall reset to zero at the completion of every stage change.

3) Stage up and down conditionals may depend on *OPLR* calculated relative to the current stage, next lower stage, or next higher stage. This is denoted with stage subscripts on OPLR in the table below. E.g. $OPLR_1$ means *OPLR* calculated using Stage 1 nominal capacity.

Chiller Stage	**Chillers on**	**Stage up to next stage if either:**		**Stage down to lower stage if:**
1	Lead	**Efficiency Condition:** for 15 minutes current stage *OPLR* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary CHW flow > the design primary flow for Stage 1] or [for 5 minutes secondary CHWST > primary CHWST + 2°F]	
2	Lead + Lag1	**Efficiency Condition:** for 15 minutes current stage *OPLR* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary CHW flow > the design primary flow for Stage 2] or [for 5 minutes secondary CHWST > primary CHWST + 2°F]	for 15 minutes next available lower stage *OPLR* less than $SPLR_{DN}$ and the next available lower stage failsafe condition is not true.
3	Lead + Lag1 and Lag2	–	–	for 15 minutes next available lower stage *OPLR* less than $SPLR_{DN}$ and the next available lower stage failsafe condition is not true.

2. Chilled Water Plant Reset

a. Differential Pressure Controlled Loops: Chilled water supply temperature setpoint CHWSTsp and pump differential pressure setpoint CHW-DPsp shall be reset based on the current value of the logic variable called "CHW Plant Reset" as shown below and described subsequently.



b. CHW Plant Reset shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters:

Variable	Value
Device	Any CHW Pump
SP_0	100%
SP_{min}	0%
SP_{max}	100%
T_d	15 minutes
T	5 minutes
I	2
R	Chilled Water Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res-max}$	+7%

c. CHWST Plant Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

d. When a plant stage change is initiated, CHW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

3. Secondary Chilled Water Pumps

a. CHW pumps shall be lead/lag controlled per Paragraph 3.1P.

b. Run lead CHW pump when Cooling Plant is enabled and shut off otherwise.

c. CHW pumps shall be staged as a function of CHWFR, the ratio of current secondary water flow, GPM_{CHW}, to design flow.

$$\text{CHWFR} = \frac{GPM_{CHW}}{CHWF_{design}}$$

1) Start the lag pump whenever the CHWFR>0.47 for 10 minutes:

2) Shut off the lag pump whenever the CHWFR≤0.47 for 10 minutes:

d. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint CHW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed (10%) at 0% to maximum pump speed at 100%.

e. Remote secondary loop DP shall be maintained at a setpoint of CHW-DPsp determined by the reset scheme described herein. CHW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalCHW-DPmax at 100% loop output.

f. When any secondary CHW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

g. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

G. Heating Plant

1. Staging

a. Heat pumps are staged in part based on required capacity, $Q_{required}$, relative to nominal capacity of a given stage, Q_{stage}. This ratio is the operative part load ratio, *OPLR.*

b. If both primary and secondary hot water temperatures and flow rates are available, use those in the primary for calculating $Q_{required}$.

c. All heat pumps are assumed to have integral primary pumps controlled by heat pump controller.

d. $Q_{required}$ is calculated based on hot water return temperature (*HWRT*), active hot water supply temperature setpoint ($HWST_{SP}$), and measured flow through the associated circuit flow meter (*GPM*), as shown in the equation below. $Q_{required}$ used in logic shall be a 5-minute rolling average of instantaneous values sampled at a minimum of every 30 seconds.

$$Q_{required} = 0.5 * GPM \quad (HWRT - HWST_{SP})\ [MBH]$$

e. When a stage up or stage down transition is initiated, hold $Q_{required}$ fixed at its last value until the longer of the successful completion of the stage change (e.g. lag heat pump proven on) and 15 minutes.

f. Q_{stage} is calculated as the sum of the design capacities of the heat pumps in a given stage.

g. *OPLR* shall be calculated as follows:

$$OPLR_{stage} = \frac{Q_{required}[MBH]}{Q_{stage}[MBH]}$$

h. Staging part load ratio, *SPLR,* shall be 90%:

i. Staging shall be executed per the table below subject to the following requirements.

1) Each stage shall have a minimum runtime of 15 minutes.

2) Timers shall reset to zero at the completion of every stage change.

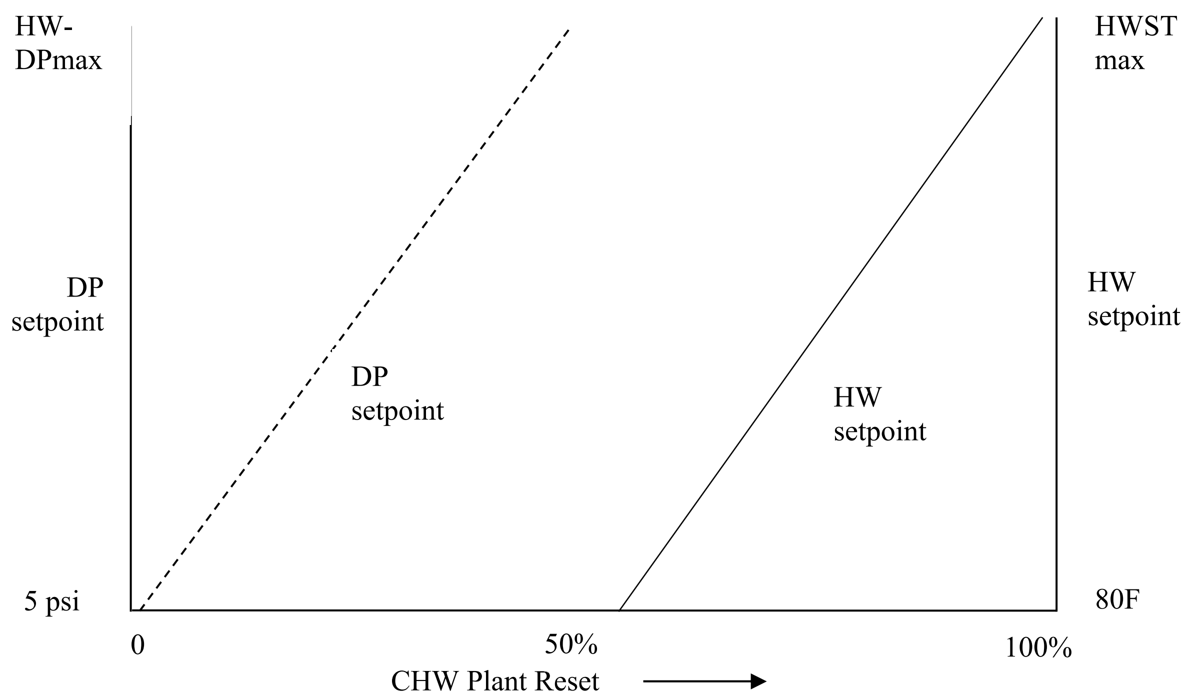
3) Stage up and down conditionals may depend on *OPLR* calculated relative to the current stage, next lower stage, or next higher stage. This is denoted with stage subscripts on OPLR in the table below. E.g. $OPLR_1$ means *OPLR* calculated using Stage 1 nominal capacity.

Heat pump Stage	**Heat pumps on**	**Stage up to next stage if either:**		**Stage down to lower stage if:**
1	Lead	**Efficiency Condition:** for 15 minutes current stage *OPLR* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary HW flow > the design primary flow for Stage 1] or [for 5 minutes secondary HWST > primary HWST + 2°F]	
2	Lead + Lag1	**Efficiency Condition:** for 15 minutes current stage *OPLR* greater than *SPLR*	**Failsafe Condition:** [for 15 minutes secondary HW flow > the design primary flow for Stage 2] or [for 5 minutes secondary HWST > primary HWST + 2°F]	for 15 minutes next available lower stage *OPLR* less than $SPLR_{DN}$ and the next available lower stage failsafe condition is not true.

Heat pump Stage	Heat pumps on	Stage up to next stage if either:		Stage down to lower stage if:
3	Lead + Lag1 and Lag2	–	–	for 15 minutes next available lower stage *OPLR* less than $SPLR_{DN}$ and the next available lower stage failsafe condition is not true.

2. Hot Water Plant Reset

   a. Differential Pressure Controlled Loops: Hot water supply temperature setpoint HWSTsp and pump differential pressure setpoint HW-DPsp shall be reset based on the current value of the logic variable called “HW Plant Reset” as shown below and described subsequently.



   b. HW Plant Reset shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters:

Variable	Value
Device	Any HW Pump
SP_0	100%
SP_{min}	0%
SP_{max}	100%

T_d	15 minutes
T	5 minutes
I	2
R	Heating HWST Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res\text{-}max}$	+7%

c. HWST Plant Reset loop shall be enabled when the plant is enabled and disabled when the plant is disabled.

d. When a plant stage change is initiated, HW Plant Reset logic shall be disabled and value fixed at its last value for the longer of 15 minutes and the time it takes for the plant to successfully stage.

3. Secondary Hot Water Pumps

a. HW pumps shall be lead/lag controlled per Paragraph 3.1P.

b. Run lead HW pump when Heating Plant is enabled and shut off otherwise.

c. HW pumps shall be staged as a function of HWFR, the ratio of current secondary water flow, GPM_{HW}, to design flow.

$$\text{HWFR} = \frac{GPM_{CHW}}{HWF_{design}}$$

1) Start the lag pump whenever the HWFR>0.47 for 10 minutes:

2) Shut off the lag pump whenever the HWFR≤0.47 for 10 minutes:

d. When any pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the differential pressure signal at a setpoint HW-DPsp determined by the reset scheme described herein. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed (10%) at 0% to maximum pump speed at 100%.

e. Remote secondary loop DP shall be maintained at a setpoint of HW-DPsp determined by the reset scheme described herein. HW-DPsp shall be maintained by a reverse acting PID loop running in the controller to which the remote sensor is wired; the loop output shall be a DP setpoint for the local secondary loop DP sensor hardwired to the secondary pump controller. Reset local DP from 5 psi at 0% loop output to LocalHW-DPmax at 100% loop output.

f. When any secondary HW pump is proven on, pump speed will be controlled by a reverse acting PID loop maintaining the local secondary DP signal at the DP setpoint output of the remote sensor control loop. All pumps receive the same speed signal. PID loop output shall be mapped from minimum pump speed at 0% to maximum pump speed at 100%.

g. Where multiple remote DP sensors exist, a PID loop shall run for each sensor. The DP setpoint for the local DP sensor shall be the highest DP setpoint output from each of those remote loops.

H. Alarms

1. Maintenance interval alarm when pump has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Maintenance interval alarm when heat pump/chiller has operated for more than 1000 hours: Level 4. Reset interval counter when alarm is acknowledged.

3. Heat pump/chiller alarm: level 2

4. High chiller leaving chilled water temperature (more than 5°F above setpoint) for more than 15 minutes when chiller has been enabled in cooling mode for longer than 15 minutes: Level 3

5. Low heat pump leaving hot water temperature (more than 5°F below setpoint) for more than 15 minutes when heat pump has been enabled in heating mode for longer than 15 minutes: Level 3

6. Pump alarm is indicated by the status input being different from the output command after a period of 15 seconds after a change in output status.

   a. Commanded on, status off: Level 2

   b. Commanded off, status on: Level 4

7. CHW System low gauge pressure

   a. if CHW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

   b. if CHW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

8. HW System low gauge pressure

   a. if HW system gauge pressure falls 1 psig below the scheduled expansion tank pre-charge pressure for 5 minutes, (indicating need to fill): Level 3.

   b. if HW system gauge pressure falls below 0.9 times the scheduled expansion tank pre-charge pressure for 1 minute, (indicating possible leak): Level 2.

3.30 BUILDING CHILLED WATER PUMPS

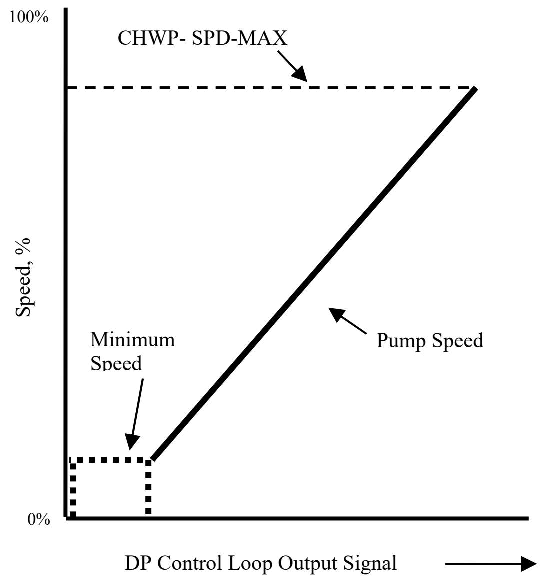
A. Pumps shall be lead/lag controlled per Paragraph 3.1P.

B. Enable/Disable

1. Enable the pumping system when it has been disabled for at least 15 minutes and the number of Chiller Plant Requests > I (I = Ignores shall default to 0, adjustable

2. Disable the pumping system when it has been enabled for at least 5 minutes and the Number of Chiller Plant Requests ≤ I for 3 minutes

C. When the pumping system is enabled, the DP control loop is enabled. The loop shall be a reverse-acting loop maintaining the differential pressure (DP) sensor at setpoint. The output of the loop shall range from 0 to 100%, mapped to pump speed up to a maximum speed of software point CHWP-SPD-MAX as shown in the figure and described below. The pressure from the plant may satisfy the building DP requirements via the check valve bypass, in which case the pumps will stay off. They will start only when the plant pressure is not adequate.



1. Pump speed will be controlled by a PID loop maintaining the differential pressure signal at a setpoint determined by the reset scheme described below. All pumps receive the same speed signal.

2. When the DP loop output is equal to the lead pump minimum speed setpoint (see Section 250000 Building Automation Systems), the lead pump shall start. Its speed shall be equal to the DP loop output up to a maximum speed of CHWP-SPD-MAX, set below. The lead pump shall stop when the pump has run for a minimum speed for 5 minutes. It shall stay off for a minimum of 5 minutes before restarting.

D. Pumps shall be staged as a function of CHW flow ratio (CHWFR = actual flow divided by total design flow). When CHWFR is above 47% for 10 minutes, start the lag pump. When CHWFR is below 47% for 15 minutes, or the lead pump is commanded off, shut off the lag pump.

E. Differential pressure setpoint shall be reset using Trim & Respond logic (see Guideline 36) with the following parameters. DP-MAX is the design DP setpoint determined under 230593 Testing, Adjusting and Balancing.

Variable	Value
Device	Any CHW Pump

SP_0	DP-MAX
SP_{min}	1 psi
SP_{max}	DP-MAX
T_d	15 minutes
T	5 minutes
I	2
R	Chilled Water Reset Requests
SP_{trim}	-2%
SP_{res}	+3%
$SP_{res\text{-}max}$	+7%

F. CHW Flow Limit

1. Flow limit %setpoint shall be the total pump design flow rate listed on drawings. The limit will ensure that one building does not take more flow than they are entitled to, starving other buildings.

2. When the pumping system is enabled, a proportional-only flow limiting loop shall be enabled to maintain measured flow at the flow limit setpoint. The output of the loop shall be a software point CHWP-SPD-MAX ranging from 0 to 100%.

3.31 BUILDING HOT WATER PUMPS

A. Pumps shall be lead/lag controlled per Paragraph 3.1P.

B. Building HW system enable/disable

1. Enable the building HW system when they have been disabled for at least 10 minutes and:

    a. Number of building Heating Hot-Water Plant Requests > I (I = Ignores shall default to 0, adjustable), and

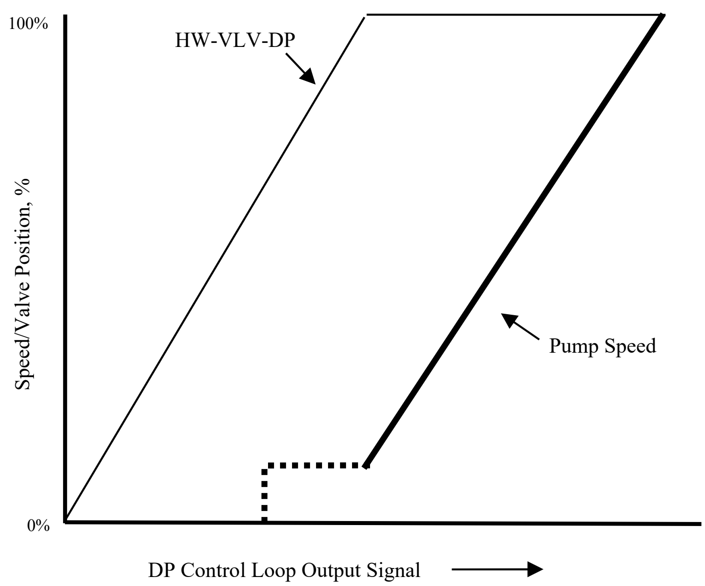
    b. OAT<HW-LOT (default to 70F, adjustable)

2. Disable the building HW system when they have been enabled for at least 3 minutes and:

    a. Number of Heating Hot-Water Plant Requests ≤ I for 3 minutes, or

    b. OAT>HW-LOT + 1°F

C. When the HW system is enabled, the building DP control loop shall be enabled. The loop shall be a reverse-acting loop maintaining the differential pressure (DP) sensor at setpoint. The output of the loop shall range from 0 to 100% and mapped to pump speed and the hot water control valve software point HW-VLV-DP as shown in the figure and described below:



1. Point HW-VLV-DP is mapped from 0% to 100% as the DP loop output ranges from 0% to 50%.

2. Once the valve is wide open (DP loop at 50%), the lead pump shall start and its speed mapped from its minimum speed (see Paragraph 3.1N) to 100% as the DP Loop signal ranges from 50% to 100% as shown in the figure. The lead pump shall stop when the valve is below 50% open and the pump has run for a minimum of 5 minutes.

3. Lag pump shall be staged as a function of HW flow ratio (HWFR = actual flow divided by total plant design flow). When HWFR is above 47% for 10 minutes, start the lag pump. Both pumps shall receive the same speed signal when both are on. When HWFR is below 47% for 15 minutes, or the lead pump is commanded off, shut off the lag pump.

4. Differential pressure setpoint shall be DP-MAX, the design DP setpoint determined under 230593 Testing, Adjusting and Balancing.

D. HW Flow Limit

1. Flow limit setpoint shall be the total pump design flow rate listed on drawings. The limit will ensure that one building does not take more flow than they are entitled to, starving other buildings.

2. When the pumping system is enabled, a proportional-only flow limiting loop shall be enabled to maintain measured flow at the flow limit setpoint. The output of the loop shall be a software point HW-VLV-FL ranging from 0 to 100%.

E. The signal to the HW valve from the central plant shall be the smaller of the signal determined from the pressure control HW-VLV-DP and the flow limiting loop HW-VLV-FL.

F. Alarms

1. Generate a Level 4 maintenance alarm when pump has operated for more than 3000 hours. Reset interval counter when alarm is acknowledged.

2. Pump alarm is indicated by the status input being different from the output command for 15 seconds.

    a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

    b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

3. Low differential pressure, below setpoint by 2 psi for 10 minutes with system enabled for 15 minutes.

3.32 DOMESTIC WATER HEATING PLANT

A. Hot water recirculation pumps shall be lead/lag alternated per Paragraph 3.1P.

B. Recirculation pump shall operate when any AH unit serving the area that includes the toilet rooms served by the recirc pump is in Occupied Mode.

C. Alarms

1. Generate a Level 4 maintenance alarm when pump has operated for more than 3000 hours. Reset interval counter when alarm is acknowledged.

2. Pump alarm is indicated by the status input being different from the output command for 15 seconds.

    a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

    b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

3. Hot water supply temperature less than 110°F when recirculation pump is proven on: Level 2.

4. DHW heater alarm: Level 2

3.33 LABORATORY EXHAUST SYSTEM CONTROL

A. Both lab exhaust fans shall run continuously. During normal operation each fan will run at approximately half design airflow.

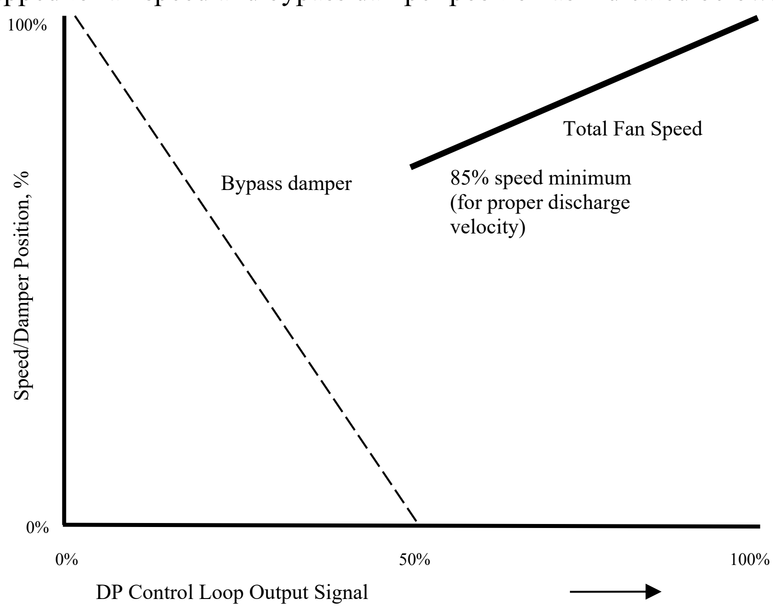
B. Exhaust Plenum Pressure Control

1. Static pressure setpoint: Setpoint shall be reset using Trim & Respond logic per Guideline 36 with the following parameters:

Variable	Value
Device	Either EF
SP0	-1.0 inches
SPmax	-0.1 inches

SPmin	-2.0 inches
Td	10 minutes
T	2 minutes
I	2
R	Zone Exhaust Static Pressure Reset Requests
SPtrim	+0.05 inches
SPres	-0.06 inches
SPres-max	-0.13 inches

2. A PID loop shall maintain the main DP sensor at setpoint, the output of which shall be mapped to fan speed and bypass damper position as indicated below.



3. Fan speed to each fan shall be equal to Total Fan Speed divided by the number of exhaust fans proven on, e.g. if Total Fan Speed is 80% and both fans are proven on, each runs at 40% speed.

C. Alarms

1. Maintenance interval alarm when fan has operated for more than 2000 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status input being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

3. Low static pressure (< 0.2" below setpoint) when fan control loop is active for longer than 5 minutes. Level 2.

3.34 LABORATORY EXHAUST SYSTEM CONTROL

A. Lab exhaust fans shall be lead/lag controlled per Paragraph 3.1P.

B. Lab Exhaust Fan Minimum Stack Airflow

1. Minimum airflow for each enabled lab exhaust fan, EFStackMin, shall vary as a function of wind speed and direction per the table below.

Wind Direction		**Anemometer Wind Speed**														
Min	**Max**	<1	1	2	3	4	5	6	7	8	9	10	11	12	13	14
350	**10**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
10	**30**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
30	**50**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
50	**70**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
70	**90**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
90	**110**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
110	**130**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
130	**150**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
150	**170**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
170	**190**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
190	**210**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
210	**230**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
230	**250**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
250	**270**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
270	**290**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
290	**310**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
310	**330**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
330	**350**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

2. Wind Measurement by Sonic Anemometer

a. Anemometer shall report wind speed and direction with minimum frequency of once every 5 seconds.

b. BAS shall record any error codes received from anemometer.

c. For every one minute of data, calculate the average wind speed (meters per second) and average wind direction (degrees).

1) Average wind speed shall be a straight arithmetic average

2) Average wind direction must account for wind direction passing through zero degrees (i.e., the average of 355° and 5° is 0 degrees, not 180°). Vector

averaging is recommended if EMCS supports trigonometry functions. Confirm calculation method with mechanical engineer.

3) Check data quality. If any of the following conditions are met, set "null signal" for average wind speed and direction for this period and discard remaining data for this one minute period.

a) If an error code is received from the anemometer during the one minute period.

b) If the wind speed is greater than 0.0 meters per second AND the difference between minimum and maximum wind speed is less than 0.05 meters per second (adjustable) during the one minute period.

c) If the wind speed is greater than 0.0 meters per second AND the difference between lowest and highest wind direction angles is less than 0.1 degree (adjustable) during the one minute period.

d. Every minute, the BAS shall calculate a rolling average of the last five one-minute wind speed and direction readings. In other words, it shall calculate a rolling five-minute average of the one-minute averages previously computed. Any one-minute periods reporting "null signal" shall be ignored. This rolling average shall be used to set EFStackMin.

e. If "null signal" is recorded for 5 consecutive one-minute periods, EFStackMin shall be set to the maximum value from the table above and a Level 2 alarm shall be generated.

C. Exhaust Fan Staging

1. The lead exhaust fan shall always be enabled.

2. Calculate the current stage total stack airflow, EFAirCurrent, as the sum of stack airflow measurements from enabled fans.

3. Calculate the current sum of airflows from all lab exhaust valves, LabEAFlow.

4. Each stage shall have a 5-minute minimum runtime during which staging shall be inhibited.

5. Stage up if any of the following sets of conditions is satisfied:

a. StageUp1**:** For 10 minutes, all of the following are true:

1) LabEAFlow > 80% of design lab exhaust flow for the current stage.

2) EFAirCurrent / Number of fans operating in next higher stage > EFStackMin*1.2.

3) Lab exhaust plenum bypass damper is 0% open.

b. StageUp2: For 10 minutes, LabEAFlow > 100% of design lab exhaust flow for the current stage.

c. StageUp3**:** For 1 minute, both of the following are true:

1) Exhaust fan speed is >= 99%.

2) Exhaust static pressure is 0.1" above setpoint.

6. Stage down if any of the following sets of conditions is satisfied:

a. StageDown1: If the plant staged up on StageUp1 or StageUp2 and for 10 minutes LabEAFlow < 80% of design lab exhaust flow for the next lower stage.

b. StageDown2: If the plant staged up on StageUp1 or StageUp2 and for 10 minutes both:

1) LabEAFlow < 100% of design lab exhaust flow for the next lower stage

2) Any lab exhaust plenum bypass damper > 10% open.

c. StageDown3: If the plant staged up on StageUp3 and for 10 minutes exhaust fan speed < 50%.

D. Exhaust Plenum Pressure Control

1. Static pressure setpoint: The plenum pressure setpoint is a negative value. Setpoint shall be reset using Trim & Respond logic per Guideline 36 with the following parameters:

Variable	Value
Device	Either EF
SP0	-1.0 inches
SPmax	-0.1 inches
SPmin	EFDPdes
Td	10 minutes
T	2 minutes
I	0
R	Zone Exhaust Static Pressure Reset Requests and Stack Pressure Reset Requests
SPtrim	+0.05 inches
SPres	-0.06 inches
SPres-max	-0.26 inches

a. Design plenum pressure setpoint, EFDPdes, shall be determined under Section 230593 Testing, Adjusting and Balancing. This shall be a negative value.

2. A PID loop shall maintain the exhaust static DP sensor at setpoint, the output of which shall be mapped to fan speed. Control point shall be the higher (less negative) of the two redundant static pressure sensor readings.

E. Stack Minimum Airflow Bypass Dampers

1. Bypass dampers are lead/lag alternated per Paragraph 3.1P.

2. A reverse acting PID loop shall maintain the lowest stack airflow of all enabled fans equal to EFStackMin. Loop output shall be mapped to bypass damper position as follows.

   a. From 0% to 50% loop output, open lead bypass damper from fully closed to fully open.

   b. From 50% to 100% loop output, open lag bypass damper from fully closed to fully open.

F. Alarms

1. Maintenance interval alarm when fan has operated for more than 2000 hours: Level 4. Reset interval counter when alarm is acknowledged.

2. Fan alarm is indicated by the status input being different from the output command for 15 seconds.

   a. Commanded on, status off: Level 2. Do not evaluate alarm until the device has been commanded on for 15 seconds.

   b. Commanded off, status on: Level 4. Do not evaluate the alarm until the device has been commanded off for 60 seconds.

3. High static pressure (>0.2” above setpoint) when fan control loop is active for longer than 5 minutes. Level 2.

4. Low stack airflow (10% below setpoint) when stack airflow control loop is active for longer than 5 minutes. Level 2.

5. Wind Station Internal Failure if either the wind sensor’s wind status register indicates the devices is in alarm or the wind sensor’s communication status is in fault. Level 2.

6. Wind Station Wind Speed Measurement Failure – If [wind speed is greater than 0.0 meters per second AND the difference between minimum and maximum wind speed is less than 0.05 meters per second during 5 consecutive one minute periods] OR [wind speed registers 0.0 meters per second for greater than 1 hour continuously]. Level 2.

7. Wind Station Wind Direction Measurement Failure – If the difference between lowest and highest wind direction angles is less than 0.1 degree during 5 consecutive one minute periods. Level 2.

8. Bypass Damper Failure if the bypass dampers are commanded shut but stack airflows are different than the sum of lab exhaust air valves by 20% for 30 minutes continuously. Level 2.

9. Airflow Measurement Station Failure if more than one fan is proven on and the airflow of any fan differs from the average of all fans by 30% for 30 minutes continuously. Level 2.

10. Exhaust Static Pressure Calibration Error if the two sensors disagree by more than 0.3” for more than 30 minutes continuously. Level 3.

G. System Requests

1. Stack Pressure Reset Requests

a. If the measured airflow out of any stack is less than 90% of EFStackMin and the lag bypass damper position is greater than 95% for 1 minute, send 3 Requests,

b. Else, if the measured airflow out of any stack is less than 95% of setpoint while the lag damper position is greater than 95% for 1 minute, send 2 Requests,

c. Else, if the lag bypass damper position is greater than 95%, send 1 Request until the damper position is less than 85%,

d. Else, if the lag bypass damper position is less than 95%, send 0 Requests.

3.35 METERING SUMMARIES

A. Provide metering summary separately for the following metering systems:

1. Electrical power

2. Potable water

3. Recycled water

B. Include all submeters including those mapped from equipment (e.g. VFDs, water treatment system, etc.)

C. Include “virtual meters” where loads are based on subtraction from or addition of other loads including:

1. Electricity

a. All HVAC equipment. Sum of all HVAC equipment meters (including those in VFDs)

b. Lighting loads

1) Each floor B2, L1, L2, L6, and two each on L6 to L18: Subtract plug load submeter from total floor power meter.

2) Sum of all interior lighting loads

3) Sum of all lighting including all exterior and garage lighting

c. Plug loads: Sum of all plug loads

d. UPS: Sum of all meters for UPS equipment.

e. Parking. Sum of all meters for electric vehicle charging.

f. Kitchens. Sum of all meters for kitchens (N1, N7, N8, N18).

2. Water

a. Kitchen. Sum of all water meters for kitchens N1, N7, N8, N18 and sum of all meters for kitchen dishwashers.

b. Irrigation: Sum of all irrigation meters

D. For each metering system:

1. Provide the system 1-line riser diagram on a summary graphic with links to subsections of the system by floor and major system.

2. On each subsection, indicate meter and virtual meter location with a title indicating end-use.

3. Through a hyperlink, show a screen summarizing meter data including:

a. Details of what is being metered

b. Pie chart or other graphical format

c. Summary of power on the following basis:

1) Current

2) Past day

3) Past month

4) Past year and year-to-date

E. Summary dashboards:

1. For both electricity and water

2. Pie chart or other graphical format showing total whole building consumption with a breakdown of the consumption by end-use, including the percentage of the total.

3.36 EQUIPMENT NOT CONTROLLED OR MONITORED BY BAS SYSTEM

A. Equipment Room Transfer Fans

1. Set setpoint to energize fan when space temperature rises above 85°F with 2°F differential.

B. Elevator Shaft Vent

1. Set setpoint to open vent damper when space temperature rises above 90°F with 2°F differential.

C. Elevator Room AC units

1. Set cooling setpoint to energize cooling when space temperature rises above 85°F with 2°F differential.

2. Set heating setpoint to energize heater when space temperature falls below 50°F with 2°F differential.

D. Chiller Room Exhaust Fan

1. Fan is enabled by emergency wall switch, wind-up timer switch or refrigerant monitor.

3.37 MISCELLANEOUS ALARMS

A. High water level or oil in sumps: Level 2

B. Points in Hand (Operator Override) via Workstation command (including name of operator who made the command) or via supervised HOA switch at output: Level 4

C. Fire alarm (via contact from Division 26 fire alarm system): Level 1

D. Fire alarm trouble (via contact from Division 26 fire alarm system): Level 2

E. Equipment alarm (for equipment with alarm contacts such as VFDs, AC units): Level 2

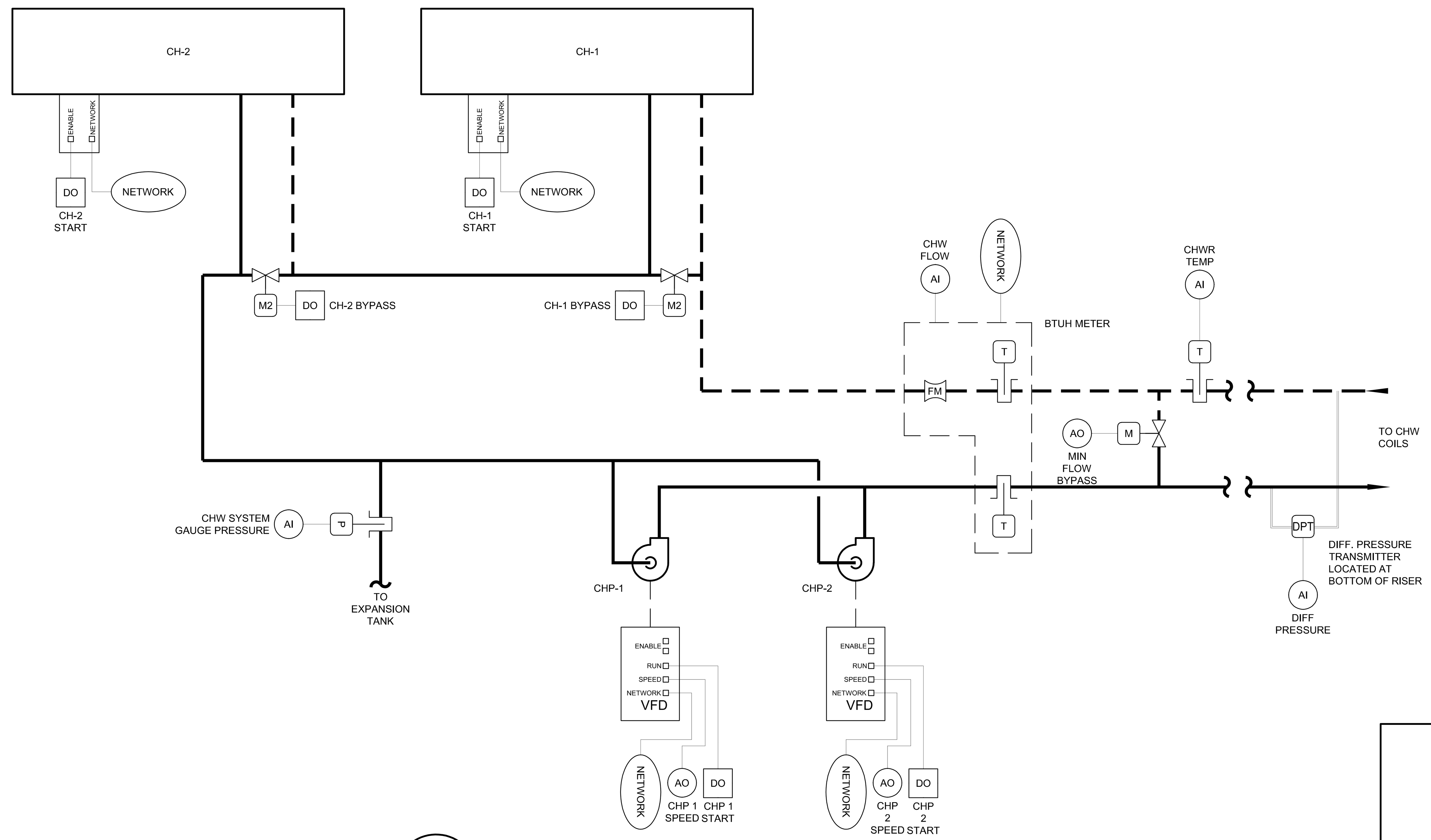
F. Failure or disconnection of a sensor as indicated by signal widely out of range: Level 2.

G. Panel or LAN failure: Level 2

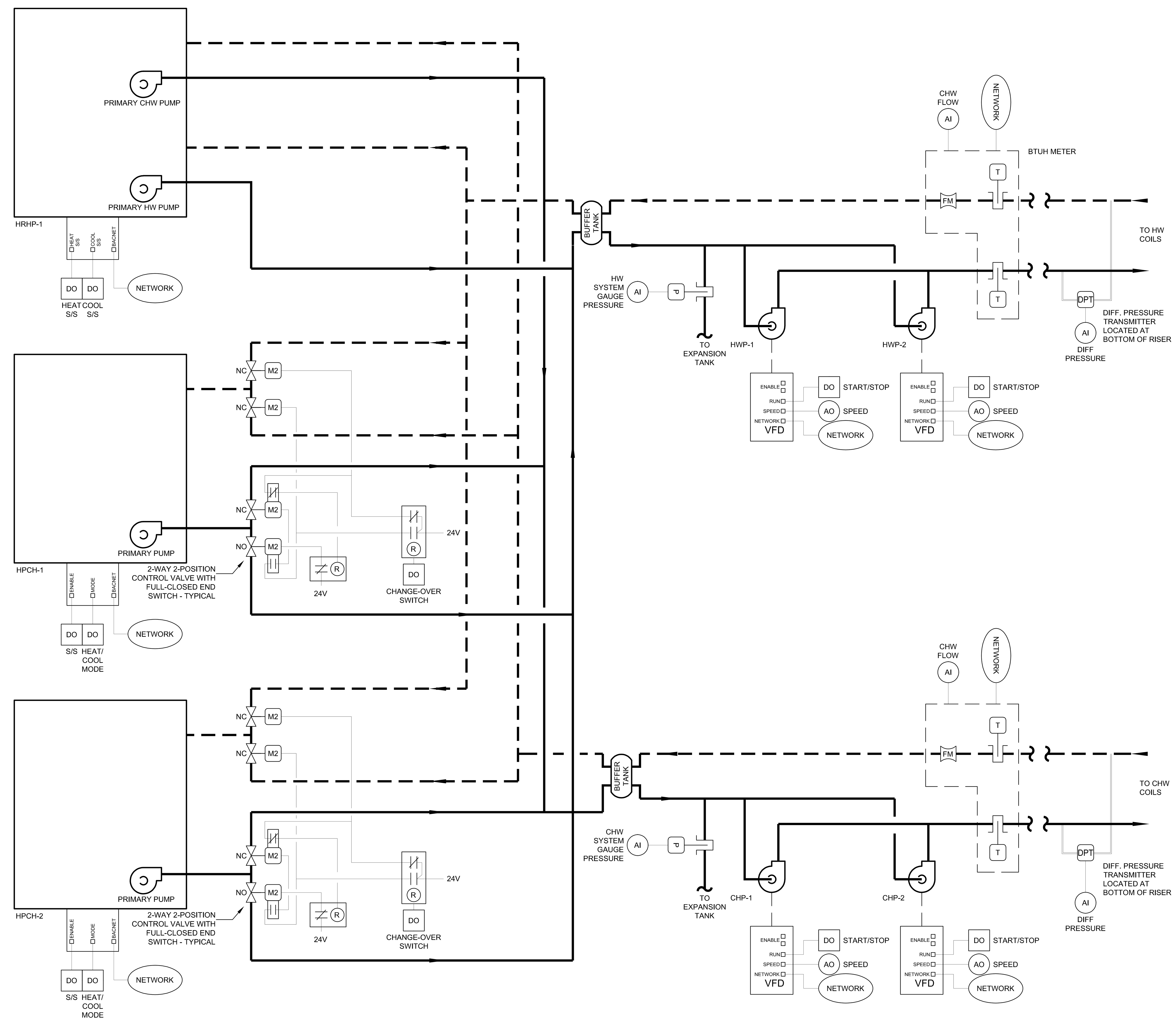
H. Loss of communication with any device via Gateway (e.g. VFD) for more than 30 seconds: Level 2 (alarm shall indicate which specific device is not responding).

I. Electrical switchgear alarm (from Electrical Power System gateway): Level 2

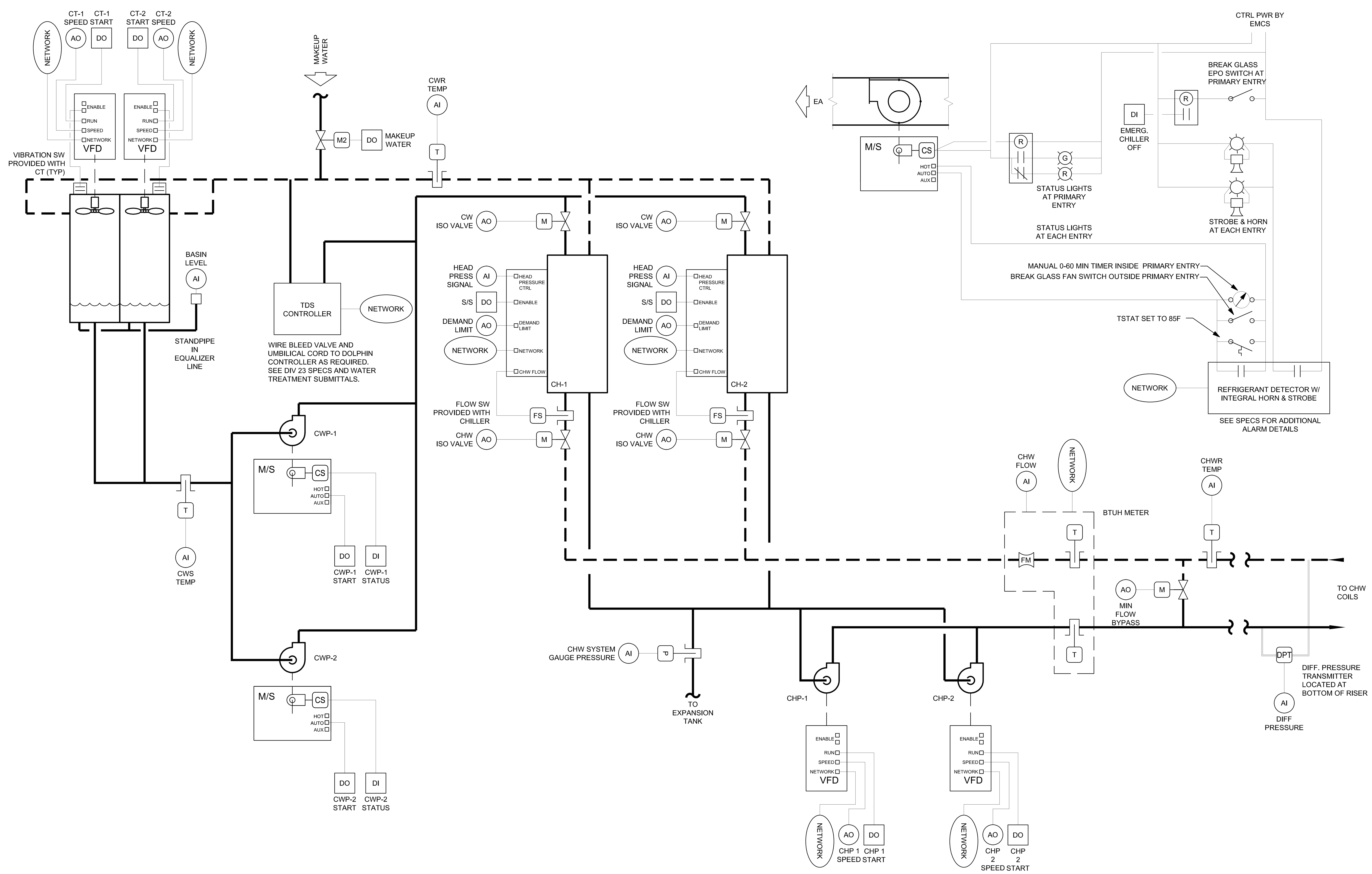
END OF SECTION 259000



X
-
SERIES AIR-COOLED CHW SYSTEM SCHEMATIC
NO SCALE



X
-
2-PIPE AND 4-PIPE AIR-SOURCE HEAT PUMP/CHW SYSTEM SCHEMATIC
NO SCALE



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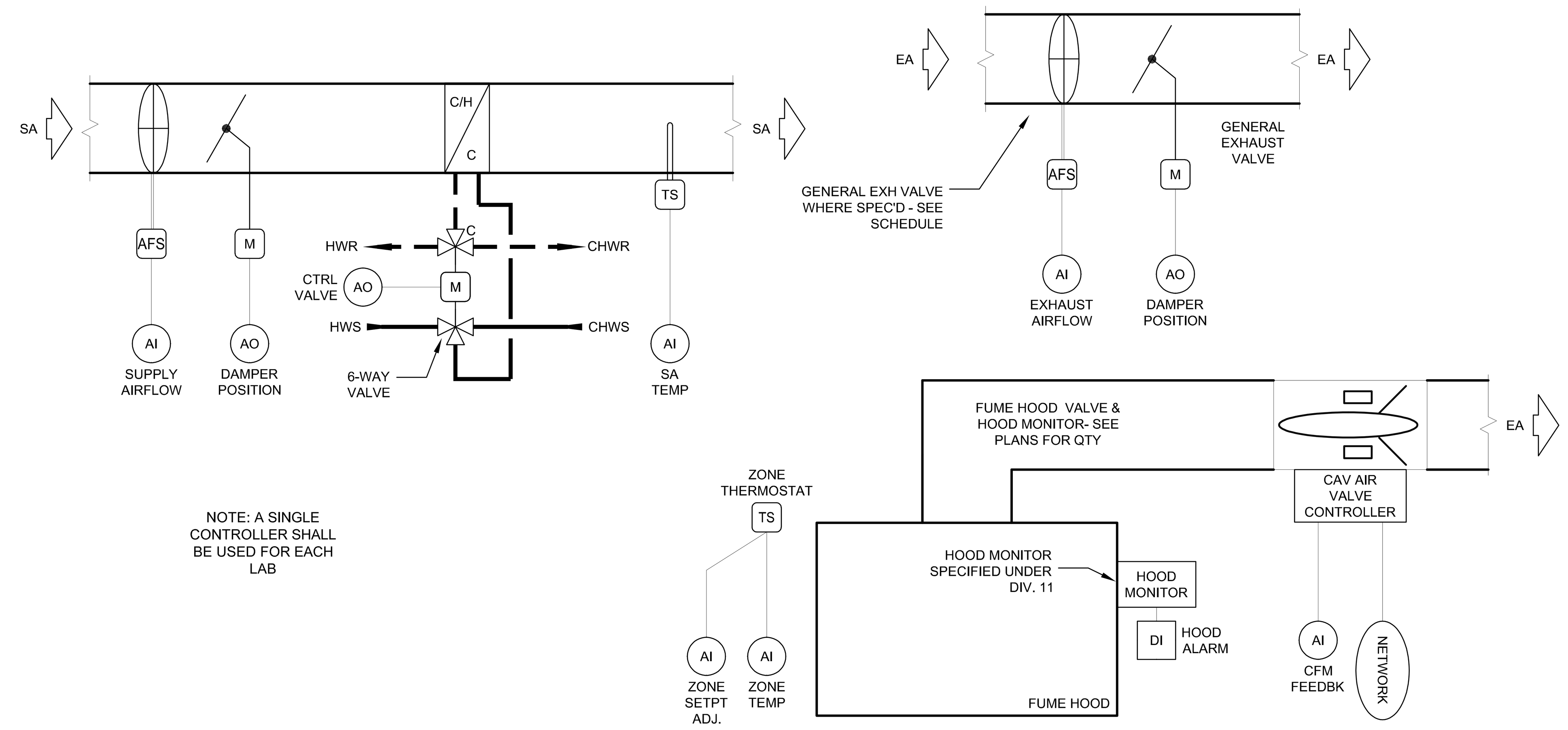
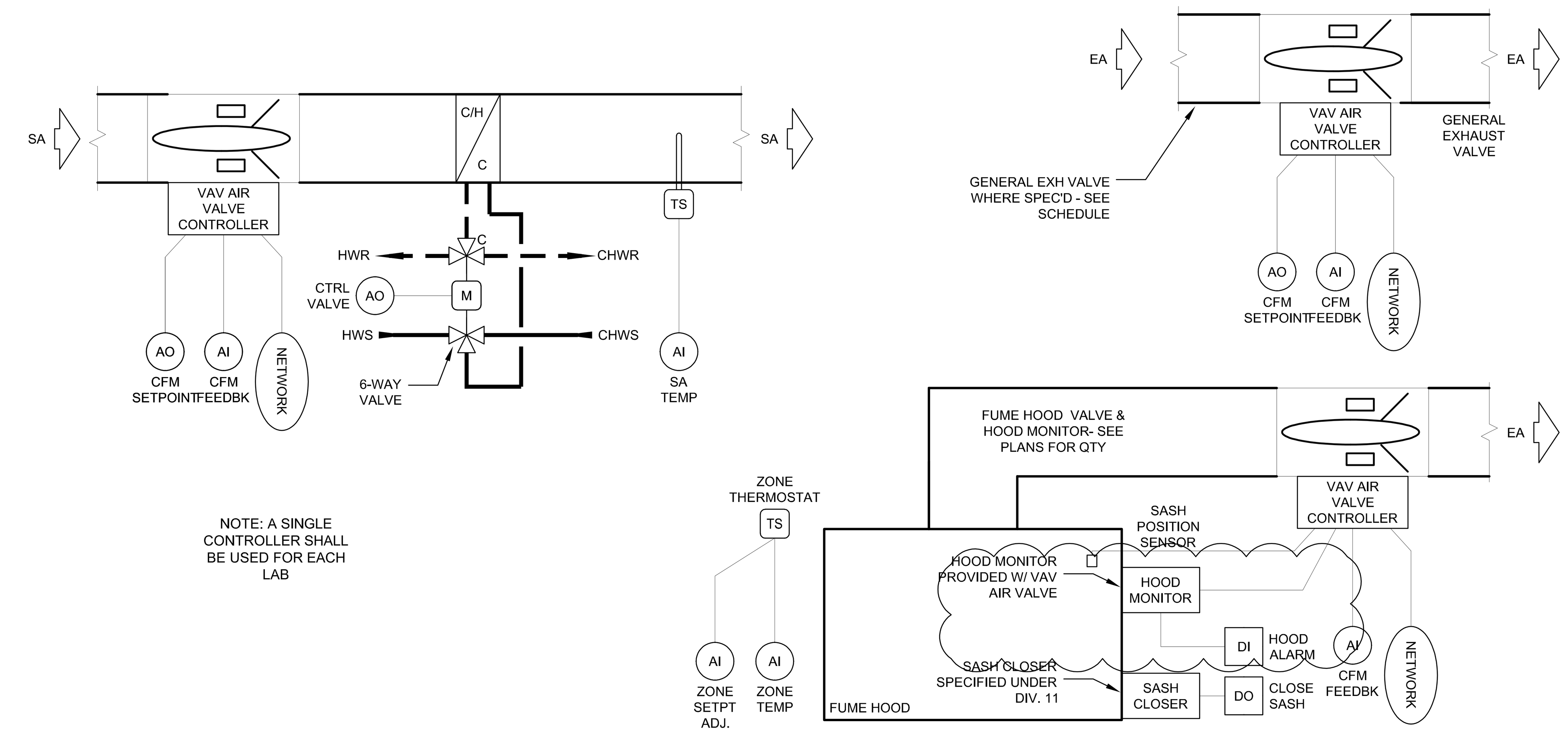
WATER-COOLED CHW SYSTEM SCHEMATIC
NO SCALE



X
-

"SLOW" LAB ZONE CONTROL DIAGRAM

NO SCALE



X
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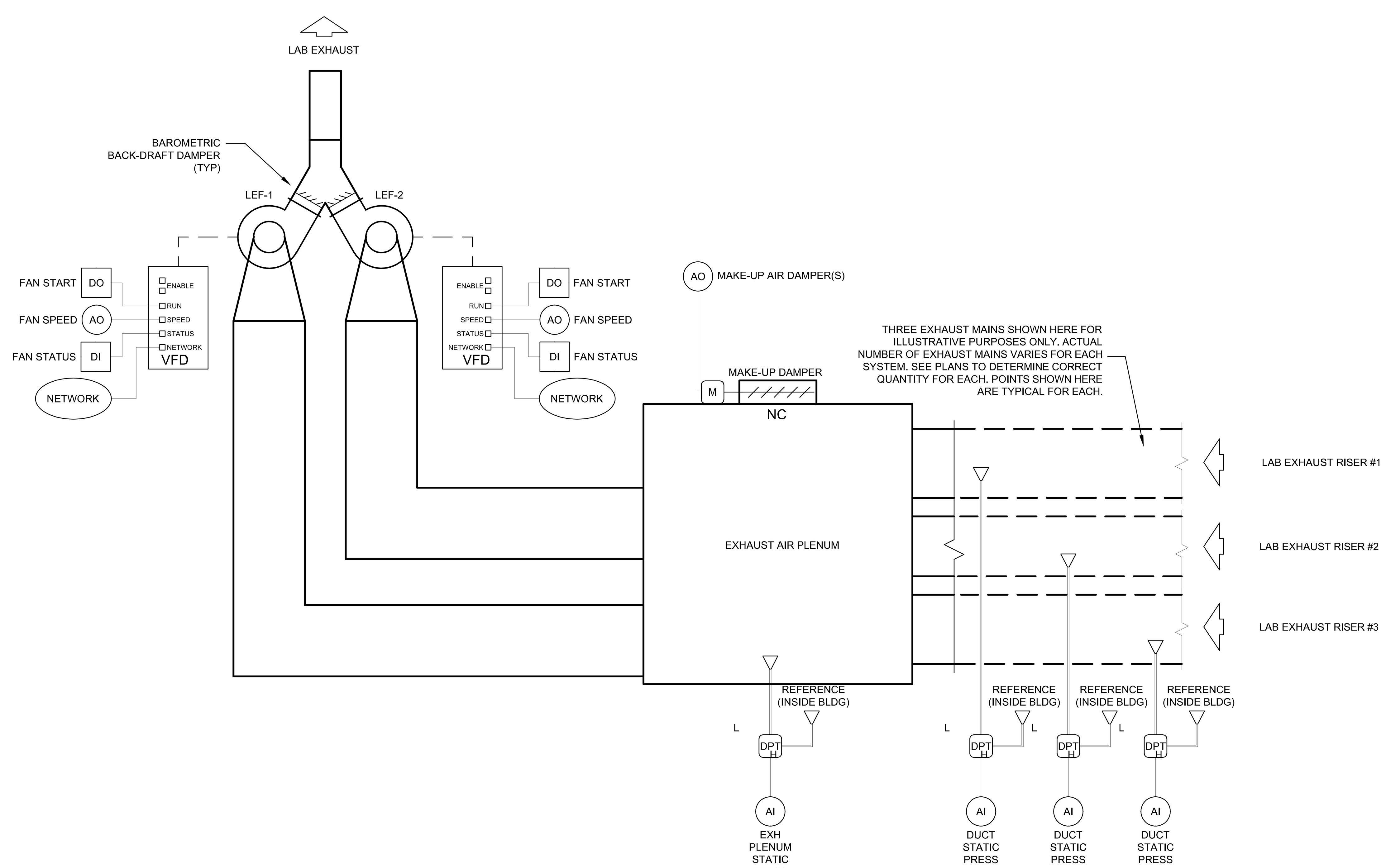
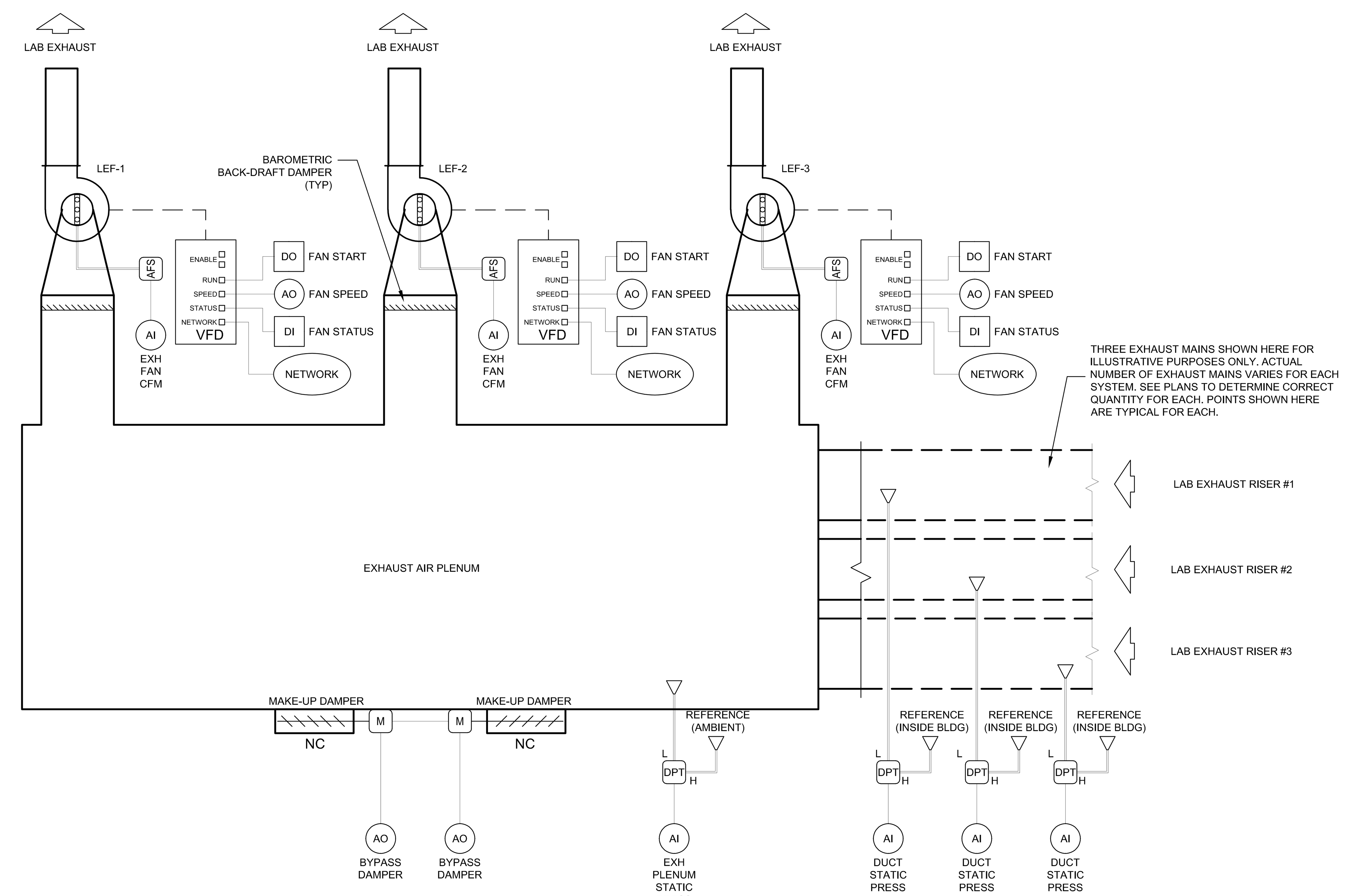
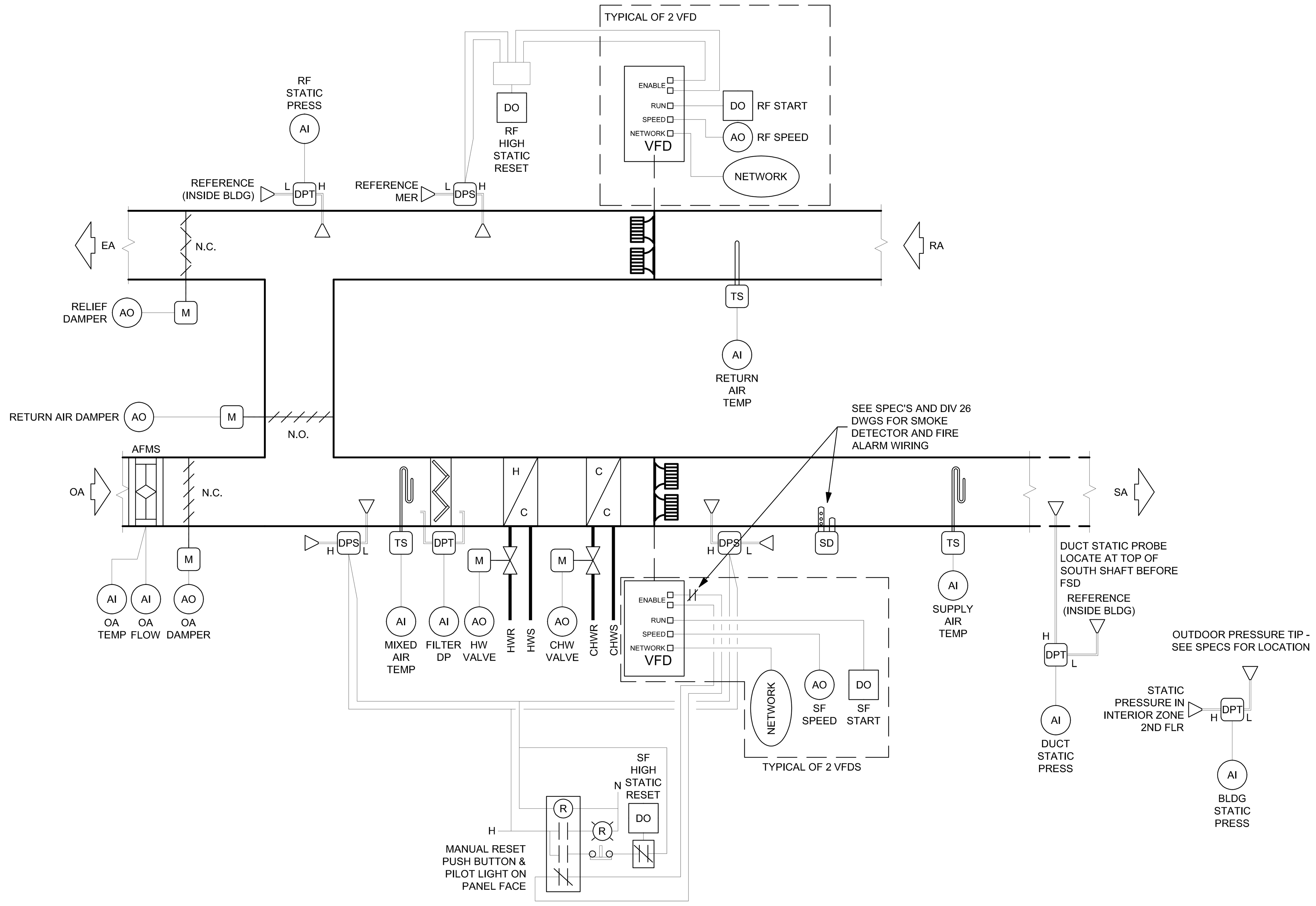
"FAST" LAB ZONE CONTROL DIAGRAM

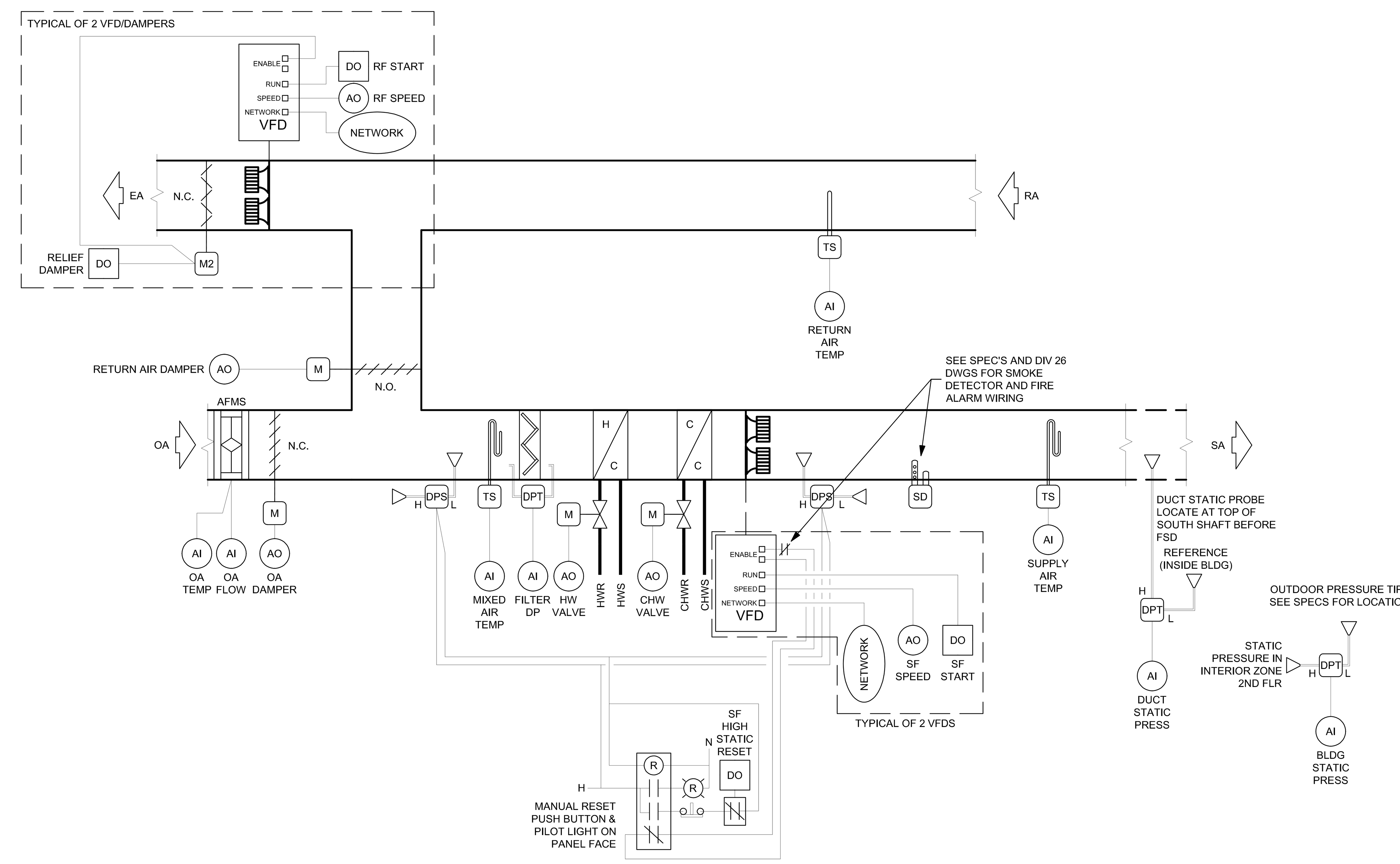
NO SCALE



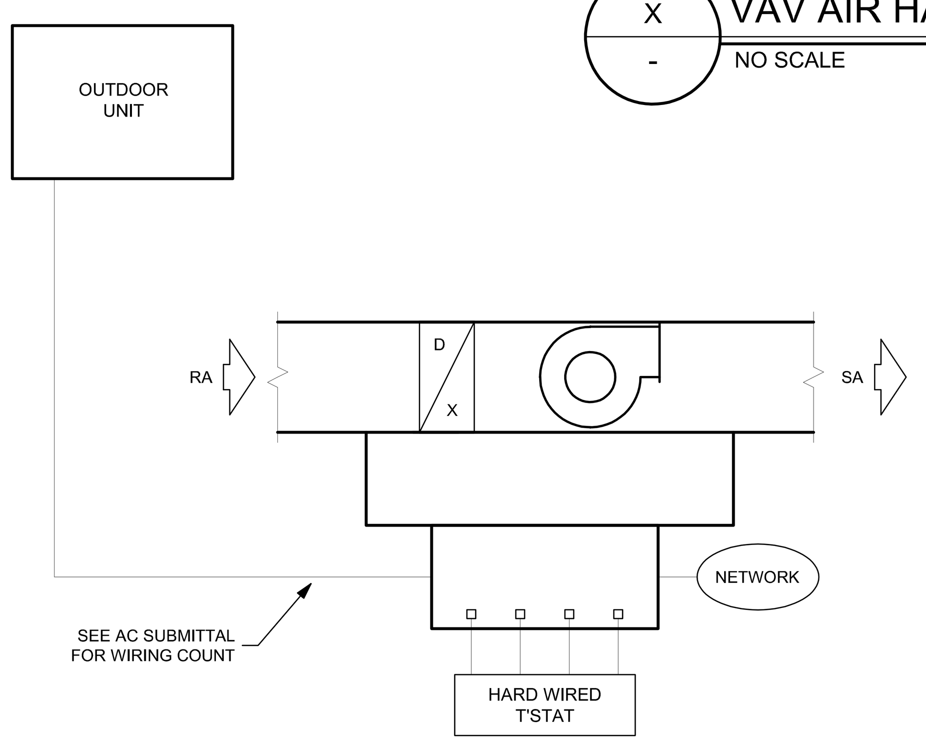




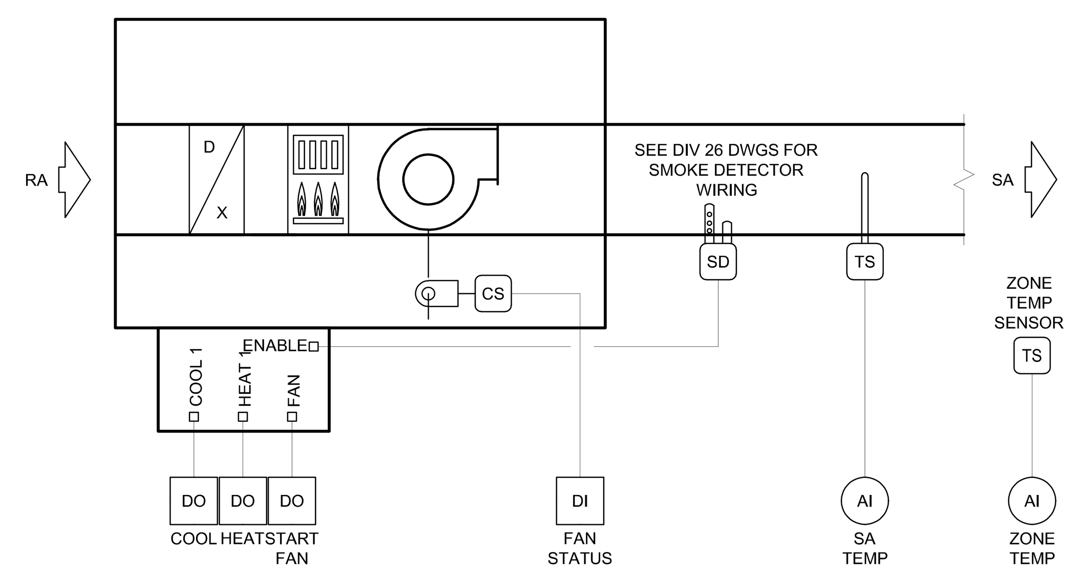
X / - VAV AIR HANDLER WITH RETURN FAN
NO SCALE



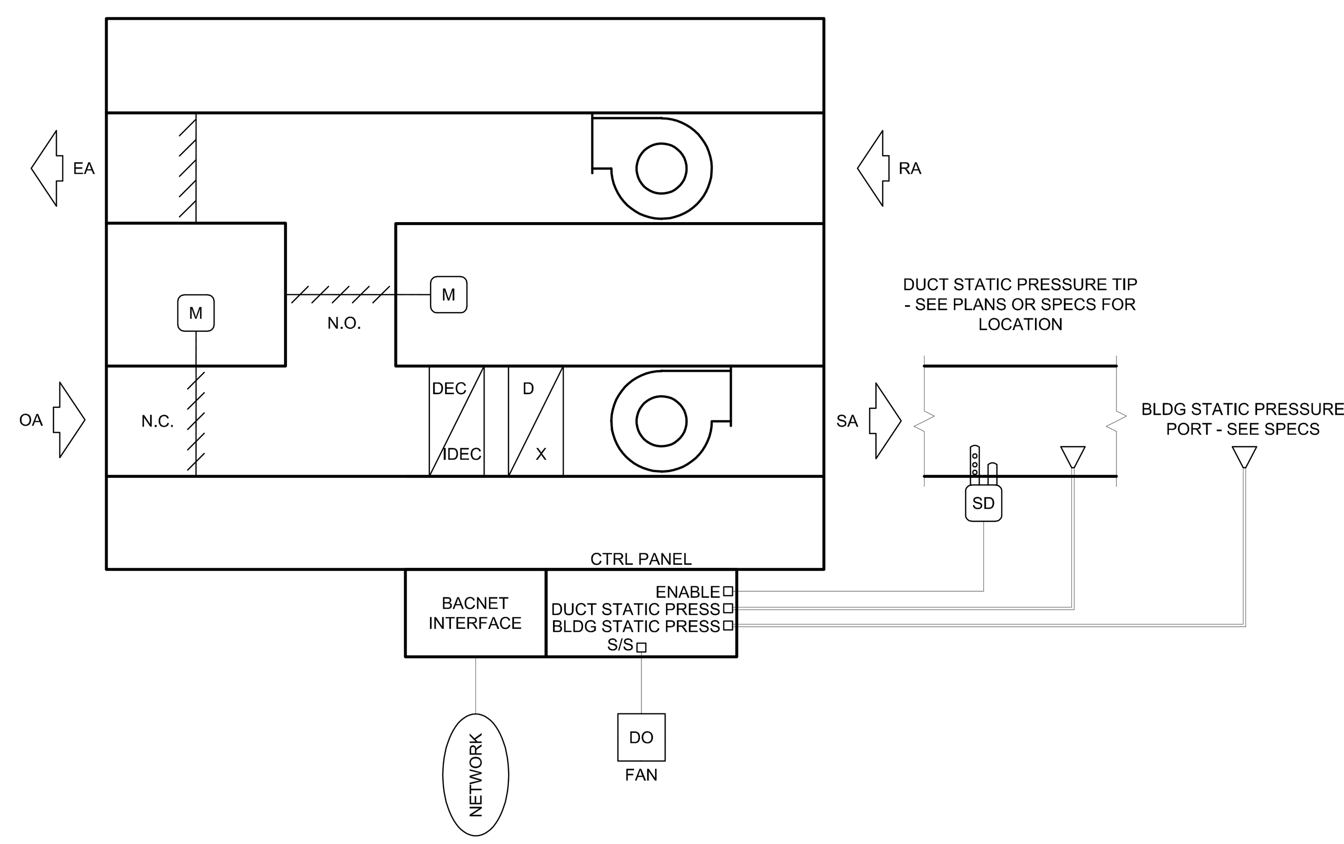
X / - VAV AIR HANDLER WITH RELIEF FAN
NO SCALE



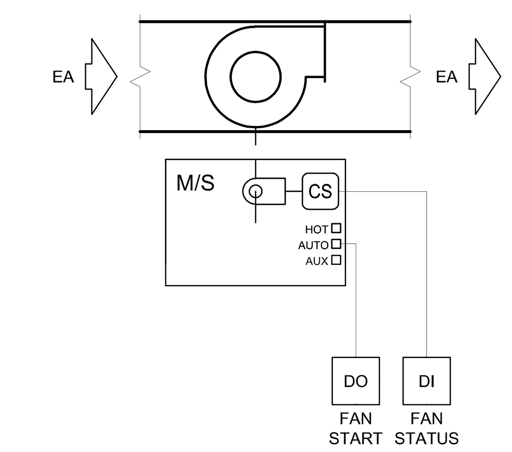
X / - SPLIT AC UNIT OR HEAT PUMP W/BACNET
NO SCALE



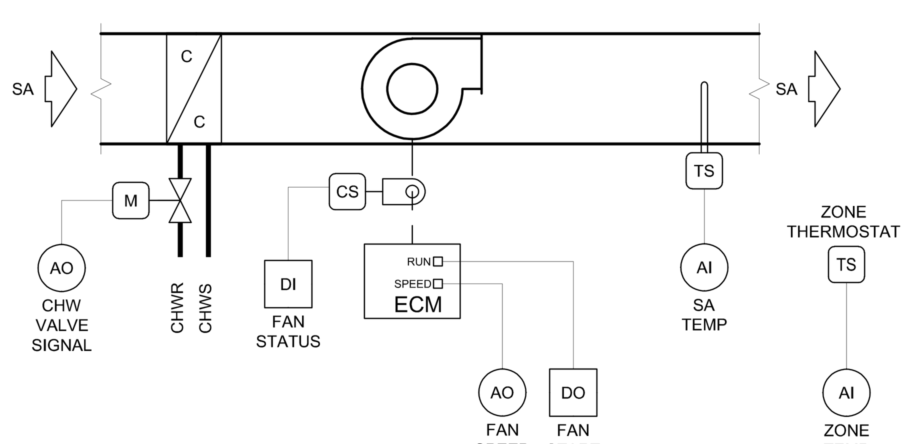
X / - PACKAGED AC UNIT OR HEAT PUMP CONTROL DIAGRAM
NO SCALE



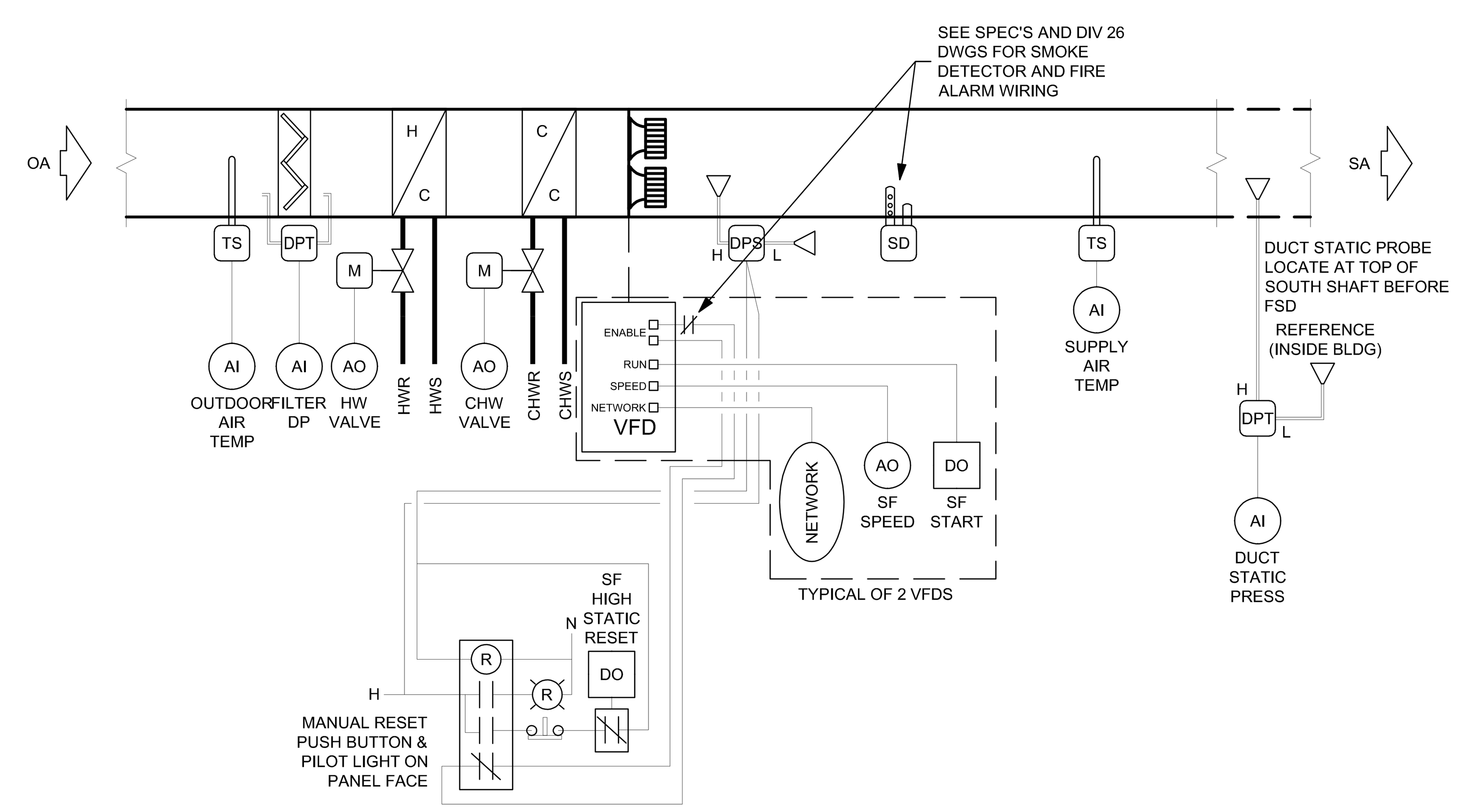
X / - PACKAGED VAV UNIT WITH BACNET
NO SCALE



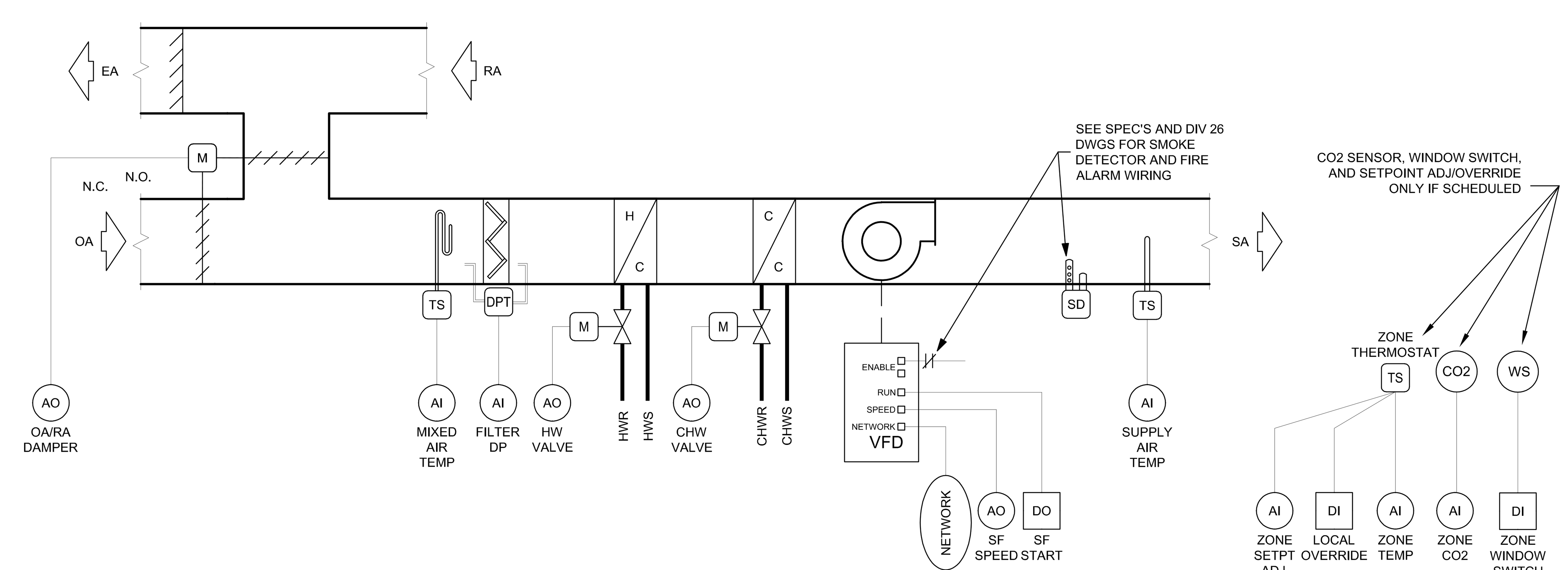
X / - EXHAUST FAN CONTROL DIAGRAM
NO SCALE



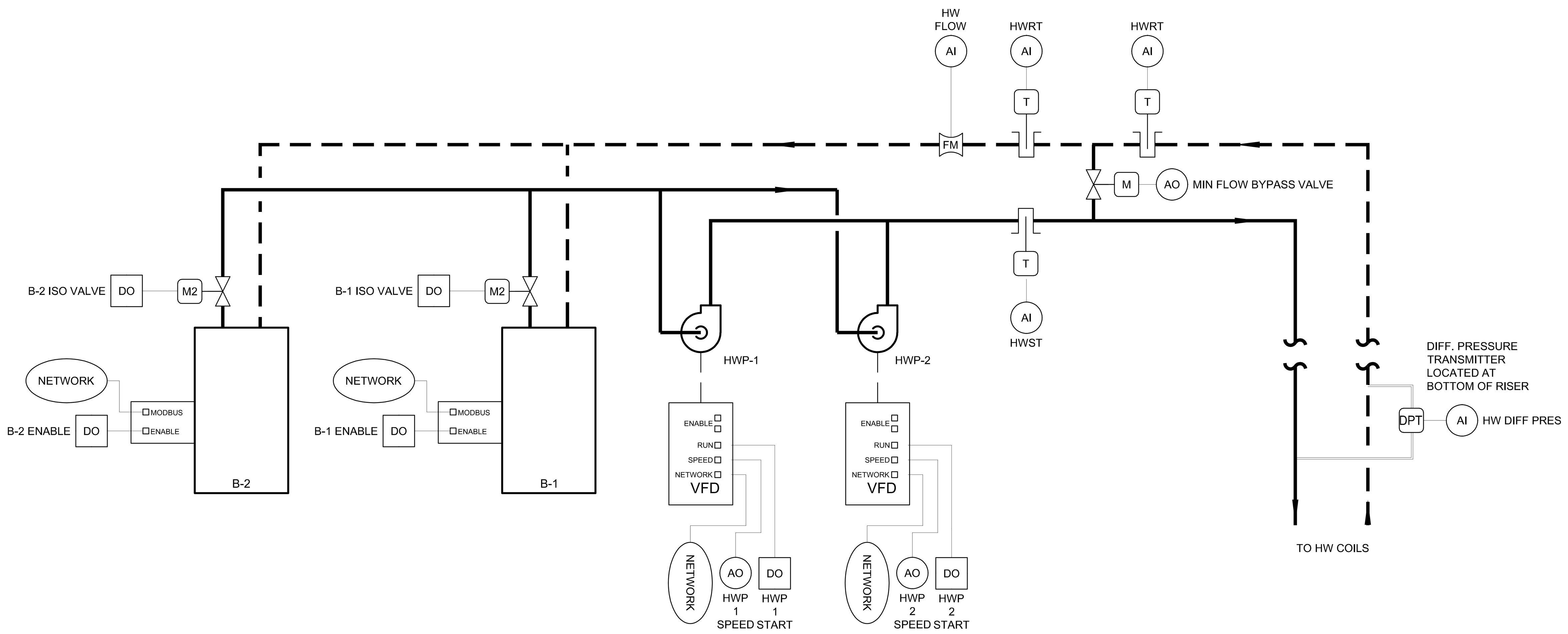
X / - VARIABLE SPEED FAN COIL CONTROL DIAGRAM (ECM)
NO SCALE



X / - DEDICATED OA VAV AIR HANDLER
NO SCALE



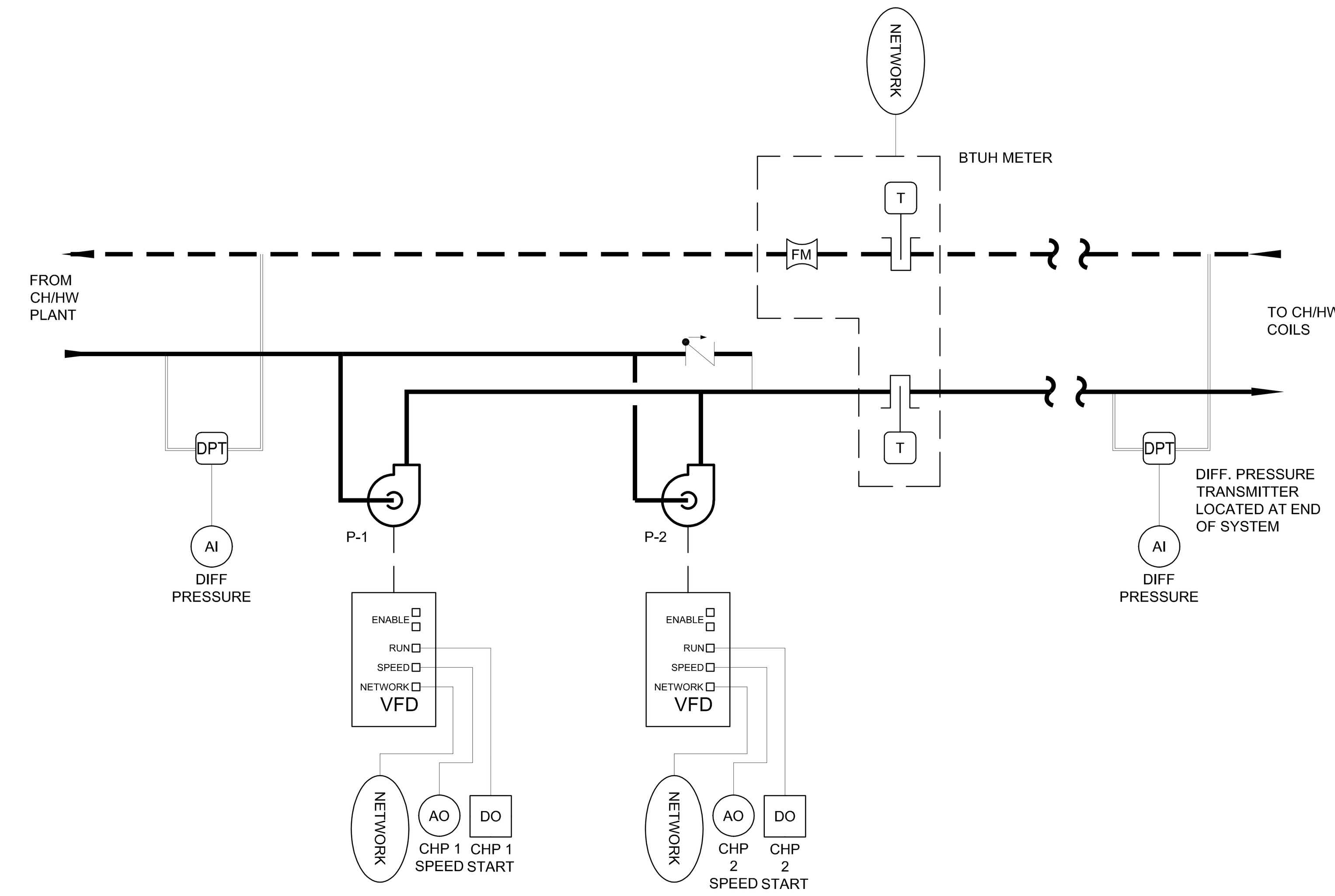
X / - VAV SINGLE ZONE AIR HANDLER
NO SCALE



HW SYSTEM SCHEMATIC

X / -

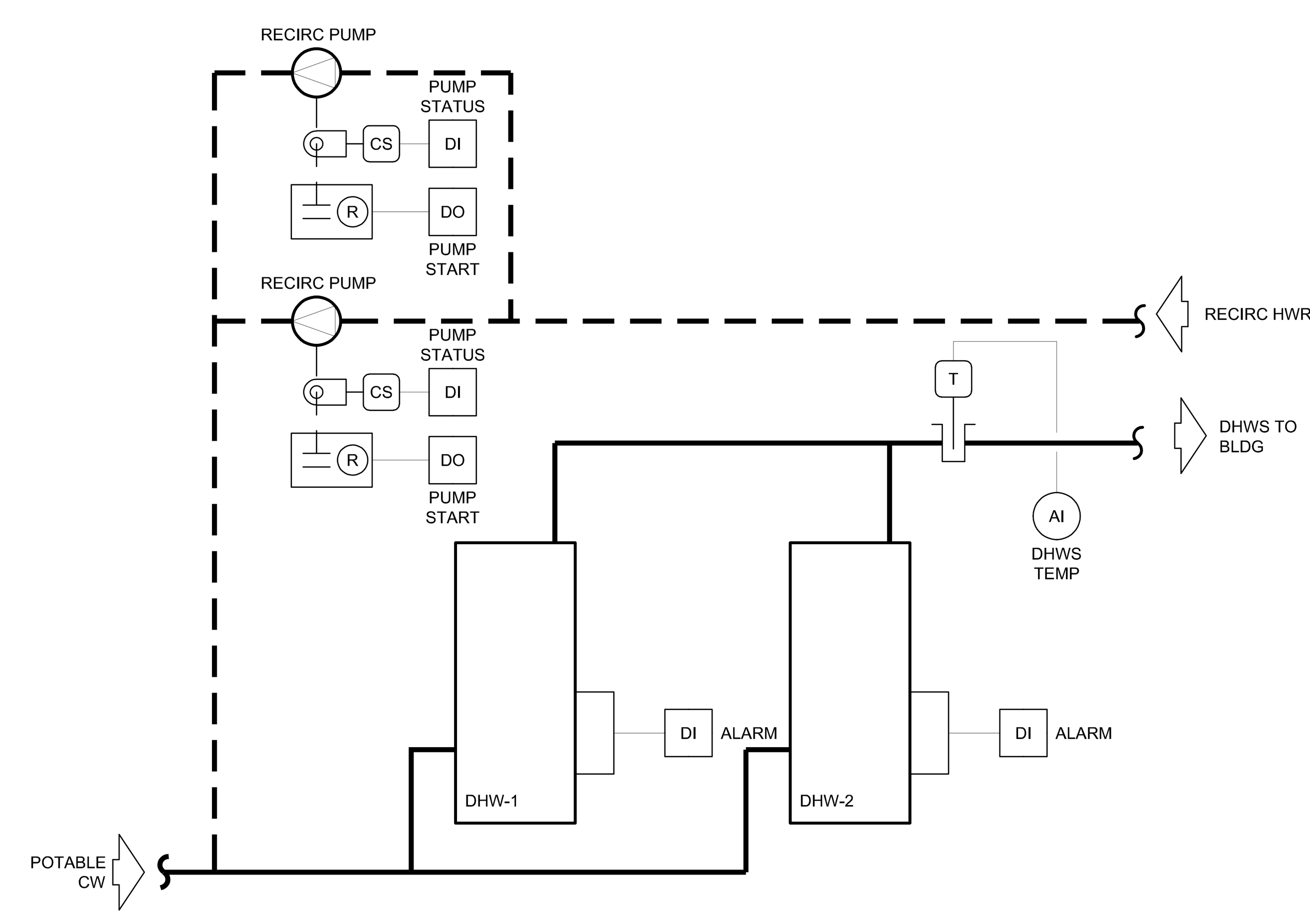
NO SCALE



CENTRAL PLANT BLDG CONNECTION CONTROL DIAGRAM

X / -

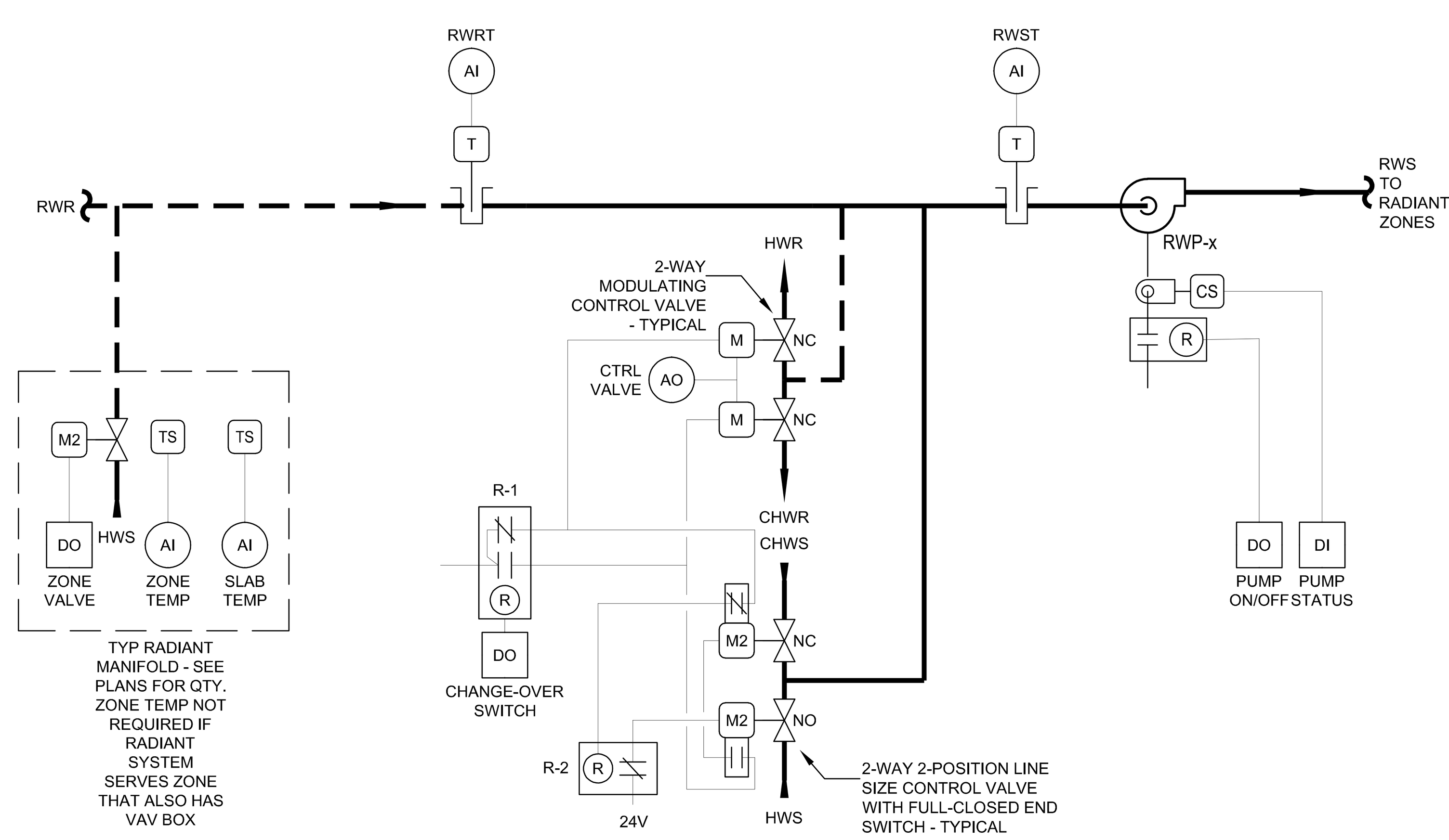
NO SCALE



DHW SYSTEM SCHEMATIC

4 / -

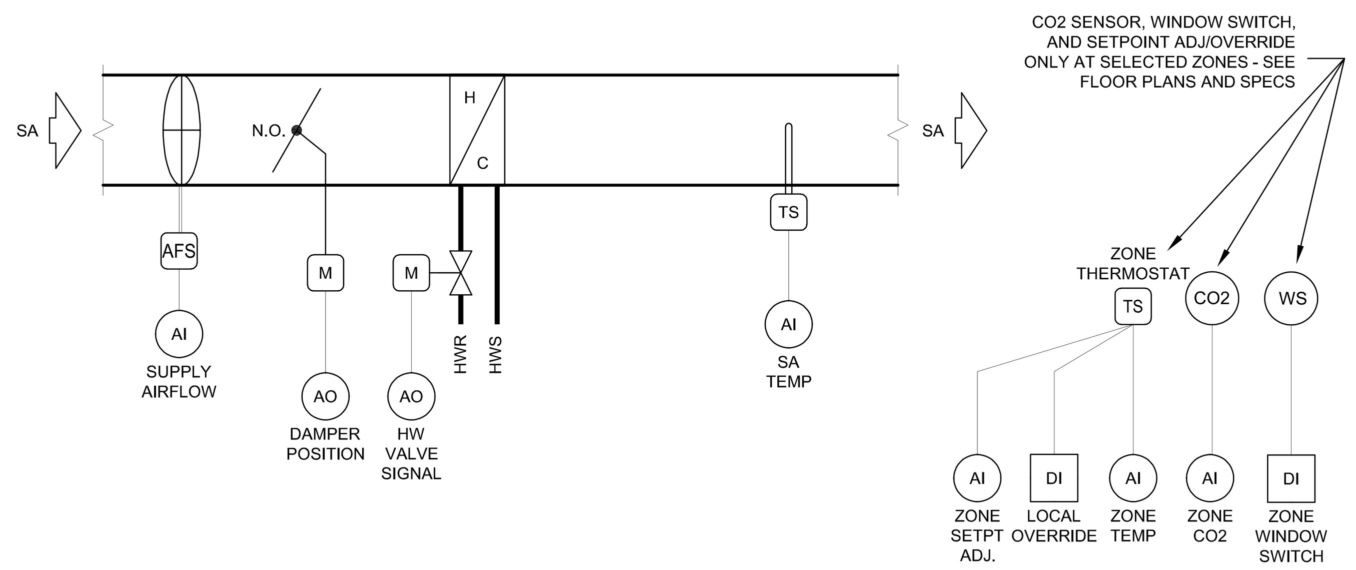
NO SCALE



RADIANT HEAT/COOL SYSTEM

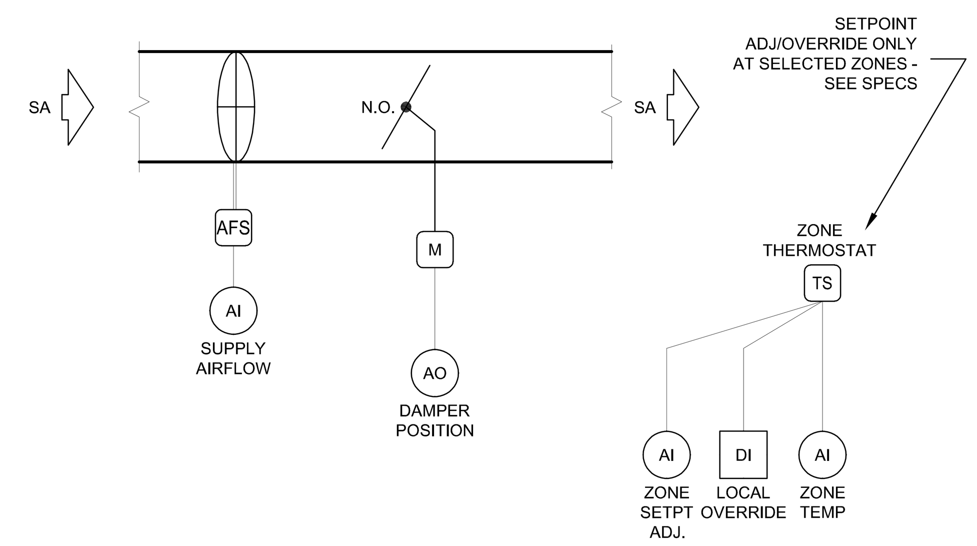
4 / -

NO SCALE



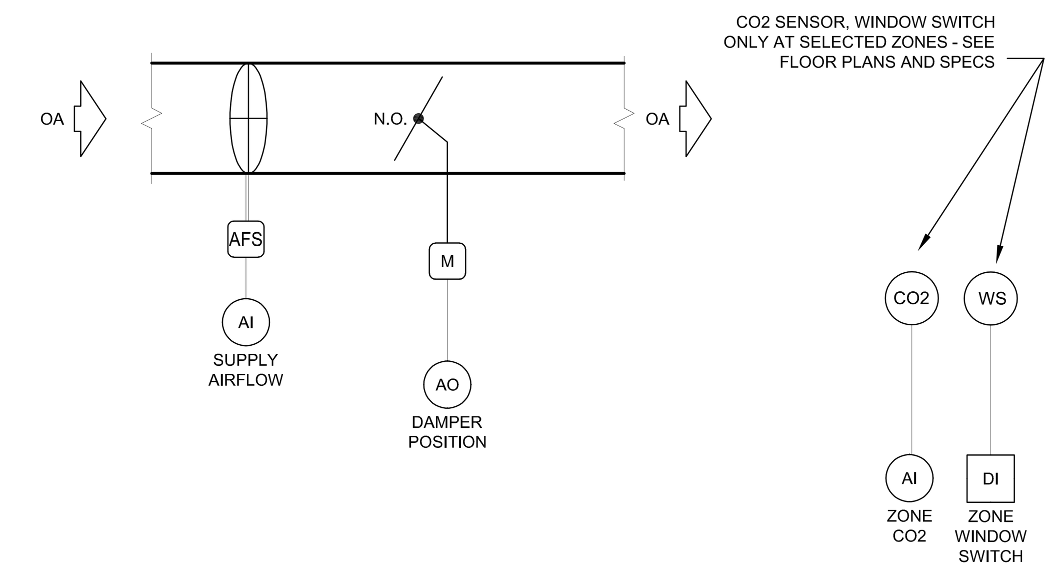
X | VAV RH ZONE CONTROL DIAGRAM

- | NO SCALE



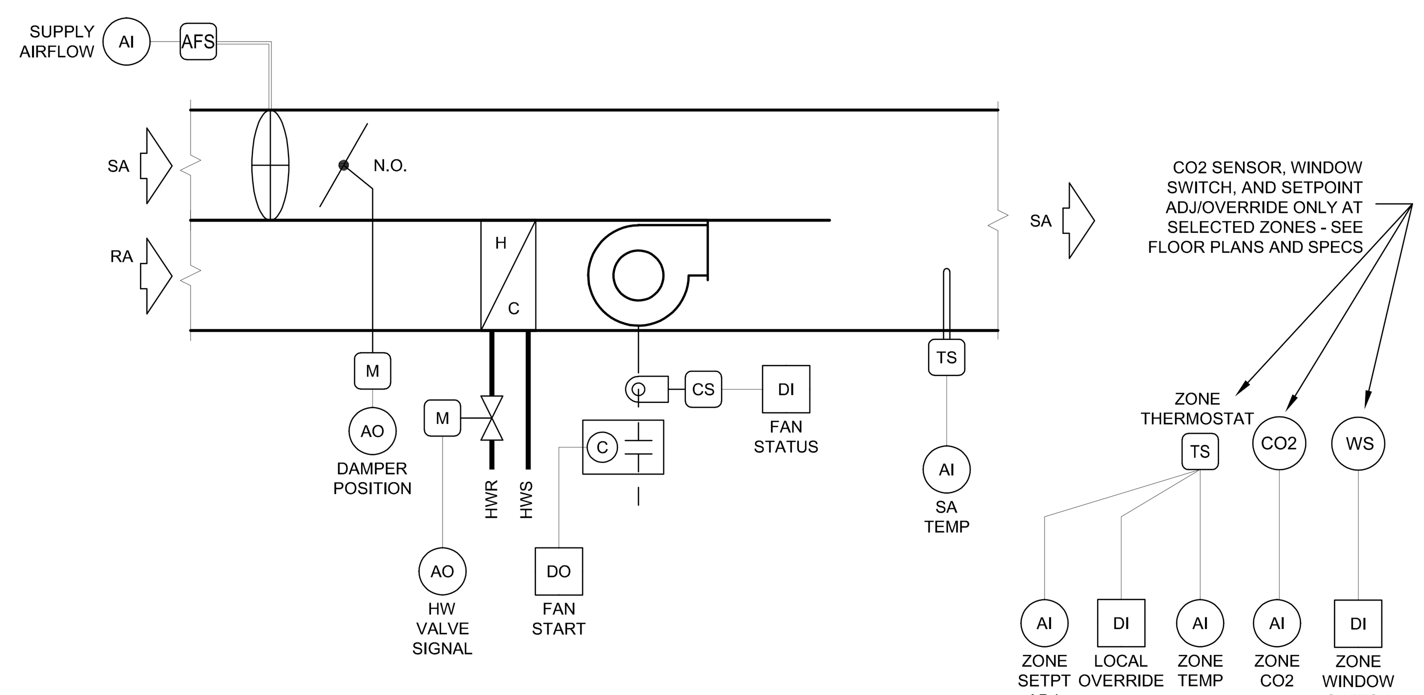
X | VAV COOLING ONLY ZONE CONTROL DIAGRAM

- | NO SCALE



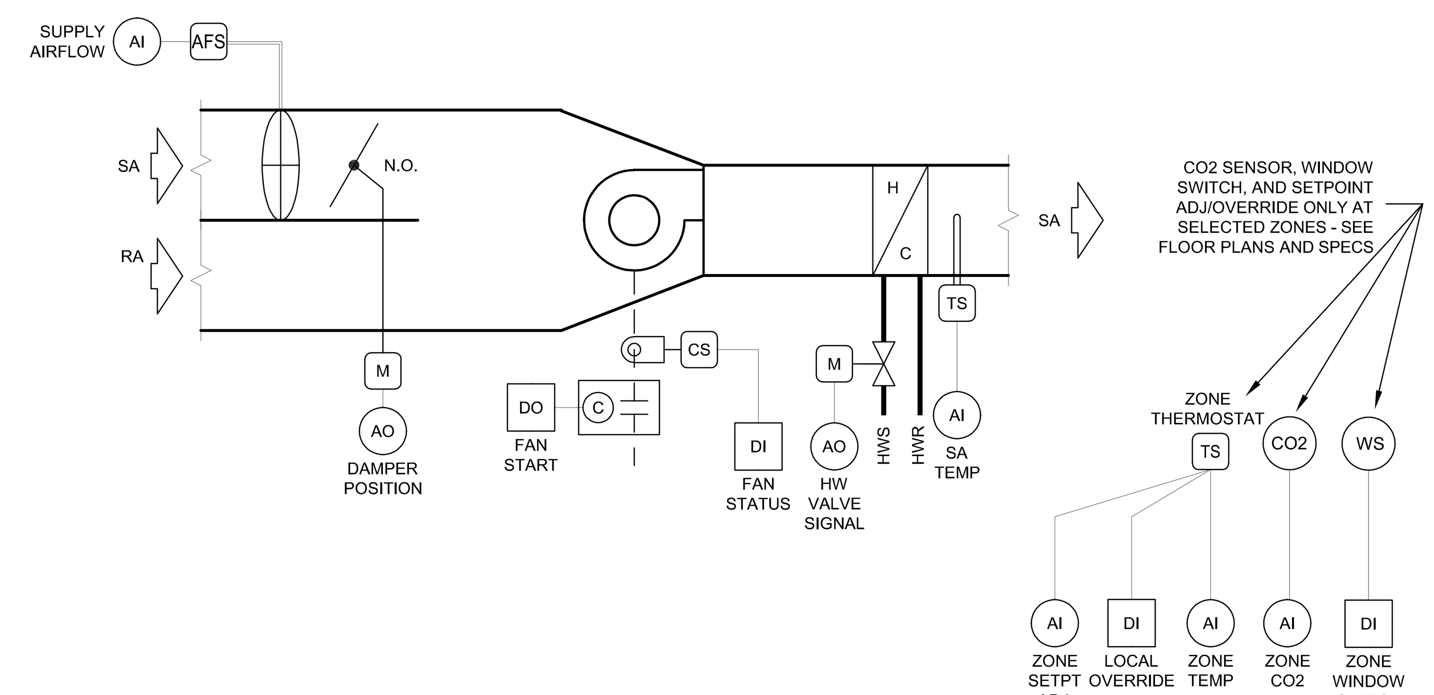
X | VENTILATION ZONE CONTROL DIAGRAM

- | NO SCALE



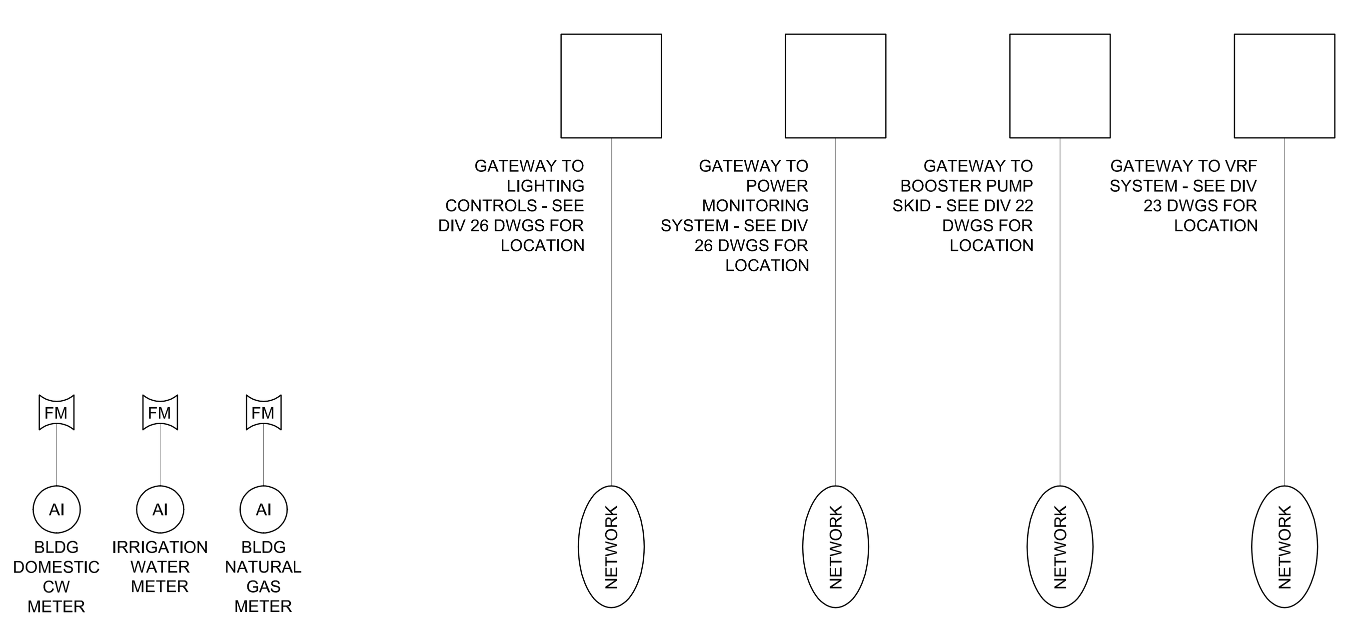
X | VAV PARALLEL FAN POWERED ZONE CONTROL DIAGRAM

- | NO SCALE



X | VAV SERIES FAN POWERED ZONE CONTROL DIAGRAM

- | NO SCALE



X | MISCELLANEOUS POINTS

- | NO SCALE