



GUIDELINE

ASHRAE Guideline 36-2021

(Supersedes ASHRAE Guideline 36-2018)

Includes ASHRAE addenda listed in Appendix C

High-Performance Sequences of Operation for HVAC Systems

See Informative Appendix C for approval dates.

This Guideline is under continuous maintenance by a Standing Guideline Project Committee (SGPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Guideline. Instructions for how to submit a change can be found on the ASHRAE® website (<https://www.ashrae.org/continuous-maintenance>).

The latest edition of an ASHRAE Guideline may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 180 Technology Parkway NW, Peachtree Corners, GA 30092. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

© 2021 ASHRAE

ISSN 1049-894X



Includes download access to the standard in Microsoft® Word® format.

ASHRAE Guideline Project Committee 36
Cognizant TC: I.4, Control Theory and Application
SPLS Liaison: Christian Taber

Jeffrey G. Boldt*, Chair	Carl A. Crow	Eric Koeppel*	Robert K. Sibley
Gwenlen Paliaga*, Vice-Chair	Clark R. Denson	Bryan Lang*	Steven C. Sill
James C. Bradburn*, Secretary	Brent R. Eubanks*	Kevin Li*	Jonathan R. Smith
Christopher R. Amundson*	Richard A. Farmer	Ed G. Morris	Ryan Soo*
Ian Bonadeo	Michael Galler*	David Morrow	Henry F. Stehmeyer IV
Barry Bridges	Christopher S. Gosline	Kevin Ng	Steven T. Taylor
Ronald Bristol*	Siddharth Goyal	Aaron Opatz*	Meziane Touati
Anthony Bruno	Milica Grahovac	Chirag D. Parikh	Levi Tully*
Cynthia A. Callaway*	Nathan Hampton*	James Parker	Chariti A. Young*
Yan Chen	David B. Kahn	Michael A. Pouchak*	Bei Zhang
C. Hwakong Cheng	Srinivas Katipamula*	David J. Pritchard	Xiaohui Zhou*
Gregory Cmar*	Adam T. Keeling	Paul Raftery*	
James J. Coogan	Reece Kiriu*	Brian W. Russell	

* Denotes members of voting status when the document was approved for publication

ASHRAE STANDARDS COMMITTEE 2021–2022

Rick M. Heiden, Chair	Srinivas Katipamula	Julie Majurin	Christian R. Taber
Susanna S. Hanson, Vice-Chair	Gerald J. Kettler	Lawrence C. Markel	Russell C. Tharp
Charles S. Barnaby	Essam E. Khalil	Margret M. Mathison	William F. Walter
Robert B. Burkhead	Malcolm D. Knight	Gwelen Paliaga	Craig P. Wray
Thomas E. Cappellin	Jay A. Kohler	Justin M. Prosser	Jaap Hogeling, BOD ExO
Douglas D. Fick	Cesar L. Lim	David Robin	Tim J. McGinn, CO
Michael W. Gallagher	Paul A. Lindahl, Jr.	Lawrence J. Schoen	
Patricia Graef	James D. Lutz	Steven C. Sill	

Connor Barbaree, Senior Manager of Standards

SPECIAL NOTE

This Guideline was developed under the auspices of ASHRAE. ASHRAE Guidelines are developed under a review process, identifying a Guideline for the design, testing, application, or evaluation of a specific product, concept, or practice. As a Guideline it is not definitive but encompasses areas where there may be a variety of approaches, none of which must be precisely correct. ASHRAE Guidelines are written to assist professionals in the area of concern and expertise of ASHRAE's Technical Committees and Task Groups.

ASHRAE Guidelines are prepared by Project Committees appointed specifically for the purpose of writing Guidelines. The Project Committee Chair and Vice-Chair must be members of ASHRAE; while other committee members may or may not be ASHRAE members, all must be technically qualified in the subject area of the Guideline.

Development of ASHRAE Guidelines follows procedures similar to those for ASHRAE Standards except that (a) committee balance is desired but not required, (b) an effort is made to achieve consensus but consensus is not required, (c) Guidelines are not appealable, and (d) Guidelines are not submitted to ANSI for approval.

The Senior Manager of Standards of ASHRAE should be contacted for

- a. interpretation of the contents of this Guideline,
- b. participation in the next review of the Guideline,
- c. offering constructive criticism for improving the Guideline, or
- d. permission to reprint portions of the Guideline.

DISCLAIMER

ASHRAE uses its best efforts to promulgate Standards and Guidelines for the benefit of the public in light of available information and accepted industry practices. However, ASHRAE does not guarantee, certify, or assure the safety or performance of any products, components, or systems tested, installed, or operated in accordance with ASHRAE's Standards or Guidelines or that any tests conducted under its Standards or Guidelines will be nonhazardous or free from risk.

ASHRAE INDUSTRIAL ADVERTISING POLICY ON STANDARDS

ASHRAE Standards and Guidelines are established to assist industry and the public by offering a uniform method of testing for rating purposes, by suggesting safe practices in designing and installing equipment, by providing proper definitions of this equipment, and by providing other information that may serve to guide the industry. The creation of ASHRAE Standards and Guidelines is determined by the need for them, and conformance to them is completely voluntary.

In referring to this Standard or Guideline and in marking of equipment and in advertising, no claim shall be made, either stated or implied, that the product has been approved by ASHRAE.

CONTENTS

ASHRAE Guideline 36-2021 High-Performance Sequences of Operation for HVAC Systems

Foreword	3
1. Purpose	3
2. Scope	3
2.1 This guideline provides detailed sequences of operation for HVAC systems.	3
2.2 This guideline describes functional tests that, when performed, will confirm implementation of the sequences of operation.	3
3. Setpoints, Design and Field Determined	3
3.1 Information Provided by Designer	3
3.2 Information Provided by (or in Conjunction with) the Testing, Adjusting, and Balancing Contractor	18
3.3 Information Determined by Control Contractor	25
4. List of Hardwired Points	25
4.1 VAV Terminal Unit—Cooling Only	26
4.2 VAV Terminal Unit with Reheat	26
4.3 Fan-Powered Terminal Unit (Series or Parallel, Constant- or Variable-Speed Fan)	27
4.4 Dual-Duct Terminal Unit with Inlet Sensors	28
4.5 Dual-Duct Terminal Unit with Discharge Sensor	28
4.6 Multiple-Zone VAV Air-Handling Unit.....	29
4.7 Dual-Fan Dual-Duct Heating VAV Air-Handling Unit.....	30
4.8 Single-Zone VAV Air-Handling Unit	31
4.9 General Constant Speed Exhaust Fan	32
4.10 Chilled Water Plant	32
4.11 Hot Water Plant.....	38
4.12 Fan Coil Unit	39
5. Sequences of Operations	40
5.1 General	40
5.2 Generic Ventilation Zones.....	57
5.3 Generic Thermal Zones	65
5.4 Zone Groups	69
5.5 VAV Terminal Unit—Cooling Only	70
5.6 VAV Terminal Unit with Reheat	73
5.7 Parallel Fan-Powered Terminal Unit—Constant-Volume Fan	77
5.8 Parallel Fan-Powered Terminal Unit—Variable-Volume Fan	81
5.9 Series Fan-Powered Terminal Unit—Constant-Volume Fan	86
5.10 Series Fan-Powered Terminal Unit—Variable-Volume Fan	89
5.11 Dual-Duct VAV Terminal Unit—Snap-Acting Control	93
5.12 Dual-Duct VAV Terminal Unit—Mixing Control with Inlet Airflow Sensors	98

5.13	Dual-Duct VAV Terminal Unit—Mixing Control with Discharge Airflow Sensor	102
5.14	Dual-Duct VAV Terminal Unit—Cold-Duct Minimum Control	105
5.15	Air-Handling Unit System Modes	109
5.16	Multiple-Zone VAV Air-Handling Unit.....	109
5.17	Dual-Fan Dual-Duct Heating VAV Air-Handling Unit.....	144
5.18	Single-Zone VAV Air-Handling Unit	150
5.19	General Constant Speed Exhaust Fan.....	169
5.20	Chilled Water Plant	170
5.21	Hot Water Plant.....	233
5.22	Fan Coil Unit	260
	Informative Appendix A—Control Diagrams	268
	Informative Appendix B—Abbreviations and Acronyms	282
	Informative Appendix C—Addenda Description.....	284

A Microsoft® Word® version of this file can be downloaded at <http://www.ashrae.org/G36-2021>.

NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE website at www.ashrae.org/technology.

© 2021 ASHRAE

180 Technology Parkway NW · Peachtree Corners, GA 30092 · www.ashrae.org · All rights reserved.
ASHRAE is a registered trademark of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline. It has not been processed according to the ANSI requirements for a guideline and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

This guideline establishes a set of standardized advanced sequences of operation for common HVAC systems. Standardized advanced control sequences provide the following benefits:

- *Reduced engineering time. Rather than develop sequences themselves, design engineers can adapt existing standard sequences that have been proven to perform.*
- *Reduced programming and commissioning time for contractors.*
- *Reduced energy consumption by making systems less dependent on proper implementation and commissioning of control sequences.*
- *Reduced energy consumption by ensuring that proven, cost-effective strategies, including those required by ASHRAE standards and building codes, are fully implemented.*
- *Improved indoor air quality by ensuring control sequences are in compliance with IAQ standards and codes such as ASHRAE Standard 62.1.*
- *Reduced energy consumption and reduced system down-time by including diagnostic software to detect and diagnose system faults and make operators aware of them before they cause performance problems.*

The intended audience for the guideline includes HVAC designers, control contractors, commissioning agents, and building owners, operators, and maintenance technicians.

This document falls under ASHRAE's continuous maintenance process. For more information, visit ASHRAE's website, or refer to the forms at the end of the guideline.

Note section numbers down to 3rd level, e.g., Section 5.1.2, will not change as addenda are developed, allowing people to reference those sections without concern they will be renumbered in the future.

A Microsoft® Word® version of this file can be downloaded at <http://www.ashrae.org/G36-2021>.

Note on Format

This guideline includes two kinds of informative notes:

Notes in bold between thick lines provide direction to the editor of these sequences so that they are properly implemented (e.g., identifying mutually exclusive options).

Notes in italics between thin lines provide guidance or additional information about specific sequences.

These notes are not a part of this guideline. They are merely informative and do not contain requirements necessary for conformance to the guideline.

1. PURPOSE

The purpose of this guideline is to provide uniform sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and allow for real-time fault detection and diagnostics.

2. SCOPE

- 2.1 This guideline provides detailed sequences of operation for HVAC systems.
- 2.2 This guideline describes functional tests that, when performed, will confirm implementation of the sequences of operation.

3. SETPOINTS, DESIGN AND FIELD DETERMINED

- 3.1 Information Provided by Designer

The design setpoints listed in this section must be scheduled in design documents for each zone and air handler by the design engineer.

3.1.1. General Zone Information

3.1.1.1. Zone Temperature Setpoints

Zone temperature initial setpoints can be specified by the designer in a number of ways. The most flexible way is to include them for each zone in variable-air-volume (VAV) box and single-zone VAV (SZVAV) air-handling unit (AHU) equipment schedules. They can also be generically listed by zone type, such as the example in (a) below.

- a. Default setpoints shall be based on zone type as shown in Table 3.1.1.1.

Table 3.1.1.1 Default Setpoints

Zone Type	Occupied		Unoccupied	
	Heating	Cooling	Heating	Cooling
VAV	21°C (70°F)	24°C (75°F)	16°C (60°F)	32°C (90°F)
Mechanical/electrical rooms	18°C (65°F)	29°C (85°F)	18°C (65°F)	29°C (85°F)
Networking/computer	18°C (65°F)	24°C (75°F)	18°C (65°F)	24°C (75°F)

3.1.1.2. Outdoor Air Ventilation Setpoints

Ventilation setpoints can be specified by the designer in a number of ways. The most flexible is to include them for each zone in VAV box and single-zone (SZ) equipment schedules.

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep subsection (a) and delete subsection (b).

If the project is to comply with California Title 24 ventilation requirements, keep subsection (b) and delete subsection (a).

- a. For projects complying with the Ventilation Rate Procedure of ASHRAE Standard 62.1-2016:
 1. The area component of the breathing zone outdoor airflow V_{bz-A}

*This is the zone floor area times the outdoor airflow rate per unit area, as given in Standard 62.1-2016, Table 6.2.2.1; i.e., $V_{bz-A} = A_z * R_a$.*

2. The population component of the breathing zone outdoor airflow V_{bz-P}

*This is the zone design population (without diversity) times the outdoor airflow rate per occupant, as given in Standard 62.1-2016, Table 6.2.2.1; i.e.; $V_{bz-P} = P_z * R_p$.*

3. Zone air distribution effectiveness EzH in heating
4. Zone air distribution effectiveness EzC in cooling

Zone air distribution effectiveness depends on the relative locations of supply and return in the space, per ASHRAE Standard 62.1-2016, Table 6.2.2.2.

5. Indicate where occupied-standby mode is allowed, based on the zone occupancy category per Standard 62.1-2016, Table 6.2.2.1.

Occupied-standby mode applies to individual zones, is considered a zonal subset of Occupied Mode and is not considered a zone-group operating mode. See Section 5.4.6 for zone-group operating modes.

- b. For projects complying with California Title 24 ventilation standards:
 - 1. *Vocc-min.* Zone minimum outdoor airflow for occupants, per California Title 24 prescribed airflow-per-occupant requirements.
 - 2. *Varea-min.* Zone minimum outdoor airflow for building area, per California Title 24 prescribed airflow-per-area requirements.
 - 3. Indicate where occupied-standby mode is allowed based on the zone occupancy category per Title 24-2019, Table 120.1-A.

Occupied-standby mode applies to individual zones, is considered a zonal subset of Occupied Mode, and is not considered a Zone Group Operating Mode. See 5.4.6 for Zone Group Operating Modes.

3.1.1.3. CO₂ Setpoints

Space CO₂ setpoints are used for demand-controlled ventilation (DCV) and monitoring/alarming as required by LEED and other green building standards.

It is the designer's responsibility to determine CO₂ setpoints. The maximum setpoint varies by ventilation standard. Some guidance is provided below for Standard 62.1 and Title 24. The designer may also decide to set lower, more conservative setpoints for improved indoor air quality but at the expense of higher energy use.

Standard 62.1 CO₂ Setpoint Guidance

Recommended maximum CO₂ is 90% of the steady state concentration per Lawrence¹:

$$CO_2\text{setpoint} = 0.9 \left(C_{OA} + \frac{8400E_z m}{R_p + R_a A_z / P_z} \right)$$

where COA is the outdoor air CO₂ concentration in ppm, Ez is the zone ventilation effectiveness, m is the metabolic rate of occupants, Rp is the people-based component of the ventilation rate, Ra is the area-based component of the ventilation rate, Az is the zone floor area, and Pz is the number of occupants.

The CO₂ setpoints in Informative Table 3.1.1.3 assume an ambient concentration of 400 ppm in lieu of using an ambient CO₂ sensor. These sequences are based on not having an ambient sensor. This will be conservative in areas with high ambient CO₂ concentrations; few areas have lower concentrations.

Setpoints vary by occupancy type, so the easiest way to include this info is by including a column in VAV box and SZ unit schedules and entering the setpoint individually for each zone.

Demand controlled ventilation (DCV) is an active area of research under ASHRAE RP-1747, "Implementation of RP-1547 CO₂-Based Demand Controlled Ventilation for Multiple Zone HVAC Systems in Direct Digital Control Systems."

Informative Table 3.1.1.3 Default CO₂ Setpoints per ASHRAE Standard 62.1

Occupancy Category	CO ₂ Setpoint (ppm)	Occupancy Category	CO ₂ Setpoint (ppm)
<i>Correctional Facilities</i>		<i>Office Buildings</i>	
<i>Cell</i>	965	<i>Office Space</i>	894
<i>Dayroom</i>	1,656	<i>Reception Areas</i>	1,656
<i>Guard Stations</i>	1,200	<i>Telephone/Data Entry</i>	1,872

1. Source: Lawrence, T. 2008. Selecting CO₂ criteria for outdoor air monitoring. ASHRAE Journal 50(12).

Occupancy Category	CO ₂ Setpoint (ppm)	Occupancy Category	CO ₂ Setpoint (ppm)
Booking/Waiting	1,200	Main Entry/Lobbies	1,391
<i>Educational Facilities</i>		<i>Miscellaneous Spaces</i>	
Day Care (Through Age 4)	1,027	Bank Vaults/Safe Deposit	805
Day Care Sickroom	716	Computer (Not Printing)	738
Classrooms (Age 5 – 8)	864	Pharmacy (Preparation Area)	820
Classrooms (Age 9+)	942	Photo Studios	983
Lecture Classroom	1,305	Transportation Waiting	1,305
Lecture Hall (Fixed Seats)	1,305	<i>Public Assembly Spaces</i>	
Art Classroom	837	Auditorium Seating Area	1,872
Science Laboratories	894	Place of Religious Worship	1,872
University/College Lab	894	Courtrooms	1,872
Wood/Metal Shop	1,156	Legislative Chambers	1,872
Computer Lab	965	Libraries	805
Media Center	965	Lobbies	2,628
Music/Theater/Dance	1,620	Museums (Children's)	1,391
Multiuse Assembly	1,778	Museum/Galleries	1,620
<i>Food and Beverage Service</i>		<i>Retail</i>	
Restaurant Dining Rooms	1,418	Sales (Except Below)	1,069
Cafeteria/Fast-Food Dining	1,536	Mall Common Areas	1,620
Bars, Cocktail Lounges	1,536	Barbershop	1,267
<i>General</i>		Beauty and Nail Salons	723
Break Rooms	1,267	Pet Shops (Animal Areas)	709
Coffee Stations	1,185	Supermarket	1,116
Conference/Meeting	1,620	Coin-operated Laundries	1,322
<i>Hotels, Motels, Resorts, Dormitories</i>		<i>Sports and Entertainment</i>	
Bedroom/Living Area	910	Spectator Areas	1,778
Barracks Sleeping Areas	1,116	Disco/Dance Floors	1,440
Laundry Rooms, Central	1,249	Health Clubs/Aerobics Room	1,735
Laundry Within Dwelling	983	Health Clubs/Weight Room	1,232
Lobbies/Prefunction	1,494	Bowling Alley (Seating)	1,232
Multipurpose Assembly	2,250	Gambling Casinos	1,368
		Game Arcades	894
		Stages, Studios	1,391

California Title 24 CO₂ Setpoint Guidance

Title 24 stipulates the setpoint for all occupancies must be 600 ppm above ambient. Ambient concentration may be assumed to be 400 ppm, or an ambient sensor may be provided. These sequences are currently based on not having an ambient sensor, so the CO₂ setpoint for all occupancy types is 1000 ppm.

3.1.2. VAV Box Design Information

For the terminal unit sequences, the engineer must provide the setpoint information in the following subsections, typically on VAV box schedules on drawings.

3.1.2.1. VAV Cooling-Only Terminal Unit

- a. Zone maximum cooling airflow setpoint ($V_{cool-max}$)
- b. Zone maximum heating airflow setpoint ($V_{heat-max}$)

Cooling-only terminal units can provide heat when the AHU supply air temperature is more than 3°C (5°F) above the room temperature. The zone maximum heating airflow setpoint should be set to no more than the zone maximum cooling airflow setpoint. If there is no zone maximum heating airflow setpoint scheduled, set $V_{heat-max}$ equal to $V_{cool-max}$.

- c. Zone minimum airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of "AUTO" is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California's Title 24 Energy Standards requirements, and it results in the lowest energy costs.

3.1.2.2. VAV Reheat Terminal Unit

- a. Zone maximum cooling airflow setpoint ($V_{cool-max}$)
- b. Zone minimum airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of "AUTO" is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California's Title 24 Energy Standards requirements, and it results in the lowest energy costs.

- c. Zone maximum heating airflow setpoint ($V_{heat-max}$)

The design engineer should set $V_{heat-max}$ such that the design heating load is met by $V_{heat-max}$ airflow at a discharge air temperature (DAT) equal to $Max\Delta T$ plus the heating setpoint. $Max\Delta T$ can be no higher than 11°C (20°F) above space temperature setpoint per ASHRAE/IES Standard 90.1-2016 (e.g., DAT no more than 32°C [90°F] at 21°C [70°F] space temperature setpoint) for systems supplying air greater than 1.8 m (6 ft) above floor, e.g., ceiling supply systems. Zone air distribution effectiveness EzH can be improved if $Max\Delta T$ is less than 8°C (15°F), provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level as indicated in ASHRAE Standard 62.1-2016, Table 6.2.2.2.

- d. Zone maximum DAT above heating setpoint ($Max\Delta T$)
- e. The heating minimum airflow setpoint ($V_{heat-min}$)

$V_{heat-min}$ is the minimum airflow required for reheat coil operation, as is often required of electric resistance coils. It should be as low as possible for best efficiency. For reheat coils with no minimum flow requirement, such as hot-water coils, $V_{heat-min}$ should be zero.

3.1.2.3. Parallel Fan-Powered Terminal Unit, Constant-Volume Fan

- a. Zone maximum cooling (primary) airflow setpoint ($V_{cool-max}$)

- b. Zone minimum primary airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California’s Title 24 Energy Standards requirements, and it results in the lowest energy costs.

- c. Zone maximum DAT above heating setpoint (ΔT_{max})

3.1.2.4. Parallel Fan-Powered Terminal Unit, Variable-Volume Fan

Fans powered by electronically commutated motors (ECMs) must be programmed with the relationship between control signal and airflow. ECMs can be programmed to control either a specific airflow (with fan curve mapped into logic) or torque (pressure dependent airflow). For these sequences, the ECM fan should be configured for airflow control. This must be addressed by the design engineer in terminal-unit specifications.

- a. Zone maximum cooling (primary) airflow setpoint ($V_{cool-max}$)
- b. Zone minimum primary airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California’s Title 24 Energy Standards requirements, and it results in the lowest energy costs.

- c. Parallel fan maximum heating airflow setpoint ($P_{fan-htgmax}$)

The design engineer should set $P_{fan-htgmax}$ such that the design heating load is met by the sum of $P_{fan-htgmax}$ and V_{min} at a DAT equal to ΔT_{max} plus the heating setpoint. ΔT_{max} can be no higher than 11°C (20°F) above space temperature setpoint per ASHRAE/IES Standard 90.1-2016 (e.g., DAT no more than 32°C [90°F] at 21°C [70°F] space temperature setpoint) for systems supplying air greater than 1.8 m (6 ft) above floor, e.g., ceiling supply systems. Zone air distribution effectiveness EzH can be improved if ΔT_{max} is less than 8°C (15°F), provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level as indicated in ASHRAE Standard 62.1-2016, Table 6.2.2.2. This can be done in most zones by setting $P_{fan-htgmax}$ to ensure these conditions are maintained.

- d. Zone maximum DAT above heating setpoint (ΔT_{max})

3.1.2.5. Series Fan-Powered Terminal Unit, Constant-Volume Fan

- a. Zone maximum cooling airflow setpoint ($V_{cool-max}$)
- b. Zone minimum airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California’s Title 24 Energy Standards requirements, and it results in the lowest energy costs.

Series fan airflow is not a design variable because it is not controlled. It must be designed and balanced to be equal to or greater than $V_{cool-max}$. Typically, the series fan airflow is equal to $V_{cool-max}$ but may be higher if some blending is desired, such as on cold primary air systems. It may also be higher to improve zone air distribution effectiveness.

The design engineer should set the series fan airflow such that the design heating load is met with a DAT equal to ΔT_{max} plus the heating setpoint. ΔT_{max} can be no higher than 11°C (20°F) above space temperature setpoint per

Standard 90.1-2016 (e.g., DAT no more than 32°C [90°F] at 21°C [70°F] space temperature setpoint) for systems supplying air greater than 1.8 m (6 ft) above floor, e.g., ceiling supply systems. Zone air distribution effectiveness EzH can be improved if ΔT is less than 8°C (15°F), provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level as indicated in ASHRAE Standard 62.1-2016, Table 6.2.2.2. This can be done in most zones by setting the series fan airflow to ensure these conditions are maintained.

- c. Zone maximum DAT above heating setpoint (ΔT)

3.1.2.6. Series Fan-Powered Terminal Unit, Variable-Volume Fan

Fans powered by electronically commutated motors (ECMs) must be programmed with the relationship between control signal and airflow. ECMs can be programmed to control either a specific airflow (with fan curve mapped into logic) or torque (pressure dependent airflow). For these sequences, the ECM fan should be configured for airflow control. This must be addressed by the design engineer in terminal unit specifications.

- a. Zone maximum cooling airflow setpoint ($V_{cool-max}$)
- b. Zone minimum airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California’s Title 24 Energy Standards requirements, and it results in the lowest energy costs.

- c. Series fan maximum heating airflow setpoint ($S_{fan-htgmax}$)

The design engineer should set $S_{fan-htgmax}$ such that the design heating load is met by the sum of $S_{fan-htgmax}$ and V_{min} at a DAT equal to ΔT plus the heating setpoint. ΔT can be no higher than 11°C (20°F) above space temperature setpoint per Standard 90.1-2016 (e.g., DAT no more than 32°C [90°F] at 21°C [70°F] space temperature setpoint) for systems supplying air greater than 1.8 m (6 ft) above floor, e.g., ceiling supply systems. Zone air distribution effectiveness EzH can be improved if ΔT is less than 8°C (15°F), provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level as indicated in ASHRAE Standard 62.1-2016, Table 6.2.2.2. This can be done in most zones by setting $S_{fan-htgmax}$ to ensure these conditions are maintained.

- d. Zone maximum DAT above heating setpoint (ΔT)

3.1.2.7. Dual-Duct VAV Terminal Unit

- a. Zone maximum cooling airflow setpoint ($V_{cool-max}$)
- b. Zone minimum airflow setpoint (V_{min}). This is an optional entry. If no value is scheduled, or a value of “AUTO” is scheduled, V_{min} will be calculated automatically and dynamically to meet ventilation requirements.

In most cases, V_{min} should be allowed to be automatically calculated. This ensures compliance with Standard 62.1 and Standard 90.1 prescriptive requirements and with California’s Title 24 Energy Standards requirements, and it results in the lowest energy costs.

- c. Zone maximum heating airflow setpoint ($V_{heat-max}$)

3.1.3. Zone Group Assignments

Zones and miscellaneous associated equipment must be assigned to Zone Groups, such as by using a table (see example Informative Table 3.1.3) either on drawings or in Building Automation System (BAS) specifications. Other formats may be used if they convey the same information.

Guidance for Zone Group Assignments

1. Each zone served by a single-zone air handler shall be its own Zone Group.

2. Rooms occupied 24/7, such as computer rooms, networking closets, mechanical, and electrical rooms served by the air handler shall be assigned to a single Zone Group. These rooms do not apply to the Zone Group restrictions below.
3. A Zone Group shall not span floors (per Section 6.4.3.3.4 of ASHRAE 90.1 2016).
4. A Zone Group shall not exceed 2,300 m² (25,000 ft²) (per Section 6.4.3.3.4 of ASHRAE 90.1 2016).
5. If future occupancy patterns are known, a single Zone Group shall not include spaces belonging to more than one tenant.
6. A zone shall not be a member of more than one Zone Group.
7. Miscellaneous equipment, such as exhaust fans, serving spaces within a Zone Group shall be included in the Zone Group.
8. Miscellaneous equipment may be included in multiple Zone Group if it serves spaces in multiple Zone Groups.

Informative Table 3.1.3 Example Zone-Group Table

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

3.1.4. Multiple-Zone VAV Air-Handler Design Information

3.1.4.1. Temperature Setpoints

AHU setpoints required by the designer are best conveyed in equipment schedules because the setpoints vary for each AHU.

- a. Min_ClgSAT, lowest cooling supply air temperature setpoint

The Min_ClgSAT variable should be set no lower than the design coil leaving air temperature to prevent excessive CHW temperature reset requests, which will reduce chiller plant efficiency.

- b. Max_ClgSAT, highest cooling supply air temperature setpoint

The Max_ClgSAT variable is typically 18°C (65°F) in mild and dry climates and 16°C (60°F) or lower in humid climates. It should not typically be greater than 18°C (65°F) because this may lead to excessive fan energy that can offset the mechanical cooling savings from economizer operation.

- c. OAT_Min, the lower value of the OAT reset range
- d. OAT_Max, the higher value of the OAT reset range

Occupied Mode supply air temperature set-point reset logic uses a combination of reset by outdoor air temperature (intended to reduce fan energy during warm weather) and zone feedback (SAT needed to satisfy the zone requiring the coldest air to meet space temperature setpoint). OAT_Min and OAT_Max define the range of outdoor air temperatures used for the OAT reset logic. Typical values are OAT_Min = 16°C (60°F) and OAT_Max = 21°C (70°F), selected to maximize economizer operation and minimize reheat losses, offset partially by higher fan energy. A lower range, e.g., 18°C (65°F) and 13°C (55°F), respectively, may improve net energy performance for some applications:

1. *The chiller plant operates continuously, so extended economizer operation does not reduce plant runtime.*
 2. *The system has very little reheat inherently, such as dual-fan dual-duct systems or fan-powered box systems with very low primary air minimums.*
 3. *The climate is warm or humid, limiting available economizer hours.*
-

3.1.4.2. Ventilation Setpoints

- a. For projects complying with the Ventilation Rate Procedure of ASHRAE Standard 62.1:
 1. DesVou, the uncorrected design outdoor air rate, including diversity where applicable
 2. DesVot, design total outdoor air rate (Vou adjusted for ventilation efficiency)

DesVou and DesVot can be determined using the 62MZCalc spreadsheet provided with Standard 62.1 User's Manual.

- b. For projects complying with California Title 24 Ventilation Standards:
 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

3.1.4.3. Economizer High Limit

The engineer must select between economizer high-limit options:

If the project is to comply with ASHRAE/IES Standard 90.1 economizer high-limit requirements, keep subsection (a) and delete subsection (b).

If the project is to comply with California Title 24 economizer high-limit requirements, keep subsection (b) and delete subsection (a).

The control logic will automatically select the correct setpoints based on climate zone and high-limit type selected. Note that points lists and schematics show herein do not include enthalpy sensors; they must be added if the designer wishes to use high-limit logic that includes enthalpy.

- a. ASHRAE/IES Standard 90.1 economizer high limit
 1. Select ASHRAE climate zone number and suffix in which air handling system is located.
 2. Choose one of the following high limit options:
 - i. Fixed dry bulb
 - ii. Differential dry bulb

While not listed as such in Standard 90.1, it is possible to use both fixed and differential dry-bulb high limits.

- iii. Fixed dry bulb + differential dry bulb

- iv. Fixed enthalpy + fixed dry bulb
 - v. Differential enthalpy + fixed dry bulb
- b. California Title 24 economizer high limit
1. Indicate California climate zone number in which air-handling system is located.
 2. Choose one of the following high limit options:
 - i. Fixed dry bulb
 - ii. Differential dry bulb

While not listed as such in Title 24, it is possible to use both fixed and differential dry-bulb high limits.

- iii. Fixed dry bulb + differential dry bulb
- iv. Fixed enthalpy + fixed dry bulb

3.1.4.4. DP100, filter high limit differential pressure at design airflow

The filter high limit differential pressure threshold shall be determined as the maximum recommended filter pressure drop at design airflow by the filter manufacturer.

3.1.4.5. Pressure Zone Group Assignments

Return/relief fans and building pressure sensors must be assigned to pressure Zone Groups, such as by using a table (see example Informative Table 3.1.4.5) either on drawings or in Building Automation Systems (BAS) specifications. Other formats may be used if they convey the same information.

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.

Informative Table 3.1.4.5 Example Pressure Zone Group Table

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

3.1.5. Dual-Fan Dual-Duct VAV Air-Handler Design Information

3.1.5.1. Temperature Setpoints

- a. Max_HtgSAT, highest heating supply air temperature, typically design heating coil leaving air temperature

Max_HtgSAT can be no higher than 11°C (20°F) above space temperature setpoint per Standard 90.1-2016 (e.g., no more than 32°C [90°F] at 21°C [70°F] space temperature setpoint) for systems supplying air greater than 1.8 m (6 ft) above floor, e.g., ceiling supply systems. Zone air distribution effectiveness EzH can be improved if Max_HtgSAT is less than 8°C (15°F), provided that the 0.8 m/s (150 fpm) supply air jet reaches to within 1.4 m (4.5 ft) of floor level as indicated in ASHRAE Standard 62.1-2016, Table 6.2.2.2.

3.1.5.2. DP100, filter high limit differential pressure at design airflow

The filter high limit differential pressure threshold shall be determined as the maximum recommended filter pressure drop at design airflow by the filter manufacturer.

3.1.6. Single-Zone VAV Air-Handler Design Information

3.1.6.1. Temperature Setpoints

- a. Cool_SAT, lowest cooling supply air temperature setpoint
- b. Heat_SAT, highest heating supply air temperature setpoint

Cool_SAT is typically the design coil leaving air temperature. Heat_SAT is typically the design coil leaving air temperature, no more than 11°C (20°F) above the active heating setpoint.

- c. MaxDPT, maximum supply air dew-point temperature

MaxDPT is used to limit supply air temperature to ensure that supply air is not too humid resulting in high space humidity. This is typically only needed in humid type "A" climates. A typical value is 17°C (62°F). For mild and dry climates, a high setpoint (e.g., 24°C [75°F]) should be entered for maximum efficiency.

3.1.6.2. Ventilation Setpoints

The engineer must select between ventilation logic options:

If the project is to comply with Standard 62.1 ventilation requirements, keep subsection "a." and delete subsection "b."

If the project is to comply with California Title 24 ventilation requirements, keep subsection "b." and delete subsection "a."

- a. For projects complying with the Ventilation Rate Procedure of ASHRAE Standard 62.1:
 1. MinOA, the design outdoor air rate when the zone with a CO₂ sensor served by the system is unpopulated. MinOA shall equal Vbz-A/EzC.
 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 (Vbz-A+Vbz-P)/EzH.
- b. 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 Vooc-min.

3.1.6.3. Economizer High Limit

The engineer must select between economizer high-limit options:

If the project is to comply with ASHRAE/IES Standard 90.1 economizer high-limit requirements, keep subsection (a) and delete subsection (b).

If the project is to comply with California Title 24 economizer high limit requirements, keep subsection (b) and delete subsection (a).

The control logic will automatically select the correct setpoints based on thermal zone and high-limit type selected. Note that points lists and schematics show herein do not include enthalpy sensors; they must be added if the designer wishes to use high-limit logic that includes enthalpy.

- a. ASHRAE 90.1 economizer high limit
 1. Select ASHRAE thermal zone number and suffix in which air handling system is located.
 2. Choose one of the following high limit options:
 - i. Fixed dry bulb
 - ii. Differential dry bulb

While not listed as such in Standard 90.1, it is possible to use both fixed and differential dry-bulb high limits.

- iii. Fixed dry bulb + differential dry bulb
 - iv. Fixed enthalpy + Fixed dry bulb
 - v. Differential enthalpy + fixed dry bulb
- b. California Title 24 economizer high limit
 1. Indicate California thermal zone number in which air handling system is located.
 2. Choose one of the following high limit options:
 - i. Fixed dry bulb
 - ii. Differential dry bulb

While not listed as such in Title 24, it is possible to use both fixed and differential dry-bulb high limits.

- iii. Fixed dry bulb + differential dry bulb
- iv. Fixed enthalpy + fixed dry bulb

3.1.6.4. DP100, filter high limit differential pressure at design airflow

The filter high limit differential pressure threshold shall be determined as the maximum recommended filter pressure drop at design airflow by the filter manufacturer.

3.1.7. Chilled Water Plant

3.1.7.1. Temperature Setpoints

- a. CHWSTminX, the lowest chilled water supply temperature setpoint for Chiller X
- b. CHWSTmax, the maximum chilled water supply temperature setpoint used in plant reset logic.

60°F is a typical value. However, CHWSTmax should be adjusted based on the constraints imposed by the chillers comprising the plant and the coils the plant serves. If a chiller's internal setpoint cannot be reset to 60°F, or there are no conditions under which 60°F will be capable of satisfying certain coil loads, using a lower CHWSTmax is advisable.

Retain the following two parameters for water-cooled plants. Delete otherwise.

- c. CWRTdesX, the condenser water return (chiller condenser leaving) temperature at chiller selection conditions for Chiller X.

- d. CWSTdesX, the condenser water supply (chiller condenser entering) temperature at chiller selection conditions for Chiller X
- e. CH-LOT, the outdoor air lockout temperature below which the chiller plant is prevented from operating.

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.

3.1.7.2. Differential Pressure Setpoints

- a. CHW-DPmin, the minimum differential pressure setpoint used in plant reset logic

CHW-DPmin is dictated by minimum flow control in primary-only plants but has no lower limit in primary-secondary plants. In primary-only plants, minimum DP needs to be high enough to drive design minimum flow for the largest chiller (CHW-MinFlowX) through the minimum flow bypass valve (usually around 5 psi when the valve is selected properly). Typically, a TAB test is NOT needed to establish this value; minimum flow bypass valve Cv and CHW-MinFlowX are sufficient to establish the required DP across the minimum flow bypass valve. Where multiple DP sensors exist, a unique CHW-DPmin should be established for each loop. Note that where primary-only plants use cascading DP sensor logic—i.e., a local DP setpoint is reset at the plant to maintain remote DPs at setpoint—only the local plant DP sensor need be assigned a minimum DP setpoint high enough to achieve design minimum flow through the minimum flow bypass.

3.1.7.3. Chiller Flow Setpoints

- a. CHW-MinFlowX, the minimum chiller chilled water flowrate per manufacturer's recommendations for Chiller X, in gpm
- b. CHW-DesFlowX, the design chiller chilled water flowrate for Chiller X, in gpm

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

- c. CW-DesFlowX, the design chiller condenser water flowrate for Chiller X, in gpm

Retain the following parameters for water-cooled plants. Delete otherwise.

3.1.7.4. 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.

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, as determined by subtracting CHWSTminX from CWRTdesX.

3.1.7.5. Capacity

- a. QchX, design capacity of Chiller X, in tons.

Retain the following parameter for variable primary-variable secondary plants with a flow meter in the decoupler, or flow meters in both the primary and secondary loops, and for primary-only plants with headered variable speed pumps using differential pressure pump speed control. Delete otherwise.

- b. PCHWFdesign, design primary loop flow, in gpm

Retain the following parameter for primary-secondary systems with a flow meter in the secondary loop. Delete otherwise.

- c. SCHWFdesign, design secondary loop flow, in gpm (for each loop)

3.1.7.6. 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.

MinUnloadCapX should be provided by the chiller manufacturer.

Retain the following parameters for plants with waterside economizers. Delete otherwise.

3.1.7.7. Waterside Economizer Design Information

- a. DA_{HX}, design heat exchanger approach
- b. DT_{WB}, design cooling tower wetbulb temperature
- c. DA_{CT}, design cooling tower approach
- d. HXFdesign, design waterside economizer chilled water flow in gpm

Retain the following parameter for plants where the CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.

- e. HX_{DP-Design}, design waterside economizer chilled water pressure drop
- f. HXCWFdesign, design waterside economizer condenser water flow in gpm

Retain the following parameters for cooling towers that have a level sensor used to control makeup water and to generate high and low water level alarms. Delete otherwise.

3.1.7.8. Cooling Tower Level Control

- a. T-level-high-alarm, maximum level just below overflow
- b. T-level-low-alarm, minimum level
- c. T-level-min-fill, lowest normal operating level
- d. T-level-max-fill, highest normal operating level

Delete this section if neither primary nor secondary chilled water pumps are headered.

3.1.7.9. Headered Pump Design Quantities

Retain the following parameters if primary chilled water pumps are headered.

- a. N-PCHWP, the number of primary chilled water pumps that operate at design conditions

Retain the following parameters if secondary chilled water pumps are headered.

- b. N-SCHWP, the number of secondary chilled water pumps that operate at design conditions

3.1.8. Hot Water Plant

3.1.8.1. Temperature Setpoints

- a. HWSTmax, the highest hot water supply temperature setpoint

Retain the following parameter for hybrid systems. Delete otherwise

- b. HWSTmax-cond, the design hot water supply temperature of the condensing boilers.
- c. HW-LOT, the outdoor air lockout temperature above which the boiler plant is prevented from operating

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.

3.1.8.2. Boiler Flow Setpoints

- a. HW-MinFlowX, the design minimum Boiler water flowrate as recommended by the manufacturer for Boiler X, in gpm.

Retain the following parameter for primary-only hot water plants with a minimum flow bypass valve. Delete otherwise.

- b. HW-DesFlowX, the design boiler hot water flowrate for Boiler X, in gpm.

Retain the following parameter for plants with condensing boilers. Delete otherwise.

3.1.8.3. Minimum Boiler Firing Rate

- a. B-FiringMinX, the lowest %-firing rate of Boiler X before cycling, e.g. 20% for a boiler with 5 to 1 turndown.

3.1.8.4. Capacity

- a. QbX, design output capacity of Boiler X, in KBtu/h.

Retain the following parameter for primary-only plants with headered variable speed pumps using differential pressure pump speed control. Delete otherwise.

- b. PHWFdesign, design primary loop flow, in gpm (each loop)

Retain the following parameter for primary-secondary plants with a flow meter in the secondary loop. Delete otherwise.

- c. SHWFdesign, design secondary loop flow, in gpm (each loop)

3.1.8.5. Headered Pump Design Quantities

Retain the following parameters if primary hot water pumps are headered.

- a. N-PHWP, the number of primary hot water pumps that operate at design conditions

Retain the following parameters if secondary hot water pumps are headered.

- b. N-SHWP, the number of secondary hot water pumps that operate at design conditions

3.1.9. Fan Coil Unit (FCU) Design Information

3.1.9.1. Cool_SAT, lowest cooling supply air temperature setpoint

Cool_SAT is typically the design coil leaving air temperature. It is not used for heating-only FCUs.

3.1.9.2. Heat_SAT, highest heating supply air temperature setpoint

Heat_SAT is typically the design coil leaving air temperature. It is not used for cooling-only FCUs.

3.1.9.3. DP100, filter high limit differential pressure at design airflow

3.2 Information Provided by (or in Conjunction with) the Testing, Adjusting, and Balancing Contractor

3.2.1. Multiple-Zone Air-Handler Information

3.2.1.1. Duct Design Maximum Static Pressure Max_DSP

3.2.1.2. Minimum Fan Speed

- a. Minimum speed setpoints for all VFD-driven equipment shall be determined in accordance with the testing, adjusting, and balancing (TAB) specifications for the following, as applicable:
 1. Supply fan
 2. Return fan
 3. Relief fan

There needs to be corresponding instructions in the TAB specifications. For example:

1. Start the fan or pump.
2. Manually set speed to 6 Hz (10%), unless otherwise indicated in control sequences. For equipment with gear boxes, use whatever minimum speed is recommended by the tower manufacturer.
3. Observe the fan/pump in the field to ensure it is visibly rotating. If it is not, gradually increase speed until it is.
4. The speed at this point shall be the minimum speed setpoint for this piece of equipment.

3.2.1.3. Ventilation Plenum Pressures. (For minimum outdoor air control with separate outdoor air damper and differential pressure [DP] control, see Section 5.16.4.)

- a. For projects complying with the Ventilation Rate Procedure of ASHRAE Standard 62.1:

1. DesMinDP, the design minimum outdoor air damper DP that provides the design minimum outdoor airflow DesVot

- b. 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.

Instructions for establishing MinDP are given in the TAB specification. For example:

1. Open the minimum outdoor air damper and return air damper fully; close the economizer outdoor air damper.
 2. Measure outdoor airflow.
 3. If outdoor airflow rate is above design minimum (DesVot for ASHRAE Standard 62.1 or DesMinOA for California Title 24), adjust damper linkage on minimum outdoor air damper so that intake is at design minimum with damper fully stroked.
 4. If outdoor airflow rate is below design minimum, temporarily adjust return air damper position via the BAS until design outdoor airflow is achieved. This position shall be used for testing only and shall not limit the return air damper position during normal operation.
 5. Note DP across the outdoor air damper. This value becomes the design minimum outdoor air DP setpoint DesMinDP in the BAS. Convey this setpoint to BAS installer and note on air balance report.
 6. With the system at the minimum outdoor air position, reduce supply air fan speed until the outdoor airflow is equal to the absolute minimum outdoor airflow setpoint (AbsMinOA for California Title 24) on AHU schedule.
 7. Note DP across the outdoor air damper. This value becomes the absolute minimum outdoor air DP setpoint (AbsMinDP for California Title 24) in the BAS. Convey this setpoint to BAS installer and note on air balance report.
-

3.2.1.4. Return-Fan Discharge Static Pressure Setpoints. (For return-fan direct building pressure control, see Section 5.16.10.)

- 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.

3.2.1.5. Return-Fan Airflow Tracking Setpoints. (For return-fan airflow tracking control, see Section 5.16.11.)

- 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, typically the scheduled design airflow rate.

3.2.2. Single-Zone Air-Handler Information

3.2.2.1. Fan Speed Setpoints

- a. MinSpeed. The speed that provides supply airflow equal to DesOA (see Section 3.1.6.2) 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.

3.2.2.2. Minimum Outdoor Air Damper Positions (for systems without outdoor airflow measuring stations; See Section 5.18.6.2.)

- 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.

3.2.2.3. Relief-Damper Positions (for relief using motorized dampers; see Section 5.18.8.)

- 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.

3.2.2.4. Return-Fan Speed Differential (for Return Fan Speed Tracking Control, see Section 5.18.10). 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.

3.2.2.5. Return fan discharge static pressure setpoints (for Return Fan Direct Building Pressure Control, see Section 5.18.10.2).

- 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.

3.2.3. Chilled Water Plant

Retain the following parameter for plants with DP controlled variable speed pumps. Delete otherwise.

3.2.3.1. CHW-DPmax, the maximum chilled water differential pressure setpoint, in psi

Instructions for establishing CHW-DPmax should be provided in the Test and Balance Specification. For example:

1. Fully open all control valves serving coils that are located downstream of the differential pressure sensor.
 2. Close the minimum flow bypass valve (if applicable).
 3. Fully close all control valves serving coils that are located upstream of the differential pressure sensor.
 4. Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.
 5. Once flow condition in previous step is achieved, note the BAS differential pressure sensor and handheld digital pressure sensor readings to verify accuracy of BAS reading; report BAS reading to controls contractor.
-

Retain the following parameter for plants that do not have a remote DP sensor wired back to the plant controller, but instead have a local plant DP sensor hardwired to the plant controller and a remote sensor(s)

communicating over the network. Delete otherwise. This is common in large buildings and campus systems. In such cases, the remote DP sensor(s) is used to reset a setpoint for the local sensor.

-
- 3.2.3.2. LocalCHW-DPmax, the maximum chilled water differential pressure setpoint local to the plant, in psi

Instructions for establishing LocalCHW-DPmax should be provided in the Test and Balance Specification and should generally follow the scheme of determining the setpoint for CHW-DPmax: the value recorded from the local DP sensor when the remote CHW-DPmax reading is recorded becomes LocalCHW-DPmax.

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

- 3.2.3.3. 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.

For plants with variable speed condenser water pumps, the speed required to yield design flow through the operating chillers and waterside economizer heat exchangers (as applicable) varies with plant stage.

Instructions for determining Cw-DesPumpSpdStage for each Stage should be provided in the Test and Balance Specification. For example:

1. Configure the plant to the lowest stage of chiller operation. Open the CW isolation valve of the chiller(s) in the stage and enable the CW pump(s) to operate in the stage and the corresponding number of cooling towers for the stage.
 2. Reduce CW pump speed in 2% increments until condenser water flow through any chiller with an open CW isolation valve drops to 100% of design as determined by condenser differential pressure.
 3. Note the speed setpoint and report to controls contractor.
 4. Repeat the preceding steps for each chiller stage.
-

Retain the following parameter for water-cooled plants with fixed speed condenser water pumps. Delete otherwise.

- 3.2.3.4. MinCWVlvPos, minimum head pressure control valve position

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%.

For constant speed pumps, instructions for establishing MinCWVlvPos should be provided in the Test and Balance Specification. For example:

1. Configure the plant for the lowest stage of chiller operation. Open the head pressure control valve of the test chiller and enable a CW pump and the corresponding number of cooling towers for that stage.
 2. Throttle the head pressure control valve of the test chiller in 2% increments until the flow rate through the chiller's condenser decreases to 110% of the minimum condenser water flow switch setpoint as determined by condenser differential pressure.
 3. Note the valve position setpoint and report to controls contractor.
-

Retain the following parameter for water-cooled plants with variable speed condenser water pumps. Delete otherwise.

3.2.3.5. MinCWPspeed, minimum condenser water pump speed

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 3.2.3.9 but no lower.

For variable speed pumps, instructions for establishing MinCWPspeed should be provided in the Test and Balance Specification. For example:

1. *Configure the plant for the lowest stage of chiller operation. Open the CW isolation valve of the test chiller and enable a CW pump and the corresponding number of cooling towers for that stage.*
 2. *Reduce CW pump speed of the test chiller in 2% increments until the flow rate through the chiller's condenser decreases to 110% of the minimum condenser water flow switch setpoint as determined by condenser differential pressure.*
 3. *Note the minimum speed setpoint and report to controls contractor.*
-

Retain the following parameter for plants with a waterside economizer where CHW flowrate through the heat exchanger is controlled by a variable speed heat exchanger pump. Delete otherwise.

3.2.3.6. 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

Instructions for establishing HxPumpDesSpd should be provided in the Test and Balance Specification. For example:

1. *Starting from 100% speed, decrease HX pump speed in 2% increments until differential pressure measured across the waterside economizer heat exchanger is within 5% of design.*
 2. *Note the design speed setpoint and report to controls contractor.*
-

Retain the following parameter for primary-only plants and primary-secondary plants with variable speed primary pumps that are intended to operate at one or more fixed speeds. Delete otherwise.

3.2.3.7. 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

Instructions for establishing Ch-MaxPriSpdStage should be provide in the Test and Balance Specification. For example:

1. *Starting from 100% speed, decrease primary chilled water pump speed in 2% increments until differential pressure measured across the chiller evaporator is within 5% of design.*
 2. *Note the design speed setpoint and report to controls contractor.*
-

Retain the following parameter for variable primary-variable secondary systems. Delete otherwise.

3.2.3.8. 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

Instructions for establishing Ch-MinPriPumpSpd should be provided in the Test and Balance Specification. For example:

1. *Open isolation valves of all chillers.*
2. *Start all non-redundant primary pumps at 100% speed.*

3. Decrease primary pump speed in 2% increments starting from 100% until flowrate through any chiller, as measured by either evaporator barrel differential pressure or a flow meter, decreases to 110% of CHW-MinFlowX.
 4. Note the speed setpoint and report to controls contractor.
-

Retain the following section for plants with variable speed pumps or fans. Delete otherwise.

3.2.3.9. 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 the test and balance specifications for the following as applicable:
 1. Cooling Tower Fans
 2. Condenser Water Pumps
 3. Chilled Water Pumps
-

There needs to be corresponding instructions in the TAB specifications. For example:

1. Start the fan or pump.
 2. Manually set speed to 6 Hz (10%) unless otherwise indicated in control sequences. For equipment with gear boxes, use whatever minimum speed is recommended by manufacturer.
 3. Observe fan/pump in field to ensure it is visibly rotating. 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.
-

Also, specifications should require the contractor to run each tower fan through entire speed range and program out speeds (using the on-board VFD software) that cause tower vibration.

3.2.4. Hot Water Plant

Retain the following parameter for plants with DP controlled variable speed pumps. Delete otherwise.

3.2.4.1. HW-DPmax, the maximum hot water differential pressure setpoint, in psi

Instructions for establishing HW-DPmax should be provided in the Test and Balance Specification. For example:

1. Fully open all control valves serving coils that are located downstream of the differential pressure sensor.
 2. Fully close all control valves serving coils that are located upstream of the differential pressure sensor.
 3. Start pump(s). Manually adjust speed slowly until design flow (or design pressure drop, for coils without calibrated balance valves) is just achieved through all open coils without modulating any balance valves. One coil should be just at design flow, while others should be at or above design flow.
 4. Once flow condition in previous step is achieved, note the BAS differential pressure sensor and handheld digital pressure sensor readings to verify accuracy of BAS reading; report BAS reading to controls contractor.
-

Retain the following parameter for plants that do not have a remote DP sensor wired back to the plant controller, but instead have a local plant DP sensor hardwired to the plant controller and a remote sensor(s) communicating over the network. Delete otherwise. This is common in large buildings and campus systems. In such cases, the remote DP sensor(s) is used to reset a setpoint for the local sensor.

3.2.4.2. LocalHW-DPmax, the maximum hot water differential pressure setpoint local to the plant, in psi

Instructions for establishing LocalHW-DPmax should be provided in the Test and Balance Specification and should generally follow the scheme of determining the setpoint for HW-DPmax: the value recorded from the local DP sensor when the remote HW-DPmax reading is recorded becomes LocalHW-DPmax.

Retain the following parameter for variable primary-variable secondary systems. Delete otherwise.

- 3.2.4.3. 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.

Instructions for establishing B-MinPriPumpSpdStage should be provide in the Test and Balance Specification. For example:

1. Open isolation valves of all boilers.
 2. Start all non-redundant primary pumps at 100% speed.
 3. Decrease primary pump speed in 2% increments starting from 100% until flowrate through any boiler, as measured by either heat exchanger differential pressure or a flow meter, decreases to 110% of HW-MinFlowX.
 4. Note the speed setpoint and report to controls contractor.
-

Retain the following section for plants with variable speed pumps or fans. Delete otherwise.

- 3.2.4.4. 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 the test and balance specifications.

There needs to be corresponding instructions in the TAB specifications. For example:

1. Start the fan or pump.
2. Manually set speed to 6 Hz (10%) unless otherwise indicated in control sequences.
3. Observe pump in field to ensure it is visibly rotating. 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.

Also, specifications should require the contractor to run each tower fan through entire speed range and program out speeds (using the on-board VFD software) that cause tower vibration.

3.2.5. 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.

FCU control sequences are intended for fans with variable speed drives or electrically commutated motors (EMCs). Control sequences will also work with constant speed motors without revision; speed will simply not change. Minimum speeds must address minimum airflow for electric heaters or DX heating or cooling.

3.3 Information Determined by Control Contractor

3.3.1. VAV Box Controllable Minimum

3.3.1.1. This section is used to determine the lowest possible VAV box airflow setpoint (other than zero) allowed by the controls (V_m) used in VAV box control sequences. The minimums shall be stored as software points.

- First, determine the velocity pressure sensor reading VP_m in Pa (in. of water) that will give a reliable flow indication using product literature from the manufacturer of the VAV box controller. If this information is not available from the controller manufacturer, assume 1% of the velocity pressure sensor's differential pressure range.

See also ASHRAE Standard 195 Method of Test for Rating Air Terminal Unit Control for guidance on determining the lowest controllable minimum velocity pressure.

- Next, determine minimum setpoint V_m using either of the following:
 - Option 1. Determine the minimum velocity v_m for each VAV box size and model. If the VAV box manufacturer provides an amplification factor F for the flow pickup, calculate the minimum velocity v_m as

$$v_m = 1.28 \sqrt{\frac{VP_m}{F}} \quad (\text{SI})$$

$$v_m = 4005 \sqrt{\frac{VP_m}{F}} \quad (\text{I-P})$$

Where F is not known, in I-P units it can be calculated from the measured airflow at 1 in. of water signal from the VP sensor

$$F = \left(\frac{4005 A}{\text{CFM}_{@1 \text{ in. of water}}} \right)^2$$

where A is the nominal inlet duct area (ft^2)

- Calculate the minimum airflow setpoint allowed by the controls (V_m) for each VAV box size as

$$V_m = v_m A$$

- Option 2: Use airflow vs. signal pressure data published by the manufacturer of the VAV box velocity pressure probe. Select a pair of values of airflow and velocity pressure signal as the rated operating point for the calculation, V_{rated} and VP_{rated} . Use these values and the minimum controllable signal pressure to calculate the minimum controllable flow as

$$V_m = V_{rated} \sqrt{\frac{VP_m}{VP_{rated}}}$$

4. LIST OF HARDWIRED POINTS

This section provides, for various equipment, a list of the minimum points required in order to implement the sequences as written. Points listed as "if applicable" are required if, and only if, the associated hardware is installed. The points listed that are required to implement the basic sequences of control have an "R" in the "Required" column; points that apply only if included by the designer for some applications have an "A" in this column; points included as optional monitoring points only have an "O" in this column; alarms are included for these points, but they are not used for sequences of operation. Additional points may be specified as desired. The design engineer should edit these lists as required for the project.

Point Types

AO = analog output

DO = digital output (also, BO = binary output)

AI = analog input

DI = digital input (aka BI = Binary Input)

Note that terminal-unit discharge air sensors are actively used for control and, therefore, must be reasonably accurate. If a single-point-probe type sensor is used, it should be located at least five duct diameters downstream of the coil due to stratification off of the heating coil, particularly at low loads. However, this is seldom practical in practice. If an averaging type sensor is used, it should be located at least 12 in. downstream of the coil if possible and 6 in. at a minimum. Averaging sensors are costlier and may present installation issues, especially if installed after ductwork is fully installed, which is typically the case. Reasonable results can be obtained by using a single-point-probe sensor 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.

Occupancy sensors are listed as an optional hardwired point. This point is also commonly a software point mapped from a networked lighting control system or security system.

4.1 VAV Terminal Unit—Cooling Only

Required?	Description	Type	Device
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Discharge airflow	AI	Differential pressure (DP) transducer connected to flow sensor
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable)	AI	Room CO ₂ sensor

4.2 VAV Terminal Unit with Reheat

Required?	Description	Type	Device
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating signal	AO OR two DOs	Modulating valve OR Floating actuator OR Modulating electric heating coil
R	Discharge airflow	AI	DP transducer connected to flow sensor

R	Discharge air temperature (DAT)	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable)	AI	Room CO ₂ sensor

4.3 Fan-Powered Terminal Unit (Series or Parallel, Constant- or Variable-Speed Fan)

Required?	Description	Type	Device
A	Fan speed command (if applicable)	AO	Connect to electronically commutated motor (ECM)
R	Fan start/stop (if separate from fan speed point)	DO	Connect to ECM
O	Fan status OR Fan speed feedback	DI OR AI	Connect to current switch OR Connect to ECM
R	VAV box damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating signal	AO OR two DOs	Modulating valve OR Floating actuator OR Modulating electric heating coil
R	Primary airflow	AI	DP transducer connected to flow sensor
R	Discharge air temperature (DAT)	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable)	AI	Room CO ₂ sensor

4.4 Dual-Duct Terminal Unit with Inlet Sensors

Required?	Description	Type	Device
R	Cooling damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Cooling airflow	AI	DP transducer connected to flow sensor
R	Heating airflow	AI	DP transducer connected to flow sensor
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable, cold-duct minimum control only)	AI	Room CO ₂ sensor

4.5 Dual-Duct Terminal Unit with Discharge Sensor

Required?	Description	Type	Device
R	Cooling damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Heating damper position	AO OR two DOs	Modulating actuator OR Floating actuator
R	Discharge airflow	AI	DP transducer connected to flow sensor
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable, mixing control only)	AI	Room CO ₂ sensor

4.6 Multiple-Zone VAV Air-Handling Unit

Required?	Description	Type	Device
R	Supply fan start/stop	DO	Connect to VFD Run
A	Supply fan high static alarm reset (optional—see control schematic)	DO	Dry contact to 120 or 24 V control circuit
R	Supply fan speed	AO	Connect to VFD Speed
O	Supply fan status	DI	Connect to VFD Status
R	Supply air temperature	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Duct static pressure (DSP)	AI	DP transducer down duct
O	Filter pressure drop	AI	DP transducer across filter
O	Heating coil supply air temperature	AI	Averaging temperature sensor
R	Economizer outdoor air damper	AO	Modulating actuator
R	Return air damper	AO	Modulating actuator
R	Outdoor air temperature	AI	Temperature sensor at outdoor air intake
O	Mixed air temperature	AI	Averaging temperature sensor
A	Return air temperature	AI	Duct temperature sensor
R	Cooling signal	AO	Modulating CHW valve
A	Heating signal	AO	Modulating HW valve OR Modulating electric heating coil

For units with a common economizer/minimum OA damper, include the following points.

A	Outdoor airflow	AI	Airflow measurement station (AFMS)
---	-----------------	----	------------------------------------

For units with a separate minimum outdoor air damper and DP sensor, include the following points.

A	Minimum outdoor air damper open/close	DO	Two position actuator
A	Minimum outdoor air damper DP	AI	DP transducer

For units with a separate minimum outdoor air damper and AFMS, include the following points.

A	Minimum outdoor air damper	AO	Modulating actuator
A	Minimum outdoor airflow	AI	Airflow measurement station

For units with actuated relief dampers but no relief fan, include the following points.

A	Relief damper open/close	AO	Modulating actuator
A	Building static pressure	AI	DP transducer between representative space and outdoors

For units with a relief fan, include the following points.

Required?	Description	Type	Device
A	Relief-fan start/stop	DO	Connect to VFD Run
O	Relief-fan status	DI	Connect to VFD Status
A	Relief-fan speed	AO	Connect to VFD Speed
A	Relief damper open/close	DO	Two position actuator
A	Building static pressure (if direct building pressure logic is used)	AI	DP transducer between representative space and outdoors

For units with a return fan, include the following points.

A	Return fan start/stop	DO	Connect to VFD Run
O	Return-fan status	DI	Connect to VFD Status
A	Return-fan high-static alarm reset (optional—see control schematic)	DO	Dry contact to 120V or 24V control circuit
A	Return-fan speed	AO	Connect to VFD Speed
A	Supply airflow (if airflow tracking logic used)	AI	Airflow measurement station at supply fan (or sum of VAV zones)
A	Return airflow (if airflow tracking logic used)	AI	Airflow measurement station at return fan
A	Return-fan discharge static pressure (if direct building pressure logic is used)	AI	DP transducer at fan
A	Exhaust damper	AO	Modulating actuator
A	Building static pressure (if direct building pressure logic is used)	AI	DP transducer between representative space and outdoors

4.7 Dual-Fan Dual-Duct Heating VAV Air-Handling Unit

Required?	Description	Type	Device
R	Supply fan start/stop	DO	Connect to VFD Run
A	Supply fan high static alarm reset (optional—see control schematic)	DO	Dry contact to 120 or 24 V control circuit
R	Supply fan speed	AO	Connect to VFD Speed
	Supply fan status	DI	Connect to VFD Status
R	Supply air temperature	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Heating signal	AO	Modulating HW valve OR Modulating electric heating coil
R	Duct static pressure	AI	DP transducer down duct

Required?	Description	Type	Device
O	Filter pressure drop	AI	DP transducer across filter
O	Return air temperature	AI	Duct temperature sensor

4.8 Single-Zone VAV Air-Handling Unit

Required?	Description	Type	Device
R	Supply fan start/stop	DO	Connect to VFD Run
R	Supply fan speed	AO	Connect to VFD Speed
O	Supply fan status	DI	Connect to VFD Status
R	Supply air temperature	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Outdoor/return air damper	AO	Modulating actuators
R	Outdoor air temperature	AI	Temperature sensor at outdoor air intake
O	Mixed air temperature	AI	Averaging temperature sensor
O	Return air temperature	AI	Duct temperature sensor
O	Filter pressure drop	AI	DP transducer across filter
R	Cooling signal	AO	Modulating CHW valve OR Variable-capacity compressor
A	Heating signal	AO	Modulating HW valve OR Modulating electric heating coil
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable)	AI	Room CO ₂ sensor

For units with an AFMS, include the following point

A	Outdoor Airflow	AI	Airflow measurement station
---	-----------------	----	-----------------------------

For units with actuated relief dampers but no relief fan, include the following points.

A	Relief damper	AO	Modulating actuator
---	---------------	----	---------------------

Required?	Description	Type	Device
-----------	-------------	------	--------

For units with a relief fan, include the following four points

A	Relief-fan start/stop	DO	Connect to VFD Run
O	Relief-fan status	DI	Connect to VFD Status
A	Relief-fan speed	AO	Connect to VFD Speed
A	Relief-damper open/close	DO	Two position actuator

For units with a return fan, include the following three points.

A	Return fan start/stop	DO	Connect to VFD Run
O	Return-fan status	DI	Current VFD Status
A	Return-fan speed	AO	Connect to VFD Speed

For units with a return fan and speed tracking control, include the following point.

A	Exhaust air damper (if applicable—damper may be barometric)	DO	Two position actuator
---	--	----	-----------------------

For units with a return fan and direct building pressure control, include the following two points.

A	Return Fan Discharge Static Pressure	AI	Differential pressure transducer at fan
A	Exhaust Air Damper	AO	Modulating actuator

For units with direct building pressure control, include the following point.

A	Building Static Pressure	AI	Differential pressure transducer between representative space and outdoors
---	--------------------------	----	--

4.9 General Constant Speed Exhaust Fan

Required?	Description	Type	Device
R	Exhaust Fan Start/Stop	DO	Connect to motor starter
O	Exhaust Fan Status	DI	Current switch

For exhaust fans controlled by temperature, include the following point.

A	Zone Temperature	AI	Room temperature sensor
---	------------------	----	-------------------------

4.10 Chilled Water Plant

4.10.1. Chillers

Required?	Description	Type	Device
R	CH on/off	DO	DI on chiller control panel or through network interface; typ. each chiller

Required?	Description	Type	Device
R	Chiller status	DI	DO on chiller control panel or through network interface; typ. each chiller
R	CHWST Setpoint Reset	AO	AI on chiller control panel or through network interface; typ. each chiller
R	Chiller Fault Code	AI	From chiller controller through network interface; typ. each chiller

Required for parallel or series piped chillers with headered primary CHW pumps. Delete otherwise.

A modulating valve is recommended on primary-only variable flow systems to allow for slow changes in flow during chiller staging. Sometimes electric valve timing may be sufficiently slow that 2-position valves can provide stable performance. Two-position valves are acceptable on primary-secondary systems.

A	CH CHW isolation valve	AO or DO	Modulating or 2-position butterfly valve, line size; typ. each chiller
---	------------------------	----------	--

Retain the following two points for optional valve end switch status feedback.

O	CH CHW isolation valve closed end switch	DI	Valve end switch contact; typ. each chiller
O	CH CHW isolation valve open end switch	DI	Valve end switch contact; typ. each chiller

Retain the following points for optional analog valve position feedback.

O	CH CHW isolation valve position feedback	AI	Valve position feedback contact; typ. each chiller
---	--	----	--

Required for series piped chillers and primary-only parallel CHW plants with waterside economizers. Delete otherwise.

A	CH CHW bypass valve	DO	2-position butterfly valve, line size; typ. each chiller for series chiller plants; only one for parallel chiller plants
---	---------------------	----	--

Required for plants with headered condenser water pumps. Delete otherwise. CW isolation valves may be two-position for chillers that do not require head pressure control or for plants with variable speed condenser pumps but no waterside economizer.

A	CH CW isolation valve	AO or DO	Modulating or 2-position butterfly valve, line size; typ. each chiller
---	-----------------------	----------	--

Retain the following two points for optional valve end switch status feedback.

O	CH CW isolation valve closed end switch	DI	Valve end switch contact; typ. each chiller
O	CH CW isolation valve open end switch	DI	Valve end switch contact; typ. each chiller

Retain the following points for optional analog valve position feedback.

O	CH CW isolation valve position feedback	AI	Valve position feedback contact; typ. each chiller
---	---	----	--

Required?	Description	Type	Device
Required for primary-only CHW plants, optional for other plant types.			
<i>Primary-only plant sequences use the demand limit point to promote stable staging. Flowrates can change rapidly through operating chiller(s) when an additional chiller is brought online; limiting output can help prevent a low supply temperature trip condition. This is not an issue for primary/secondary plants, but the demand limit point may be retained for custom electric utility driven load shed logic not covered by this guideline. Note that load shed logic is covered in Thermal Zone Guideline 36 sequences and the reduced demand generated by zones ultimately serves to reduce plant output.</i>			
A	CH Demand Limit	AO	AI on chiller control panel or through network interface; typ. each chiller
Head pressure control output required only for chillers that require head pressure control. This is an output from the chiller controller head pressure control loop.			
A	Head pressure control signal from CH	AI	AO from chiller control panel; typ. each chiller
CH CHW supply temperature is required for (1) variable primary-variable secondary plants using primary and secondary supply temperatures to reset primary pump speed that do not have a CHWST sensor in the primary loop, (2) head pressure control for chillers that do not have a head pressure control signal. Optional otherwise.			
A	CH CHW supply temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
CH CW return temperature is required for head pressure control for chillers that do not have a head pressure control signal. Optional otherwise.			
A	CH CW return temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH CHW return temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH CW supply temperature	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH evaporator bundle CHW differential pressure	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH condenser bundle CW differential pressure	AI	From chiller controller via interface or via temperature sensor; typ. each chiller
O	CH refrigerant evaporator temperature	AI	From chiller controller via interface; typ. each chiller
O	CH refrigerant condenser temperature	AI	From chiller controller via interface; typ. each chiller
O	Chiller local/auto switch	DI	From chiller controller via interface; typ. each chiller

4.10.2. Chilled Water Pumps

Required?	Description	Type	Device
R	CHWP Start	DO	Connect to VFD Run or Starter Contact; typ. each CHWP
R	CHWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each CHWP

Provide one speed point for each group of variable speed CHW pumps controlled to the same speed (e.g., all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.

A	CHWP Speed	AO	Connect to VFD Speed on all CHW pumps controlled to same speed
Provide a CHW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller.			
A	CHW Differential Pressure	AI	Differential Pressure Transducer
O	CHWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CHWP

4.10.3. Primary CHW Loop

Required?	Description	Type	Device
CHW flow required for primary-only plants; the flow meter must be located on the plant side of the CHW minimum flow bypass where provided. Optional for variable primary-variable secondary plants. Not required nor recommended for constant primary-variable secondary plants.			
A	CHW supply or return flow	AI	Flow meter
CHW bypass valve is required for variable flow primary-only plants. Delete otherwise.			
A	CHW Min Flow Bypass Valve	AO	Modulating valve sized for minimum flow of one chiller
CHW supply temperature sensor required for primary-only plants. Optional for primary-secondary Plants.			
A	CHW supply temperature	AI	Temperature sensor
CHW return temperature required for primary-only plants; locate on plant side of the CHW minimum flow bypass to allow for correct load calculations. Optional for primary-secondary plants.			
A	Plant CHW return temperature	AI	Temperature sensor
Optional sensor for monitoring temperature coming back from coils in primary-only plants with a CHW bypass and no waterside economizer. Located on the load side of minimum flow bypass. Delete for all other plant configurations.			
O	Loop CHW return temperature	AI	Temperature sensor
O	CHW system gauge pressure	AI	Gauge pressure transducer
Optional flow meter for primary pump speed control in variable primary-variable secondary plants.			
O	Decoupler flow	AI	Bi-directional flow meter

The following points apply if the plant has a secondary loop. Delete otherwise. "R" in this section should be interpreted as required for secondary loop operation.

4.10.4. Secondary CHW Loop

Required?	Description	Type	Device
R	Secondary CHW supply temperature	AI	Temperature sensor
Retain this sensor for primary-secondary plants without waterside economizers. Delete otherwise. For plants with waterside economizers, this reading is captured by the sensor upstream of the WSE defined in 4.10.8.			
A	Secondary CHW return temperature	AI	Temperature sensor
R	Secondary CHW supply or return flow	AI	Flow meter

The following points apply for water-cooled plants. Delete otherwise.

4.10.5. Condenser Water Pumps

Required?	Description	Type	Device
R	CWP Start	DO	Connect to VFD Run or Starter Contact; typ. each CWP
R	CWP Status	DI	Status through VFD interface, VFD status contact or current switch; typ. each CWP

CWP speed is required for WSE applications and optional for others. If VFDs are provided on CWPs in applications where one CWP is dedicated to each chiller, provide a unique CWP speed point per chiller; otherwise a single common speed point is appropriate.

A	CWP Speed	AO	Connect to VFD Speed on all CWPs
O	CWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CWP

The following points apply for water-cooled plants. Delete otherwise.

4.10.6. Cooling Towers

Required?	Description	Type	Device
R	Start CT	DO	Connect to VFD Run; typ. each tower
R	CT Status	DI	Status through VFD interface, VFD status contact, or current switch; typ. each tower
R	CT Speed	AO	Connect to VFD Speed on all cooling towers
O	CT Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each CT
R	Tower basin level	AI	Level sensor mounted in standpipe connected to equalizer

Keep the following inlet and outlet isolation valve points if cooling towers have actuated isolation valves. They may have a valve only on the supply with an oversized equalizer used to avoid valves on the outlet, or they may have valves at both inlet and outlet. Delete otherwise.

A	CT inlet (and outlet) isolation valve	DO	2-position line size valve; typ. each tower
---	---------------------------------------	----	---

Retain the following two points for optional valve end switch status feedback. Delete otherwise.

O	CT inlet (and outlet) isolation valve closed end switch	DI	Valve end switch contact; typ. each tower
O	CT inlet (and outlet) isolation valve open end switch	DI	Valve end switch contact; typ. each tower

Keep the following tower bypass, basin heater, and basin temperature points for freezing climates where basins will not be drained during winter months due to continued plant operation. Delete otherwise.

A	CT bypass valve to cold water basin	DO	2-position line size 3-way valve
A	CT basin heater enable	DO	Connect to basin heater enable contact; typ. each tower
A	CT basin heater status	DI	Connect to basin heater status contact; typ. each tower
A	CT basin temperature	AI	Temperature sensor; typ. each tower

Keep the following piping heat trace points for freezing climates with outdoor piping. Delete otherwise.

A	Piping heat trace enable	DO	Connect to heat trace enable contact
A	Piping heat trace status	DI	Connect to heat trace status contact

The following points apply for water-cooled plants. Delete otherwise.

4.10.7. Condenser Water Loop

Required?	Description	Type	Device
If controlling cooling towers to maintain CWST (see 5.20.12.2), CWST sensor must be hardwired to the same controller as the cooling towers.			
R	Common CW supply temperature from towers	AI	Temperature sensor
If controlling cooling towers to maintain CWRT (as opposed to CWST, see 5.20.12.2), CWRT sensor must be hardwired to the same controller as the cooling towers.			
R	Common CW return temperature to towers	AI	Temperature sensor
R	Makeup water valve	DO	Line sized ball valve

Retain the following points if the plant has a waterside economizer. Delete otherwise. "R" in this section should be interpreted as required for waterside economizer operation.

4.10.8. Waterside Economizer

Required?	Description	Type	Device
R	WSE HX CW isolation valve	DO	2-position line size valve
Retain the following two points for optional valve end switch status feedback.			
O	WSE HX CW isolation valve closed end switch	DI	Valve position feedback contact
O	WSE HX CW isolation valve open end switch	DI	Valve position feedback contact
R	WSE CW return temperature	AI	Temperature sensor
R	CHW return temperature before WSE	AI	Temperature sensor
A	CHW return temperature after WSE	AI	Temperature sensor

Retain the following two points if CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.

A	WSE CHW bypass valve	AO	Modulating butterfly valve, line size
A	WSE CHW differential pressure	AI	Differential pressure transducer

Retain the following four points if the plant has a waterside economizer and CHW flowrate through the heat exchanger is controlled by a heat exchanger pump. Delete otherwise. Note: WSE entering CHW temperatures is located in the pipe entering the HX, not the CHWR main upstream of the WSE.

A	CHW HX Pump Start	DO	Connect to VFD Run
A	CHW HX Pump Speed	AO	Connect to VFD Speed
A	CHW HX Pump Status	DI	Status through VFD interface, VFD status contact or current switch
O	CHW HX Pump Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each HX pump.
A	WSE entering CHW temperature	AI	Temperature sensor

4.10.9. Miscellaneous Plant Points

Required?	Description	Type	Device
Temperature and relative humidity sensors are necessary for calculating wet bulb temperature for waterside economizer sequences. Sensors are optional for plants without waterside economizers.			
A	Outdoor Air Temperature	AI	Temperature sensor
A	Relative humidity sensor	AI	Relative humidity sensor
The Emergency Chiller Off switch is required by most codes and ASHRAE Standard 15. This point is not needed if Emergency Chiller Off switch is hardwired to shut off chillers.			
O	Emergency Chiller Off Switch	DI	Connect to break glass switch contacts located outside chiller room primary entry

4.11 Hot Water Plant

4.11.1. Boilers

Required?	Description	Type	Device
R	Boiler enable	DO	Connect to boiler enable contact; typ. each boiler
R	HW supply temperature setpoint	AO	AI to boiler control panels or AI through boiler network interfaces.
Optional point for monitoring boiler firing rate.			
O	Boiler firing rate	AI	Firing rate from boiler controller (may be via network connection rather than hardwired). Use gas valve position if firing rate is not known. Typ. each boiler.

Required for boiler plants with headered primary pumps. Delete otherwise.

A	Boiler isolation valve	DO	2-position line sized valve; typ. each boiler
---	------------------------	----	---

Retain the following two points for optional valve end switch status feedback.

O	Boiler isolation valve closed end switch	DI	Valve end switch contact; typ. each boiler
O	Boiler isolation valve open end switch	DI	Valve end switch contact; typ. each boiler
O	Boiler natural gas flow	DI (pulse)	Flow meter serving all boilers

4.11.2. HW Pumps

Required?	Description	Type	Device
R	HWP Start	DO	Connect to VFD Run or Starter Contact; typ. each HWP
R	HWP Status	DI	Status through VFD interface or VFD status contact or current switch; typ. each HWP

Provide one speed point for each group of variable speed HW pumps controlled to the same speed (e.g. all primary pumps or all secondary pumps, if applicable). Speed point not required for constant speed pumps.

A	HWP Speed	AO	Connect to VFD Speed on all HW pumps controlled to same speed
---	-----------	----	---

Provide a HW differential pressure sensor hardwired to the pump controller for any pump or set of pumps serving multiple control valves. Additional pressure sensors may be provided with feedback sent over the network to the pump controller.

A	HW Differential Pressure	AI	Differential Pressure Transducer
O	HWP Alarm	DI	Fault point through VFD interface or programmed VFD contact; typ. each HWP

4.11.3. Primary HW Loop

Required?	Description	Type	Device
HW flow required for primary-only plants; the flow meter must be located on the plant side of the HW minimum flow bypass where provided. Optional for variable primary-variable secondary plants. Not required nor recommended for constant primary-variable secondary plants.			
A	HW supply or return flow	AI	Flow meter
HW bypass valve is required for variable flow primary-only plants with boilers with non-zero minimum flow. Delete otherwise.			
A	HW Min flow bypass valve	AO	Modulating valve sized for minimum flow of one boiler
HW supply temperature sensor required for primary-only plants. Optional for primary-secondary plants.			
A	HW supply temperature	AI	Temperature sensor
HW return temperature is required for primary-only plants and primary-secondary plants with non-condensing boilers. For primary-only plants, locate on plant side of the HW minimum flow bypass to allow for correct load calculations.			
A	Plant HW return temperature	AI	Temperature sensor
Optional sensor for monitoring temperature coming back from coils in primary-only plants with a HW bypass. Delete for all other plant configurations.			
O	Loop HW return temperature	AI	Temperature sensor
O	HW system gauge pressure	AI	Gauge pressure transducer
Optional flow meter for primary pump speed control in variable primary-variable secondary plants.			
O	Decoupler flow	AI	Bi-directional flow meter

The following points apply if the plant has a secondary loop. Delete otherwise. "R" in this section should be interpreted as required for secondary loop operation.

4.11.4. Secondary HW Loop

Re-required?	Description	Type	Device
R	Secondary HW supply temperature	AI	Temperature sensor
R	Secondary HW return temperature	AI	Temperature sensor
A	Secondary HW supply or return flow	AI	Flow meter

Retain the following sensor for hybrid boiler plants. Delete otherwise. Sensor is to be located in the secondary loop downstream of the condensing boiler primary loop decoupler but upstream of the non-condensing boiler primary loop decoupler.

A	Intermediate HW supply temperature	AI	Temperature sensor
---	------------------------------------	----	--------------------

4.12 Fan Coil Unit

Required?	Description	Type	Device
R	Fan start/stop	DO	Connect to VFD Run or to contactor for ECMS

Required?	Description	Type	Device
R	Fan speed	AO	Connect to VFD or ECM Speed
O	Supply fan status	DI	Connect to VFD Status or ECM Status or to current switch
R	Supply air temperature	AI	Duct temperature sensor
O	Return air temperature	AI	Duct temperature sensor
O	Filter pressure drop	AI	DP transducer across filter

For FCUs with a cooling coil, include the following point:

R	Cooling signal	AO	Modulating CHW valve OR Floating actuator OR Variable-capacity compressor
---	----------------	----	---

For FCUs with a heating coil, include the following point:

R	Heating signal	AO	Modulating valve OR Floating actuator OR Modulating electric heating coil OR Variable-capacity heat pump compressor
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature setpoint adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO ₂ level (if applicable)	AI	Room CO ₂ sensor

5. SEQUENCES OF OPERATIONS

5.1 General

5.1.1. These sequences are intended to be performance based. Implementations that provide the same functional result using different underlying detailed logic will be acceptable.

The intention of these sequences is to specify the functional result of the programming logic. While all sequences are described using specific programming logic as a way to clearly document the resulting functionality, implementations using alternative logic that result in the same functional performance are acceptable. Verification of conformance to these sequences will eventually be through functional performance tests (FPTs) that demonstrate that the sequences were properly implemented, rather than verification of the detailed logic. FPTs for RP-1455

sequences are currently under development through RP-1746; they will be adapted to Guideline 36 sequences and issued as an appendix in a future addendum.

- 5.1.2. Unless otherwise indicated, control loops shall be enabled and disabled based on the status of the system being controlled to prevent windup.
- 5.1.3. 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.
- 5.1.4. 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.
- 5.1.5. 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.
 - 5.1.5.1. 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.
 - 5.1.5.2. 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.
- 5.1.6. 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.
- 5.1.7. 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).
- 5.1.8. 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.
 - 5.1.8.1. Use proportional only (P-only) loops for limiting loops (such as zone CO₂ control loops, etc.).

Limits loops are used to prevent controlled variables from rising above or dropping below setpoint (depending on the application) by defining a fixed threshold at which the loop output reaches 100%. Limiting loops should use proportional-only control to prevent integral windup from causing the controlled sensor to overshoot setpoint due to the sensor generally being far from setpoint.

- 5.1.8.2. Do not use the derivative term on any loops unless field tuning is not possible without it.

Use of the derivative term makes loop tuning difficult in practice. It can make loops unstable because it increases as the rate of change of the error increases, amplifying the error signal. It is used in industrial process controls and systems that have to react quickly but is rarely if ever needed in HVAC system.

- 5.1.9. 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.
- 5.1.10. 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.
- 5.1.11. 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.

All hardware points, not just inputs, should be capable of being overridden for purposes of testing and commissioning. For example, the commissioning agent should be able to command damper positions, valve positions, fan speeds, etc. directly through BAS overrides.

The requirement to equate hardware points to software points is necessary for systems that do not allow overriding real input points.

It is recommended that the user interface allow the user to set an expiration period that automatically releases the override after the period has expired. The system should also keep track of who initiates each override and when.

5.1.12. Alarms

Defining the operator's interface falls outside the scope of Guideline 36, but effective use of alarms by building personnel requires an effective user interface. We recommend including at least the following requirements in the specification for the BAS graphical user interface:

1. *All alarms shall include a time/date stamp using the standalone control module time and date.*
 2. *Each alarm can be configured in terms of level, latching (Requires Acknowledgment of a Return to Normal/Does Not Require Acknowledgment of a Return to Normal), entry delay, exit deadband, and postsuppression period.*
 3. *An operator shall be able to sort alarms based on level, time/date, and current status.*
 - a. *Alarms should be reported with the following information:*
 - b. *Date and time of the alarm*
 - c. *Level of the alarm*
 - d. *Description of the alarm*
 - e. *Equipment tags for the units in alarm*
 - f. *Possible causes of the alarm if provided by the fault detection routines*
 - g. *The source, per Section 5.1.19, that serves the equipment in alarm.*
-

5.1.12.1. 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

5.1.12.2. 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 daily Level 3 alarm at a scheduled time indicating that the device is still in maintenance mode.

5.1.12.3. 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.

Examples of Exit Hysteresis

If a high-temperature alarm is triggered at 100°F and has an exit hysteresis of 5% for 1 minute, the alarm will remain active until the alarmed temperature drops below 95°F (100°F minus 5%) continuously for 1 minute.

If a low-pressure alarm is triggered at 0.5 in. of water and has exit hysteresis of 20% for 10 seconds, the alarm will remain active until the alarmed pressure rises above 0.6 in. of water (0.5 in. of water plus 20%) continuously for 10 seconds.

5.1.12.4. 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

5.1.12.5. 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

Note that postsuppression only applies to a particular instance of an alarm, e.g., a high SAT alarm on AHU-1 will suppress more high SAT alarms on AHU-1 but not on AHU-2.

5.1.13. 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.

5.1.13.1. 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.

5.1.13.2. 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 3.2.1.2 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.

5.1.14. Trim & Respond Set-Point Reset Logic

Trim & Respond (T&R) logic resets a setpoint for pressure, temperature, or other variables at an air handler or plant. It reduces the setpoint at a fixed rate until a downstream zone is no longer satisfied and generates a request. When a sufficient number of requests are present, the setpoint is increased in response. The importance of each zone’s requests can be adjusted to ensure that critical zones are always satisfied. When a sufficient number of requests no longer exist, the setpoint resumes decreasing at its fixed rate. A running total of the requests generated by each zone is kept to identify zones that are driving the reset logic.

T&R logic is optimal for controlling a single variable that is subject to the requirements of multiple downstream zones (such as the static pressure setpoint for a VAV air handler). In this application, it is easier to tune than a conventional control loop and provides for fast response without high-frequency chatter or loss of control of the downstream devices. It typically does generate low-frequency cyclic hunting, but this behavior is slow enough to be nondisruptive.

See Section 5.1.14.4 for an example of T&R implementation.

- 5.1.14.1. T&R set-point reset logic and zone/system reset requests, where referenced in sequences, shall be implemented as described below.
- 5.1.14.2. 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 5.1.19) 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:
 - i. Reset automatically for an individual zone/system when the System Run-Hours Total exceeds 400 hours.
 - ii. 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.
- 5.1.14.3. 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.

- 5.1.14.4. 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 $R \leq I$, 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 $R \leq I$, change Setpoint by SPtrim
 If $R > I$, change setpoint by $(R - I) * SPres$ but no larger than SPres-max

The following is an example of a sequence that uses T&R to control the static pressure setpoint of a VAV AHU serving multiple downstream zones. This sequence defines the T&R variables as shown in Informative Table 5.1.14.4.

Informative Table 5.1.14.4 Example Sequence T&R Variables

Variable	Definition
Device	Supply fan
SP0	120 Pa (0.5 in. of water)
SPmin	37 Pa (0.15 in. of water)
SPmax	370 Pa (1.50 in. of water)
Td	5
T	2
I	2
SPtrim	-10 Pa (-0.04 in. of water)
SPres	15 Pa (0.06 in. of water)
SPres-max	37 Pa (0.15 in. of water)

Description of General Operation

Starting 5 minutes after the fan status indicates the supply fan is ON, the sequence will slowly reduce the AHUs static pressure setpoint by 10 Pa (0.04 in. of water) every 2 minutes if $R \leq I$. As static pressure drops, downstream VAV box dampers will open further for a given load. When the combination of reduced static pressure and changes in load drives more than two VAV boxes more than 95% open, the system will respond by increasing static pressure setpoint by 15 Pa (0.06 in. of water) for every request but no more than a maximum of 37 Pa (0.15 in. of water), regardless of the number of requests. The setpoint will continue to increase every 2 minutes until all but 2 VAV boxes (for Ignored Request value of 2) are satisfied (damper position < 85%). Subsequently, the setpoint will continue to decrease by 10 Pa (0.04 in. of water) every 2 minutes.

Example

(Note: for the example below, the net result for each time step is separately calculated using the variables in Pascal units and in units of inches of water column, in order to facilitate following the example in either units. Thus, the unit conversion of the net result is not exact at each time step.)

System starts at 11:55. Initial setpoint is 120 Pa (0.5 in. of water). At 12:00 (Td after start time), the reset begins.

At 12:02 (i.e., $1 * T$ after reset begins), there is one request (i.e., $R = 1$). Since $R < I$, trim component reduces setpoint by SPtrim, which is 10 Pa (0.04 in. of water). Net result: setpoint is 110 Pa (0.46 in. of water).

At 12:04 (i.e., $2 * T$), there are two requests (i.e., $R = 2$). Since $R = I$, trim component reduces setpoint by 10 Pa (0.04 in. of water). Net result: setpoint is 100 Pa (0.42 in. of water).

At 12:06 (i.e., $3 * T$), there are three requests (i.e., $R = 3$): Trim component reduces setpoint by 10 Pa (0.04 in. of water); because $R - I = 1$, response component increases setpoint by 15 Pa (0.06 in. of water) (i.e., $I * SPres$). Net result: setpoint is 115 Pa (0.48 in. of water).

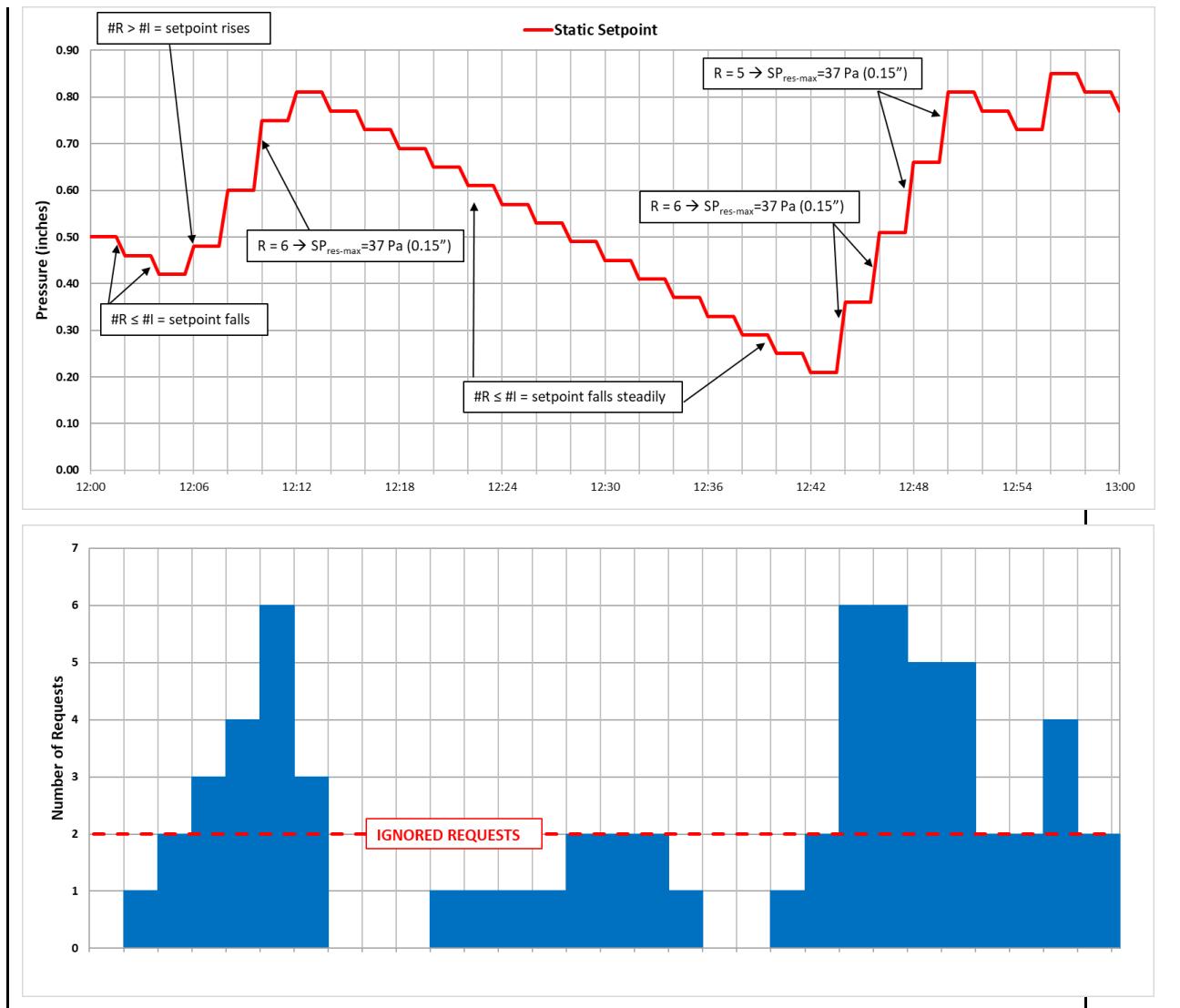
At 12:08 (i.e., $4*T$), there are four requests (i.e., $R = 4$). Because $R - I = 2$, response component increases setpoint by 30 Pa (0.12 in. of water) (i.e., $2*SPres$). Net result: setpoint is 145 Pa (0.60 in. of water).

At 12:10 (i.e., $5*T$), there are six requests (i.e., $R = 6$). Because $R - I = 4$, but $SPres_{max} = 37$ Pa (0.15 in. of water), response component increases setpoint by the maximum of 37 Pa (0.15 in. of water) (i.e., not $4*SPres = 60$ Pa [0.24 in. of water]). Net result: setpoint is 182 Pa (0.75 in. of water).

At 12:12 (i.e., $6*T$), there are three requests (i.e., $R = 3$). Because $R - I = 1$, response component increases setpoint by 15 Pa (0.06 in. of water) (i.e., $1*SPres$). Net result: setpoint is 197 Pa (0.81 in. of water).

At 12:14 (i.e., $7*T$), there are zero requests (i.e., $R = 0$). Because $R < 1$, trim component reduces setpoint by 10 Pa (0.04 in. of water). Net result: setpoint is 187 Pa (0.77 in. of water).

Informative Figure 5.1.14.4 shows a trend graph of the example above, continued for a period of an hour.



Informative Figure 5.1.14.4 Example sequence trend graph.

The system will tend toward minimum static pressure (thus saving energy) but respond rapidly to increasing demand from the terminal units. A cyclic pattern is characteristic of a robust T&R loop—the setpoint is not expected to remain static except at its minimum and maximum values. Note that Informative Figure 5.1.14.4 was created to

illustrate how requests are used to reset the setpoint and does not necessarily represent the expected behavior of an actual T&R loop, although the long, slow cycling of the setpoint value is typical of T&R control.

5.1.15. Equipment Staging and Rotation

5.1.15.1. Parallel equipment shall be lead/lag or lead/standby rotated to maintain even wear.

5.1.15.2. Two runtime points shall be defined for each equipment:

- 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.

- 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.

5.1.15.3. 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:

- P-1 (1000 hours), 2 (950 hours), and 3 (900 hours) are all off. Staging logic makes lead/lag order: 3, 2, 1.
- P-3 starts. Logic does not change its order since it is on by itself.
- 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.
- 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.

5.1.15.4. 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.

Retain the following section for plants with variable speed fans or pumps. Delete otherwise.

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).

5.1.15.5. 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 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.

i. Fans and Pumps

- (a) Status point not matching its on/off point for 3 seconds after a time delay of 15 seconds while the equipment is commanded on.

ii. Chillers

- (a) Safety shutdown alarm condition either through network or hardwired alarm contact

- (b) Chiller is manually shut off as indicated by the status of the Local/Auto switch from chiller gateway, or
- (c) 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

Retain the following sentence for plants with parallel chillers and CHW isolation valve position feedback. Delete otherwise.

- (d) CHW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or

Retain the following sentence for plants with series chillers and CHW isolation valve position feedback. Delete otherwise.

- (e) CHW isolation valve feedback indicates valve is not closed 90 seconds after valve is commanded closed, or

Retain the following sentence for chillers with CW isolation valve position feedback. Delete otherwise.

- (f) CW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or
- (g) 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).

iii. Boilers

- (a) Safety shutdown alarm condition either through network or hardwired alarm contact, or

Retain the following sentence for boilers with HW isolation valve position feedback. Delete otherwise.

- (b) HW isolation valve feedback indicates valve is not open 90 seconds after valve is commanded open, or
- (c) 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).

iv. Cooling Towers

- (a) Tower fan has failed as defined above, or

Retain the following sentence for cooling towers with inlet isolation valve position feedback. Delete otherwise.

- (b) Inlet end switch indicates valve is not open 90 seconds after valve is commanded open, or

Retain the following sentence for cooling towers with outlet isolation valve position feedback. Delete otherwise.

- (c) Outlet end switch indicates valve is not open 90 seconds after valve is commanded open.

2. Upon identification of a fault condition:

- i. For fans, pumps, and cooling towers:
 - (a) The next commanded off equipment in the staging order, Equipment “B”, shall be commanded on while alarming Equipment “A” remains commanded on.
 - (b) 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.
 - (c) 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).
 - (d) 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.
 - (e) Equipment in alarm shall run if so called for by the lead/lag or lead/standby staging order and present stage.

Both this and the subsequent chiller and boiler sequence do not lock out equipment that are in alarm. Instead, they move all equipment in alarm to the end of the rotation sequence such that they will be the last equipment called to run. The sequences will only call for the equipment in alarm if all of the equipment not in alarm are already enabled and there is a call for a stage-up. Equipment in alarm will respond if called to run only if it can do so (e.g., not locked out on internal safety, locked out on an HOA switch at the starter, or otherwise disabled). It is important to note that this staging does not override the equipment’s internal safeties so it will not damage equipment.

Note some alarm conditions could be triggered when the underlying equipment is fully operable. For example, a status point not matching the on/off command could be triggered by a faulty status signal. The same is true for a supervised HOA at a control panel: the operator might have been testing the equipment and simply forgot to turn the HOA back to AUTO.

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 of the equipment, so A and B are running. Then A goes into alarm. C is then commanded on and starts with no alarm. Since the required quantity of equipment has proven on (2), A is moved to the end of staging order since it is in alarm and disabled. The staging order is now B, C, D, A. Equipment B and C are running with no alarms.

Then the staging logic calls for a third equipment. D is commanded on, but goes into alarm. Then A is commanded on. Since D entered an alarm state after A and all equipment are commanded on, D is set to last in the lead/lag staging order. The staging order is now B, C, A, D, and all equipment remain enabled since (3) are called but only (2) are running without alarms.

ii. For chillers and boilers:

- (a) 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.
- (b) 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.
- (c) 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.

- (d) 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.
- (e) 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 5.20.4.13 and 5.21.3.8.

- 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

- i. 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.

5.1.16. Not Used

This section was deleted in Addendum a. To avoid section numbering changes, an empty section was inserted.

5.1.17. Air Economizer High Limits

- 5.1.17.1. Economizer shall be disabled whenever the outdoor air conditions exceed the economizer high-limit setpoint as specified by local code. 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 3.1.4.3 or 3.1.6.2. Setpoints listed below are for current ASHRAE and California Energy Standards.

The engineer must specify the code basis of the economizer high limit and the high-limit control device being used. See Sections 3.1.4.3 and 3.1.6.2.

5.1.17.2. ASHRAE 90.1-2019

Device Type	Allowed only in these ASHRAE Climate Zones	Required High Limit (Economizer OFF when)
Fixed dry bulb	1b, 2b, 3b, 3c, 4b, 4c, 5b, 5c, 6b, 7, 8	TOA > 24°C (75°F)
	5a, 6a	TOA > 21°C (70°F)
	1a, 2a, 3a, 4a	TOA > 18°C (65°F)
Differential dry bulb	1b, 2b, 3b, 3c, 4b, 4c, 5a, 5b, 5c, 6a, 6b, 7, 8	TOA > TRA
Fixed enthalpy + fixed dry bulb	All	hOA > 66 kJ/kg (28 Btu/lb) or TOA > 24°C (75°F)
Differential enthalpy + fixed dry bulb	All	hOA > hRA TOA > 24°C (75°F)

5.1.17.3. 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)

5.1.18. Damper/Valve Position

5.1.18.1. Knowledge of damper and valve position are required for proper generation of T&R reset requests.

5.1.18.2. The following are acceptable methods for determining position:

- a. Analog actuator. Position may be assumed to be equal to analog signal to actuator.
- b. Floating actuator. Provide either
 1. Position feedback AI

The engineer may choose to disallow the following option, which is less accurate than the other options for determining damper position, but doing so may limit controller manufacturer because not all manufacturers offer the other options.

- 2. Position estimated by timing pulse-open and pulse-closed commands with autozeroing whenever zone is in Unoccupied Mode and damper is driven full closed. This option is not acceptable for 24/7 applications.

5.1.19. Hierarchical Alarm Suppression

Hierarchical alarm suppression is described in the January 2006 HVAC&R Research paper, “A Hierarchical Rule-Based Fault Detection and Diagnostic Method for HVAC Systems,” by Jeffrey Schein and Steven Bushby.

It is a technique for suppressing extraneous or nuisance alarms based on the principle that if a fault occurs both at a source (e.g., AHU) and a load (e.g., VAV box), then the fault at the load is likely caused by the fault at the source and is, at any rate, a lower priority than the source fault; as such, the alarm for the load fault is suppressed in favor of the alarm for the source fault, so that the operator’s attention is focused on the problem at the source. This principle can be extended up the hierarchy, e.g., a fault at the chiller system would suppress faults at the AHUs that it serves, which would in turn suppress faults at the VAV boxes served by the suppressed AHUs.

Alarm suppression is based on the “OK” or fault state of upstream systems, rather than individual pieces of equipment. For example, in a plant with multiple redundant boilers, a single boiler failure would not necessarily impede the ability of the boiler plant to serve the load, so suppression of downstream alarms would not be appropriate in this case. It will necessarily be up to the designer to determine the appropriate threshold for setting a system fault based on the number of component faults (e.g., two out of three boilers must be OFF or in alarm before a system-level fault is set, triggering suppression of downstream alarms).

Note that this logic is intended to suppress alarm visual and audible displays, notifications (e.g., email or SMS), listing in primary alarm logs, and other actions that can distract the operator or make it more difficult to diagnose and respond to alarms. The alarm may still be generated and recorded to a database.

- 5.1.19.1. 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.”

For equipment that participates in a T&R loop, the equipment generating the requests will always be the load component, and the equipment receiving and responding to the requests will be a source component.

- 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):
 - i. 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.
 - ii. 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).

Example:

Consider a building with four cooling tower cells, each with its own pump, two chillers with two CHW pumps in a headered arrangement, three air handlers, and 10 VAV boxes on each AHU, with each VAV box serving multiple rooms.

The cooling towers together constitute a system, which is a source to the chillers.

The chillers together constitute a system, which is a load to the cooling tower system and a source to the CHW pump system.

The CHW pumps together constitute a system, which is a load to the chillers and a source to the air handlers.

Each air handler constitutes its own separate system because they do not share a load in common. Each AHU is a load to the CHW pump system and a source to its own VAV boxes.

Each VAV box constitutes its own system because they do not share a load in common. Each VAV box is a load to its AHU only (no relationship to the other AHUs) and a source to the rooms that it serves.

Each interior space is a load to its associated VAV box.

- 5.1.19.2. For each system as defined in Section 5.1.19.1.d, there shall be a SystemOK flag, which is either TRUE or FALSE.
- 5.1.19.3. 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
- 5.1.19.4. 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.

Examples

If a boiler system consists of a pair of boilers sized for 100% of the design load in a lead-standby relationship, then SystemOK is TRUE if at least one boiler is operational and achieving setpoint.

If a chiller system consists of three chillers each sized for 50% of the design load, then SystemOK is TRUE if at least two chillers are available to run. If only one chiller is available to run, then SystemOK will be FALSE (even though the one remaining chiller may be sufficient to serve off-peak loads).

- 5.1.19.5. 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.
- 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.
 - 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.
 - 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.
- 5.1.19.6. This hierarchical suppression shall cascade through multiple levels of load-source relationship such that alarms at downstream loads shall also be suppressed.

Example

A building has a cooling-tower system (towers and CW pumps), a chiller system (chillers and CHW pumps), and a boiler system (boilers and HW pumps). These systems serve several air handlers (each considered its own system), and each air handler serves a series of VAV boxes (each also considered its own system).

If SystemOK is FALSE for the cooling-tower system, then high- temperature alarms are suppressed for the chillers, the air handlers, and the VAV boxes and zones but not for the boilers. Low-temperature alarms are not suppressed. (Note that, in actuality, the hard-wired interlock between cooling tower and chiller would inhibit chiller operation if the cooling towers are OFF or locked out. The example is retained for illustrative purposes.)

If SystemOK is FALSE for the chiller system, then high-temperature alarms are suppressed for the air handlers and VAV boxes but not for the cooling towers or boilers. Low-temperature alarms are not suppressed.

If SystemOK is FALSE for the boiler system, then low temperature alarms are suppressed for the air handlers and the VAV boxes but not for the cooling towers or chillers. High-temperature alarms are not suppressed.

If SystemOK is FALSE for one of the air handlers, then all alarms (low temperature, high temperature, and airflow) are suppressed for all VAV boxes served by that air handler only. Alarms are not suppressed for the cooling towers, chillers, boilers, or the other AHU or its VAV boxes.

If one VAV box is in alarm, then all alarms (e.g., zone temperature, CO₂) are suppressed for the zone served by that VAV box only. No other alarms are suppressed.

- 5.1.19.7. The following types of alarms will never be suppressed by this logic:
- Life/safety and Level 1 alarms
 - Failure-to-start alarms (i.e., equipment is commanded ON, but status point shows equipment to be OFF)
 - Failure-to-stop/hand alarms (i.e., equipment is commanded OFF, but status point shows equipment to be ON)

5.1.20. Time-Based Suppression

- 5.1.20.1. 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:

Time-based suppression is used to suppress reset requests and alarms after a change in setpoint. This includes automatic changes in setpoint, e.g., due to a change in window switch or occupancy sensor status, as well as changes made by occupants.

- For thermal zone temperature alarms: 18 minutes per °C (10 minutes per °F) of difference but no longer than 120 minutes

*For example, if setpoint changes from 20°C (68°F) to 21°C (70°F), and the zone temperature is 20.2°C (68.5°F) at the time of the change, inhibit alarm for 15 minutes ($0.8^{\circ}\text{C} * 18 \text{ minutes per } ^{\circ}\text{C}$ [$1.5^{\circ}\text{F} * 10 \text{ minutes per } ^{\circ}\text{F}$]) after the change.*

- 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

5.2 Generic Ventilation Zones

A ventilation zone is a space or group of spaces served by one ventilation control device. For VAV systems, ventilation zones and thermal zones are one and the same, but Guideline 36 will eventually be expanded to include dedicated outdoor air systems (DOAS) serving one or more thermal zones controlled by radiant systems, chilled beams, fan-coils, etc.

5.2.1. Zone Minimum Outdoor Air and Minimum Airflow Setpoints

- 5.2.1.1. 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.
 - 5.2.1.2. See Section 3.1.2 for zone minimum airflow setpoint V_{min} .
-

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, use Section 5.2.1.3 and delete Section 5.2.1.4.

If the project is to comply with California Title 24 ventilation requirements, use Section 5.2.1.4 and delete Section 5.2.1.3.

- 5.2.1.3. For compliance with the Ventilation Rate Procedure of ASHRAE Standard 62.1-2016, outdoor air and zone minimum setpoints shall be calculated as follows:
 - a. See Section 3.1.1.2 for zone ventilation setpoints.
 - b. Determine zone air distribution effectiveness E_z .
 - 1. If the DAT at the terminal unit is less than or equal to zone space temperature, E_z shall be equal to EzC (default to 1.0 if no value is scheduled).
 - 2. If the DAT at the terminal unit is greater than zone space temperature, E_z shall be equal to EzH (default to 0.8 if no value is scheduled).
 - c. V_{bz-P}^* is the population component of the required breathing zone outdoor airflow. The normal value of V_{bz-P}^* shall be V_{bz-P} . V_{bz-A}^* is the area component of the required breathing zone outdoor airflow. The normal value of V_{bz-A}^* shall be V_{bz-A} .
 - d. V_{min}
 1. Shall be equal to V_{oz} as calculated in Section 5.2.1.3.f below if V_{min} in Section 3.1.2 is “AUTO” and the associated air handler has been supplying 100% outdoor air (outdoor air damper fully open; return air damper fully closed) for 10 minutes;
 2. Else shall be equal to $1.5 * V_{oz}$ as calculated in Section 5.2.1.3.f below if V_{min} in Section 3.1.2 is “AUTO” and the associated air handler is not supplying 100% outdoor air;
 3. Else shall be equal V_{min} as entered in Section 3.1.2.

- e. The occupied minimum airflow V_{min}^* shall be equal to V_{min} except as noted in Section 5.2.1.3.f.
- f. The required zone outdoor airflow V_{oz} shall be calculated as $V_{oz} = (V_{bz-A}^* + V_{bz-P}^*)/E_z$, where the normal values of V_{bz-A}^* and V_{bz-P}^* are modified if any of the following conditions are met, in order from higher to lower priority:
 - 1. If the zone is in any mode other than Occupied Mode, and for zones that have window switches and the window is open: $V_{bz-P}^* = 0$, $V_{bz-A}^* = 0$, and $V_{min}^* = 0$.
 - 2. If the zone has an occupancy sensor, is unpopulated, and occupied-standby mode is permitted: $V_{bz-P}^* = 0$, $V_{bz-A}^* = 0$, and $V_{min}^* = 0$.
 - 3. Else, if the zone has an occupancy sensor, is unpopulated, but occupied-standby mode is not permitted: $V_{bz-P}^* = 0$ and $V_{min}^* = V_{min}$.

Occupied-standby mode applies to individual zones, is considered a zonal subset of Occupied Mode, and is not considered a zone-group operating mode.

- 4. If the zone has a CO₂ sensor:
 - i. See Section 3.1.1.2.b.3 for CO₂ setpoints.
 - ii. 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.
 - iii. Loop is disabled and output set to zero when the zone is not in Occupied Mode.

CO₂ DCV is not yet well defined for Standard 62.1. RP-1747 is under way and should provide a detailed procedure. In the meantime, sequences have been included at the zone level, matching California's DCV approach as a first step. Because outdoor air rates at the AHU level dynamically calculate outdoor air rates using the Standard 62.1 multiple-spaces procedure, compliance with the standard is assured. Doing no DCV at all is not an option, because it is required by Standard 90.1-2016.

- iv. 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:
 - (a) The CO₂ control loop output shall reset both the occupied minimum airflow setpoint (V_{min}^*) and the population component of the required breathing zone outdoor airflow (V_{bz-P}^*) in parallel. V_{min}^* shall be reset from the zone minimum airflow setpoint V_{min} at 0% loop output up to maximum cooling airflow setpoint $V_{cool-max}$ at 100% loop output. V_{bz-P}^* shall be reset from 0 L/s (0 cfm) at 0% loop output up to the V_{bz-P} at 100% loop output. See Figure 5.2.1.3-1.

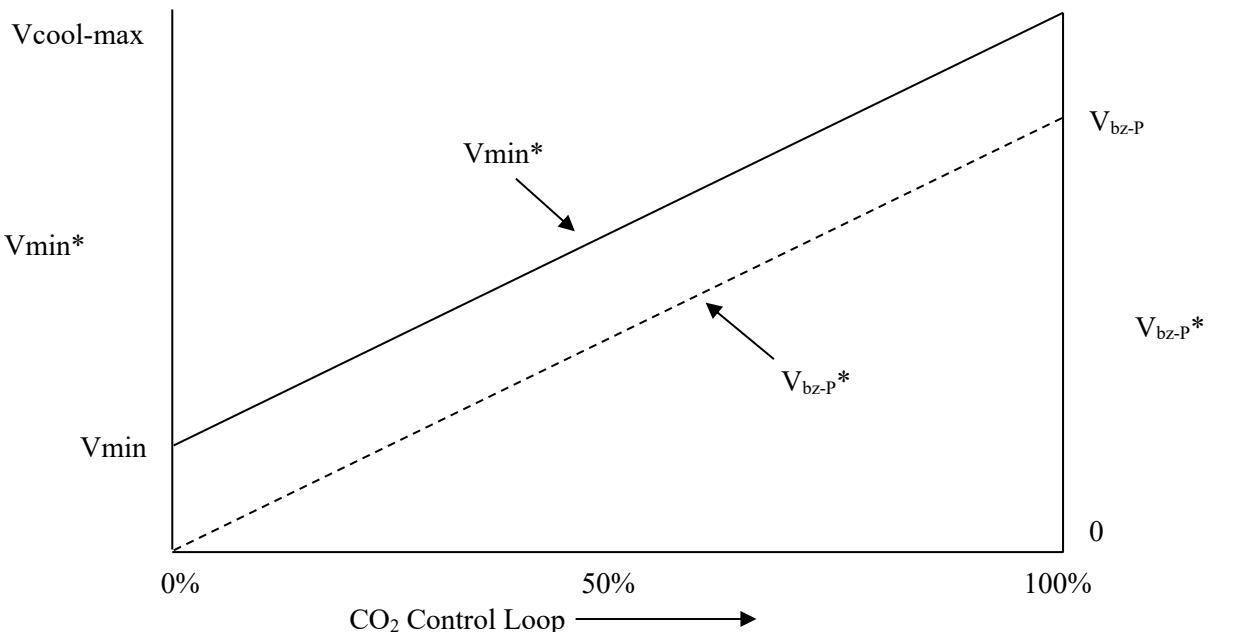


Figure 5.2.1.3-1 Vmin* and Vbz-P* reset with CO2 loop.

The CO₂ control loop graph in Figure 5.2.1.3-1 is provided as a visual representation of the reset logic and is not representative of magnitude of Vbz-P* in relation to Vbz-A or Vmin*.

v. For parallel fan-powered terminal units:

(a) Determine VCO2-max as follows:

- (1) When the Zone State is cooling, VCO2-max is equal to the maximum cooling airflow setpoint Vcool-max.
- (2) 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.

(b) The CO₂ control loop output shall reset both the occupied minimum airflow setpoint Vmin* and the population component of the required breathing zone outdoor airflow Vbz-P* in parallel. Vmin* shall be reset from the zone minimum airflow setpoint Vmin at 0% loop output up to maximum cooling airflow setpoint VCO2-max at 100% loop output. Vbz-P* shall be reset from 0 L/s (0 cfm) at 0% loop output up to the Vbz-P at 100% loop output. See Figure 5.2.1.3-2.

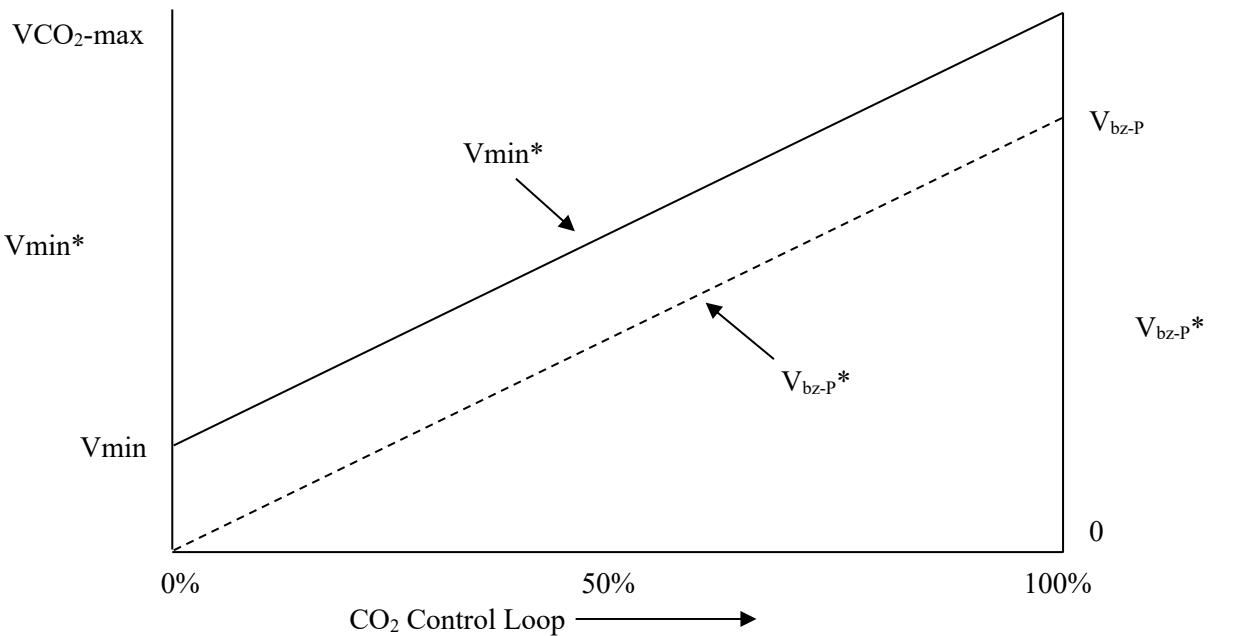


Figure 5.2.1.3-2 V_{min}^* and V_{bz-P}^* reset with CO_2 loop (parallel fan-powered).

The CO_2 control loop graph in Figure 5.1.2.1.3-2 is provided as a visual representation of the reset logic and is not representative of magnitude of V_{bz-P}^* in relation to V_{bz-A} or V_{min}^* .

vi. For SZVAV AHUs:

- (a) The minimum outdoor air setpoint $MinOAsp$ is equal to V_{oz} . The CO_2 control loop output shall reset the population component of the required breathing zone outdoor airflow V_{bz-P}^* from 0 L/s (0 cfm) at 0% loop output up to V_{bz-P} at 100% loop output. See Figure 5.2.1.3-3.

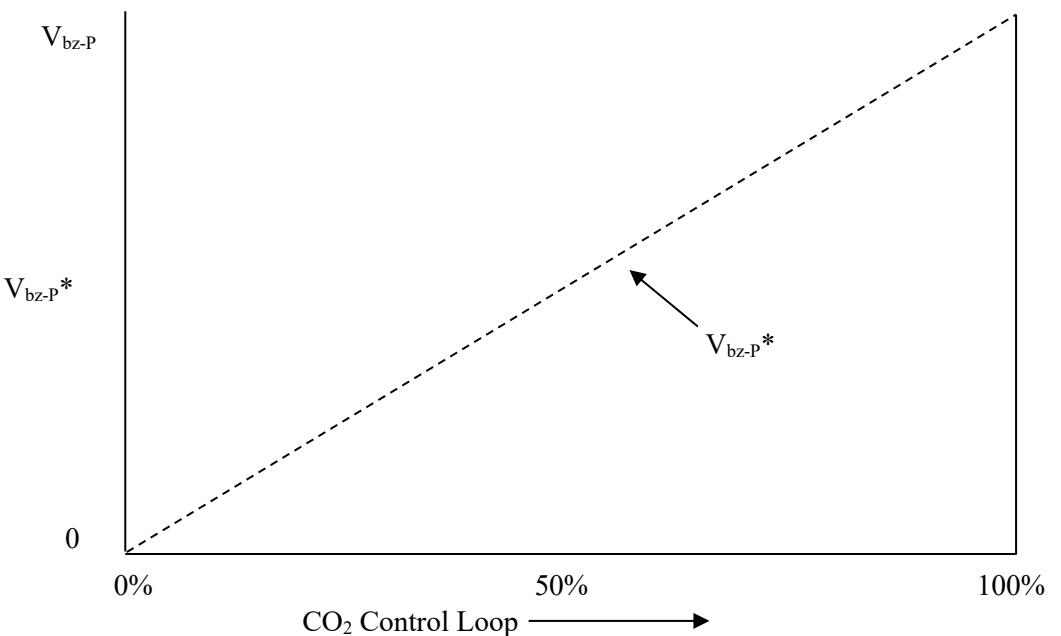


Figure 5.2.1.3-3 V_{bz-P}^* reset with CO_2 loop (SZVAV).

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, use Section 5.2.1.3 and delete Section 5.2.1.4.

If the project is to comply with California Title 24 ventilation requirements, use Section 5.2.1.4 and delete Section 5.2.1.3.

- 5.2.1.4. For compliance with California Title 24, outdoor air setpoints shall be calculated as follows:
- See Section 3.1.1.2 for zone ventilation setpoints.
 - 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.

- Zone-Abs-OA-min shall be reset based on the following conditions in order from highest to lowest priority:
 - Zero if the zone has a window switch and the window is open.
 - Zero if the zone has an occupancy sensor and is unpopulated and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3.

The term “populated” is used instead of “occupied” to mean that a zone occupancy sensor senses the presence of people, because the term “occupied” is used elsewhere to mean “scheduled to be occupied.”

- Varea-min if the zone has a CO₂ sensor.
 - Zone-Des-OA-min otherwise.
- Zone-Des-OA-min is equal to the following, in order from highest to lowest priority:
 - Zero if the zone has a window switch and the window is open.
 - Zero if the zone has an occupancy sensor, is unpopulated, and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3.
 - The larger of Varea-min and Vocc-min otherwise.
- Vmin
 - Shall be equal to Zone-Abs-OA-min if Vmin in Section 3.1.2 is “AUTO”;
 - Else shall be equal to Vmin as entered in Section 3.1.2.
- The occupied minimum airflow Vmin* shall be equal to Vmin except as noted below, in order from highest to lowest priority:
 - If the zone has an occupancy sensor and is permitted to be in occupied-standby mode per Section 3.1.1.2.b.3, Vmin* shall be equal to zero when the room is unpopulated.
 - If the zone has a window switch, Vmin* shall be zero when the window is open.
 - If the zone has a CO₂ sensor:
 - See Section 3.1.1.2.b.3 for CO₂ setpoints.
 - 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.

- iii. Loop is disabled and output set to zero when the zone is not in Occupied Mode.
- iv. 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:
 - (a) The CO₂ control loop output shall reset the occupied minimum airflow setpoint V_{min}^* from the zone minimum airflow setpoint V_{min} at 0% up to maximum cooling airflow setpoint $V_{cool-max}$ 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.

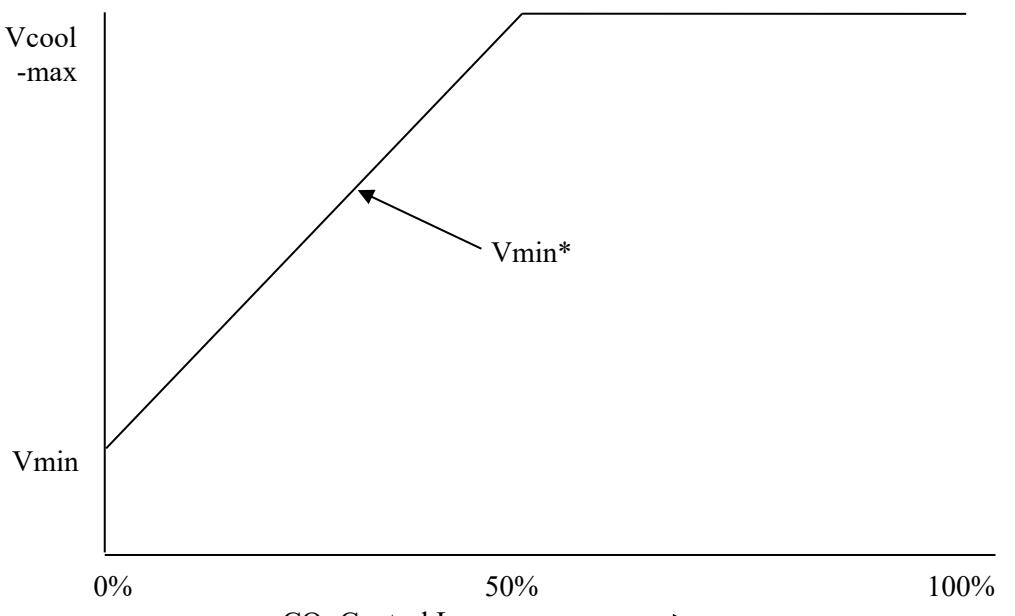


Figure 5.2.1.4-1 V_{min}^* reset with CO₂ loop.

- v. For parallel fan-powered terminal units:

- (a) Determine $V_{CO2-max}$ as follows:
 - (1) When the Zone State is cooling, $V_{CO2-max}$ is equal to the maximum cooling airflow setpoint $V_{cool-max}$.
 - (2) When the Zone State is heating or deadband, $V_{CO2-max}$ is equal to $V_{cool-max}$ minus the parallel fan airflow

This logic prevents the total supply airflow from exceeding $V_{cool-max}$, which could create diffuser noise problems.

- (b) The CO₂ control loop output shall reset the occupied minimum airflow setpoint V_{min}^* from the zone minimum airflow setpoint V_{min} at 0% up to maximum cooling airflow setpoint $V_{CO2-max}$ 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.

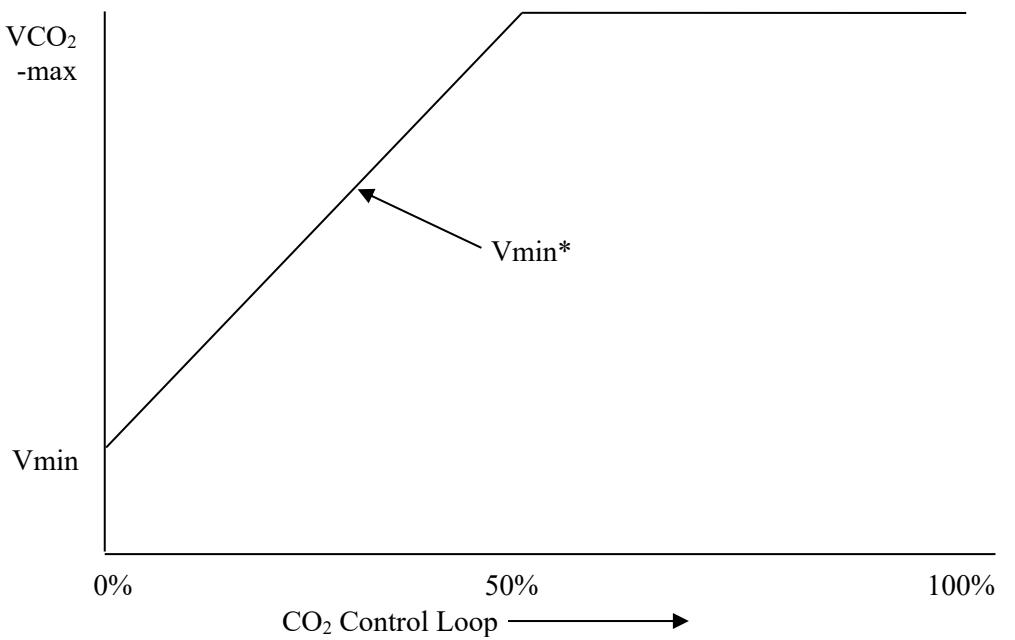


Figure 5.2.1.4-2 V_{min}^* reset with CO_2 loop (parallel fan-powered).

vi. For SZVAV AHUs:

- (a) The minimum outdoor air setpoint $\text{MinOA}_{\text{asp}}$ shall be reset based on the zone CO_2 control-loop signal from MinOA at 0% signal to DesOA at 100% signal. See Figure 5.2.1.4-3.

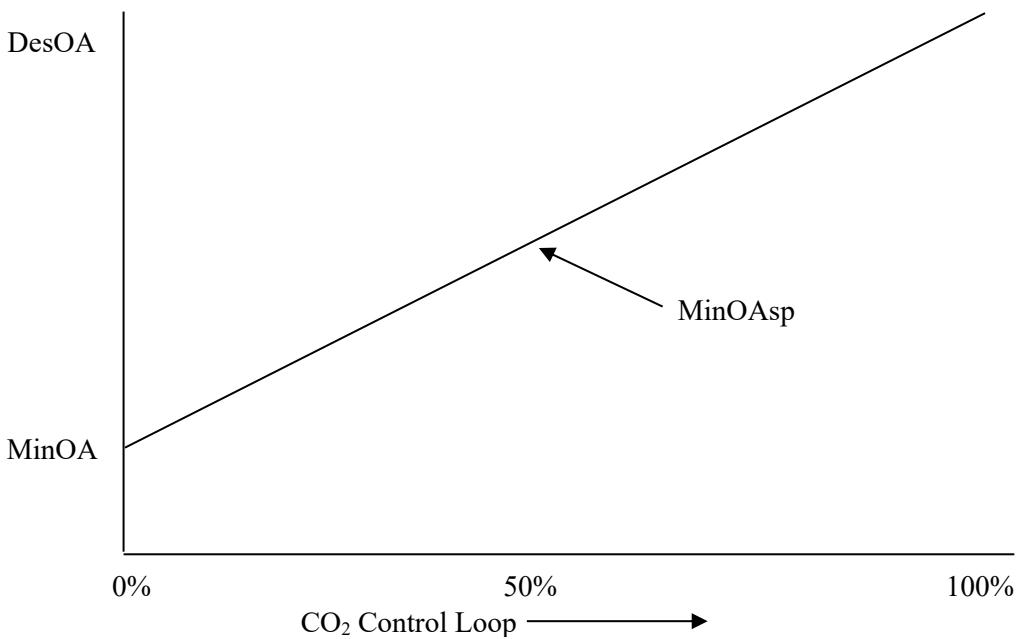


Figure 5.2.1.4-3 V_{min}^* reset with CO_2 loop (SZVAV).

This concludes the section where the ventilation logic is selected. When the sequences are complete, only one of Sections 5.2.1.3 and 5.2.1.4 should remain. The other section should be deleted, along with these flag notes.

5.2.2. 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.

- 5.2.2.1. When the active airflow setpoint V_{spt} is nonzero and is less than the lowest possible airflow setpoint allowed by the controls (V_m), the airflow setpoint shall be pulse width modulated as follows:
- The time-averaged ventilation (TAV) ratio shall be determined as $TAVratio = V_{spt}/V_m$
 - The total cycle time (TCT) shall be 15 minutes (adjustable)
 - Open period. During the open period, the TAV airflow setpoint V_{spt}^* shall be equal to V_m for a period of time OP , which is the larger of the following:
 - 1.5 minutes or
 - TCT multiplied by $TAVratio$
 - Closed period. During the closed period, V_{spt}^* 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.
 - During TAV mode, each cycle shall consist of an open and closed period that alternate until V_{spt} is greater than V_m .

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.

- 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.

- 5.2.2.2. When in TAV mode, the active airflow setpoint, V_{spt} , shall be overridden to V_{spt}^* .

- 5.2.2.3. For zones with CO₂ sensors:

- 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.
- If the CO₂ concentration exceeds setpoint plus 10% for more than 10 minutes, generate a Level 3 alarm.

5.3 Generic Thermal Zones

- 5.3.1. This section applies to all single-zone systems and subzones of air-handling systems, such as VAV boxes, fan-powered boxes, etc.
- 5.3.2. Setpoints
- 5.3.2.1. See Section 3.1.1.1 for zone temperature setpoints.
 - 5.3.2.2. Each zone shall have separate occupied and unoccupied heating and cooling setpoints.
 - 5.3.2.3. The active setpoints shall be determined by the operating mode of the Zone Group (see Section 5.4.6).
 - a. The set points shall be the occupied set points during occupied mode, warm-up mode, and cooldown mode.
 - b. The set points shall be the unoccupied set points during unoccupied mode, setback mode, and setup mode.
 - 5.3.2.4. 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.
 - 5.3.2.5. 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 described 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., $\pm 4^{\circ}\text{F}$) 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 5.3.2.3.a and 5.3.2.5.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 5.3.2.5.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.

Demand limits can be triggered for different reasons, including initiating utility demand shed events, exceeding a predefined threshold, or to prevent excessive rates in a ratchet schedule. Additional logic (not provided here) is needed to define the demand-limit levels.

For example:

1. *Sliding Window.* The demand control function shall use a sliding window method selectable in increments of 1 minute, up to 60 minutes, with a 15-minute default.
2. *Demand-Limit Levels.* Demand time periods shall be set up as per utility rate schedule. For each on-peak or partial-peak period, three demand limits can be defined. When the measured demand exceeds the limit, the demand-limit level switch for that level shall be set; when demand is less than 10% below the limit for a minimum of 15 minutes, and the time is no longer within the on-peak or partial-peak window, the switch shall be reset. These levels are used at the zone level (see Sections 5.3.2.6 and 5.3.2.7) to shed demand.
3. *Utility Demand Limiting.* The Utility Company shall send the building automation system a demand limiting request via a network connection to limit building demand during peak periods as required per California Title 24. The demand limit level request sent by the Utility Company shall be used at the zone level (see Sections 5.3.2.6 and 5.3.2.7) to shed demand.

An override for critical zones such as data centers or equipment rooms should be provided through the graphical user interface (GUI). This override feature should require some level of supervision so that all zones do not declare themselves critical.

Demand limits can also be simultaneously applied to lighting for systems with daylighting/dimming capability and that are integrated with the HVAC BAS.

- 5.3.2.6. 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).
- 5.3.2.7. 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.

- 5.3.2.8. 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.
- 5.3.2.9. 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).

The mild 0.5°C (1°F) setback/setup is per ASHRAE/IES Standard 90.1. It is deliberately mild for the following reasons:

1. *Complaints are likely if the space temperature is too uncomfortable when occupants return.*
2. *Spaces recovering from setback/setup can become temporary rogues zones, pushing supply air temperature and static pressure setpoints to less efficient values;*
3. *The primary purpose of the reset is to push the zone into deadband to minimize airflow and eliminate simultaneous heating and cooling. This can occur with only a minor setback.*
4. *Heating and cooling loads are only slightly affected by setback/setup (and not affected at all for interior zones), so there is not much value in larger setback/setup offsets.*

-
- 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.

Occupancy sensors are often provided as part of the lighting control system due to ASHRAE/IES Standard 90.1 and California Title 24 requirements. The point can be tied into the HVAC BAS in several ways to avoid the cost of an additional occupancy sensor:

1. *If the occupancy sensor is an addressable point and the lighting controls have BACnet or other interface capability, the point can be mapped to the BAS via this interface.*
2. *Some occupancy sensors include auxiliary dry contacts that can be wired to a digital input at the zone controller.*

5.3.2.10. **Hierarchy of Set-Point Adjustments.** The following adjustment restrictions shall prevail in order from highest to lowest priority:

- a. Setpoint overlap restriction (Section 5.3.2.3.a)
- b. Absolute limits on local setpoint adjustment (Section 5.3.2.5.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

5.3.3. **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 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.

5.3.4. **Control Loops**

5.3.4.1. **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.

5.3.4.2. 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).

5.3.4.3. 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).

5.3.4.4. 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.

5.3.4.5. See other sections for how the outputs from these loops are used.

5.3.5. Zone State

5.3.5.1. Heating. When the output of the space Heating Loop is nonzero and the output of the Cooling Loop is equal to zero.

5.3.5.2. Cooling. When the output of the space Cooling Loop is nonzero and the output of the Heating Loop is equal to zero.

5.3.5.3. Deadband. When not in either heating or cooling.

5.3.6. Zone Alarms

5.3.6.1. 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 5.1.20.
2. While Zone Group is in Warmup Mode or Cooldown Mode.

Zone alarms are not suppressed in setup, setback, or Unoccupied Modes so that heating or cooling equipment or control failures are detected that could result in excessive pull-down or pick-up loads and even freezing of pipes if left undetected. See Section 5.4.6 for description of zone-group operating modes.

5.4 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 2016, Section 6.4.3.3.4.

- 5.4.1. 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 3.1.3 for Zone Group assignments.
- 5.4.2. 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.

- 5.4.3. All zones in each Zone Group shall be in the same zone-group operating mode as defined in Section 5.4.6. 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.

- 5.4.4. A Zone Group may be in only one mode at a given time.
- 5.4.5. 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.

- 5.4.6. 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.

- 5.4.6.1. 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.

Occupant override system is a Web-based system to allow individuals to modify the schedule of their zone. This is a best-in-class feature that will not be available on all projects.

- c. Any zone local override timer (initiated by local override button) is nonzero.
- 5.4.6.2. Warm-Up Mode. For each zone, the BAS shall calculate the required warm-up time based on the zone's occupied heating set point, the current zone temperature, the outdoor air temperature, and a mass/capacity factor for each zone. Zones where the window switch indicates that a window is open shall be ignored. The mass factor shall be manually adjusted or 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. Warm-up mode shall start based on the zone with the longest calculated warm-up time requirement, but no earlier than 3 hours before the start of the scheduled occupied period, and shall end at the scheduled occupied start hour.
- 5.4.6.3. Cooldown Mode. For each zone, the BAS shall calculate the required cooldown time based on the zone's occupied cooling set point, the current zone temperature, the outdoor air temperature, and a mass/capacity factor for each zone. Zones where the window switch indicates that a window is open shall be ignored. The mass factor shall be manually adjusted or 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. Cooldown mode shall start based on the zone with the longest calculated cooldown time requirement, but no earlier than 3 hours before the start of the scheduled occupied period, and shall end at the scheduled occupied start hour.

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.

- 5.4.6.4. Setback Mode. During unoccupied mode, if any 5 zones (or all zones if fewer than 5) in the zone group fall below their unoccupied heating set points, or if the average zone temperature of the zone group falls below the average unoccupied heating set point, the zone group shall enter setback mode until all spaces in the zone group are 1°C (2°F) above their unoccupied set points.
- 5.4.6.5. Freeze Protection Setback Mode. During unoccupied mode, if any single zone falls below 4°C (40°F), the zone group shall enter setback mode until all zones are above 7°C (45°F), and a Level 3 alarm shall be set.

Setup Mode. During unoccupied mode, if any 5 zones (or all zones if fewer than 5) in the zone group rise above their unoccupied cooling set points, or if the average zone temperature of the zone group rises above the average unoccupied cooling set point, the zone group shall enter setup mode until all spaces in the zone group are 1°C (2°F) below their unoccupied set points. Zones where the window switch indicates that a window is open shall be ignored. 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 minimum number of zones (set at 5 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.

5.5 VAV Terminal Unit—Cooling Only

- 5.5.1. See "Generic Thermal Zones" (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.5.2. See "Generic Ventilation Zones" (Section 5.2) for calculation of zone minimum outdoor airflow.

CO₂ DCV for cooling-only zones can lead to overcooling due to the faster rise in CO₂ levels from people in the room versus the increase in cooling loads from people. Including heat in all zones with CO₂ DCV is therefore recommended.

5.5.3. See Section 3.1.2.1 for zone minimum airflow setpoint V_{min}, zone maximum cooling airflow setpoint V_{cool-max}, and zone maximum heating airflow setpoint V_{heat-max}.

If the minimum ventilation rate is more than 25% or so of the cooling maximum, or DCV is used, a reheat box is recommended to avoid overcooling. DCV logic is not provided for cooling-only boxes, because doing so results in periods of overcooling, as the CO₂ levels due to occupants rises much faster than the cooling load due to occupants because of thermal mass.

Cooling-only terminal units can provide heating only when the AHU supply air temperature is more than 3°C (5°F) above the room temperature.

5.5.4. 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	V _{cool-max}	V _{cool-max}	V _{cool-max}	0	0	0
Minimum	V _{min} *	0	0	0	0	0
Heating maximum	V _{heat-max}	0	0	V _{cool-max}	V _{cool-max}	0

5.5.5. Control logic is depicted schematically in Figure 5.5.5 and described in the following subsections.

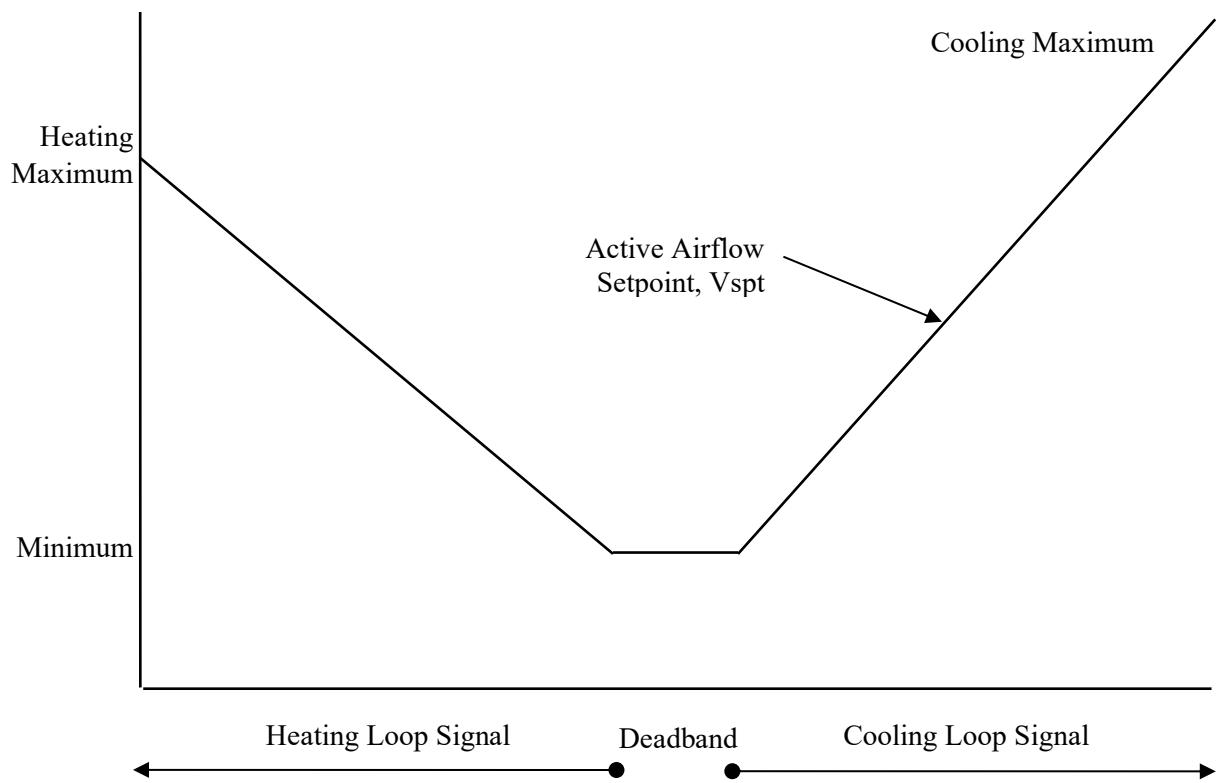


Figure 5.5.5 Control logic for cooling-only VAV zone.

- 5.5.5.1. 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.
- 5.5.5.2. When the Zone State is deadband, the active airflow setpoint shall be the minimum endpoint.
- 5.5.5.3. 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.
- 5.5.5.4. The VAV damper shall be modulated by a control loop to maintain the measured airflow at the active setpoint.

5.5.6. Alarms

- 5.5.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.
- 5.5.6.2. 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.
- 5.5.6.3. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

- 5.5.7. 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).

Per Section 5.1.11, 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 5.4.5.

For example, the commissioning authority (CxA) can check for leaking dampers by forcing all VAV boxes in a Zone Group closed and then recording airflow at the AHU.

5.5.8. System Requests

5.5.8.1. 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 5.1.20, 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 5.1.20, 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.

5.5.8.2. 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.

If the minimum ventilation rate is more than 25% or so of the cooling maximum, or demand-controlled ventilation is used, a reheat box is recommended to avoid overcooling.

5.6 VAV Terminal Unit with Reheat

- 5.6.1. See "Generic Thermal Zones" (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.6.2. See "Generic Ventilation Zones" (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.6.3. See Section 3.1.2.2 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.
- 5.6.4. 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, min*)	Vheat-min	0	Vheat-max	Vheat-max	0
Heating maximum	Max (Vheat-max, min*)	Vheat-max	0	Vcool-max	Vcool-max	0

These sequences use different maximum airflow setpoints for heating and cooling. This dual-max logic allows the minimum airflow setpoint to be lower than in a conventional sequence where the minimum airflow equals the heating airflow.

Heating endpoints are nonzero in cooldown to allow for individual zones within a Zone Group that may need heating while the Zone Group is in cooldown.

The warmup and setback minimum endpoints are set to zero to ensure spaces that do not want heat during these modes receive no air; because the supply air temperature can be warm in these modes if the AHU has a heating coil, any minimum could cause overheating. The heating minimum endpoint is set to Vheat-max and the heating maximum endpoint is set to Vcool-max to provide faster response. This also ensures nonzero flow for the first half of the Heating Loop, avoiding instabilities.

5.6.5. Control logic is depicted schematically in Figure 5.6.5 and described in the following subsections.

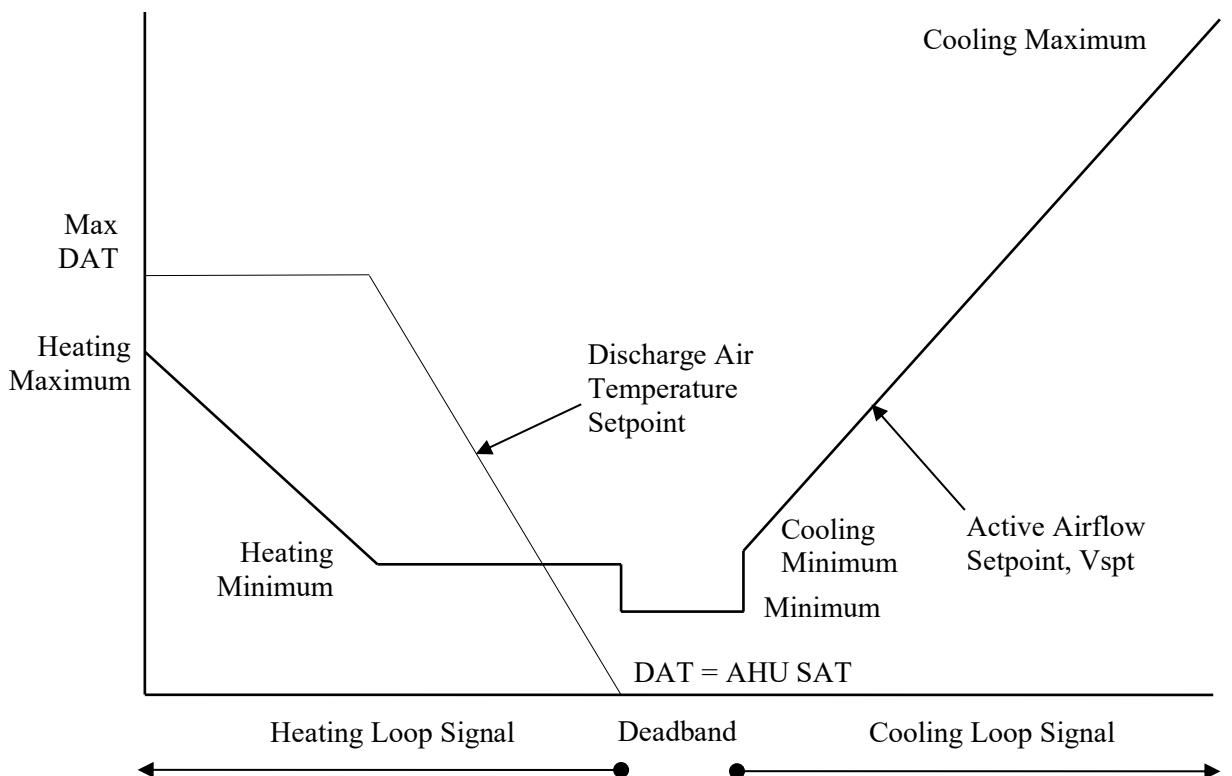


Figure 5.6.5 Control logic for VAV reheat zone.

- 5.6.5.1. 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 5.6.5.4).
- 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.
- 5.6.5.2. 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 5.6.5.4).
- 5.6.5.3. When the Zone State is heating, the Heating Loop shall maintain space temperature at the heating setpoint as follows:

The purpose of the following heating sequence is to minimize the reheat energy consumption by first increasing the SAT while maintaining minimum flow, and only increasing the total airflow if needed to satisfy the zone.

- a. From 0% to 50%, the heating-loop output shall reset the discharge temperature setpoint from the current AHU SAT setpoint to a maximum of Max Δ T above space temperature setpoint. The active airflow setpoint shall be the heating minimum endpoint.

Standard 90.1-2016 limits overhead supply air to 11°C (20°F) above space temperature (e.g., 32°C (90°F) at 21°C (70°F) space temperature setpoint) to minimize stratification.

- b. From 51% to 100%, if the DAT is greater than room temperature plus 3°C (5°F), the heating-loop output shall reset the active airflow setpoint from the heating minimum endpoint to the heating maximum endpoint.
- c. 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 5.2.2, the heating coil and PID loop shall be disabled, with output set to 0 during closed periods.

- 5.6.5.4. In Occupied Mode, the heating coil shall be modulated to maintain a DAT no lower than 10°C (50°F).

This prevents excessively cold DATs if the AHU is providing high outdoor airflows and does not have a heating coil.

- 5.6.5.5. The VAV damper shall be modulated by a control loop to maintain the measured airflow at the active setpoint.

5.6.6. Alarms

5.6.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.6.6.2. 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 5.1.14.2.a.1) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

5.6.6.3. 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.

5.6.6.4. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

- 5.6.6.5. 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.
- 5.6.7. Testing/Commissioning Overrides. Provide software switches that interlock to a system level point to
- force zone airflow setpoint to zero,
 - force zone airflow setpoint to Vcool-max,
 - force zone airflow setpoint to Vmin,
 - force zone airflow setpoint to Vheat-max,
 - force damper full closed/open,
 - force heating to OFF/closed, and
 - reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.6.8. System Requests

5.6.8.1. Cooling SAT Reset Requests

- 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 5.1.20, send 3 requests.
- 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 5.1.20, send 2 requests.
- Else if the Cooling Loop is greater than 95%, send 1 request until the Cooling Loop is less than 85%.
- Else if the Cooling Loop is less than 95%, send 0 requests.

5.6.8.2. Static Pressure Reset Requests

- 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.
- 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.
- Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.
- Else if the damper position is less than 95%, send 0 requests.

- 5.6.8.3. 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.
- 5.6.8.4. 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.

5.7 Parallel Fan-Powered Terminal Unit – Constant-Volume Fan

- 5.7.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.7.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.7.3. See Section 3.1.2.3 for zone minimum airflow setpoint V_{min} , zone maximum cooling airflow setpoint $V_{cool-max}$, and the maximum DAT rise above heating setpoint $Max\Delta T$.
- 5.7.4. Active endpoints used in the control logic depicted in Figures 5.7.5-1 and 5.7.5-2 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.7.4).

Table 5.7.4 Endpoints as a Function of Zone Group Mode

Endpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	$V_{cool-max}$	$V_{cool-max}$	$V_{cool-max}$	0	0	0
Minimum	V_{min}^*	0	0	0	0	0

- 5.7.5. Control logic is depicted schematically in Figures 5.7.5-1 and 5.7.5-2 and described in the following subsections. In Figures 5.7.5-1 and 5.7.5-2, OA-min is V_{oz} (if using ASHRAE Standard 62.1 ventilation logic) or Zone-Abs-OA-min (if using California Title 24 ventilation logic).

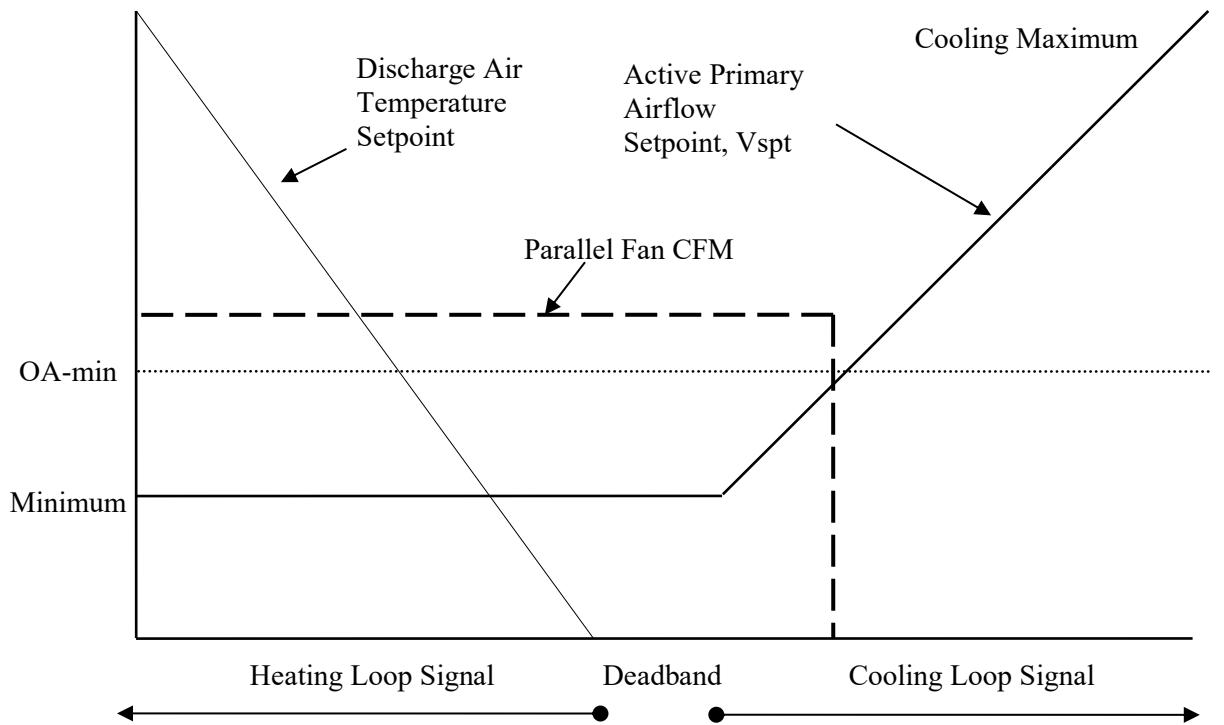


Figure 5.7.5-1 Control logic for constant-volume parallel fan-powered VAV zone ($OA_{-min} > V_{min}$).

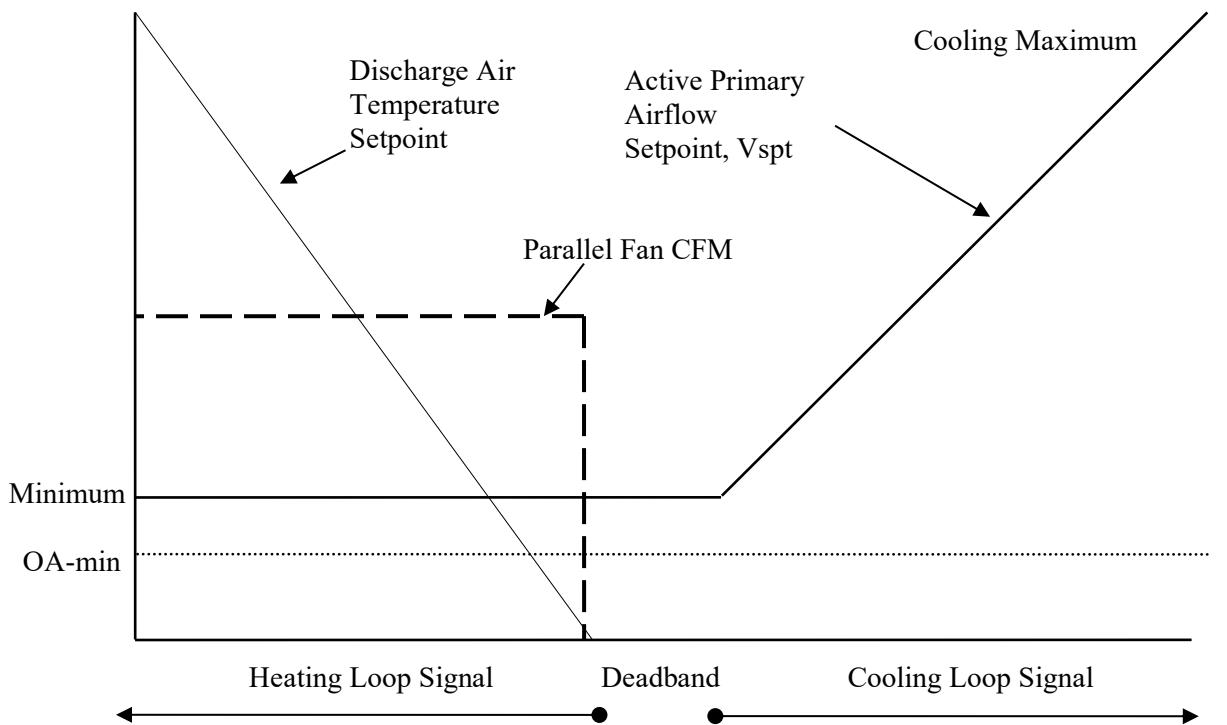


Figure 5.7.5-2 Control logic for constant-volume parallel fan-powered VAV zone ($OA_{-min} < V_{min}$).

5.7.5.1. 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 airflow setpoint shall be no higher than the minimum endpoint.
- b. Heating coil is OFF.

5.7.5.2. When the Zone State Is Deadband

- a. The primary airflow setpoint shall be the minimum endpoint.
- b. Heating coil is OFF.

5.7.5.3. When Zone State Is Heating

- a. The active primary airflow setpoint shall be the minimum endpoint.
- b. As the heating-loop output increases from 0% to 100%, it shall reset the discharge temperature from the current AHU SAT setpoint to a maximum of MaxΔT above space temperature setpoint.

ASHRAE/IES Standard 90.1-2016 limits overhead supply air to 11°C (20°F) above space temperature (e.g., 32°C [90°F] at 21°C [70°F] space temperature setpoint) to minimize stratification.

- c. The heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heat off zone temperature control loop is not acceptable).

5.7.5.4. The VAV damper shall be modulated to maintain the measured primary airflow at setpoint.

5.7.5.5. Fan Control

- a. Fan shall run whenever Zone State is heating.
- b. If ventilation is according to ASHRAE Standard 62.1-2016, the fan shall run in Deadband and Cooling when the primary air volume is less than V_{oz} for 1 minute and shall shut off when primary air volume is above V_{oz} by 10% for 3 minutes.
- c. If ventilation is according to California Title 24, the fan shall run in Deadband and Cooling when the primary air volume is less than Zone-Abs-OA-min for 1 minute, and shall shut off when primary air volume is above Zone-Abs-OA-min by 10% for 3 minutes.

The designer must ensure that the sum of the indirect ventilation provided by the fan plus the ventilation provided by the primary air at minimum setpoint meet Standard 62.1 requirements.

5.7.6. Alarms

5.7.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

- 5.7.6.2. Low-Discharge Air Temperature
- 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.
 - 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.
 - If a zone has an Importance-Multiplier of 0 (see Section 5.1.14.2.a.1) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.
- 5.7.6.3. 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.
- Commanded on, status off: Level 2
 - Commanded off, status on: Level 4
- 5.7.6.4. 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.
- 5.7.6.5. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

- 5.7.6.6. 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.
- 5.7.7. Testing/Commissioning Overrides. Provide software switches that interlock to a system level point to
- force zone airflow setpoint to zero,
 - force zone airflow setpoint to Vcool-max,
 - force zone airflow setpoint to Vmin,
 - force damper full closed/open,
 - force heating to OFF/closed,
 - turn fan ON/OFF, and
 - reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.7.8. System Requests

5.7.8.1. 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 5.1.20, 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 5.1.20, 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.

5.7.8.2. 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.

5.7.8.3. 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.

5.7.8.4. 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.

5.8 Parallel Fan-Powered Terminal Unit –Variable-Volume Fan

- 5.8.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.8.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.8.3. See Section 3.1.2.4 for zone minimum airflow setpoint Vmin, zone maximum cooling airflow setpoint Vcool-max, the parallel fan maximum heating airflow setpoint Pfant-htgmax, and the maximum DAT rise above heating setpoint MaxΔT.
- 5.8.3.1. Pfant-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.
- 5.8.4. 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	Coldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Minimum	Vmin*	0	0	0	0	0

5.8.5. Control logic is depicted schematically in Figure 5.8.5 and described in the following subsections. In Figure 5.8.5, OA-min is V_{oz} (if using ASHRAE Standard 62.1 ventilation logic) or Zone-Abs-OA-min (if using California Title 24 ventilation logic).

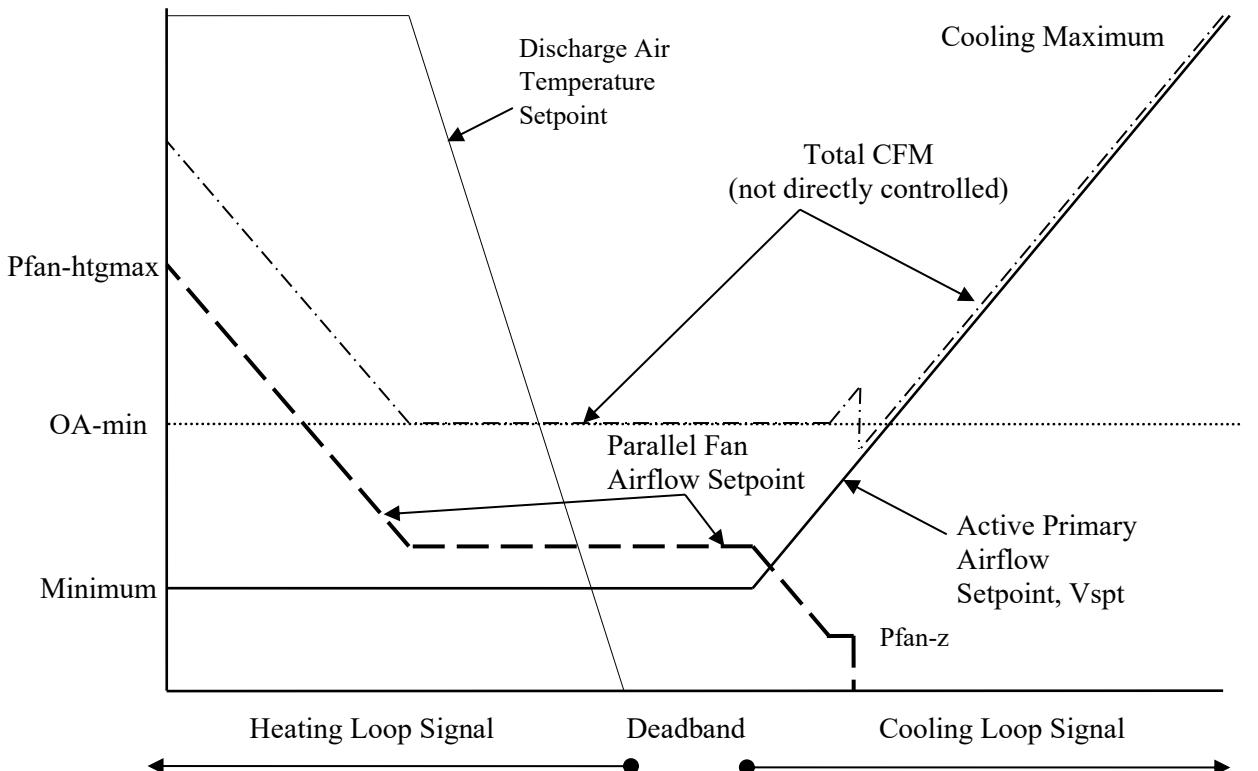


Figure 5.8.5 Control logic for variable-volume parallel fan-powered VAV zone.

In the heating Zone State, the logic keeps the fan airflow rate low while supply air temperature is increased as the first heating stage. This presumes that the temperature of the air the fan is supplying is neutral or below the space temperature, as it would be if the fan draws air directly from the space, and as it might be if the fan draws air from a return air plenum that is cooled by roof and wall heat losses. In the past, return air plenums were warmed by recessed light fixtures, but pendent lights are increasingly common, so the potential for free heating from the plenum is smaller than it was. Because there is the potential that the plenum is colder than the space due to envelope loads, the logic leads with the supply air temperature rather than with an increase in fan speed. If the designer is confident that the plenum will always be warmer, the logic can be reversed.

5.8.5.1. 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 ASHRAE Standard 62.1-2016, in Occupied Mode only, parallel fan starts when primary airflow drops below V_{oz} minus one half of P_{fan-z} and shuts off when primary airflow rises above V_{oz} . Fan airflow rate setpoint is equal to V_{oz} minus the current primary airflow setpoint.
- d. 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 P_{fan-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.

The designer must ensure that the sum of the indirect ventilation provided by the fan plus the ventilation provided by the primary air at minimum setpoint meet Standard 62.1 requirements.

5.8.5.2. 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 ASHRAE Standard 62.1-2016, parallel fan runs if the active primary airflow setpoint is below V_{oz} . Fan airflow rate setpoint is equal to V_{oz} minus the active primary airflow setpoint.
- d. 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.

The designer must ensure that the sum of the indirect ventilation provided by the fan plus the ventilation provided by the primary air at minimum setpoint meet Standard 62.1 requirements.

5.8.5.3. When Zone State is Heating

For systems with electric reheat, ensure that the minimum airflow provided by the parallel fan at minimum speed exceeds the minimum required airflow for the electric heater.

- 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 $\text{Max}\Delta T$ above space temperature setpoint.

ASHRAE/IES Standard 90.1-2016 limits overhead supply air to 11°C (20°F) above space temperature (e.g., 32°C [90°F] at 21°C [70°F] space temperature setpoint) to minimize stratification.

- 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 P_{fan-z} if deadband setpoint is less than P_{fan-z}) proportionally up to the maximum heating-fan airflow setpoint ($P_{fan-htgmax}$).

5.8.5.4. The heating coil shall be modulated to maintain the discharge temperature at setpoint. (Directly controlling heating off zone temperature control loop is not acceptable).

5.8.5.5. The VAV damper shall be modulated to maintain the measured primary airflow at the primary airflow setpoint.

5.8.6. Alarms

5.8.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.8.6.2. 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 5.1.14.2.a.1) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

5.8.6.3. 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

5.8.6.4. 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.

5.8.6.5. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

5.8.6.6. 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.

5.8.7. 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).

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.8.8. System Requests

5.8.8.1. 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 5.1.20, 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 5.1.20, 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.

5.8.8.2. 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.

5.8.8.3. 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.

5.8.8.4. 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.

5.9 Series Fan-Powered Terminal Unit – Constant-Volume Fan

- 5.9.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.9.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.9.3. See Section 3.1.2.5 for zone minimum airflow setpoints V_{min} , zone maximum cooling airflow setpoint $V_{cool-max}$, and the maximum DAT rise above heating setpoint $Max\Delta T$.
- 5.9.4. 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	Coldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	$V_{cool-max}$	$V_{cool-max}$	$V_{cool-max}$	0	0	0
Minimum	V_{min}^*	0	0	0	0	0

- 5.9.5. Control logic is depicted schematically in Figure 5.9.5 and described in the following subsections.

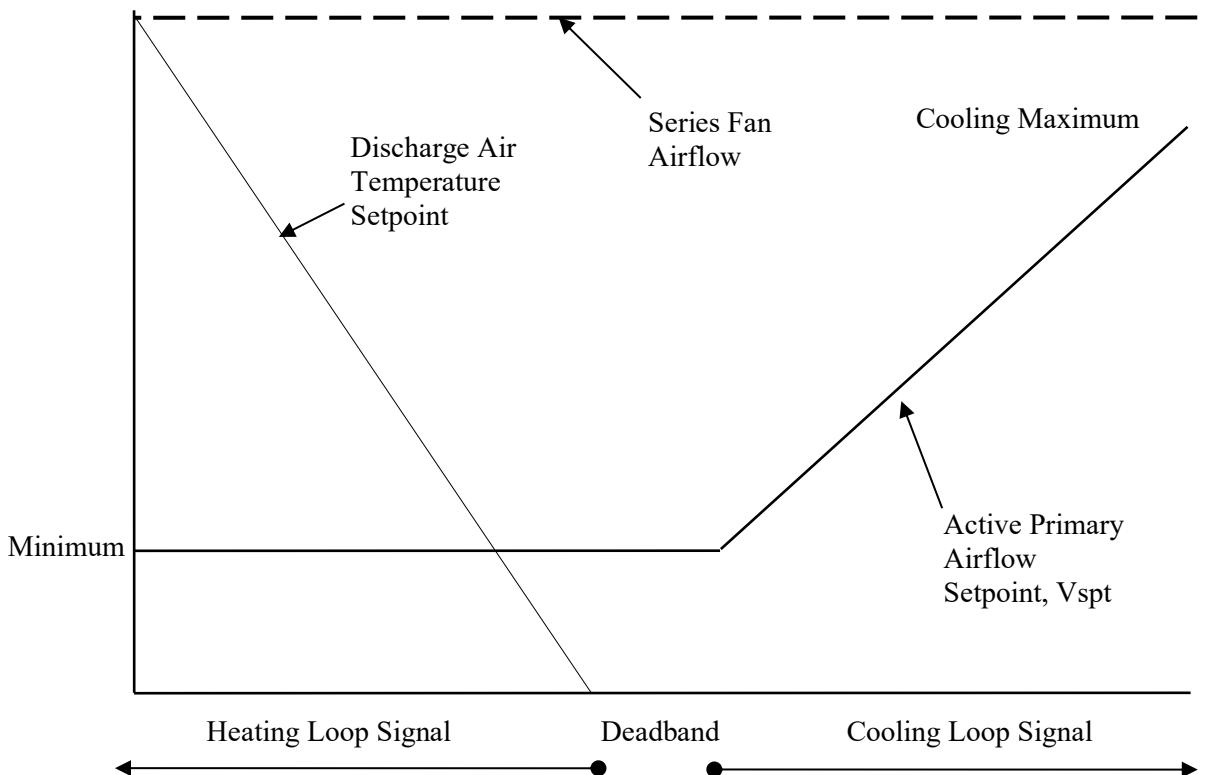


Figure 5.9.5 Control logic for constant-volume series fan-powered VAV zone.

- 5.9.5.1. 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.

5.9.5.2. When the Zone State Is Deadband

- a. The active primary airflow setpoint shall be the minimum endpoint.
- b. Heating coil is OFF.

5.9.5.3. When Zone State Is Heating

ASHRAE/IES Standard 90.1-2016 limits overhead supply air to 11°C (20°F) above space temperature (e.g., 32°C [90°F] at 21°C [70°F] space temperature setpoint) to minimize stratification.

- 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).

5.9.5.4. The VAV damper shall be modulated to maintain the measured airflow at setpoint.

5.9.5.5. 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.

5.9.6. Alarms

5.9.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.9.6.2. 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 5.1.14.2.a.1) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

5.9.6.3. 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

- 5.9.6.4. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

- 5.9.6.5. 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.

- 5.9.6.6. 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.

- 5.9.7. 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).

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.9.8. System Requests

5.9.8.1. 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 5.1.20, 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 5.1.20, 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.

5.9.8.2. 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.

5.9.8.3. 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.

5.9.8.4. 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.

5.10 Series Fan-Powered Terminal Unit – Variable-Volume Fan

- 5.10.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.10.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.10.3. See Section 3.1.2.6 for zone minimum airflow setpoint Vmin, zone maximum cooling airflow setpoint Vcool-max, the series fan maximum heating airflow Sfan-htgmax, and the maximum DAT rise above heating setpoint MaxΔT.
- 5.10.4. Active endpoints used in the control logic depicted in Figure 5.10.4 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.10.4).

Table 5.10.4 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

- 5.10.5. Control logic is depicted schematically in Figure 5.10.5 and described in the following subsections. In Figure 5.10.5, OA-min is Voz (if using ASHRAE Standard 62.1 ventilation logic) or Zone-Abs-OA-min (if using California Title 24 ventilation logic).

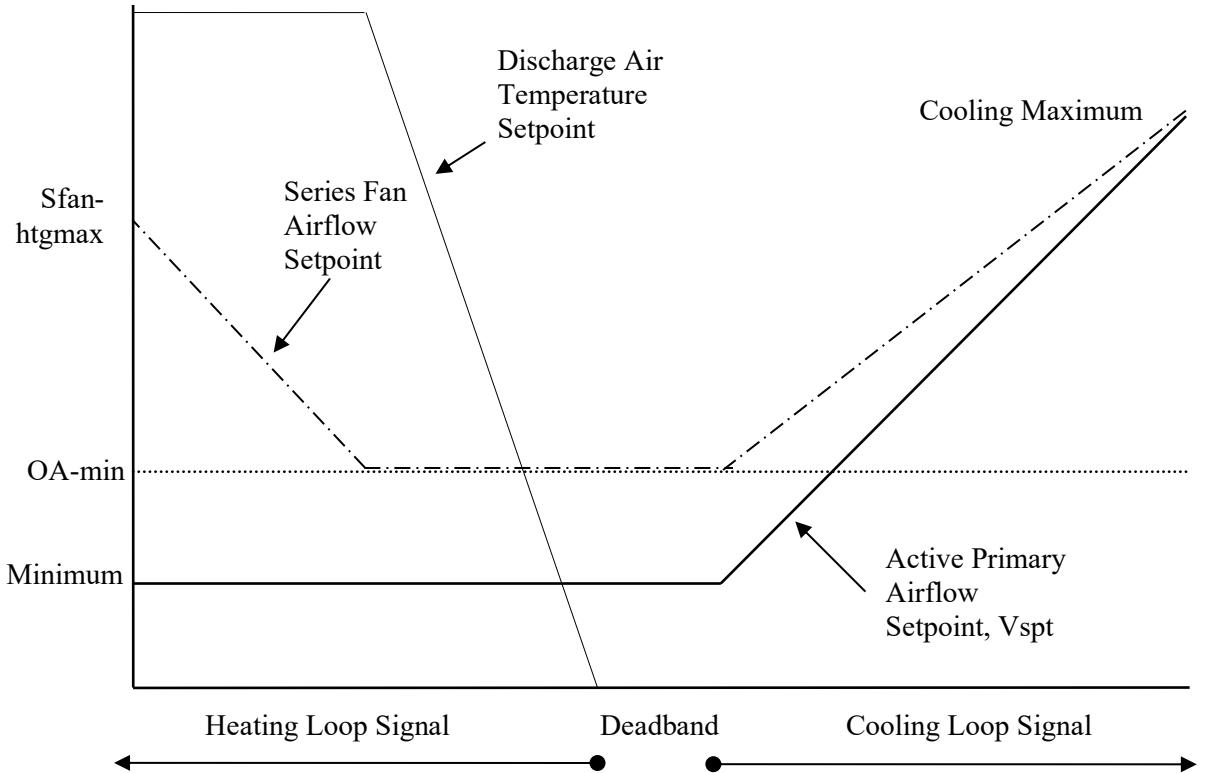


Figure 5.10.5 Control logic for variable-volume series fan-powered VAV zone.

In the heating Zone State, the logic keeps the fan airflow rate low while supply air temperature is increased as the first heating stage. This presumes that the temperature of the air the fan is supplying is neutral or below the space temperature, as it would be if the fan draws air directly from the space, and as it might be if the fan draws air from a return air plenum that is cooled by roof and wall heat losses. In the past, return air plenums were warmed by recessed light fixtures, but pendent lights are increasingly common, so the potential for free heating from the plenum is smaller than it was. Because there is the potential that the plenum is colder than the space due to envelope loads, the logic leads with the supply air temperature rather than with an increase in fan speed. If the designer is confident that the plenum will always be warmer, the logic can be reversed.

5.10.5.1. When the Zone State Is Cooling

- The cooling-loop output shall be mapped to the active primary airflow setpoint from the minimum endpoint to the cooling maximum endpoint.
 - 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 and the series fan airflow setpoint shall be no higher than OA-min.
- The Cooling Loop output shall be mapped to the series fan airflow setpoint from the larger of OA-min and the primary airflow minimum endpoint to the cooling maximum endpoint.
- Heating coil is OFF.

5.10.5.2. When the Zone State Is Deadband

- The primary airflow setpoint shall be the minimum endpoint.

- b. The series fan airflow setpoint shall be equal to OA-min.
- c. Heating coil is OFF.

5.10.5.3. When Zone State Is Heating

ASHRAE/IES Standard 90.1-2016 limits overhead supply air to 11°C (20°F) above space temperature (e.g., 32°C [90°F] at 21°C [70°F] space temperature setpoint) to minimize stratification.

- a. From 0% to 50%, the Heating Loop output shall reset the discharge temperature setpoint from the current AHU SAT setpoint to a maximum of MaxΔT above space temperature setpoint. The primary airflow setpoint shall be the minimum endpoint, and the series fan airflow setpoint shall be OA-min.
- b. From 50% to 100%, the Heating Loop output shall reset the series fan airflow setpoint from OA-min to a Sfan-htgmax. The active primary airflow setpoint shall be the minimum endpoint.
- 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).

5.10.5.4. The VAV damper shall be modulated to maintain the measured airflow at setpoint.

5.10.5.5. 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.

5.10.6. Alarms

5.10.6.1. 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 5.1.14.2.a.1 for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.10.6.2. 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 5.1.14.2.a.1) for its hot-water reset T&R control loop, low-DAT alarms shall be suppressed for that zone.

5.10.6.3. 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

5.10.6.4. 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.

- 5.10.6.5. 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.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

- 5.10.6.6. 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.

- 5.10.7. 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).

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.10.8. System Requests

5.10.8.1. 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 5.1.20, 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 5.1.20, 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.

5.10.8.2. 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.
- 5.10.8.3. 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.
- 5.10.8.4. 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.

5.11 Dual-Duct VAV Terminal Unit – Snap-Acting Control

Snap-acting control logic is the first choice among the various DD control schemes, as it is the most efficient and does not require DD boxes with mixing sections that have a high pressure drop. It allows use of dual standard airflow sensors, one at each inlet, with standard pressure independent logic blocks; alternatively, a single discharge airflow sensor may be used.

However, snap-acting logic is not ideal for CO₂ control because it can cause the zone to oscillate between cooling and heating. This occurs when the CO₂ control pushes the Vmin up to Vcool-max; at that point, temperature control is lost, and if the space is overcooled it will be pushed into heating, where it will be overheated, then back again. If CO₂ demand-controlled ventilation is required, the mixing logic described in the next section should be used.*

This logic assumes no ability to mix hot and cold air to prevent overly low supply air temperatures that may occur on systems with high outdoor airflows and no preheat coil. So a preheat coil is likely to be required on such systems if mixed air temperature can fall below 7°C (45°F) or so in winter.

Note that snap-acting logic can also be problematic for zones with high minimums, because the room itself is acting as the mixing box.

Because no cold-duct air is supplied during heating mode, the heating system must include ventilation air either with direct outdoor air intake or indirectly via transfer air from overventilated spaces on the same system. Refer to Standard 62.1-2016 and Standard 62.1 User's Manual.

- 5.11.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.11.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.11.3. See Section 3.1.2.7 for zone minimum airflow setpoint Vmin, maximum cooling airflow setpoint Vcool-max, and the zone maximum heating airflow setpoint Vheat-max.
- 5.11.4. Active endpoints used in the control logic depicted in Figures 5.11.5-1 and 5.11.5-2 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.11.4).

Table 5.11.4 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	Vheat-max	Vheat-max	0

5.11.5. Control logic is depicted schematically in Figures 5.11.5-1 and 5.11.5-2 and described in the following subsections.

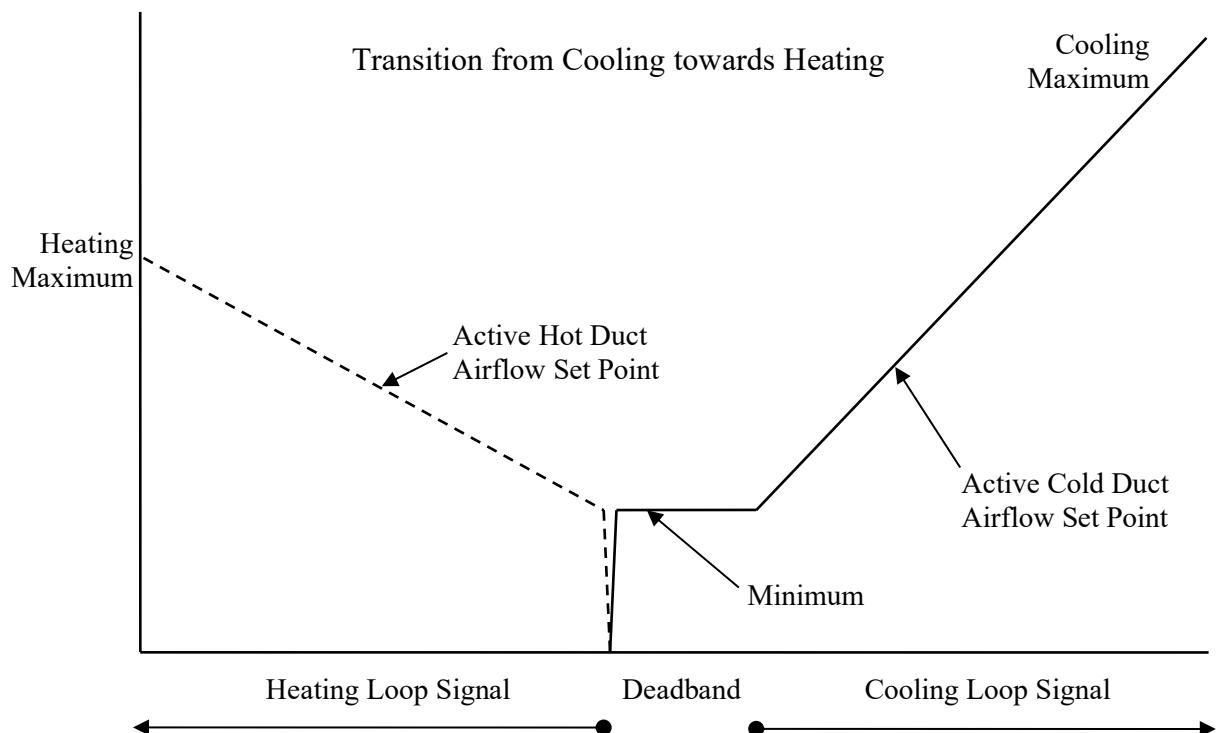


Figure 5.11.5-1 Control logic for snap-acting dual-duct VAV zone (transition from cooling towards heating).

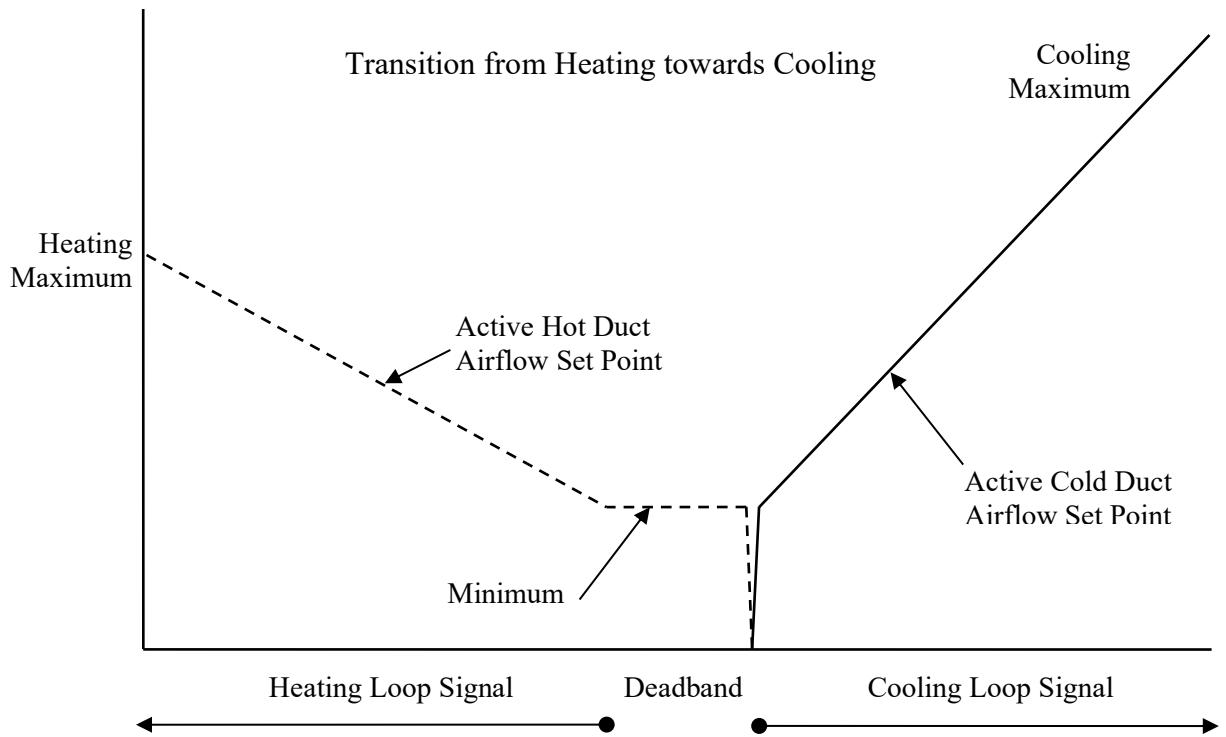


Figure 5.11.5-2 Control logic for snap-acting dual-duct VAV zone (transition from heating towards cooling).

The engineer must select between ventilation logic options:

If there are airflow sensors at both inlets to the box, use Section 5.11.5.1 and delete Section 5.11.5.2.

If there is a single airflow sensor at the box discharge, use Section 5.11.5.2 and delete Section 5.11.5.1.

5.11.5.1. Temperature and Damper Control with Dual Inlet Airflow Sensors

- When the Zone State is cooling, the cooling-loop output shall reset the active cold duct airflow setpoint from the minimum endpoint to cooling maximum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cooling airflow at the active cold duct airflow setpoint. The hot duct damper shall be closed.
 - If cold-deck supply air temperature from the air handler is greater than room temperature, the active cold duct airflow setpoint shall be no higher than the minimum endpoint.
- When the Zone State is deadband, the active cold duct and hot duct airflow setpoints shall be their last setpoints just before entering deadband. In other words, when going from cooling to deadband, the active cold duct airflow setpoint is equal to the minimum endpoint, and the active hot duct airflow setpoint is zero. When going from heating to deadband, the active hot duct airflow setpoint is equal to the minimum endpoint, and the active cold duct airflow setpoint is zero. This results in a snap-action switch in the damper setpoint as indicated in Figures 5.11.5-1 and 5.11.5-2.

With snap-acting logic, the deadband airflow is maintained by the damper from the last mode, rather than always using the cold deck, as per the mixing sequences below. This is to avoid instability when transitioning from heating to deadband.

- c. When the Zone State is heating, the heating-loop output shall reset the active hot duct airflow setpoint from the minimum endpoint to heating maximum endpoint. The hot duct damper shall be modulated by a control loop to maintain the measured heating airflow at the active hot duct airflow setpoint. The cold duct damper shall be closed.
 - 1. If hot-deck supply air temperature from the air handler is less than room temperature, the active hot duct airflow setpoint shall be no higher than the minimum endpoint.

The engineer must select between airflow sensor configuration options:

If there is a single airflow sensor at the box discharge, use Section 5.11.5.2 and delete Section 5.11.5.1.

If there are airflow sensors at both inlets to the box, use Section 5.11.5.1 and delete Section 5.11.5.2.

5.11.5.2. Temperature and Damper Control with a Single Discharge Airflow Sensor

- a. When the Zone States is cooling, the cooling-loop output shall reset the active discharge airflow setpoint from the minimum endpoint to cooling maximum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured discharge airflow at active discharge airflow setpoint. The hot duct damper shall be closed.
- b. When the Zone State is deadband, the active discharge airflow setpoint shall be the minimum endpoint, maintained by the damper that was operative just before entering deadband. The other damper shall remain closed. In other words, when going from cooling to deadband, the cold duct damper shall maintain the discharge airflow at the minimum endpoint, and the hot duct damper shall be closed. When going from heating to deadband, the hot duct damper shall maintain the discharge airflow at the zone minimum endpoint, and the cold duct damper shall be closed. This results in a snap-action switch in the damper setpoint as indicated in Figures 5.11.5-1 and 5.11.5-2.
- c. When the Zone State is heating, the heating-loop output shall reset the active discharge airflow setpoint from the minimum endpoint to heating maximum endpoint. The hot duct damper shall be modulated by a control loop to maintain the measured discharge airflow at the active discharge airflow setpoint. The cooling damper shall be closed.

This concludes the section where the airflow sensor configuration is selected.

When the sequences are complete, only one of Section 5.11.5.1 and Section 5.11.5.2 should remain. The other section should be deleted, along with these flag notes.

5.11.5.3. Overriding Sections 5.11.5.1 and 5.11.5.2 Logic (to Avoid Backflow from One Duct to the Other)

- a. If heating air handler is not proven ON, the heating damper shall be closed.
- b. If cooling air handler is not proven ON, the cooling damper shall be closed.

5.11.6. Alarms

5.11.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.11.6.2. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5.11.6.3. 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 damper is proven ON, generate a Level 4 alarm.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

5.11.7. 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 cooling damper full closed/open,
- f. force heating damper full closed/open, and
- g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

5.11.8. System Requests

5.11.8.1. 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 5.1.20, 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 5.1.20, 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.

5.11.8.2. Cold-Duct 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.

5.11.8.3. Heating SAT Reset Requests

- a. If the zone temperature is below the zone's heating setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 3 requests.
- b. Else if the zone temperature is below the zone's heating setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 2 requests.
- c. Else if the Heating Loop is greater than 95%, send 1 request until the Heating Loop is less than 85%.
- d. Else if the Heating Loop is less than 95%, send 0 requests

5.11.8.4. Hot-Duct 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.

5.11.8.5. Heating-Fan Requests. Send the heating fan that serves the zone a heating-fan request as follows:

- a. If the Heating Loop is greater than 15%, send 1 request until the Heating Loop is less than 1%.
- b. Else if the Heating Loop is less than 15%, send 0 requests.

5.12 Dual-Duct VAV Terminal Unit – Mixing Control with Inlet Airflow Sensors

Mixing control logic is the preferred option for use with DCV. If the box serves more than one room, it requires a DD box with mixing capability; a pair of single-duct boxes strapped together with a common plenum will not work because the discharge air will stratify rather than mix. However, if only a single room is served, as is typical for a zone using DCV, then the room becomes the mixing box and this issue can be disregarded.

This sequence uses two airflow sensors, one at each inlet. This eliminates the need for a restriction at the discharge to facilitate flow measurement (and its associated pressure drop). A discharge restriction may still be required for mixing; see previous section.

When the majority of the airflow is through one duct, the airflow velocity in the other duct may be too low to read and result in hunting at that damper. This is not a problem, because the absolute airflow in that duct will be too low for minor fluctuations to be detectable, while the airflow in the dominant duct is sufficient to provide a clear velocity signal.

Because no cold-duct air is supplied during most of the heating mode, the heating system must include ventilation air either with direct outdoor air intake or indirectly via transfer air from overventilated spaces on the same system. Refer to Standard 62.1-2016 and Standard 62.1 User's Manual.

- 5.12.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.12.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.12.3. See Section 3.1.2.7 for zone minimum airflow setpoint V_{min} , zone maximum cooling airflow setpoint $V_{cool-max}$, and the zone maximum heating airflow setpoint $V_{heat-max}$.
- 5.12.4. Active endpoints used in the control logic depicted in Figure 5.12.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.12.4).

Table 5.12.4 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	Vheat-max	Vheat-max	0

5.12.5. Control logic is depicted schematically in Figure 5.12.5 and described in the following sections.

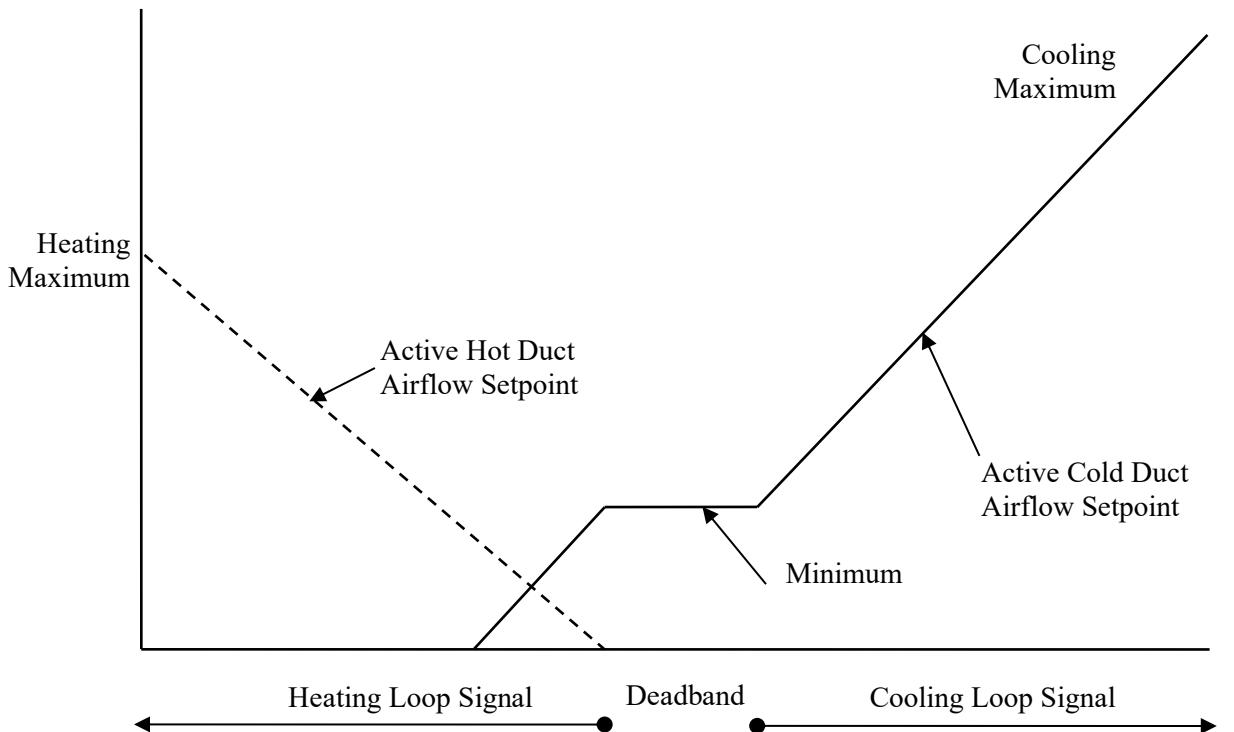


Figure 5.12.5 Control logic for mixing dual-duct VAV zone with inlet sensors.

5.12.5.1. Temperature Control

- a. When the Zone State is cooling, the Cooling Loop output shall reset the active cold duct airflow setpoint from minimum endpoint to the cooling maximum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint.
 - 1. If cold duct supply air temperature from the air handler is greater than room temperature, the active cold duct supply airflow setpoint shall be no higher than the minimum endpoint.
- b. When the Zone State is deadband, the active cold duct airflow setpoint shall be the minimum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint. The hot duct damper shall be closed.

The deadband airflow is maintained by the cooling damper, as the cooling system has a definite source of ventilation. With dual-fan dual-duct, the heating fan generally has no direct ventilation source; typically, ventilation is indirect via return air from interior zones that are overventilated due to the outdoor air economizer.

- c. When the Zone State is heating, the heating-loop output shall reset the active hot duct airflow setpoint from zero to the heating maximum endpoint. The hot duct damper shall be modulated by a control loop to maintain the measured hot duct airflow at the active hot duct airflow setpoint. The cooling damper shall be controlled to maintain the sum of the measured inlet airflows at the minimum endpoint.
 - 1. If hot-deck supply air temperature from air handler is less than room temperature, the active hot duct airflow setpoint shall be no higher than the minimum endpoint.

5.12.5.2. Overriding Section 5.12.5.1 Logic (to Avoid Backflow from One Duct to the Other)

- a. If heating air handler is not proven ON, the heating damper shall be closed.
- b. If cooling air handler is not proven ON, the cooling damper shall be closed.

5.12.6. Alarms

5.12.6.1. 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 4 alarm.
- c. If a zone has an Importance-Multiplier of 0 (see Section 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.12.6.2. Airflow Sensor Calibration. If the fan serving the zone is OFF and airflow sensor reading is above the larger of 10% of the maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5.12.6.3. 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 damper is proven ON, generate a Level 4 alarm.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

5.12.7. 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 cooling damper full closed/open,
- f. force heating damper full closed/open, and
- g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

5.12.8. System Requests

5.12.8.1. 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 5.1.20, 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 5.1.20, 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.

5.12.8.2. Cold-Duct 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.

5.12.8.3. Heating SAT Reset Requests

- a. If the zone temperature is below the zone's heating setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 3 requests.
- b. Else if the zone temperature is below the zone's heating setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 2 requests.
- c. Else if the Heating Loop is greater than 95%, send 1 request until the Heating Loop is less than 85%.
- d. Else if the Heating Loop is less than 95%, send 0 requests.

5.12.8.4. Hot-Duct 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.

5.12.8.5. Heating-Fan Requests. Send the heating fan that serves the zone a heating-fan request as follows:

- a. If the Heating Loop is greater than 15%, send 1 request until the Heating Loop is less than 1%.
- b. Else if the Heating Loop is less than 15%, send 0 requests.

5.13 Dual-Duct VAV Terminal Unit – Mixing Control with Discharge Airflow Sensor

Mixing control logic is the preferred option for use with DCV. If the box serves more than one room, it requires a DD box with mixing capability; a pair of single-duct boxes strapped together with a common plenum will not work because the discharge air will stratify rather than mix. However, if only a single room is served, as is typical for a zone using DCV, then the room becomes the mixing box and this issue can be disregarded.

This sequence uses a single airflow sensor at the discharge outlet. This requires a restriction at the outlet to ensure that airflow velocity is high enough to measure, which adds extra pressure drop. It is somewhat of a legacy approach from when adding a second airflow sensor was much more expensive. As dual-airflow-sensor controllers are now more common, the previous sequence (mixing control with inlet airflow sensors) is generally preferred.

Because no cold-duct air is supplied during heating mode, the heating system must include ventilation air either with direct outdoor air intake or indirectly via transfer air from overventilated spaces on the same system. Refer to Standard 62.1-2016 and Standard 62.1 User's Manual.

- 5.13.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.13.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.13.3. See Section 3.1.2.7 for zone minimum airflow setpoint V_{min} , zone maximum cooling airflow setpoint $V_{cool-max}$, and the zone maximum heating airflow setpoint $V_{heat-max}$.
- 5.13.4. Active endpoints used in the control logic depicted in Figure 5.13.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.13.4).

Table 5.13.4 Endpoints as a Function of Zone Group Mode

Setpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	$V_{cool-max}$	$V_{cool-max}$	$V_{cool-max}$	0	0	0
Minimum	V_{min}^*	0	0	0	0	0
Heating maximum	$V_{heat-max}$	0	0	$V_{heat-max}$	$V_{heat-max}$	0

5.13.5. Control logic is depicted schematically in Figure 5.13.5 and described in the following subsections.

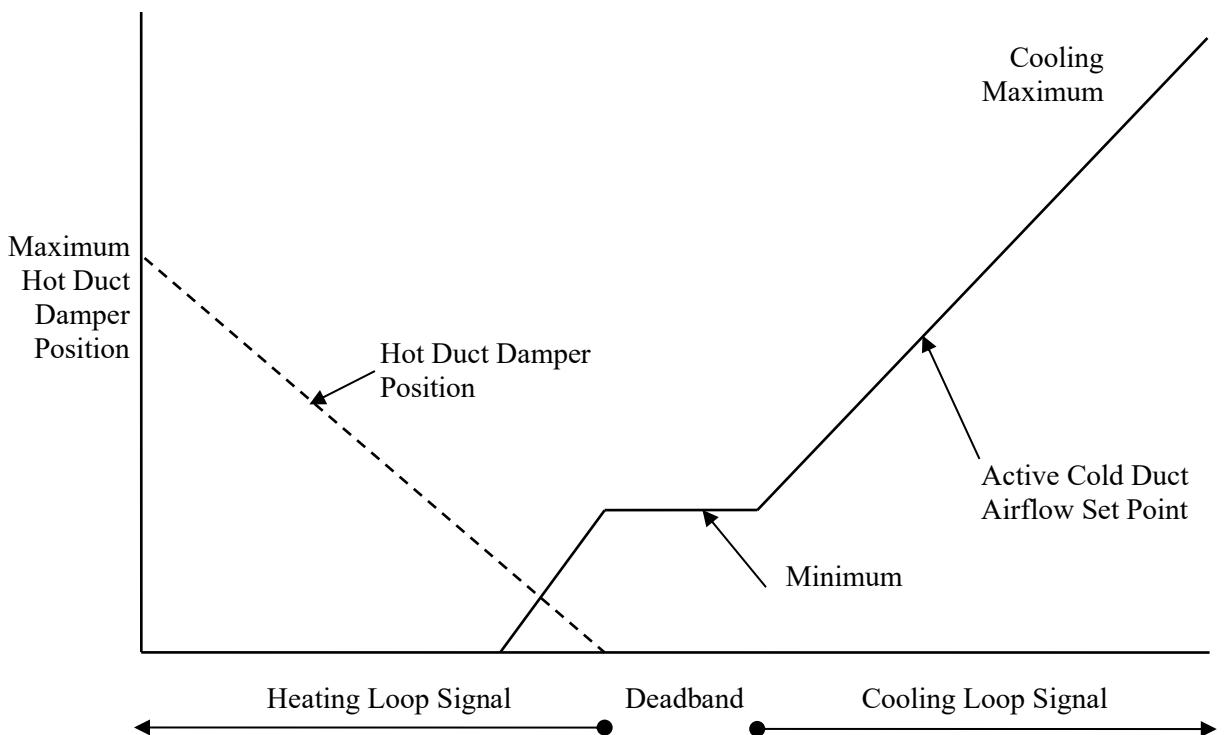


Figure 5.13.5 Control logic for mixing dual-duct VAV zone with discharge sensor.

5.13.5.1. Temperature Control

Because there is only a single airflow sensor on the combined discharge, typical pressure-independent control will not work for both dampers. Instead, the cooling damper is controlled using pressure-independent control, while the heating damper position equals the Heating Loop signal (i.e., pressure-dependent control).

- When the Zone State is cooling, the cooling-loop output shall reset the active cold duct airflow setpoint from minimum endpoint to the cooling maximum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint.
 - If cold duct supply air temperature from the air handler is greater than room temperature, the active cold duct airflow setpoint shall be no higher than the minimum endpoint.
- When the Zone State is deadband, the active cold duct airflow setpoint shall be the minimum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint. The hot duct damper shall be closed.

The deadband airflow is maintained by the cooling damper, as the cooling system has a definite source of ventilation. With dual-fan dual-duct, the heating fan generally has no direct ventilation source; typically, ventilation is indirect via return air from interior zones that are overventilated due to the outdoor air economizer.

- When the Zone State is heating, the Heating Loop output shall be mapped to the hot duct damper position. The cold duct damper is modulated to maintain measured discharge airflow at the minimum endpoint.
 - If hot duct supply air temperature from the air handler is less than room temperature, the hot duct damper shall be closed.

2. Maximum hot duct airflow shall be limited by a reverse-acting P-only loop whose setpoint is the heating maximum endpoint and whose output is the maximum hot duct damper position ranging from 0% to 100%.

Because the heating damper is operating in a pressure-dependent manner, a loop must be added to limit heating damper position to Vheat-max. When this comes into play, the only air passing through the discharge airflow sensor is heating air.

5.13.5.2. Overriding Section 5.13.5.1 Logic (to Avoid Backflow from One Duct to the Other)

- a. If heating air handler is not proven ON, the heating damper shall be closed.
- b. If cooling air handler is not proven ON, the cooling damper shall be closed.

5.13.6. Alarms

5.13.6.1. 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 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.13.6.2. Airflow Sensor Calibration. If the fan serving the zone is OFF and airflow sensor reading is above the larger of 10% of the maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5.13.6.3. 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 damper is proven ON, generate a Level 4 alarm.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

5.13.7. 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 cooling damper full closed/open,
- f. force heating damper full closed/open, and
- g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

5.13.8. System Requests

5.13.8.1. 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 5.1.20, 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 5.1.20, 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.

5.13.8.2. Cold-Duct 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.

5.13.8.3. Heating SAT Reset Requests

- a. If the zone temperature is below the zone's heating setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 3 requests.
- b. Else if the zone temperature is below the zone's heating setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 2 requests.
- c. Else if the Heating Loop is greater than 95%, send 1 request until the Heating Loop is less than 85%.
- d. Else if the Heating Loop is less than 95%, send 0 requests.

5.13.8.4. Hot-Duct Static Pressure Reset Requests

- a. If the damper position is greater than 95%, send 1 request until the damper position is less than 85%.
- b. Else if the damper position is less than 95%, send 0 requests.

5.13.8.5. Heating-Fan Requests. Send the heating fan that serves the zone a heating-fan request as follows:

- a. If the Heating Loop is greater than 15%, send 1 request until the Heating Loop is less than 1%.
- b. Else if the Heating Loop is less than 15%, send 0 requests.

5.14 Dual-Duct VAV Terminal Unit – Cold-Duct Minimum Control

Cold-duct minimum control logic is the most conventional, but least efficient, dual-duct control strategy. It ensures ventilation rates without Standard 62.1-2016 generalized multiple spaces considerations, because only the cold duct has ventilation air with DFDD systems.

This strategy uses dual airflow sensors, one at each inlet. It may be used with or without DCV.

The designer must ensure that the minimum and heating maximum sum to less than the cooling maximum to avoid oversupplying the diffusers.

- 5.14.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.
- 5.14.2. See “Generic Ventilation Zones” (Section 5.2) for calculation of zone minimum outdoor airflow.
- 5.14.3. See Section 3.1.2.7 for zone minimum airflow setpoint V_{min} , zone maximum cooling airflow setpoint $V_{cool-max}$, and the zone maximum heating airflow setpoint $V_{heat-max}$.
- 5.14.4. Active endpoints used in the control logic depicted in Figure 5.14.5 shall vary depending on the mode of the Zone Group the zone is a part of (see Table 5.14.4).

Table 5.14.4 Endpoints as a Function of Zone Group Mode

Setpoint	Occupied	Cooldown	Setup	Warmup	Setback	Unoccupied
Cooling maximum	$V_{cool-max}$	$V_{cool-max}$	$V_{cool-max}$	0	0	0
Minimum	V_{min}^*	0	0	0	0	0
Heating maximum	$V_{heat-max}$	0	0	$V_{heat-max}$	$V_{heat-max}$	0

- 5.14.5. Control logic is depicted schematically in Figure 5.14.5 and described in the following subsections.

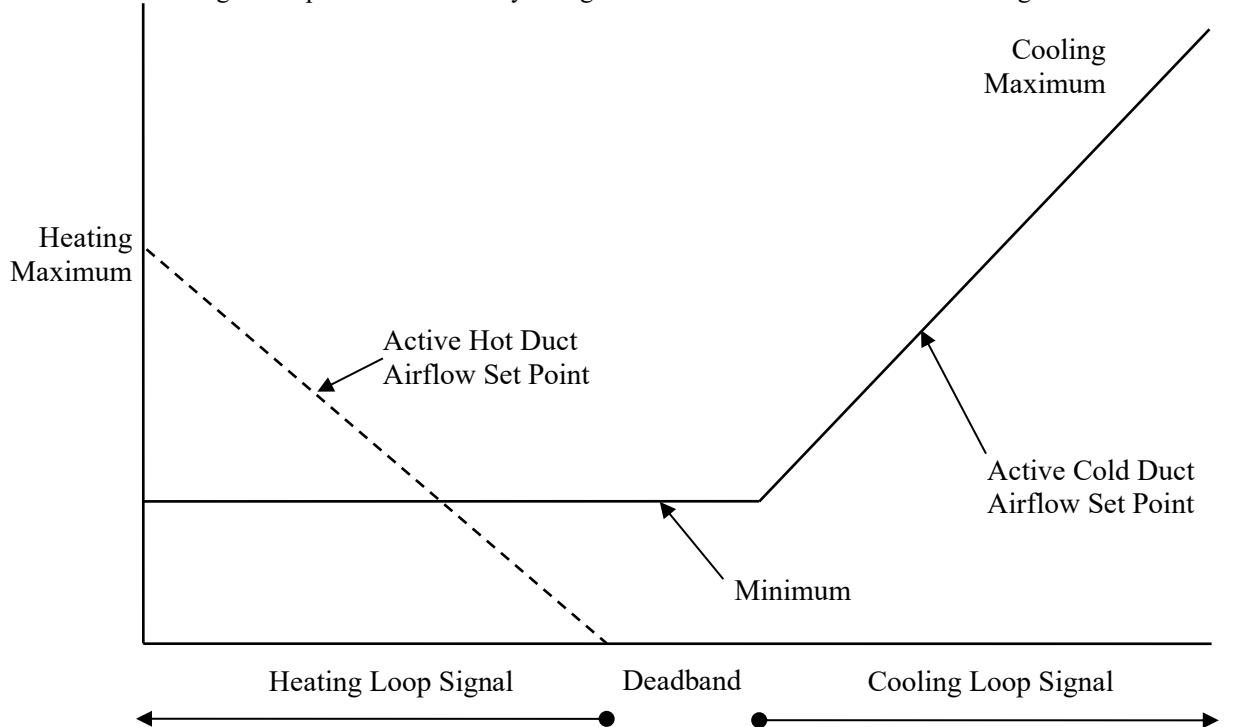


Figure 5.14.5 Control logic for mixing dual-duct VAV zone with cold-duct minimum.

- 5.14.5.1. Temperature and Damper Control

- a. When the Zone State is cooling, the Cooling Loop output shall reset the active cold duct airflow setpoint from the minimum endpoint to cooling maximum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint. The hot duct damper shall be closed.

1. If cold duct supply air temperature from air handler is greater than room temperature, the active cold duct airflow setpoint shall be no higher than the minimum endpoint.
- b. When the Zone State is deadband, the active cold duct airflow setpoint shall be the minimum endpoint. The cold duct damper shall be modulated by a control loop to maintain the measured cold duct airflow at the active cold duct airflow setpoint. The hot duct damper shall be closed.
- c. When the Zone State is heating:
 1. The Heating Loop output shall reset the active hot duct airflow setpoint from zero to heating maximum endpoint. The hot duct damper shall be modulated by a control loop to maintain the measured hot duct airflow at the active hot duct airflow setpoint.
 2. The active cold duct airflow setpoint shall be the minimum endpoint. The cooling damper shall be modulated by a control loop to maintain the measured cold duct airflow at active cold duct airflow setpoint.
 3. If hot duct supply air temperature from the air handler is less than room temperature, the hot duct damper shall be closed.

5.14.5.2. Overriding Section 5.14.5.1 Logic (to Avoid Backflow from One Duct to the Other)

- a. If heating air handler is not proven ON, the heating damper shall be closed.
- b. If cooling air handler is not proven ON, the cooling damper shall be closed.

5.14.6. Alarms

5.14.6.1. 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 4 alarm.
- c. If a zone has an Importance-Multiplier of 0 (see Section 5.1.14.2.a.1) for its static pressure reset T&R control loop, low airflow alarms shall be suppressed for that zone.

5.14.6.2. Airflow Sensor Calibration. If the fan serving the zone is off and airflow sensor reading is above the larger of 10% of the maximum airflow setpoint or 50 cfm for 30 minutes, generate a Level 3 alarm.

5.14.6.3. 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 damper is proven ON, generate a Level 4 alarm.

The constant value thresholds for the airflow sensor calibration and leaking damper alarms are a function of the transducer and A/D converter used to measure airflow. The value used should be determined as the minimum accuracy of the transducer and A/D converter combination.

5.14.7. 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 cooling damper full closed/open,
- f. force heating damper full closed/open, and
- g. reset request-hours accumulator point to zero (provide one point for each reset type listed in the next section).

Per Section 5.1.11, 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 5.4.5.

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.

5.14.8. System Requests

5.14.8.1. 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 5.1.20, 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 5.1.20, 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.

5.14.8.2. Cold-Duct 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.

5.14.8.3. Heating SAT Reset Requests

- a. If the zone temperature is below the zone's heating setpoint by 3°C (5°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 3 requests.
- b. Else if the zone temperature is below the zone's heating setpoint by 2°C (3°F) for 2 minutes and after suppression period due to setpoint change per Section 5.1.20, send 2 requests.
- c. Else if the Heating Loop is greater than 95%, send 1 request until the Heating Loop is less than 85%.
- d. Else if the Heating Loop is less than 95%, send 0 requests.

5.14.8.4. Hot-Duct Static Pressure Reset Requests

- a. If the measured airflow is less than 50% of setpoint while setpoint is greater than zero for 1 minute, send 3 requests.
- b. Else if the measured airflow is less than 70% of setpoint while setpoint is greater than zero 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.

- 5.14.8.5. Heating-Fan Requests. Send the heating fan that serves the zone a heating-fan request as follows:
- a. If the Heating Loop is greater than 15%, send 1 request until the Heating Loop is less than 1%.
 - b. Else if the Heating Loop is less than 15%, send 0 requests.

5.15 Air-Handling Unit System Modes

5.15.1. 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

5.16 Multiple-Zone VAV Air-Handling Unit

This section applies primarily to a cooling VAV air-handling system. It can be adapted to apply to a heating air handler serving a dual-duct VAV system by editing out logic that does not apply and by adjusting supply air temperature setpoints.

5.16.1. Supply Fan Control

5.16.1.1. 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).

Delete the following section if the air-handler serves dual-duct boxes that do not have hot-duct inlet airflow sensors, i.e., those that have only a box discharge airflow sensor. This section may also be deleted if there is a supply AFMS.

- 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.

5.16.1.2. Static Pressure Set-Point Reset

- a. Static pressure setpoint. Setpoint shall be reset using T&R logic (see Section 5.1.14) 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 3.2.1.1)
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.

5.16.1.3. 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.

5.16.2. Supply Air Temperature Control

5.16.2.1. Control loop is enabled when the supply air fan is proven ON, and disabled and output set to deadband (no heating, minimum economizer) otherwise.

5.16.2.2. 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 3.1.4.1 for Min_ClgSAT, Max_ClgSAT, OAT_Min, and OAT_Max setpoints.

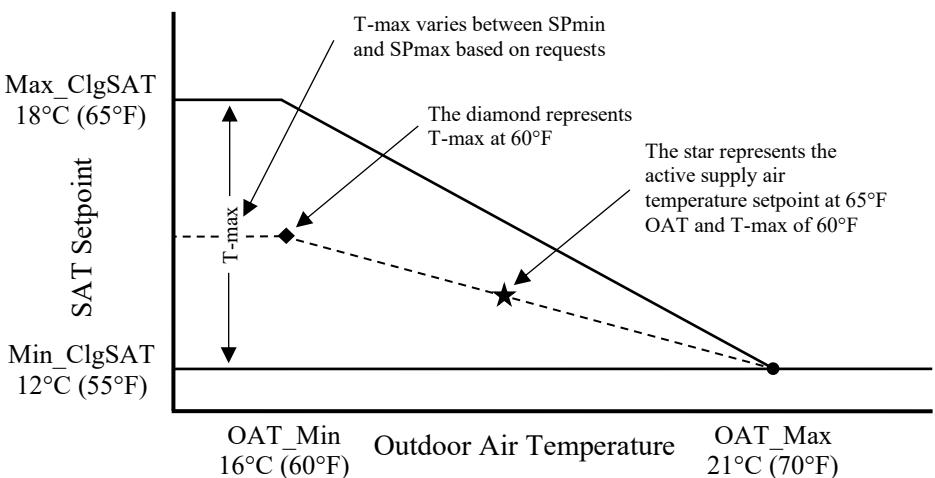
- b. During Occupied Mode and Setup Mode, setpoint shall be reset from Min_ClgSAT when the outdoor air temperature is OAT_Max and above, proportionally up to T-max when the outdoor air temperature is OAT_Min and below.
1. T-max shall be reset using T&R logic (see Section 5.1.14) between Min_ClgSAT and 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.

- 5.16.2.3. 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.

The engineer must specify whether the unit has a return fan, relief damper or relief fans.

If there is a return fan, keep subsection (a) and delete subsection (b).

If there are relief dampers or relief fans, keep subsection (b) and delete subsection (a).

Delete this flag note after selections have been made.

- a. For units with return fans
 - 1. Return air damper maximum position MaxRA-P is modulated to control minimum outdoor air volume (see Sections 5.16.4.4, 5.16.5.4 and 5.16.6.3).
- 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 5.16.4.4, 5.16.5.4 and 5.16.6.3).

The engineer must specify whether minimum outdoor air and economizer functions use separate dedicated dampers or a single common damper.

If there are separate dedicated dampers, keep subsection (2) and delete subsection (3).

If there is a single common damper, keep subsection (3) and delete subsection (2).

Note that a single common damper requires an outdoor air AFMS. It is not a valid choice if minimum outdoor air control is being done by DP (i.e., if is being used).

Delete this flag note after selection has been made.

- 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 5.16.4 and 5.16.5).
- 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 5.16.6). 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.

The engineer must specify whether the AHU has a return fan or relief fan(s)/damper(s), and, if a return fan, how it is controlled.

If there are relief fan(s) or damper(s), retain Figure 5.16.2.3-1, and delete Figures 5.16.2.3-2 and 5.16.2.3-3 and their associated explanatory notes. Rename Figure 5.16.2.3-1 as Figure 5.16.2.3 (delete “-1”) to avoid confusion.

If there is a return fan controlled by airflow tracking, retain Figure 5.16.2.3-2, and delete Figures 5.16.2.3-1 and 5.16.2.3-3 and their associated explanatory notes. Rename Figure 5.16.2.3-2 as Figure 5.16.2.3 (delete “-2”) to avoid confusion.

If there is a return fan controlled by direct building pressure, retain Figure 5.16.2.3-3, and delete Figures 5.16.2.3-1 and 5.16.2.3-2 and their associated explanatory notes. Rename Figure 5.16.2.3-3 as Figure 5.16.2.3 (delete “-3”) to avoid confusion.

Delete this flag note after selection has been made.

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.

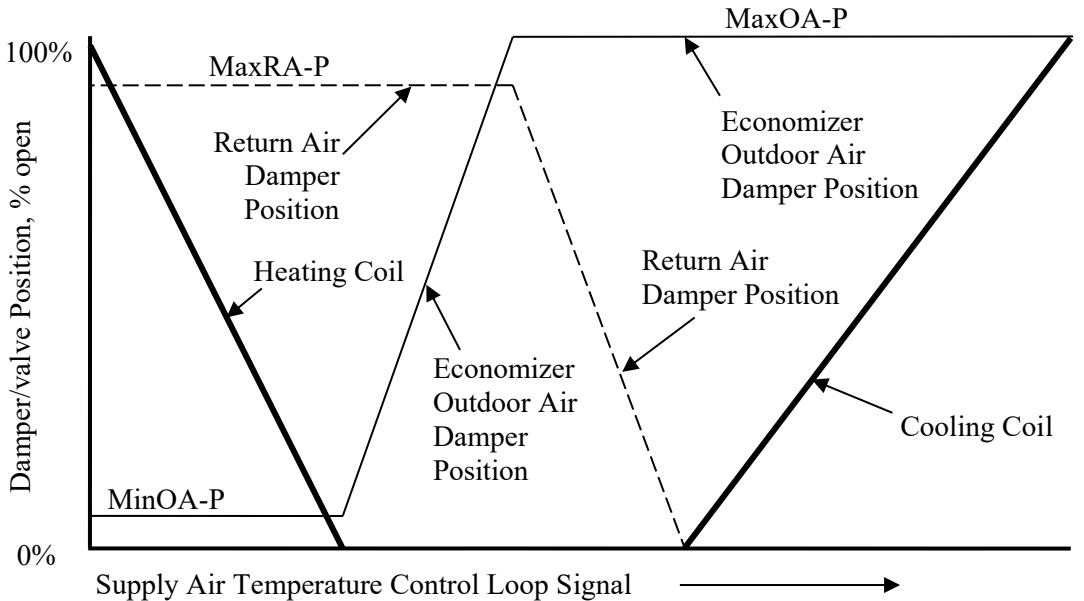


Figure 5.16.2.3-1 SAT loop mapping with relief damper or relief fan.

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.

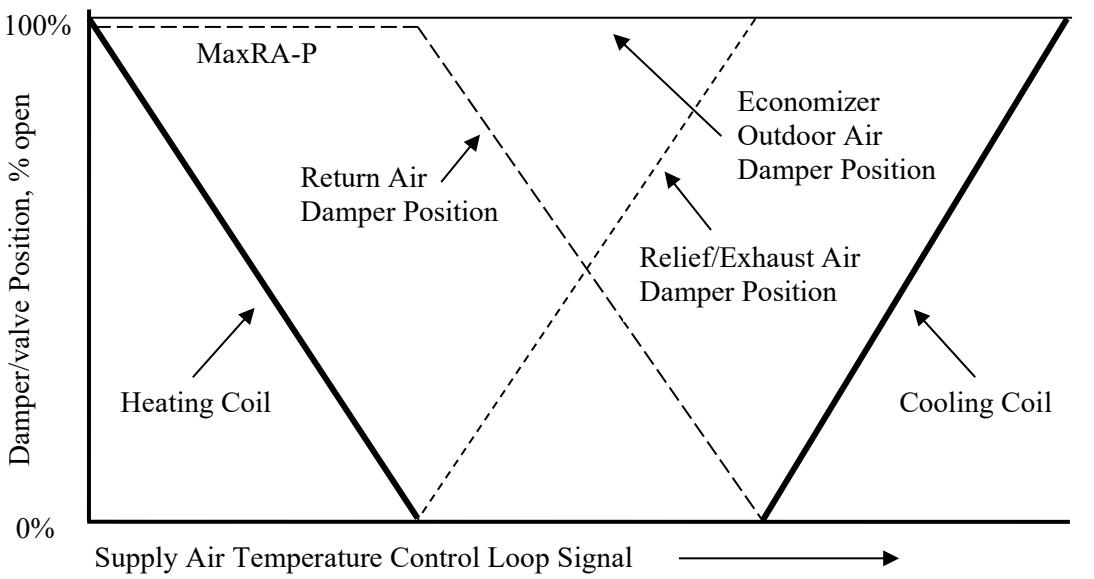


Figure 5.16.2.3-2 SAT loop mapping with return-fan control with airflow tracking.

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.

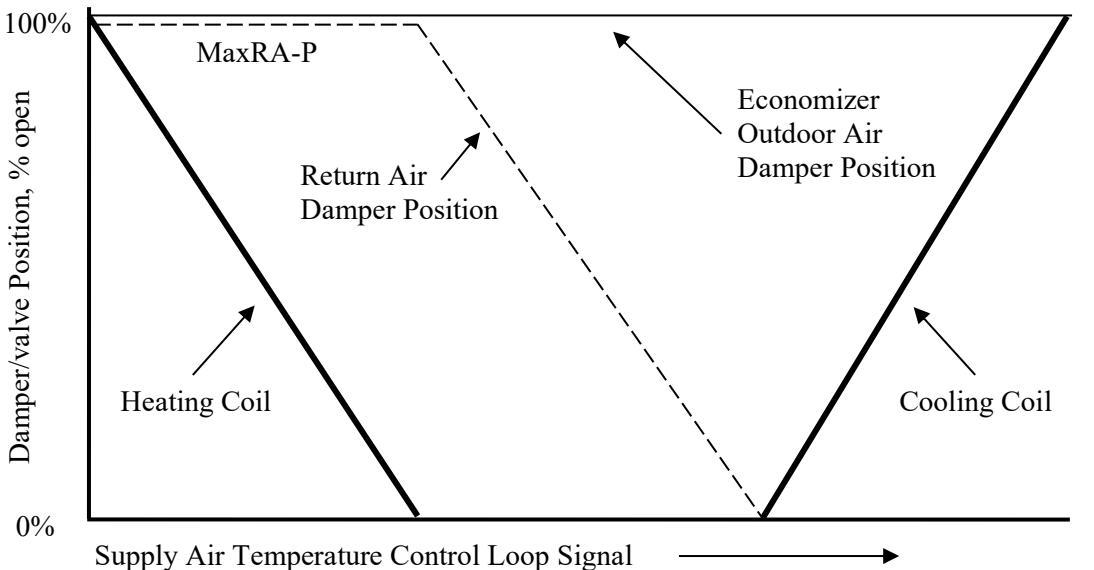


Figure 5.16.2.3-3 SAT loop mapping with return-fan control with direct building pressure controls.

5.16.3. Minimum Outdoor Airflow Setpoints

The engineer must select between options for determining the outdoor airflow setpoint based on the ventilation logic being used.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.3.1 and delete Section 5.16.3.2.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.3.2 and delete Section 5.16.3.1.

5.16.3.1. Outdoor Airflow Setpoint for ASHRAE Standard 62.1-2016 Ventilation

The CO₂ DCV strategy for Standard 62.1 currently increases both the zone primary airflow and the population component of the breathing zone outdoor airflow in response to increasing CO₂ concentrations. Through the dynamic implementation of the Standard 62.1 Multiple Spaces Equation (see Vou and Ev calculations in this section), the minimum outdoor airflow setpoint is adjusted accordingly in tandem with the zone DCV response. Though this combined response increases ventilation with rising CO₂ concentrations, it is not strictly adherent with Standard 62.1. ASHRAE research projects RP-1547 and RP-1747 developed and tested a technically rigorous DCV approach that may be considered for future versions of the guideline pending further confirmation of its stability in real-world applications.

- a. See Section 5.2.1.3 for zone outdoor air requirement Voz.
- b. See Section 3.1.4.2.a for setpoints DesVou and DesVot.

The following logic solves the Standard 62.1 multiple-spaces equation dynamically. This is required prescriptively by ASHRAE/IES Standard 90.1 for single-duct VAV systems. The logic does not strictly apply to VAV systems with multiple recirculation paths, such as dual-fan dual-duct systems and systems with fan-powered terminals, nor is it required by Standard 90.1 for these systems. Logic for dynamic reset for these systems has yet to be developed.

- c. The uncorrected outdoor air rate setpoint Vou is recalculated continuously based on the adjusted ventilation rates Vbz-A* and Vbz-P* of the zones being served determined in accordance with Section 5.2.1.3.

Some diversity factor is included in Vou, calculated below, because the ventilation requirements have been zeroed out for unoccupied zones and those with open window switches. But there is additional diversity in areas with occupancy sensors because only one person in the room will trigger the sensor. There is also diversity in other areas without occupancy sensors. Therefore operating Vou is limited to design Vou, and the diversity value of D in the calculation of DesVou is not required.

1. Calculate the uncorrected outdoor air rate Vou for all zones in all Zone Groups that are in Occupied Mode, but note that Vou shall be no larger than the design uncorrected outdoor air rate DesVou.

$$V_{ou} = \text{MIN}(\text{DesV}_{ou} | (\sum V_{bz-A^*} + \sum V_{bz-P^*}))$$

- d. Vps is the sum of the zone primary airflow rates Vpz as measured by VAV boxes for all zones in all Zone Groups that are in Occupied Mode.
- e. For each zone in Occupied Mode, calculate the zone primary outdoor air fraction Zpz:

$$Z_{pz} = V_{oz}/V_{pz}$$

See ASHRAE Guideline 13 for best practices in locating programming logic for the zone primary outdoor air fraction calculation based on network architecture.

- f. Calculate the maximum zone outdoor air fraction Zp:

$$Z_p = \max(Z_{pz})$$

- g. Calculate the current system ventilation efficiency E_v :

$$E_v = 1 + (V_{ou}/V_{ps}) - Z_p$$

- h. Calculate the effective minimum outdoor air setpoint $MinOA_{asp}$ as the uncorrected outdoor air intake divided by the system ventilation efficiency, but no larger than the design total outdoor air rate $DesV_{ot}$:

$$MinOA_{asp} = \text{MIN} \left(\frac{V_{ou}}{E_v} \mid DesV_{ot} \right)$$

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.3.2 and delete Section 5.16.3.1.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.3.1 and delete Section 5.16.3.2.

5.16.3.2. Outdoor Airflow Setpoint for California Title 24 Ventilation

- a. See Section 5.2.1.4 for zone outdoor air rates Zone-Abs-OA-min and Zone-Des-OA-min.
- b. See Section 3.1.4.2.b 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.

This concludes the section where the method for determining the outdoor airflow setpoint is selected.

When the sequences are complete, only one of Section 5.16.3.1 or Section 5.16.3.2 should remain. The other subsection should be deleted along with these flag notes.

The engineer must select among options for minimum outdoor air control logic based on two criteria:

Do the minimum outdoor air and economizer functions use separate dedicated dampers or a single common damper?

Is outdoor air volume measured by DP ΔP or an airflow measurement station (AFMS)?

Control logic selections should be made as follows:

For AHUs with separate dedicated dampers and OA measurement by ΔP , use Section 5.16.4 and delete Sections 5.16.5 and 5.16.6.

For AHUs with separate dedicated dampers and OA measurement by AFMS, use Section 5.16.5 and delete Sections 5.16.4 and 5.16.6.

For AHUs with a single common damper and OA measurement by AFMS, use Section 5.16.6 and delete Sections 5.16.4 and 5.16.5.

AHUs with a single common damper and OA measurement by ΔP are not supported because OA measurements are not accurate in this configuration.

DCV is supported in all three options but only for California Title 24 ventilation.

5.16.4. Minimum Outdoor Air Control with a Separate Minimum Outdoor Air Damper and Differential Pressure Control

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.4.1 and delete Section 5.16.4.2.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.4.2 and delete Section 5.16.4.1.

5.16.4.1. DP Setpoint for ASHRAE Standard 62.1 Ventilation

- a. See Section 3.2.1.3.a for design OA DP setpoints.
- b. See Section 5.16.3.1 for calculation of current outdoor air setpoint MinOAsp.
- c. The minimum outdoor air DP setpoint MinDPsp shall be calculated as

$$\text{MinDPsp} = \text{DesMinDP} \left[\frac{\text{MinOAsp}}{\text{DesV}_{ot}} \right]^2$$

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.4.2 and delete Section 5.16.4.1.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.4.1 and delete Section 5.16.4.2.

5.16.4.2. DP setpoint for California Title 24 Ventilation

- a. See Section 3.2.1.3.b for design OA DP setpoints.
- b. See Section 5.16.3.2 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.

This concludes the section where the ventilation logic option is selected.

When the sequences are complete, only one of Section 5.16.4.1 and Section 5.16.4.2 should remain. The other section should be deleted along with these flag notes.

5.16.4.3. 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.

5.16.4.4. Outdoor Air and Return Air Dampers

The engineer must specify whether the unit has a return fan, relief damper or relief fans.

If there is a return fan, keep subsection (a) and delete subsection (b).

If there are relief damper or relief fans, keep subsection (b) and delete subsection (a).

Delete this flag note after selections have been made.

- 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:
 - i. The economizer high limit conditions in Section 5.1.17 are exceeded.
 - ii. 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 5.16.2 shall be suspended per the following sequence:
 - i. 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.

- ii. Wait 15 seconds, then close the economizer outdoor air damper; and
- iii. Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 5.16.2. Economizer outdoor air damper remains closed.
- iv. 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:
 - i. The economizer high limit conditions in Section 5.1.17 are not exceeded.
 - ii. 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:
 - i. Economizer outdoor air damper shall be fully opened.
 - ii. MaxRA-P shall be set to 100%.
 - iii. Economizer and return air damper positions shall be controlled by the SAT control loop per Section 5.16.2.
- 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:
 - i. The economizer high limit conditions in Section 5.1.17 are exceeded.
 - ii. 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 5.16.2 shall be suspended per the following sequence:
 - i. 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.

- ii. Wait 15 seconds, then close the economizer outdoor air damper; and
- iii. Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 5.16.2. Economizer outdoor air damper remains closed.

- iv. 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:
 - i. The economizer high limit conditions in Section 5.1.17 are not exceeded.
 - ii. 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:
 - i. MaxRA-P shall be set to 100%.
 - ii. Economizer and return air damper positions shall be controlled by the SAT control loop per Section 5.16.2.

The engineer must select among options for minimum outdoor air control logic based on two criteria:

Do the minimum outdoor air and economizer functions use separate dedicated dampers or a single common damper?

Is outdoor air volume measured by DP ΔP or an airflow measurement station (AFMS)?

Control logic selections should be made as follows:

For AHUs with separate dedicated dampers and OA measurement by AFMS, use Section 5.16.5 and delete Sections 5.16.4 and 5.16.6.

For AHUs with separate dedicated dampers and OA measurement by ΔP, use Section 5.16.4 and delete Sections 5.16.5 and 5.16.6.

For AHUs with a single common damper and OA measurement by AFMS, use Section 5.16.6 and delete Sections 5.16.4 and 5.16.5.

AHUs with a single common damper and OA measurement by ΔP are not supported because OA measurements are not accurate in this configuration.

DCV is supported in all three options but only for California Title 24 ventilation.

5.16.5. Minimum Outdoor Air Control with a Separate Minimum Outdoor Air Damper and Airflow Measurement

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.5.1 and delete Section 5.16.5.2.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.5.2 and delete Section 5.16.5.1.

5.16.5.1. Outdoor Airflow Setpoint for ASHRAE Standard 62.1-2016 Ventilation

- a. See Section 5.16.3.1 for calculation of current outdoor air setpoint MinOAsp.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.5.2 and delete Section 5.16.5.1.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.5.1 and delete Section 5.16.5.2.

- 5.16.5.2. Outdoor Airflow Setpoint for California Title 24 Ventilation
- See Section 5.16.3.2 for calculation of current setpoints AbsMinOA* and DesMinOA*.
 - See zone CO₂ control logic under terminal unit sequences.
 - 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.

This concludes the section where the ventilation logic option is selected.

When the sequences are complete, only one of Section 5.16.5.1 and Section 5.16.5.2 should remain. The other section should be deleted along with these flag notes.

- 5.16.5.3. 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.
- 5.16.5.4. Outdoor Air and Return Air Dampers
-

The engineer must specify whether the unit has a return fan, relief damper or relief fans.

If there is a return fan, keep subsection (a) and delete subsection (b).

If there are relief dampers or relief fans, keep subsection (b) and delete subsection (a).

Delete this flag note after selections have been made.

- 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.

- 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%.
- 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:
 - The economizer high limit conditions in Section 5.1.17 are exceeded.
 - When the minimum outdoor air damper is open and the return air damper position is greater than MRA-P.
- When minimum outdoor air control is enabled, the normal sequencing of economizer outdoor air and return air dampers per Section 5.16.2 shall be suspended per the following sequence:
 - 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.

- Wait 15 seconds, then close the economizer outdoor air damper; and

- iii. Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 5.16.2. Economizer outdoor air damper remains closed.
- iv. 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:
 - i. The economizer high limit conditions in Section 5.1.17 are exceeded.
 - ii. 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:
 - i. Economizer outdoor air damper shall be fully opened.
 - ii. MaxRA-P shall be set to 100%.
 - iii. Economizer and return air damper positions shall be controlled by the SAT control loop per Section 5.16.2.

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:
 - i. The economizer high limit conditions in Section 5.1.17 are exceeded.
 - ii. 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 5.16.2 shall be superseded per the following:

- i. 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.

- ii. Wait 15 seconds, then close the economizer outdoor air damper; and
- iii. Wait 3 minutes, then release return air damper position for control by the SAT control loop in Section 5.16.2. Economizer outdoor air damper remains closed.
- iv. 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:
 - i. The economizer high limit conditions in Section 5.1.17 are not exceeded.
 - ii. 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:
 - i. MaxRA-P shall be set to 100%.
 - ii. Economizer and return air damper positions shall be controlled by the SAT control loop per Section 5.16.2.

The engineer must select among options for minimum outdoor air control logic based on two criteria:

Do the minimum outdoor air and economizer functions use separate dedicated dampers or a single common damper?

Is outdoor air volume measured by DP ΔP or an airflow measurement station (AFMS)?

Control logic selections should be made as follows:

For AHUs with a single common damper and OA measurement by AFMS, use Section 5.16.6 and delete Sections 5.16.4 and 5.16.5.

For AHUs with separate dedicated dampers and OA measurement by ΔP, use Section 5.16.4 and delete Sections 5.16.5 and 5.16.6.

For AHUs with separate dedicated dampers and OA measurement by AFMS, use Section 5.16.5 and delete Sections 5.16.4 and 5.16.6.

AHUs with a single common damper and OA measurement by ΔP are not supported because OA measurements are not accurate in this configuration.

DCV is supported in all three options but only for California Title 24 ventilation.

5.16.6. Minimum Outdoor Air Control with a Single Common Damper for Minimum Outdoor Air and Economizer Functions and Airflow Measurement

The engineer must select between ventilation logic options:

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.6.1 and delete Section 5.16.6.2.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.6.2 and delete Section 5.16.6.1.

5.16.6.1. Outdoor Airflow Setpoint for ASHRAE Standard 62.1-2016 Ventilation

- See Section 5.16.3.1 for calculation of current outdoor air setpoint MinOAsp.

If the project is to comply with California Title 24 ventilation requirements, keep Section 5.16.6.2 and delete Section 5.16.6.1.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Section 5.16.6.1 and delete Section 5.16.6.2.

5.16.6.2. Outdoor Airflow Setpoint for California Title 24 Ventilation

- See Section 5.16.3.2 for calculation of current setpoints AbsMinOA* and DesMinOA*.
- See zone CO₂ control logic under terminal unit sequences.
- 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.

This concludes the section where the ventilation logic option is selected.

When the sequences are complete, only one of Section 5.16.6.1 and Section 5.16.6.2 should remain. The other section should be deleted along with these flag notes.

5.16.6.3. Minimum Outdoor Air Control Loop

- 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.

The engineer must specify whether the unit has a return fan, relief damper or relief fans.

If there is a return fan, keep subsection (b) and delete subsection (c).

If there are relief damper or relief fans, keep subsection (c) and delete subsection (b).

Delete this flag note after selections have been made.

- 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 5.1.17 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 5.1.17 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 MinOA_{Asp} 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.

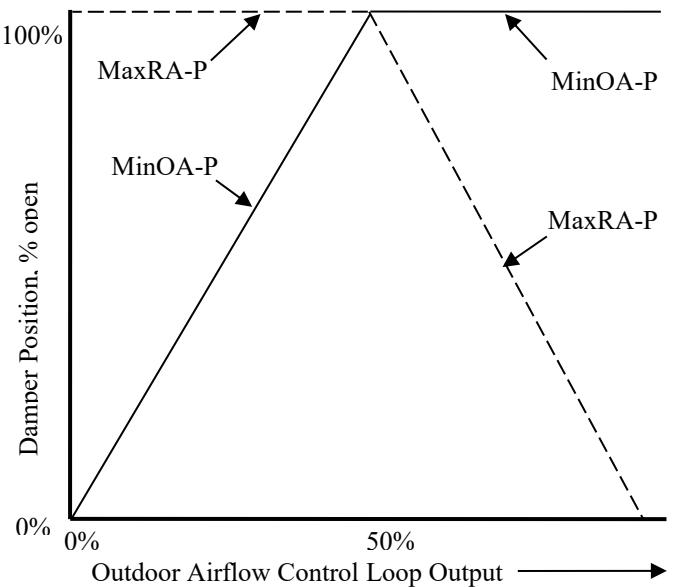


Figure 5.16.6.3 Minimum outdoor airflow control mapping with single damper.

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 5.1.17 are exceeded for 10 minutes, outdoor airflow shall be controlled to the minimum outdoor airflow setpoint, MinOA_{Asp}. When this occurs, the normal sequencing of the return air damper by the SAT control loop is suspended as follows:
 - i. Fully open the return air damper
 - ii. Wait 15 seconds, then set MaxOA-P equal to MinOA-P
 - iii. Wait 3 minutes, then modulate the return air damper to maintain the measured airflow at MinOA_{Asp} (i.e. return air damper position shall equal MaxRA-P).
3. If the economizer high limit conditions in Section 5.1.17 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).

This concludes the section where the minimum outdoor air control logic is selected.

When the sequences are complete, only one of Section 5.16.4, 5.16.5, and 5.16.6 should remain. The other two sections should be deleted along with these flag notes.

5.16.7. Not Used

This section was deleted in Addendum s. To avoid section numbering changes, an empty section was inserted.

The engineer must select among control logic options for return/relief/exhaust. This decision is based on the AHU configuration.

Control logic selections should be made as follows:

For AHUs using actuated relief dampers with relief fan(s), use Section 5.16.9 and delete Sections 5.16.8, 5.16.10, and 5.16.11.

For AHUs using actuated relief dampers without a fan, use Section 5.16.8 and delete Sections 5.16.9, 5.16.10, and 5.16.11.

For AHUs using a return fan with direct building pressure control, use Section 5.16.10 and delete Sections 5.16.8, 5.16.9, and 5.16.11.

For AHUs using a return fan with airflow tracking control, use Section 5.16.11 and delete Sections 5.16.8, 5.16.9, and 5.16.10.

For AHUs using nonactuated barometric relief only, delete all four Sections 5.16.8, 5.16.9, 5.16.10, and 5.16.11.

A building pressure sensor is required for options in Sections 5.16.8, 5.16.9, 5.16.10.

5.16.8. Control of Actuated Relief Dampers without Fans

5.16.8.1. Relief dampers shall be enabled when the associated supply fan is proven ON, and disabled otherwise.

5.16.8.2. 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.

The engineer must select among control logic options for return/relief/exhaust. This decision is based on the AHU configuration.

Control logic selections should be made as follows:

For AHUs using actuated relief dampers without a fan, use Section 5.16.8 and delete Sections 5.16.9, 5.16.10, and 5.16.11.

For AHUs using actuated relief dampers with relief fan(s), use Section 5.16.9 and delete Sections 5.16.8, 5.16.10, and 5.16.11.

For AHUs using a return fan with direct building pressure control, use Section 5.16.10 and delete Sections 5.16.8, 5.16.9, and 5.16.11.

For AHUs using a return fan with airflow tracking control, use Section 5.16.11 and delete Sections 5.16.8, 5.16.9, and 5.16.10.

For AHUs using nonactuated barometric relief only, delete all four Sections 5.16.8, 5.16.9, 5.16.10, and 5.16.11.

A building pressure sensor is required for options in Sections 5.16.8, 5.16.9, 5.16.10.

5.16.9. 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.

- 5.16.9.1. See Section 3.1.4.5 for pressure Zone Group assignments.
- 5.16.9.2. Relief fans shall be lead/lag alternated per Section 5.1.15.3.
- 5.16.9.3. 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.
- 5.16.9.4. A relief fan shall be enabled when its associated supply fan is proven on, and shall be disabled otherwise.
- 5.16.9.5. 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.
- 5.16.9.6. A single P-only control loop for each pressure zone shall 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 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.

- 5.16.9.7. 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).
- 5.16.9.8. For fans in a Level 2 alarm and status is OFF, discharge damper shall be closed when stage is above Stage 0.

The engineer must select among control logic options for return/relief/exhaust. This decision is based on the AHU configuration.

Control logic selections should be made as follows:

For AHUs using a return fan with direct building pressure control, use Section 5.16.10 and delete Sections 5.16.8, 5.16.9, and 5.16.11.

For AHUs using actuated relief dampers without a fan, use Section 5.16.8 and delete Sections 5.16.9, 5.16.10, and 5.16.11.

For AHUs using actuated relief dampers with relief fan(s), use Section 5.16.9 and delete Sections 5.16.8, 5.16.10, and 5.16.11.

For AHUs using a return fan with airflow tracking control, use Section 5.16.11 and delete Sections 5.16.8, 5.16.9, and 5.16.10.

For AHUs using nonactuated barometric relief only, delete all four Sections 5.16.8, 5.16.9, 5.16.10, and 5.16.11.

A building pressure sensor is required for options in Sections 5.16.8, 5.16.9, 5.16.10.

5.16.10. Return-Fan Control – Direct Building Pressure

- 5.16.10.1. See Section 3.1.4.5 for pressure Zone Group assignments.
- 5.16.10.2. Return fan operates whenever the associated supply fan is proven ON and shall be off otherwise.
- 5.16.10.3. Return fans shall be controlled to maintain return-fan discharge static pressure at setpoint (Section 5.16.10.5).
- 5.16.10.4. 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.

- 5.16.10.5. 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.setpointsetpoint

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 3.2.1.4 for RFDSPmin and RFDSPmax.

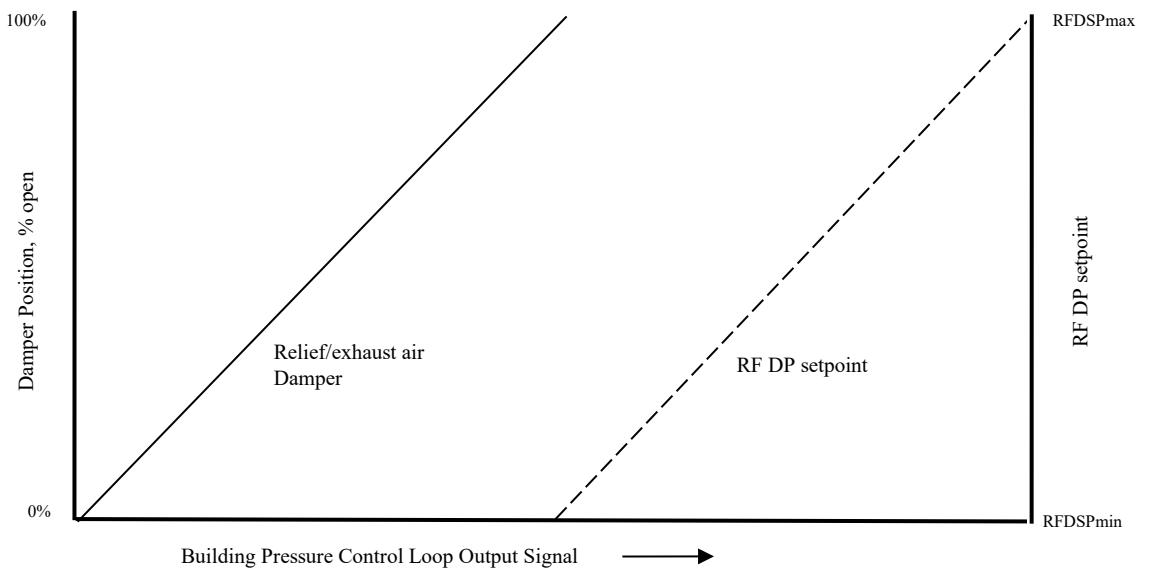


Figure 5.16.10.5 Exhaust damper position and return-fan DP reset

The engineer must select among control logic options for return/relief/exhaust. This decision is based on the AHU configuration.

Control logic selections should be made as follows:

For AHUs using a return fan with airflow tracking control, use Section 5.16.11 and delete Sections 5.16.8, 5.16.9, and 5.16.10.

For AHUs using actuated relief dampers without a fan, use Section 5.16.8 and delete Sections 5.16.9, 5.16.10, and 5.16.11.

For AHUs using actuated relief dampers with relief fan(s), use Section 5.16.9 and delete Sections 5.16.8, 5.16.10, and 5.16.11.

For AHUs using a return fan with direct building pressure control, use Section 5.16.10 and delete Sections 5.16.8, 5.16.9, and 5.16.11.

For AHUs using nonactuated barometric relief only, delete all four Sections 5.16.8, 5.16.9, 5.16.10, and 5.16.11.

A building pressure sensor is required for options in Sections 5.16.8, 5.16.9, 5.16.10.

5.16.11. Return-Fan Control – Airflow Tracking

- 5.16.11.1. Return fan operates whenever associated supply fan is proven ON.
- 5.16.11.2. The active differential airflow setpoint S-R-DIFF* shall be S-R-DIFF for the entire system (see Section 3.2.1.5) 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.

If the project is to comply with California Title 24 ventilation requirements, keep Equation b. and delete Equation a.

If the project is to comply with ASHRAE Standard 62.1 ventilation requirements, keep Equation a. and delete Equation b.

- a. $S - R - DIFF^* = S - R - DIFF \frac{\sum_{all\ Occupied\ Zones} V_{bz-A}}{\sum_{all\ Zones} V_{bz-A}}$
- b. $S - R - DIFF^* = S - R - DIFF \frac{\sum_{all\ Occupied\ Zones} V_{area-min}}{\sum_{all\ Zones} V_{area-min}}$

- 5.16.11.3. 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.*

- 5.16.11.4. 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%.
- 5.16.11.5. 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 5.16.2.3.

Airflow tracking requires a measurement of supply airflow and return airflow. Appendix A-9 shows 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.

This concludes the section where the control logic for return/relief/exhaust is selected.

When the sequences are complete, at most, one of Sections 5.16.8, 5.16.9, 5.16.10, and 5.16.11 should remain. If relief is barometric (without actuators) only, then all four subsections should be deleted. Delete these flag notes after the decision has been made.

There are three stages of freeze protection. The first stage modulates the heating valve to maintain a safe SAT. The second stage eliminates outdoor air ventilation in case heating is not available for whatever reason. The third stage shuts down the unit and activates coil valves and pumps to circulate water in case the second stage does not work (e.g., stuck economizer damper).

If a freeze-stat is present, it may be hardwired to perform some or all of these functions. In that case, delete those functions from sequence logic in Section 5.16.12 but maintain the alarms. Delete this flag note when sequences are complete.

5.16.12. Freeze Protection

There are three stages of freeze protection. The first stage modulates the heating valve to maintain a safe SAT. The second stage eliminates outdoor air ventilation in case heating is not available for whatever reason. The third stage shuts down the unit and activates coil valves and pumps to circulate water in case the second stage does not work (e.g., stuck economizer damper).

- 5.16.12.1. If the supply air temperature drops below 4.4°C (40°F) for 5 minutes, send two (or more, as required to ensure that heating plant is active) heating hot-water plant requests, override the outdoor air damper to the minimum position, and modulate the heating coil to maintain a supply air temperature of at least 6°C (42°F). Disable this function when supply air temperature rises above 7°C (45°F) for 5 minutes.

The first stage of freeze protection locks out the economizer. Most likely this has already occurred by this time, but this logic provides insurance.

- 5.16.12.2. If the supply air temperature drops below 3.3°C (38°F) for 5 minutes, fully close both the economizer damper and the minimum outdoor air damper for 1 hour and set a Level 3 alarm noting that minimum ventilation was interrupted. After 1 hour, the unit shall resume minimum outdoor air ventilation and enter the previous stage of freeze protection (see Section 5.16.12.1).

A timer is used (rather than an OAT threshold) to exit the second stage of freeze protection because a bad OAT sensor could lock out ventilation indefinitely; whereas a timer should just work and thus avoid problems with the unit becoming stuck in this mode with no ventilation.

Upon timer expiration, the unit will reenter the previous stage of freeze protection (MinOA ventilation, with heating to maintain SAT of 6°C [42°F]), after which one of three possibilities will occur:

- If it is warm enough that the SAT rises above 7°C (45°F) with minimum ventilation, the unit will remain in Stage 1 freeze protection for 5 minutes then resume normal operation.

If it is cold enough that SAT remains between 3.3°C (38°F) and 7°C (45°F) with heating and minimum ventilation, the unit will remain in Stage 1 freeze protection indefinitely until outdoor conditions warm up.

If it is so cold that SAT is less than 3.3°F (38°F) with minimum ventilation, despite heating, then the unit will revert to Stage 2 freeze protection where it will remain for 1 hour. This process will then repeat.

- 5.16.12.3. Upon signal from the freeze-stat (if installed), or if supply air temperature drops below 3.3°C (38°F) for 15 minutes or below 1°C (34°F) for 5 minutes, shut down supply and return/relief fan(s), close outdoor air damper, open the cooling-coil valve to 100%, and energize the CHW pump system. Also send two (or more, as required to ensure that heating plant is active) heating hot-water plant requests, modulate the heating coil to maintain the higher of the supply air temperature or the mixed air temperature at 27°C (80°F), and set a Level 2 alarm indicating the unit is shut down by freeze protection.
- If a freeze-protection shutdown is triggered by a low air temperature sensor reading, it shall remain in effect until it is reset by a software switch from the operator's workstation. (If a freeze-stat with a physical reset switch is used instead, there shall be no software reset switch.)

Stage 3 can be triggered by either of two conditions. The second condition is meant to respond to an extreme and sudden cold snap.

Protecting the cooling coil in this situation will require water movement through the coil, which means that the CHW pumps need to be energized.

Heating coil is controlled to an air temperature setpoint. The sensors will not read accurately with the fan OFF, but they will be influenced by proximity to the heating coil. A temperature of 27°C (80°F) at either of these sensors indicates that the interior of the unit is sufficiently warm. This avoids the situation where a fixed valve position leads to very high (and potentially damaging) temperatures inside the unit.

5.16.13. Alarms

- 5.16.13.1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval count when alarm is acknowledged.
- 5.16.13.2. 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
- 5.16.13.3. 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 DP_x 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 3.1.4.4 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.

- 5.16.13.4. High building pressure (more than 25 Pa [0.10 in. of water]) for 5 minutes: Level 3.
 - 5.16.13.5. 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.

5.16.14. 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.

5.16.14.1. AFDD conditions are evaluated continuously and separately for each operating AHU.

The engineer must specify whether the unit has a return fan, relief dampers or relief fans and a separate minimum outdoor air damper or relief dampers or relief fans and a single common damper for minimum outdoor air and economizer functions.

If there is a return fan, keep Section 5.16.14.2 and delete Sections 5.16.14.3 and 5.16.14.4.

If there are relief dampers or relief fans and a separate minimum outdoor air damper, keep Section 5.16.14.3 and delete Sections 5.16.14.2 and 5.16.14.4.

If there are relief dampers or relief fans and a single common damper for minimum outdoor air and economizer functions, keep Section 5.16.14.4 and delete Sections 5.16.14.2 and 5.16.14.3.

Delete this flag note after selections have been made.

5.16.14.2. 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 5.16.14.2.

Table 5.16.14.2 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		

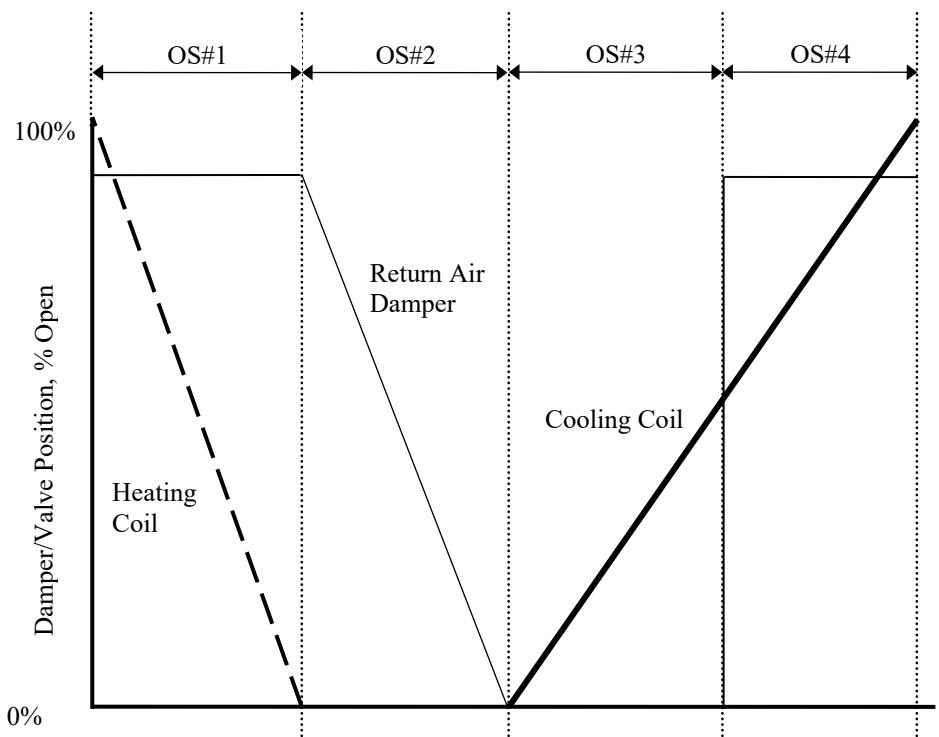


Figure 5.16.14.2 VAV AHU operating states.

5.16.14.3. 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 5.16.14.3 and Figure 5.16.14.3.

Table 5.16.14.3 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		

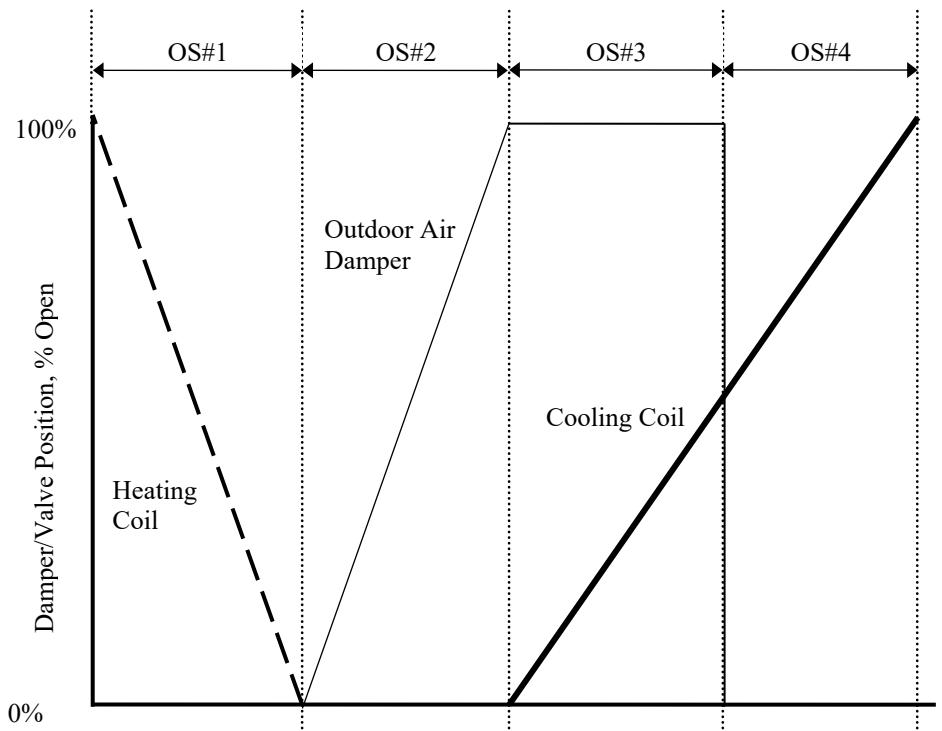


Figure 5.16.14.3 VAV AHU operating states.

5.16.14.4. 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 5.16.14.4 and Figure 5.16.14.4.

Table 5.16.14.4 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		

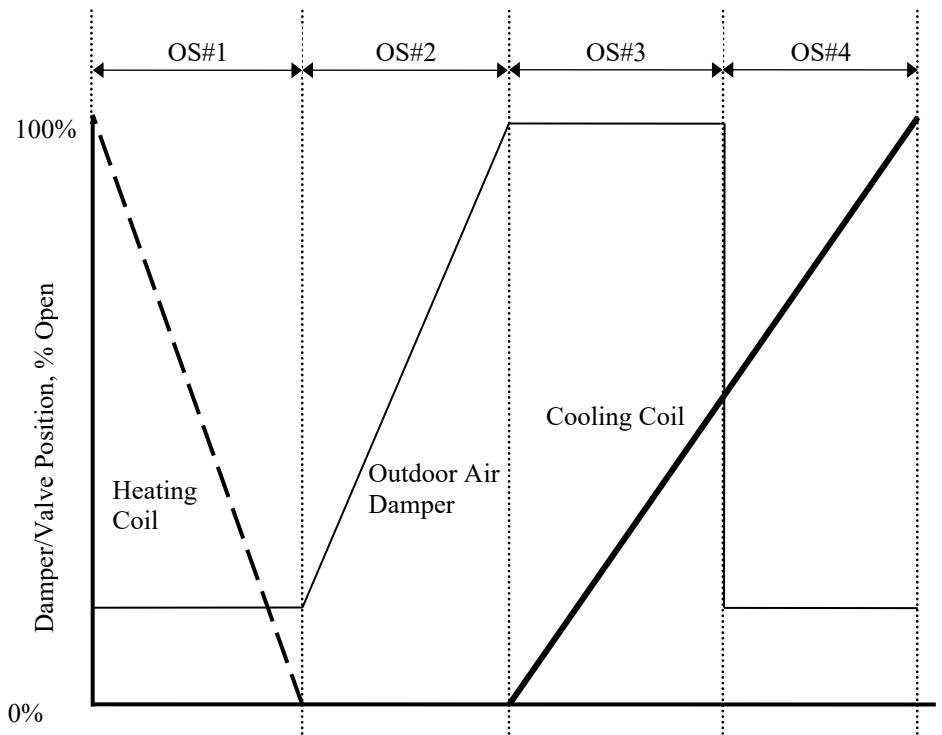


Figure 5.16.14.4 VAV AHU operating states.

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 5.16.14.2 through 5.16.14.4) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 5.16.14.8. 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.

5.16.14.5. 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; $0\% \leq HC \leq 100\%$
 - i. CC = cooling-coil valve position command; $0\% \leq CC \leq 100\%$
 - j. FS = fan speed command; $0\% \leq FS \leq 100\%$
 - 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.)
- 5.16.14.6. 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. SAT_{avg} = rolling average of supply air temperature
 - 2. MAT_{avg} = rolling average of mixed air temperature
 - 3. RAT_{avg} = rolling average of return air temperature
 - 4. OAT_{avg} = rolling average of outdoor air temperature
 - 5. DSP_{avg} = rolling average of duct static pressure
 - 6. $CCET_{avg}$ = rolling average of cooling-coil entering temperature
 - 7. $CCLT_{avg}$ = rolling average of cooling-coil leaving temperature
 - 8. $HCET_{avg}$ = rolling average of heating-coil entering temperature
 - 9. $HCLT_{avg}$ = 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)

5.16.14.7. 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 5.16.14.7 VAV AHU AFDD Internal Variables

Variable Name	Description	Default Value
ΔT_{SF}	Temperature rise across supply fan	1°C (2°F)
ΔT_{MIN}	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10° F)
ε_{SAT}	Temperature error threshold for SAT sensor	1°C (2°F)
ε_{RAT}	Temperature error threshold for RAT sensor	1°C (2°F)
ε_{MAT}	Temperature error threshold for MAT sensor	3°C (5°F)
ε_{OAT}	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
ε_F	Airflow error threshold	30%
ε_{VFDSPD}	VFD speed error threshold	5%
ε_{DSP}	Duct static pressure error threshold	25 Pa (0.1")
ε_{CCET}	Cooling coil entering temperature sensor error. Equal to ε_{MAT} or dedicated sensor error	Varies, see Description
ε_{CCLT}	Cooling coil leaving temperature sensor error. Equal to ε_{SAT} or dedicated sensor error	Varies, see Description

Variable Name	Description	Default Value
ε_{HCET}	Heating coil entering temperature sensor error; equal to ε_{MAT} or dedicated sensor error	
ε_{HCLT}	Heating coil leaving temperature sensor error. Equal to ε_{SAT} or dedicated sensor error	
ΔOS_{MAX}	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 Δt_{min} 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 $RAT \sim MAT$, 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 5.16.14.14.

- 5.16.14.8. Table 5.16.14.8 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 5.16.14.8 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 5.16.14.8 VAV AHU Fault Conditions

FC#1	Equation	$DSP_{AVG} < DSP_{SP} - \varepsilon_{DSP}$ and $VFDSPD \geq 99\% - \varepsilon_{VFDSPD}$	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	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$	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	$MAT_{AVG} - \varepsilon_{MAT} > \max[(RAT_{AVG} + \varepsilon_{RAT}), (OAT_{AVG} + \varepsilon_{OAT})]$	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	$\Delta OS > \Delta OS_{MAX}$	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	$SAT_{AVG} + \varepsilon_{SAT} \leq MAT_{AVG} - \varepsilon_{MAT} + \Delta T_{SF}$	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	$ RAT_{AVG} - OAT_{AVG} \geq \Delta T_{MIN}$ and $ \%OA - \%OA_{MIN} > \varepsilon_F$	Applies to OS #1, #4
	Description	OA fraction is too low or too high; should equal $\%OA_{MIN}$	
	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	$SAT_{AVG} < SAT_{SP} - \varepsilon_{SAT}$ 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 unavailable DX cooling stuck on Leaking or stuck economizer damper or actuator	

FC#8 (omit if no MAT sensor)	Equation	$ \text{SAT}_{\text{AVG}} - \Delta T_{\text{SF}} - \text{MAT}_{\text{AVG}} > \sqrt{\varepsilon_{\text{SAT}}^2 + \varepsilon_{\text{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	$\text{OAT}_{\text{AVG}} - \varepsilon_{\text{OAT}} > \text{SAT}_{\text{SP}} - \Delta T_{\text{SF}} + \varepsilon_{\text{SAT}}$	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	$ \text{MAT}_{\text{AVG}} - \text{OAT}_{\text{AVG}} > \sqrt{\varepsilon_{\text{MAT}}^2 + \varepsilon_{\text{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	$\text{OAT}_{\text{AVG}} + \varepsilon_{\text{OAT}} < \text{SAT}_{\text{SP}} - \Delta T_{\text{SF}} - \varepsilon_{\text{SAT}}$	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	$\text{SAT}_{\text{AVG}} - \varepsilon_{\text{SAT}} - \Delta T_{\text{SF}} \geq \text{MAT}_{\text{AVG}} + \varepsilon_{\text{MAT}}$	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	$SAT_{AVG} > SAT_{SP} + \epsilon_{SAT}$ 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	$CCET_{AVG} - CCLT_{AVG} \geq \sqrt{\epsilon_{CCET}^2 + \epsilon_{CCLT}^2 + \Delta T_{SF}^*}$ *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	$HCLT_{AVG} - HCET_{AVG} \geq \sqrt{\epsilon_{HCET}^2 + \epsilon_{HCLT}^2 + \Delta T_{SF}^*}$ *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.	

5.16.14.9. 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 %OAmix
 - 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 %OAmix
 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

- 5.16.14.10. For each air handler, the operator shall be able to suppress the alarm for any fault condition.
- 5.16.14.11. Evaluation of fault conditions shall be suspended under the following conditions:
- When AHU is not operating
 - 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
- 5.16.14.12. Fault conditions that are not applicable to the current OS shall not be evaluated.
- 5.16.14.13. A fault condition that evaluates as TRUE must do so continuously for AlarmDelay minutes before it is reported to the operator.
- 5.16.14.14. 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.
- 5.16.14.15. 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 5.16.14.8.
- 5.16.15. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to
- force HW valve full open if there is a hot-water coil,
 - force HW valve full closed if there is a hot-water coil,
 - force CHW valve full open, and
 - force CHW valve full closed.

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the chiller or heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Chilled-water and hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.16.16. Plant Requests

5.16.16.1. Chilled-Water Reset Requests

- If the supply air temperature exceeds the supply air temperature setpoint by 3°C (5°F) for 2 minutes, send 3 requests.
- Else if the supply air temperature exceeds the supply air temperature setpoint by 2°C (3°F) for 2 minutes, send 2 requests.
- Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.
- Else if the CHW valve position is less than 95%, send 0 requests.

- 5.16.16.2. Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:
- If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.
 - Else if the CHW valve position is less than 95%, send 0 requests.
- 5.16.16.3. If There Is a Hot-Water Coil, Hot-Water Reset Requests
- If the supply air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.
 - Else if the supply air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.
 - Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
 - Else if the HW valve position is less than 95%, send 0 requests.
- 5.16.16.4. 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:
- If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.
 - Else if the HW valve position is less than 95%, send 0 requests.

5.17 Dual-Fan Dual-Duct Heating VAV Air-Handling Unit

5.17.1. Supply Fan Control

5.17.1.1. Supply Fan Start/Stop

- Fan shall run when system is in the Warmup Mode and Setback Mode, and during Occupied Mode while there are any heating-fan requests with a minimum runtime of 15 minutes.

Delete the following section if an air handler serves dual-duct boxes that do not have hot-duct inlet airflow sensors, i.e., those that have only a box discharge airflow sensor. This section may also be deleted if there is a supply AFMS.

- Totalize current airflow rate from VAV boxes to a software point.

VAV box airflow rates are summed to obtain overall supply air rate without the need for an AFMS at the air-handler discharge. This is used only for display and diagnostics and filter alarm.

5.17.1.2. Static Pressure Set-Point Reset

- Static pressure setpoint. Setpoint shall be reset using T&R logic (see Section 5.1.14) using the parameters in Table 5.17.1.2.

The T&R reset parameters in Table 5.17.1.2 are suggested as a starting place; they will most likely require adjustment during the commissioning/tuning phase.

Table 5.17.1.2 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 3.2.1.1)
Td	10 min
T	2 min
I	2
R	Zone hot-duct 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)

5.17.1.3. 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 FSD designs, the dampers are interlocked to the fan status rather than being controlled by smoke detectors).

5.17.2. Supply Air Temperature Control

- #### 5.17.2.1. Control loop is enabled when the supply air fan is proven ON, and disabled and output set to zero otherwise.

5.17.2.2. Supply Air Temperature Setpoint

- a. During Occupied Mode (Table 5.17.2.2). Setpoint shall be reset using T&R logic (see Section 5.1.14) between 21°C (70°F) and Max_HtgSAT. See Section 3.1.5.1 for Max_HtgSAT.

The T&R reset parameters in Table 5.17.2.2 are suggested as a starting place; they will most likely require adjustment during the commissioning/tuning phase.

Table 5.17.2.2 Trim & Respond Variables

Variable	Value
Device	Heating supply fan
SP0	SPmax
SPmin	21°C (70°F)
SPmax	Max_HtgSAT
Td	10 min
T	2 min
I	2
R	Zone heating SAT requests
SPtrim	-0.2°C (-0.4°F)
SPres	+0.3°C (+0.6°F)
SPres-max	+0.8°C (+1.4°F)

- b. During Warmup Mode and Setback Mode. Setpoint shall be Max_HtgSAT.

5.17.2.3. Supply air temperature shall be maintained at setpoint by a PID loop modulating the heating coil.

5.17.3. Alarms

5.17.3.1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.

5.17.3.2. 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

5.17.3.3. 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 3.1.5.2 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.

5.17.4. 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. 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. The AFDD routines listed in this section are intended for heating ducts only; AFDD routines for cooling ducts are listed in Sections 5.16.14 and 5.18.13.

5.17.4.1. AFDD conditions are evaluated continuously and separately for each operating AHU.

5.17.4.2. 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.

- a. SAT = supply air temperature
- b. RAT = return air temperature
- c. DSP = duct static pressure
- d. SATSP = supply air temperature setpoint
- e. DSPSP = duct static pressure setpoint
- f. HC = heating coil valve position command; $0\% \leq HC \leq 100\%$
- g. FS = fan speed command; $0\% \leq FS \leq 100\%$

5.17.4.3. 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. SAT_{avg} = rolling average of supply air temperature
 2. RAT_{avg} = rolling average of return air temperature
 3. DSP_{avg} = rolling average of duct static pressure

5.17.4.4. The internal variables shown in Table 5.17.4.4 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 5.17.4.4 DFDD Heating AHU AFDD Internal Variables

Variable Name	Description	Default Value
ΔT_{SF}	Temperature rise across supply fan	1°C (2° F)
ε_{SAT}	Temperature error threshold for SAT sensor	1°C (2° F)
ε_{RAT}	Temperature error threshold for RAT sensor	1°C (2° F)
ε_{VFDSPD}	VFD speed error threshold	5%
ε_{DSP}	Duct static pressure error threshold	25 Pa (0.1")
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

5.17.4.5. Table 5.17.4.5 shows potential fault conditions that can be evaluated by the AFDD routines. If the equation statement is TRUE, then the specified fault condition exists.

Table 5.17.4.5 DFDD Heating AHU Fault Conditions

FC#1	Equation	$DSP < DSPSP - \varepsilon_{DSP}$ and $VFDSPD \geq 99\% - \varepsilon_{VFDSPD}$
	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	Equation	$SAT_{AVG} < SATSP - \varepsilon_{SAT}$ and $HC \geq 99\%$
	Description	SAT too low in full heating
	Possible Diagnosis	SAT sensor error 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#3	Equation	$RAT_{AVG} - SAT_{AVG} \geq \sqrt{\varepsilon_{SAT}^2 + \varepsilon_{RAT}^2 + \Delta T_{SF}}$ and $HC = 0\%$
	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

- 5.17.4.6. For each air handler, the operator shall be able to suppress the alarm for any fault condition.
 - 5.17.4.7. 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
 - 5.17.4.8. A fault condition that evaluates as TRUE must do so continuously for AlarmDelay minutes before it is reported to the operator.
 - 5.17.4.9. 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.
 - 5.17.4.10. 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 5.17.4.5.
- 5.17.5. Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to
- a. force hot water valve full open and
 - b. force hot water valve full closed.

Per Section 5.1.11, 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 5.4.5.

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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Table 5.17.4.5 DFDD Heating AHU Fault Conditions

FC#1	Equation	DSP _{AVG} < DSP _{SP} - ε _{DSP} and VFDSPD ≥ 99% - ε _{VFDSPD}
	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)

	Equation	$SAT_{AVG} < SAT_{SP} - \epsilon_{SAT}$ and $HC \geq 99\%$
FC#2	Description	SAT too low in full heating
	Possible Diagnosis	SAT sensor error 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#3	Equation	$RAT_{AVG} - SAT_{AVG} \geq \sqrt{\epsilon_{SAT}^2 + \epsilon_{RAT}^2} + \Delta T_{SF}$ and $HC = 0\%$
	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

Hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.17.6. Plant Requests

5.17.6.1. Hot-Water Reset Requests

- If the supply air temperature is 17°C (30°F) less than setpoint for 5 minutes, send 3 requests.
- Else if the supply air temperature is 8°C (15°F) less than setpoint for 5 minutes, send 2 requests.
- Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
- Else if the HW valve position is less than 95%, send 0 requests.

5.17.6.2. Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

- If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.
- Else if the HW valve position is less than 95%, send 0 requests.

5.18 Single-Zone VAV Air-Handling Unit

5.18.1. See “Generic Thermal Zones” (Section 5.2.2.3) for setpoints, loops, control modes, alarms, etc.

5.18.2. See Section 3.1.6.1 for Cool_SAT, Heat_SAT, and MaxDPT.

5.18.3. See Section 3.2.2 for MinSpeed, MaxHeatSpeed, MaxCoolSpeed, MinPosMin, MinPosMax, DesPosMin, DesPosMax, MinRelief, MaxRelief, and S-R-DIFF.

5.18.4. 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.

- 5.18.4.1. The supply fan shall run whenever the unit is in any mode other than Unoccupied Mode.
- 5.18.4.2. Provide a ramp function to prevent changes in fan speed of more than 10% per minute.
- 5.18.4.3. 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 3.2.1.
 - 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.

- 5.18.4.4. 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.

- 5.18.4.5. 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.

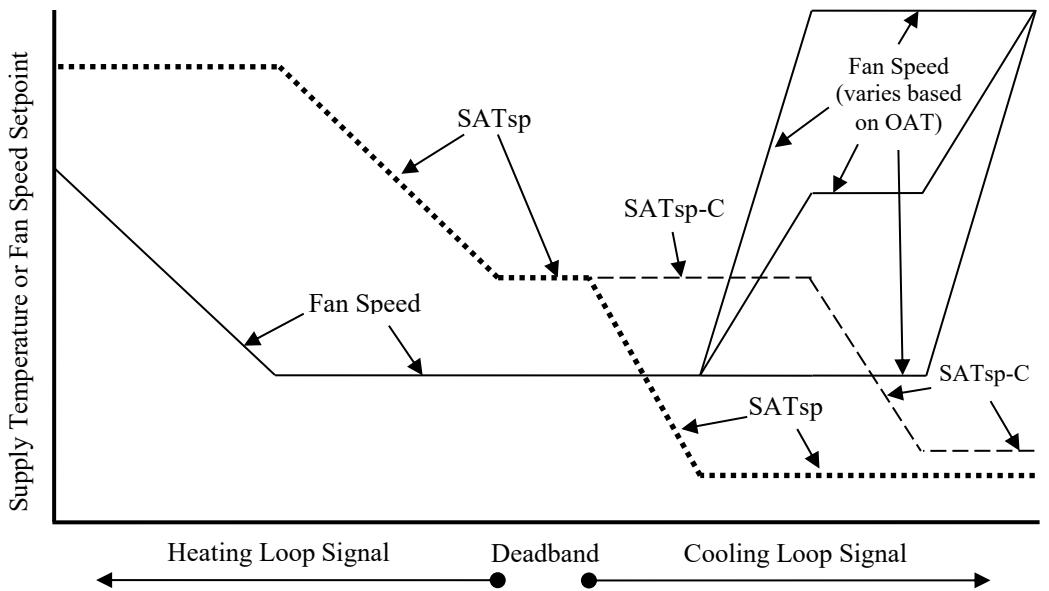


Figure 5.18.4.5-1 Control diagram for SZVAV AHU.

5.18.4.6. 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.

- For a heating-loop signal of 100% to 50%, fan speed is reset from MaxHeatSpeed to MinSpeed.
- For a heating-loop signal of 50% to 0%, fan speed setpoint is MinSpeed.
- In deadband, fan speed setpoint is MinSpeed.
- For a cooling-loop signal of 0% to 25%, fan speed is MinSpeed.
- For a cooling-loop signal of 25% to 50%, fan speed is reset from MinSpeed to MedSpeed.
- For a cooling-loop signal of 50% to 75%, fan speed is MedSpeed.
- For a cooling-loop signal of 75% to 100%, fan speed is reset from MedSpeed to MaxCoolSpeed.
- For a heating-loop signal of 100% to 50%, SATsp is Heat_SAT.
- For a heating-loop signal of 50% to 0%, SATsp is reset from Heat_SAT to the deadband value.
- In deadband, SATsp is the deadband value.
- 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.
- For a cooling-loop signal of 25% to 50%, SATsp and SATsp-C are unchanged.
- 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.
- 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., $SAT_{sp} < SAT_{sp-C}$) so that a low-temperature excursion does not cause the economizer to close inadvertently while cooling with mechanical cooling.

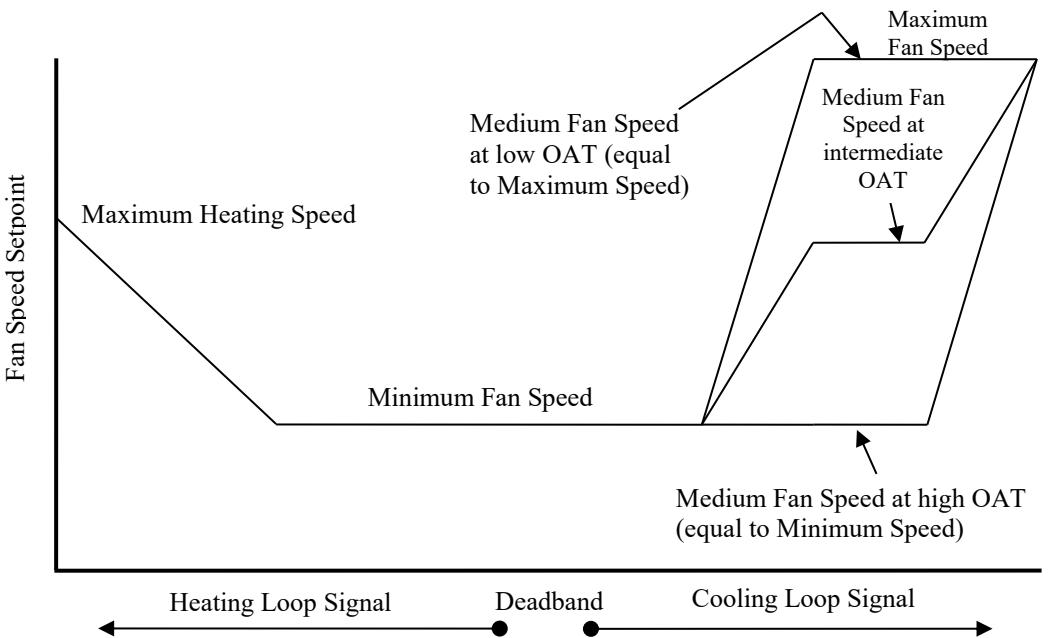


Figure 5.18.4.5-2 Control diagram for SZVAV AHU—fan speed.

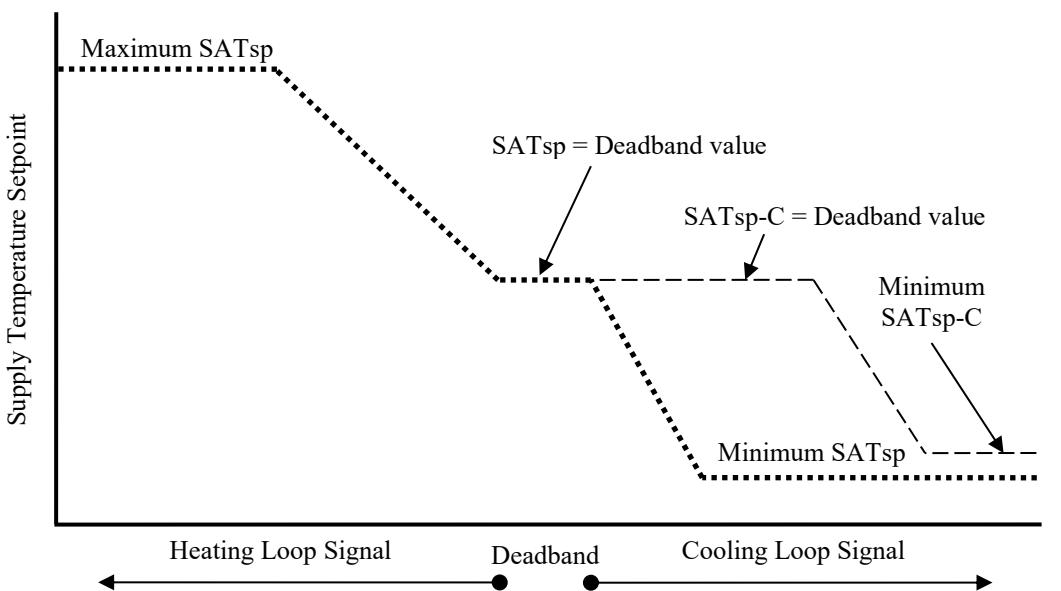


Figure 5.18.4.5-3 Control diagram for SZVAV AHU—supply air temperature.

5.18.5. Supply Air Temperature Control

- 5.18.5.1. 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.
- 5.18.5.2. The control loop for SATsp is enabled when the supply air fan is proven ON and disabled and set to neutral otherwise.
- 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 5.18.6 and 5.18.6.3.

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.

- 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.

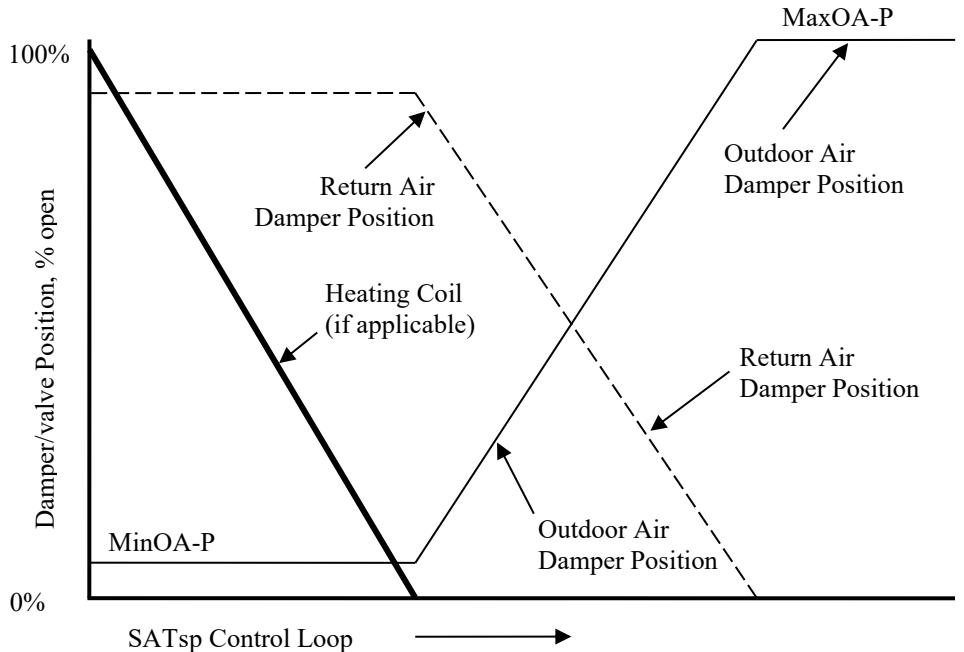


Figure 5.18.5.2 SZVAV AHU supply air temperature loop mapping.

- 5.18.5.3. 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.

5.18.6. Minimum Outdoor Air Control

5.18.6.1. See Section 5.2 for calculation of zone minimum outdoor airflow setpoint.

The engineer must select among control logic options for minimum outdoor airflow control. This decision is based on whether the unit has an outdoor airflow measurement station.

Control logic selections should be made as follows:

For AHUs without an outdoor airflow measurement station, use Section 5.18.6.2 below and delete Section “5.18.6.3” below.

For AHUs with an outdoor airflow measurement station, use Section “5.18.6.3” below and delete Section “5.18.6.2” below.

5.18.6.2. 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 3.2.2.2 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).

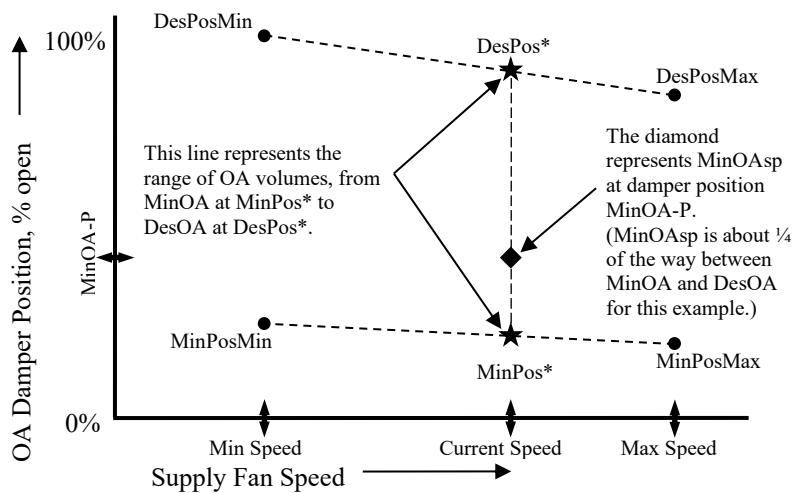


Figure 5.18.6.2 SZVAV AHU minimum outdoor air control.

5.18.6.3. 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 MinOA_{Sp} by a reverse-acting control loop whose output is mapped to MinOA-P.

5.18.7. 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.

- 5.18.7.1. The normal sequencing of the economizer dampers shall be disabled in accordance with Section 5.1.17.
- 5.18.7.2. Once the economizer is disabled, it shall not be reenabled within 10 minutes and vice versa.
- 5.18.7.3. When economizer is enabled, MaxOA-P = 100%. When economizer is disabled, set MaxOA-P equal to MinOA-P. See Section 5.16.5, "Supply Air Temperature Control," and Section 5.18.6, "Minimum Outdoor Air Control," for outdoor air damper minimum setpoint.

The engineer must select among control logic options for return/relief/exhaust. This decision is based on the AHU configuration.

Control logic selections should be made as follows:

For AHUs using actuated relief dampers without a fan, use Section 5.18.8 and delete Sections 5.18.9, 5.18.10, and 5.18.10.2.

For AHUs using actuated relief dampers with relief fan(s), use Section 5.18.9 and delete Sections 5.18.8, 5.18.10, and 5.18.10.2.

For AHUs using a return fan with speed tracking, use Section 5.18.10 and delete Sections 5.18.8, 5.18.9, and 5.18.10.2.

For AHUs using a return fan with direct building pressure control, use Section 5.18.10.2 and delete Sections 5.18.8, 5.18.9, and 5.18.10.

For AHUs using nonactuated barometric relief only, delete *all four* Sections 5.18.8, 5.18.9, 5.18.10, and 5.18.10.2.

A building pressure sensor is required for the option in Section 5.18.9 and , and 5.18.10.2. One is not required for Sections 5.18.8 or 5.18.10.

5.18.8. Control of Actuated Relief Dampers without Fans

The engineer must specify whether a building pressure sensor is utilized.

If a building pressure sensor is used, keep subsection (1) and delete subsection (2) for direct building pressure control.

If a building pressure is not used, keep subsection (2) and delete subsection (1) for passive building pressure control.

Delete this flag note after selection has been made.

5.18.8.1. 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.

5.18.8.2. Passive Building Pressure Control

- a. See Section 3.2.2.3 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, MinOA_{Asp}, is reset from MinOA to DesOA.

Relief-fan control logic is incorporated by reference in Section 5.18.9.1. If the project includes both single-zone and multiple-zone AHUs, then no change is required. However, if the project includes only single-zone AHUs, we recommend deleting Section 5.18.9 below and copying the full text of Section 5.16.9 in its place.

5.18.9. Relief-Fan Control

5.18.9.1. Refer to Section 5.16.9, "Relief-Fan Control" for multiple-zone air handlers.

5.18.10. Return-Fan Control

5.18.10.1. Return-Fan Control – Speed Tracking

Exhaust damper may be barometric (no actuator). In that case, delete Sections 5.18.10.1.a.

- 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 3.2.2.4) adjusted by the active minimum outdoor airflow setpoint, MinOA_{Asp} relative to the design outdoor airflow setpoint, DesOA.

$$S - R - SPD - DIFF^* = S - R - SPD - DIFF \frac{MinOA_{Asp}}{DesOA}$$

- d. Return-fan speed shall be controlled to maintain return fan speed equal to supply fan speed less differential S-R-SPD-DIFF*.

5.18.10.2. Return Fan Control – Direct Building Pressure

Return fan control logic is incorporated by reference in Section 5.18.10.2.a below. If the project includes both single-zone and multiple-zone AHUs, then no change is required. However, if the project includes only single-zone AHUs, we recommend deleting Section 5.18.10.2 below and copying the full text of Section 5.16.10 in its place.

- a. Refer to Section 5.16.10 Return Fan Control – Direct Building Pressure for multiple-zone air handlers.

This concludes the section where the control logic for return/relief/exhaust is selected.

When the sequences are complete, *at most* one of Sections 5.18.8, 5.18.9, 5.18.10, or 5.18.10.2 should remain. If relief is barometric (without actuators) only, then all four subsections should be deleted. Delete these flag notes after the decision has been made.

If a freeze-stat is present, it may be hardwired to perform some or all of these functions. In that case, delete those functions from sequence logic but maintain the alarms. Delete this flag note when sequences are complete.

5.18.11. Freeze Protection

There are three stages of freeze protection. The first stage modulates the heating valve to maintain a safe SAT. The second stage eliminates outdoor air ventilation in case heating is not available for whatever reason. The third stage shuts down the unit and activates coil valves and pumps to circulate water in case the second stage does not work (e.g., stuck economizer damper).

- 5.18.11.1. If the supply air temperature drops below 4°C (40°F) for 5 minutes, send two (or more, as required to ensure that heating plant is active) heating hot-water plant requests, override the outdoor air damper to the minimum position, and modulate the heating coil to maintain a supply air temperature of at least 6°C (42°F). Disable this function when supply air temperature rises above 7°C (45°F) for 5 minutes.

The first stage of freeze protection locks out the economizer. Most likely this has already occurred by this time, but this logic provides insurance.

- 5.18.11.2. If the supply air temperature drops below 3°C (38°F) for 5 minutes, fully close both the economizer damper and the minimum outdoor air damper for 1 hour and set a Level 3 alarm noting that minimum ventilation was interrupted. After 1 hour, the unit shall resume minimum outdoor air ventilation and enter the previous stage of freeze protection (see Section 5.18.11.1).

A timer is used (rather than an OAT threshold) to exit the second stage of freeze protection because a bad OAT sensor could lock out ventilation indefinitely; whereas a timer should just work and thus avoid problems with the unit becoming stuck in this mode with no ventilation.

Upon timer expiration, the unit will reenter the previous stage of freeze protection (MinOA ventilation, with heating to maintain SAT of 6°C [42°F]), after which one of three possibilities will occur:

If it is warm enough that the SAT rises above 7°C (45°F) with minimum ventilation, the unit will remain in Stage 1 freeze protection for 5 minutes then resume normal operation.

If it is cold enough that SAT remains between 3°C (38°F) and 7°C (45°F) with heating and minimum ventilation, the unit will remain in Stage 1 freeze protection indefinitely until outdoor conditions warm up.

If it is so cold that SAT is less than 3°C (38°F) with minimum ventilation, despite heating, then the unit will revert to Stage 2 freeze protection where it will remain for 1 hour. This process will then repeat.

- 5.18.11.3. Upon signal from the freeze-stat (if installed), or if supply air temperature drops below 3°C (38°F) for 15 minutes or below 1°C (34°F) for 5 minutes, shut down supply and return/relief fan(s), close outdoor air damper, make the minimum cooling-coil valve position 100%, and energize the CHW pump system. Send two (or more, as required to ensure that heating plant is active) heating hot-water plant requests, modulate the heating coil to maintain the higher of the supply air temperature or the mixed air temperature at 27°C (80°F), and set a Level 2 alarm indicating the unit is shut down by freeze protection.

- If a freeze protection shutdown is triggered by a low air temperature sensor reading, it shall remain in effect until it is reset by a software switch from the operator's workstation. (If a freeze stat with a physical reset switch is used instead, there shall be no software reset switch).

Stage 3 can be triggered by either of two conditions. The second condition is meant to respond to an extreme and sudden cold snap.

Protecting the cooling coil in this situation will require water movement through the coil, which means that the CHW pumps need to be energized.

Heating coil is controlled to an air temperature setpoint. The sensors will not read accurately with the fan OFF, but they will be influenced by proximity to the heating coil. A temperature of 27°C (80°F) at either of these sensors indicates that the interior of the unit is sufficiently warm. This avoids the situation where a fixed valve position leads to very high (and potentially damaging) temperatures inside the unit.

5.18.12. Alarms

- 5.18.12.1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.
- 5.18.12.2. 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
- 5.18.12.3. 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 3.2.2.1 for MaxCoolSpeed and Section 3.1.6.4 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.

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.

5.18.13. 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.

- 5.18.13.1. AFDD conditions are evaluated continuously and separately for each operating AHU.
- 5.18.13.2. 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		

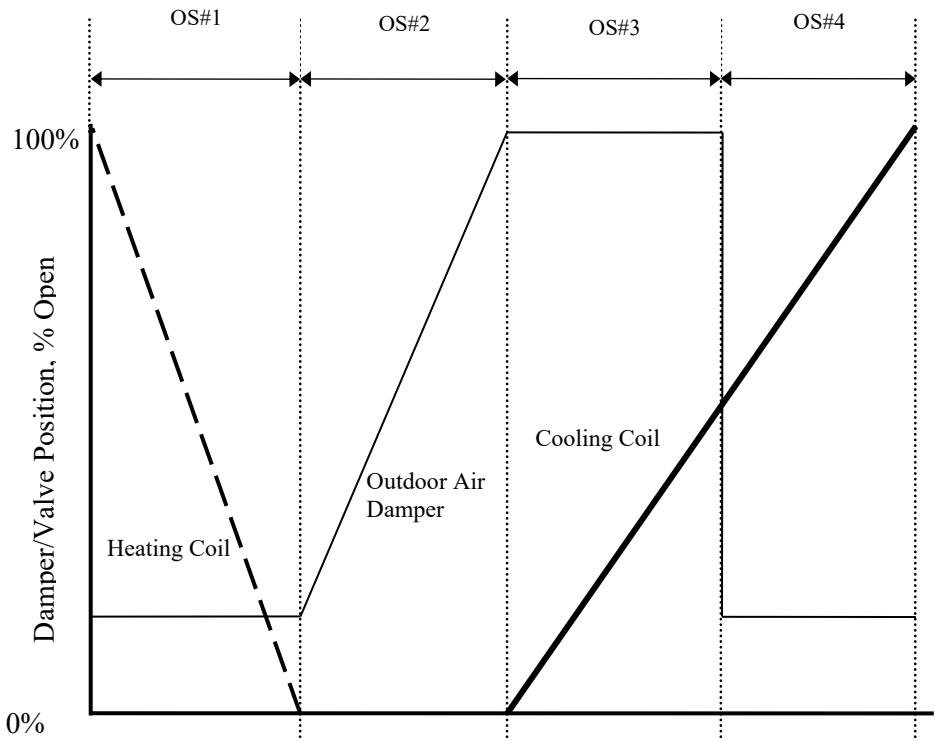


Figure 5.18.13.2 SZVAV AHU operating states.

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 5.18.13.6. 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.

5.18.13.3. 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; $0\% \leq HC \leq 100\%$
- i. CC = cooling-coil valve position command; $0\% \leq CC \leq 100\%$
- j. FS = fan-speed command; $0\% \leq FS \leq 100\%$
- 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.)

5.18.13.4. 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. SAT_{avg} = rolling average of supply air temperature
 2. MAT_{avg} = rolling average of mixed air temperature
 3. RAT_{avg} = rolling average of return air temperature
 4. OAT_{avg} = rolling average of outdoor air temperature
 5. $CCET_{avg}$ = rolling average of cooling-coil entering temperature
 6. $CCLT_{avg}$ = rolling average of cooling-coil leaving temperature
 7. $HCET_{avg}$ = rolling average of heating-coil entering temperature
 8. $HCLT_{avg}$ = rolling average of heating-coil leaving temperature
 9. ΔOS = number of changes in OS during the previous 60 minutes (moving window)

5.18.13.5. 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 SZAV AHU Internal Variables

Variable Name	Description	Default Value
ΔT_{SF}	Temperature rise across supply fan	0.5°C (1°F)
ΔT_{MIN}	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10°F)
ε_{SAT}	Temperature error threshold for SAT sensor	1°C (2°F)
ε_{RAT}	Temperature error threshold for RAT sensor	1°C (2°F)
ε_{MAT}	Temperature error threshold for MAT sensor	3°C (5°F)
ε_{OAT}	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
ε_{CCET}	Cooling coil entering temperature sensor error. Equal to ε_{MAT} or dedicated sensor error	Varies; see description.
ε_{CCLT}	Cooling coil leaving temperature sensor error. Equal to ε_{SAT} or dedicated sensor error	
ε_{HCET}	Heating coil entering temperature sensor error; equal to ε_{MAT} or dedicated sensor error	
ε_{HCLT}	Heating coil leaving temperature sensor error. Equal to ε_{SAT} or dedicated sensor error	
ΔOS_{max}	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 ΔT_{min} 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 $RAT \approx MAT$, 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 5.18.13.12.

- 5.18.13.6. 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	$MAT_{AVG} + \varepsilon_{MAT} < \min[(RAT_{AVG} - \varepsilon_{RAT}), (OAT_{AVG} - \varepsilon_{OAT})]$	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	$MAT_{AVG} - \varepsilon_{MAT} > \min[(RAT_{AVG} + \varepsilon_{RAT}), (OAT_{AVG} + \varepsilon_{OAT})]$	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	$\Delta OS > \Delta OS_{MAX}$	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	$SAT_{AVG} + \varepsilon_{SAT} \leq MAT_{AVG} - \varepsilon_{MAT} + \Delta T_{SF}$	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	$ RAT_{AVG} - OAT_{AVG} \geq \Delta T_{MIN}$ and $ RAT_{AVG} - MAT_{AVG} > OAT_{AVG} - MAT_{AVG} $	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	$SAT_{AVG} < SAT_{SP} - \varepsilon_{SAT}$ 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	$ SAT_{AVG} - \Delta T_{SF} - MAT_{AVG} > \sqrt{\epsilon_{SAT}^2 + \epsilon_{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	$OAT_{AVG} + \epsilon_{OAT} > SAT_{SP} - \Delta T_{SF} + \epsilon_{SAT}$	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 DX cooling stuck on	
FC #10 (omit if no MAT sensor)	Equation	$ MAT_{AVG} - OAT_{AVG} > \sqrt{\epsilon_{MAT}^2 + \epsilon_{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	$OAT_{AVG} + \epsilon_{OAT} < SAT_{SP} - \Delta T_{SF} - \epsilon_{SAT}$	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 Gas or electric heat stuck on Leaking or stuck economizer damper or actuator	
FC #12 (omit if no MAT sensor)	Equation	$SAT_{AVG} - \epsilon_{SAT} - \Delta T_{SF} \geq MAT_{AVG} + \epsilon_{MAT}$	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	$SAT_{AVG} > SAT_{SP-C} + \epsilon_{SAT}$ 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 low or CHW unavailable DX cooling unavailable Gas or electric heat stuck on Heating coil valve leaking or stuck open	
FC#14	Equation	$CCET_{AVG} - CCLT_{AVG} \geq \sqrt{\epsilon_{CCET}^2 + \epsilon_{CCLT}^2 + \Delta T_{SF}}$ *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	$HCLT_{AVG} - HCET_{AVG} \geq \sqrt{\epsilon_{HCET}^2 + \epsilon_{HCLT}^2 + \Delta T_{SF}}$ *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	

5.18.13.7. 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
- 5.18.13.8. For each air handler, the operator shall be able to suppress the alarm for any fault condition.
- 5.18.13.9. 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
- 5.18.13.10. Fault conditions that are not applicable to the current OS shall not be evaluated.
- 5.18.13.11. A fault condition that evaluates as TRUE must do so continuously for AlarmDelay minutes before it is reported to the operator.
- 5.18.13.12. 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.
- 5.18.13.13. 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.
- 5.18.14. 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 AHUs served by the chiller plant and then recording flow at the chiller.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the chiller or heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Chilled-water and hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and AHU demands.

5.18.15. Plant Requests

5.18.15.1. 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.

- 5.18.15.2. Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:
- If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.
 - Else if the CHW valve position is less than 95%, send 0 requests.
- 5.18.15.3. If There Is a Hot-Water Coil, Hot-Water Reset Requests
- If the supply air temperature is 17°C (30°F) less than SATsp for 5 minutes, send 3 requests.
 - Else if the supply air temperature is 8°C (15°F) less than SATsp for 5 minutes, send 2 requests.
 - Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
 - Else if the HW valve position is less than 95%, send 0 requests.
- 5.18.15.4. 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:
- If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.
 - Else if the HW valve position is less than 95%, send 0 requests.

5.19 General Constant Speed Exhaust Fan

5.19.1. Exhaust Fan Control

5.19.1.1. Exhaust Fan Start/Stop

The engineer must select between control options:

If the exhaust fan is to be operated with associated Zone Groups, keep subsection “5.19.1.1.a” and delete subsection “b”

If the exhaust fan is to be cycled to maintain room temperature, keep subsection “b” and delete subsection “a”.

- 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 3.1.3 for Zone Group assignments.
- 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).

5.19.2. Alarms

- 5.19.2.1. Maintenance interval alarm when fan has operated for more than 3,000 hours: Level 4. Reset interval counter when alarm is acknowledged.
- 5.19.2.2. Fan alarm is indicated by the status being different from the command for a period of 15 seconds.
- Commanded on, status off: Level 2
 - Commanded off, status off: Level 4

5.20 Chilled Water Plant

Retain the applicable variables listed in Sections 3.1.7 and 3.2.3. Delete variables that are not applicable.

5.20.1. See Section 3.1.7 for CHWSTminX, CWRTdesX, CWSTdesX, CH-LOT, CHW-MinFlowX, CHW-DesFlowX, LIFTminX, LIFTmaxX, QchX, PCHWFdesign, SCHWFdesign, MinUnloadCapX, DA_{HX}, DT_{WB}, DA_{CT}, HXFdesign, and HX_{DP}-Design. See Section 3.2.3 for CHW-DPmax, LocalCHW-DPmax, Cw-DesPumpSpdStage, MinCWVlvPos, MinCWPspeed, HxPumpDesSpd, Ch-MaxPriPumpSpdStage, and CH-MinPriPumpSpdStage.

5.20.2. Plant Enable/Disable

5.20.2.1. 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).

5.20.2.2. Enable the plant in the lowest stage when the plant has been disabled for at least 15 minutes and:

- Number of Chiller Plant Requests > I (I = Ignores shall default to 0, adjustable), and
- OAT>CH-LOT, and
- The chiller plant enable schedule is active.

5.20.2.3. Disable the plant when it has been enabled for at least 15 minutes and:

- Number of Chiller Plant Requests ≤ I for 3 minutes, or
- OAT<CH-LOT – 1°F, or
- 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.

Retain the following two sections (5.20.2.4 and 5.20.2.5) if the plant has a waterside economizer. Delete otherwise.

5.20.2.4. When the plant is enabled:

- If the plant is enabled in WSE Mode (see Section 5.20.4.15):
 - Open the CW isolation valve of the waterside economizer.

Retain the following sentence for primary-only plants. Delete otherwise.

- Stage on lead primary CHW pump, CW pump, and cooling tower(s) per Sections 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-secondary plants. Delete otherwise.

- Stage on lead secondary CHW pump, CW pump, and cooling towers per Sections 5.20.7, 5.20.9, and 5.20.12 respectively.

- b. If the plant is enabled in Chiller Mode (see Section 5.20.4.15):

Retain the following sentence for plants with headered primary CHW pumps. Delete otherwise.

1. Open the CHW isolation valve of the lead chiller.

Retain the following sentence for plants with headered CW pumps. Delete otherwise.

2. Open the CW isolation valve of the lead chiller.

Retain the following sentence for primary-secondary plants. Delete otherwise.

3. Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per Sections 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-only plants. Delete otherwise.

4. Stage on lead primary CHW pump, CW pump, and cooling towers per Sections 5.20.6, 5.20.9, and 5.20.12 respectively.

5. Once the lead pumps are proven on, enable the lead chiller.

5.20.2.5. When the plant is disabled:

- a. Shut off all enabled chillers, if any.

Retain the following sentence for plants with headered primary CHW pumps. Delete otherwise.

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.

Retain the following sentence for plants with headered CW pumps. Delete otherwise.

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.

Retain the following sentence for primary-secondary plants. Delete otherwise.

- d. Disable the operating primary CHW pump(s) (if enabled), secondary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for primary-only plants. Delete otherwise.

- e. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following two sections (5.20.2.6 and 5.20.2.7) if the plant does not have a waterside economizer. Delete otherwise.

5.20.2.6. When the plant is enabled:

Retain the following sentence for plants with parallel chillers and headered primary CHW pumps. Delete otherwise.

- a. Open the CHW isolation valve of the lead chiller.

Retain the following sentence for plants with series chillers and headered primary CHW pumps. Delete otherwise.

- b. Close the CHW isolation valve of the lead chiller.

Retain the following sentence for water-cooled plants with headered CW pumps. Delete otherwise.

- c. Open the CW isolation valve of the lead chiller.

Retain the following sentence for water-cooled primary-secondary plants. Delete otherwise.

- d. Stage on lead primary CHW pump, secondary CHW pump, CW pump, and cooling towers per Sections 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-secondary plants. Delete otherwise.

- e. Stage on lead primary CHW pump and secondary CHW pump per Sections 5.20.6 and 5.20.7 respectively.

Retain the following sentence for water-cooled primary-only plants. Delete otherwise.

- f. Stage on lead primary CHW pump, CW pump, and cooling towers per Sections 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence (g) for air-cooled primary-only plants. Delete otherwise.

- g. Stage on lead primary CHW pump per Section 5.20.6.
 - h. Once the lead pumps are proven on, enable the lead chiller.
- 5.20.2.7. When the plant is disabled:
- a. Shut off the enabled chiller(s).

Retain the following sentence for plants with parallel chillers and headered primary CHW pumps. Delete otherwise.

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.

Retain the following sentence for plants with series chillers and headered primary CHW pumps. Delete otherwise.

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.

Retain the following sentence for water-cooled plants with headered CW pumps. Delete otherwise.

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.

Retain the following sentence for water-cooled primary-secondary plants. Delete otherwise.

- e. Disable the operating primary CHW pump(s), secondary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 5.20.6, 5.20.7, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-secondary plants. Delete otherwise.

- f. Disable the operating primary CHW pump(s) and secondary CHW pump(s) per Sections 5.20.6, 5.20.7 respectively.

Retain the following sentence for water-cooled primary-only plants. Delete otherwise.

- g. Disable the operating primary CHW pump(s), CW pump(s), and cooling tower(s) per Sections 5.20.6, 5.20.9, and 5.20.12 respectively.

Retain the following sentence for air-cooled primary-only plants. Delete otherwise.

- h. Disable the operating primary CHW pump(s) per Sections 5.20.6.

Retain Section 5.20.3 if the plant has a waterside economizer. Delete otherwise.

5.20.3. Waterside Economizer Control

- 5.20.3.1. 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:

$$\begin{aligned} PHXLWT &= T_{WB} + PA_{HX} + PA_{CT} \\ PA_{HX} &= DA_{HX} * PLR_{HX} \\ PA_{CT} &= m * (DT_{WB} - T_{WB}) + DA_{CT} \end{aligned}$$

where

T_{WB} = current wetbulb temperature

PA_{HX} = predicted heat exchanger approach

PA_{CT} = predicted cooling tower approach

DA_{HX} = design heat exchanger approach

Retain the following PLR_{HX} definition for primary-only plants. Delete otherwise.

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)

Retain the following PLR_{HX} definition for primary-secondary plants. Delete otherwise.

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 5.20.3.3 below.

This algorithm predicts the achievable HXLWT based on current plant load conditions, as estimated by PLR_{HX} , 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.

5.20.3.2. 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 1°F for 2 minutes (i.e., if the HX is not reducing the CHW temp by at least 1°F).

5.20.3.3. 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 5.20.12.2.c.1.ii 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.

Use the following three sections for plants where CHW flow through the WSE is controlled using a modulating heat exchanger bypass valve. See schematics in Informative Appendix A for examples.

5.20.3.4. When economizer is enabled, start next CW pump and/or adjust CW pump speed per Section 5.20.9.6, open CW isolation valve to the HX, and enable the WSE in-line CHW return line valve.

5.20.3.5. 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 $HX_{DP-Design}$. 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.

5.20.3.6. 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 5.20.9.6.

Use the following four sections for plants where CHW flow through the WSE is controlled by a variable speed HX pump. Delete otherwise. See schematics in Informative Appendix A for examples.

5.20.3.7. When economizer is enabled, start next CW pump and/or adjust CW pump speed per Section 5.20.9.6, open CW isolation valve to the HX and enable the CHW HX Pump.

5.20.3.8. 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.

5.20.3.9. 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
SP ₀	HxPumpDesSpd
SP _{min}	Minimum Speed
SP _{max}	HxPumpDesSpd
T _d	15 minutes
T	2 minutes
I	0
R	WSE HX Pump Speed Reset Requests
SP _{trim}	+2%
SP _{res}	-3%
SP _{res-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.

- 5.20.3.10. 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 5.20.9.6.

Retain the following section where a chiller bypass valve is needed to operate the WSE without flowing water through any of the chillers. This is typically true of primary-only parallel chiller plants. Delete otherwise.

- 5.20.3.11. 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.

5.20.4. Chiller Staging

- 5.20.4.1. Chiller stages shall be defined as follows:

The following table is project specific and must indicate the chillers that are required to run in each stage. Where chillers are interchangeable and should be lead/lag alternated, that must be indicated with an “or” in the enabled chillers column.

For instance in the example table below, if there is a swing chiller (CH-1) and two identical larger chillers (CH-2, CH-3), there are 5 possible chiller capacity stages.

The waterside economizer-only stage and column should be deleted if there is no waterside economizer.

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.

Retain the following section for water-cooled plants with parallel chillers. Delete otherwise.

- 5.20.4.2. Interchangeable chillers indicated with “or” in the table above shall be lead/lag controlled per Section 5.1.15.3. If a chiller is in alarm per Section 5.1.15.5.b, its CHW and CW isolation valves shall be closed.

Retain the following section for water-cooled plants with series chillers. Delete otherwise.

- 5.20.4.3. Interchangeable chillers indicated with “or” in the table above shall be lead/lag controlled per Section 5.1.15.3. If a chiller is in alarm per Section 5.1.15.5.b, its CHW valve shall be opened and CW isolation valve shall be closed.

Retain the following section for air-cooled plants with parallel chillers. Delete otherwise.

- 5.20.4.4. Interchangeable chillers indicated with “or” in the table above shall be lead/lag controlled per Section 5.1.15.3. If a chiller is in alarm per Section 5.1.15.5.b, its CHW isolation valve shall be closed.

Retain the following section for air-cooled plants with series chillers. Delete otherwise.

- 5.20.4.5. Interchangeable chillers indicated with “or” in the table above shall be lead/lag controlled per Section 5.1.15.3. If a chiller is in alarm per Section 5.1.15.5.b, its CHW valve shall be opened.

- 5.20.4.6. Chillers are staged in part based on required capacity, $Q_{required}$, 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, $OPLR$.

Retain the following section for primary-only plants and primary-secondary plants without flow meters in all secondary loops (if more than one). Delete otherwise.

- 5.20.4.7. $Q_{required}$ is calculated based on chilled water return temperature ($CHWRT$) entering the chillers, active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the primary circuit flow meter ($FLOW_P$), 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.

$$Q_{required} = \frac{FLOW_P(CHWRT - CHWST_{SP})}{24} \text{ [tons]}$$

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.

Retain the following section for primary-secondary plants with flow meters in all secondary loops (if more than one). Delete otherwise.

- 5.20.4.8. Q_{required} is calculated based on secondary chilled water return temperature ($SCHWRT$), active chilled water supply temperature setpoint ($CHWST_{SP}$), and measured flow through the secondary circuit flow meter ($FLOW_S$), 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.

$$Q_{\text{required}} = \frac{FLOW_S(SCHWRT - CHWST_{SP})}{24} [\text{tons}]$$

- 5.20.4.9. 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.

As staging occurs, flowrate and return temperature may fluctuate, so Q_{required} may be unstable. As detailed subsequently, Q_{required} impacts plant part load ratio, which drives condenser water return temperature setpoint and tower control. As such, if Q_{required} is unstable, so too would be condenser water return temperature, and thus chiller lift.

- 5.20.4.10. $OPLR$ shall be calculated as follows:

$$OPLR = \frac{Q_{\text{required}} [\text{tons}]}{\text{Sum of } Q_{chX} \text{ for Chillers in stage}}$$

- 5.20.4.11. Minimum cycling part load ratio, $OPLR_{MIN}$, shall be calculated as:

$$OPLR_{MIN,stage} = \frac{\text{Sum of MinUnloadTonsX for Chillers in stage}}{\text{Sum of } Q_{chX} \text{ for Chillers in stage}}$$

- 5.20.4.12. Stage up events are initiated in part based on current stage $OPLR$ exceeding a stage up part load ratio, $SPLR_{UP}$; stage down events are initiated in part based on $OPLR$ for the next lower stage falling below a stage down part load ratio, $SPLR_{DN}$.

- 5.20.4.13. 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 5.1.15.5.b.1.ii or a chilled water or condenser water pump dedicated to that chiller is faulted per Section 5.1.15.5.b.1.i; otherwise, the stage shall be deemed available.

- 5.20.4.14. $SPLR_{UP}$ and $SPLR_{DN}$ 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 $SPLR_{UP}$ as follows:

Retain the next section for plants with any constant speed centrifugal chillers. Delete otherwise.

1. When any chillers in the next higher stage are constant speed centrifugal, $SPLR_{UP}$ 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.

Retain the next section if the plant has any stage with all positive displacement (screw or scroll) chillers. Delete otherwise.

2. When all chillers operating in the current stage are positive displacement, $SPLR_{UP}$ 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.

Retain the next section for plants with any variable speed centrifugal chillers. Delete otherwise.

3. When any chillers in the current operating stage are variable speed centrifugal, $SPLR_{UP}$ shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{UP} = \text{Min}(\text{Max}(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

- i. $LIFT_{min}$ and $LIFT_{max}$ shall be calculated as the averages of $LIFT_{minX}$ and $LIFT_{maxX}$ 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 $SPLR_{DN}$ 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 5.20.4.12, 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.

Retain the next section for plants with any constant speed centrifugal chillers. Delete otherwise.

1. When any chillers in the current stage are constant speed centrifugal, $SPLR_{DN}$ shall be 90%.

Retain the next section if the plant has any stage with all positive displacement (screw or scroll) chillers. Delete otherwise.

2. When all chillers operating in the next lower stage are positive displacement, $SPLR_{DN}$ shall be 80%.

Retain the next section for plants with any variable speed centrifugal chillers. Delete otherwise.

3. When a variable speed centrifugal chiller operates in the next lower stage, $SPLR_{DN}$ shall be calculated as the 5 minute rolling average of the following equation sampled at least every 30 seconds:

$$SPLR_{DN} = \text{Min}(\text{Max}(0.45, E * LIFT + F), 0.9)$$

$$LIFT = CWRT - CHWST_{SP}$$

$$E = \frac{0.9}{(LIFT_{MAX} - LIFT_{MIN})}$$

$$F = E * (0.4 * LIFT_{MAX} - 1.4 * LIFT_{MIN})$$

- i. $LIFT_{min}$ and $LIFT_{max}$ shall be calculated as the averages of $LIFT_{minX}$ and $LIFT_{maxX}$ for all variable speed centrifugal chillers operating in the next lower stage respectively.

5.20.4.15. 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 5.20.4.13) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

Retain the following section for plants with waterside economizers. Delete otherwise.

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.

Retain the following section for primary-secondary chiller plants with CHW isolation valves where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples. Delete otherwise.

- 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.

Retain the following section for primary-secondary chiller plants with dedicated primary CHW pumps where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples. Delete otherwise.

- 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.

Retain the following two sections for Primary-only chiller plants without waterside economizers. Delete otherwise.

- 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 $OPLR > SPLR_{UP}$ 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:

Retain the following condition for parallel chiller plants, delete otherwise.

- i. CHW DP is 2 psi < setpoint for 15 minutes; or
- ii. CHW supply temperature is $2^{\circ}\text{F} >$ setpoint for 15 minutes.
- h. Stage down if both of the following are true:
 1. Next available lower stage $OPLR < SPLR_{DN}$ 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.

Retain the following five sections for Primary-only chiller plants with waterside economizers. Delete otherwise.

- i. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLR_{HX} set equal to 1 is not $1^{\circ}\text{F} < \text{CHWST}$ setpoint.
- j. When only the Waterside Economizer is enabled, stage up if either of the following is true:
 - 1. CHW supply temperature is $2^{\circ}\text{F} >$ setpoint for 20 minutes; or
 - 2. CHW supply temperature is $4^{\circ}\text{F} >$ 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 $OPLR > SPLR_{UP}$ 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:

Retain the following condition for parallel chiller plants. Delete otherwise.

- i. CHW DP is $2 \text{ psi} <$ setpoint for 15 minutes; or
- ii. CHW supply temperature is $2^{\circ}\text{F} >$ 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 $1^{\circ}\text{F} < \text{CHW supply temp setpoint}$.
- m. In all other stages, stage down if both of the following are true:
 - 1. Next available lower stage $OPLR < SPLR_{DN}$ 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.

Retain the following two sections for Primary-secondary chiller plants without waterside economizers. Delete otherwise.

- 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 $OPLR > SPLR_{UP}$ 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:
 - i. Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or
 - ii. 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 $OPLR < SPLR_{DN}$ 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).

Retain the following five sections for Primary-secondary chiller plants with waterside economizers. Delete otherwise.

- p. When enabling the plant, skip the Waterside Economizer Only Stage (lowest stage) if PHXLWT with PLR_{HX} set equal to 1 is not $1^{\circ}\text{F} < \text{CHWST setpoint}$.
- q. When only the Waterside Economizer is operating, stage up if either of the following is true:
 - 1. Secondary CHW supply temperature is $2^{\circ}\text{F} > \text{setpoint}$ for 20 minutes; or
 - 2. Secondary CHW supply temperature is $4^{\circ}\text{F} > \text{setpoint}$ 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 $OPLR > SPLR_{UP}$ 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:
 - i. Secondary CHW supply temperature > primary CHW supply temperature + 2°F for 10 minutes and the enabled primary pumps are at maximum speed; or
 - ii. 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 $OPLR < SPLR_{DN}$ 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.

Sections 5.20.4.16 through 5.20.4.35 present 10 pairs (2 sections each) of mutually exclusive options for steps to take when a stage change is initiated. Staging steps vary based on: (1) whether the plant is primary-only parallel piped, primary-secondary piped, or primary-only series piped, and (2) whether the primary CHW and CW pumps are headered or dedicated.

Retain all references to condenser water pumps and head pressure control in the selected pair of sections for water-cooled chiller plants. Delete otherwise.

Retain Sections 5.20.4.16 and 5.20.4.17 for water-cooled primary-only parallel chiller plants with headered chilled water pumps and headered condenser water pumps or air-cooled primary-only parallel chiller plants with headered chilled water pumps. Delete otherwise.

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.

5.20.4.16. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.20.8.3. 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 5.20.8.1. 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.

Retain the following section for water-cooled plants. Delete otherwise.

- d. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 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).

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

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 5.20.8.1.
- h. Release the demand limit.

5.20.4.17. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 OPLR_{MIN}, 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 5.20.8.3. 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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

- 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 5.20.9.
- e. Change the chilled water minimum flow bypass control setpoint to that appropriate for the new stage as indicated in Section 5.20.8.1.

Retain Sections 5.20.4.18 and 5.20.4.19 for water-cooled primary-only parallel chiller plants with headered chilled water pumps and dedicated condenser water pumps. Delete otherwise.

5.20.4.18. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.20.8.1. 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).

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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 5.20.8 below.
- h. Release the demand limit.

5.20.4.19. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 OPLR_{MIN}, 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 5.20.8.3. 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 5.1.15.5.b.1.ii), 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 5.20.8.1.

Retain Sections 5.20.4.20 and 5.20.4.21 for water-cooled primary-only parallel chiller plants with dedicated chilled water pumps and headered condenser water pumps or air-cooled primary-only parallel chiller plants with dedicated chilled water pumps. Delete otherwise.

5.20.4.20. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.20.8.1. 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.

Retain the following section for water-cooled plants. Delete otherwise.

- d. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

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 5.20.8.1 below.
- h. Release the demand limit.

5.20.4.21. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 OPLR_{MIN}, 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 5.20.8.3. Wait 1 minute after setpoint has been achieved or primary CHW pump speed has reached 100%.

Retain the following section for water-cooled plants. Delete otherwise.

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 5.1.15.5.b.1.ii), 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.

- a. If staging down from any other stage, shut off the last stage chiller.
- b. 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.

Retain the following section for water-cooled plants. Delete otherwise.

- c. 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 5.20.9.
- d. Change the chilled water minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 5.20.8.1.

Retain Sections 5.20.4.22 and 5.20.4.23 for water-cooled primary-only parallel chiller plants with dedicated chilled water pumps and dedicated condenser water pumps. Delete otherwise.

5.20.4.22. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.20.8.1. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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 5.20.8 below.
- h. Release the demand limit.

5.20.4.23. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 OPLR_{MIN}, 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 5.20.8.3. 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 5.1.15.5.b.1.ii), 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 5.20.8.1.

Retain Sections 5.20.4.24 and 5.20.4.25 for water-cooled primary-secondary parallel chiller plants with headered primary CHW pumps and headered CW pumps or air-cooled primary-secondary parallel plants with headered CHW pumps. Delete otherwise.

5.20.4.24. Whenever there is a stage-up command:

Retain the following section for water-cooled plants. Delete otherwise.

- a. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 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).

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

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.

5.20.4.25. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

Retain the following section for water-cooled plants. Delete otherwise.

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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

- 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 5.20.9.

Retain Sections 5.20.4.26 and 5.20.4.27 for water-cooled primary-secondary parallel chiller plants with headered primary CHW pumps and dedicated CW pumps. Delete otherwise.

5.20.4.26. 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).

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

5.20.4.27. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

Retain Section 5.20.4.28 and 5.20.4.29 for water-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps and headered CW pumps or air-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps. Delete otherwise.

5.20.4.28. Whenever there is a stage-up command:

Retain the following section for water-cooled plants. Delete otherwise.

- a. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

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.

5.20.4.29. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- a. For any stage change during which a smaller chiller is enabled and a larger chiller is disabled:

Retain the following section for water-cooled plants. Delete otherwise.

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 5.1.15.5.b.1.ii), 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.

Retain the following section for water-cooled plants. Delete otherwise.

- 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 5.20.9.

Retain Section 5.20.4.30 and 5.20.4.31 for water-cooled primary-secondary parallel chiller plants with dedicated primary CHW pumps and dedicated CW pumps. Delete otherwise.

5.20.4.30. 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.

Retain the following section if a smaller chiller is staged off while a larger chiller is staged on during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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 5.1.15.5.b.1.ii), 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.

5.20.4.31. Whenever there is a stage-down command:

Retain the following section if a smaller chiller is staged on while a larger chiller is staged off during any stage change (e.g., for plants with swing chillers). Delete otherwise.

- 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.
- 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.

Retain Sections 5.20.4.32 and 5.20.4.33 for water-cooled primary-only series chiller plants with headered CW pumps or air-cooled primary-only series chiller plants. Delete otherwise.

5.20.4.32. 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.

Retain the following section for water-cooled plants. Delete otherwise.

- c. Start the next CW pump and/or change CW pump speed to that required of the new stage per Section 5.20.9 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).
- 5.20.4.33. 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.

Retain the following section for water-cooled plants. Delete otherwise.

- 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 5.20.9.

Retain Sections 5.20.4.34 and 5.20.4.35 for water-cooled primary-only series chiller plants with dedicated CW pumps. Delete otherwise.

- 5.20.4.34. 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 5.20.5.7.
 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).
- 5.20.4.35. Whenever there is a stage-down command:
- a. Shut off the last stage chiller.

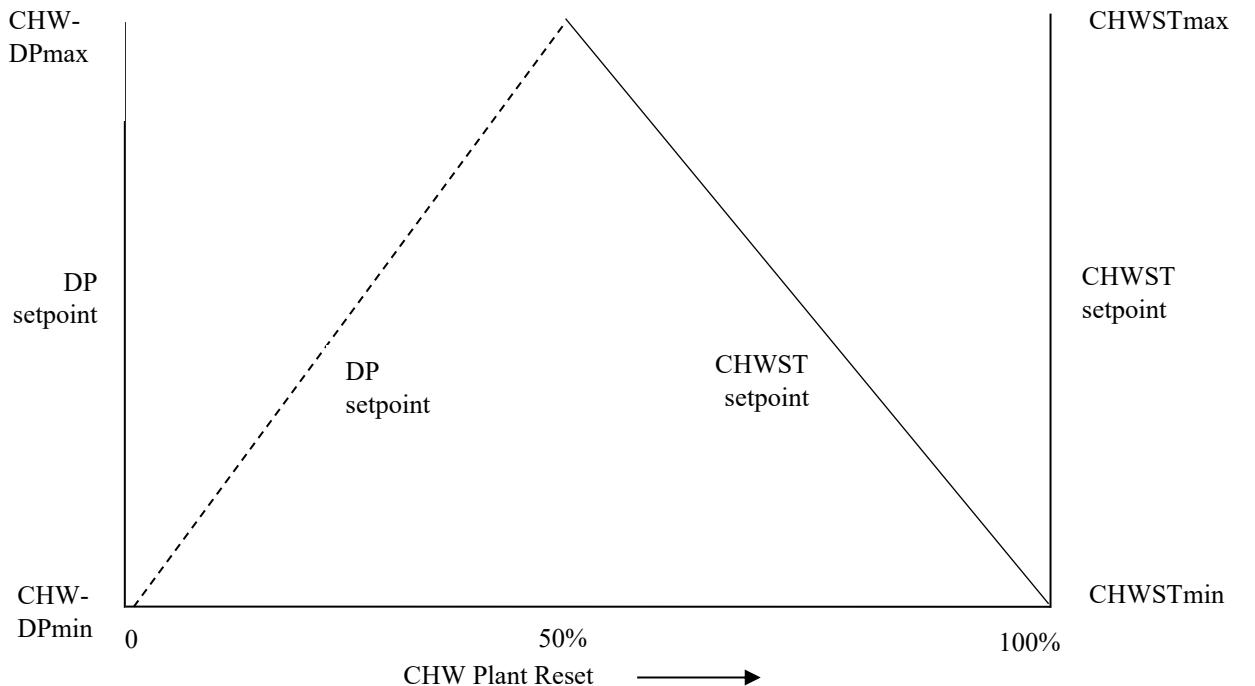
- b. If the disabled chiller is the downstream chiller, reset the upstream chiller's CHWST setpoint to the current plant CHWST setpoint (do not ramp).
- c. When the controller of the chiller being shut off indicates no request for chilled water flow or 3 minutes has elapsed, slowly open the chiller's 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, shut off the chiller's CW pump.

5.20.5. Chilled Water Plant Reset

- 5.20.5.1. CHWSTmin in the following logic shall be the lowest CHWSTminX of chillers in the plant.

Retain the following section for primary-only and primary-secondary systems serving differential pressure controlled pumps. Delete otherwise.

- 5.20.5.2. 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
SP ₀	100%
SP _{min}	0%
SP _{max}	100%
T _d	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SP _{trim}	-2%
SP _{res}	+3%
SP _{res-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.

Retain the following section for primary-secondary plants serving more than one set of differential pressure controlled pumps. Delete otherwise.

- 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).

Retain the following section for plants where more than one remote DP sensor serves a given set of primary or secondary pumps.

- 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.

Retain the following section for Primary-only CHW plants serving a single large load (typically a very large air handler). Delete otherwise.

- 5.20.5.3. 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.

Retain the following two sections for primary-secondary systems where there are any coil pumps. Delete otherwise.

- 5.20.5.4. 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
SP ₀	CHWSTmin
SP _{min}	CHWSTmin
SP _{max}	60°F
T _d	15 minutes
T	5 minutes
I	2
R	Cooling CHWST Reset Requests
SP _{trim}	+0.75°F
SP _{res}	-1°F
SP _{res-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.

- 5.20.5.5. A unique instance of the above reset shall be used for each set of coil pumps.

Retain the following section if the plant has multiple reset loops. Delete otherwise.

- 5.20.5.6. The CHWST setpoint used at the plant shall be the lowest value output from each of the active reset loops.

Retain the following two sections for series chiller plants. Delete otherwise.

- 5.20.5.7. When only one chiller is enabled, CHWST setpoint shall be the setpoint resulting from the plant reset loop(s).

- 5.20.5.8. 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:

$$CWHST_{\text{upstream}} = CHWRT - (CHWRT - CHWST_{\text{sp downstream}}) * \frac{QchX_{\text{upstream}}}{QchX_{\text{upstream}} + QchX_{\text{downstream}}}$$

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.

5.20.6. Primary Chilled Water Pumps

Retain the following section for plants with headered primary chilled water pumps. Delete otherwise.

- 5.20.6.1. Primary CHW pumps shall be lead/lag controlled per Section 5.1.15.3.

Retain the following section for plants with parallel chillers, headered primary chilled water pumps, and without a waterside economizer. Delete otherwise.

- 5.20.6.2. 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.

Retain the following section for plants with parallel chillers, headered primary chilled water pumps, and a waterside economizer. Delete otherwise.

- 5.20.6.3. 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.

Retain the following section for plants with series chillers and without a waterside economizer. Delete otherwise.

- 5.20.6.4. 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.

Retain the following section for plants with series chillers and a waterside economizer. Delete otherwise.

- 5.20.6.5. 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.

Retain the following section for plants with dedicated primary chilled water pumps. Delete otherwise.

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.

- 5.20.6.6. 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.

Retain the following section for primary-only plants with headered variable speed primary pumps using differential pressure pump speed control. Delete otherwise.

- 5.20.6.7. CHW pumps shall be staged as a function of CHWFR, the ratio of current chilled water flow, $FLOW_p$, to design primary pump flow, $PCHWF_{\text{design}}$, and the number of pumps, N_{PCHWP} , that operate at design conditions. Pumps are assumed to be equally sized.

$$\text{CHWFR} = \frac{\text{FLOW}_P}{P\text{CHWF}_{\text{design}}}$$

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:

$$\text{CHWFR} > \frac{\text{Number of Operating Pumps}}{N} - .03$$

- b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{CHWFR} \leq \frac{\text{Number of Operating Pumps} - 1}{N} - .03$$

Retain the following two sections for primary-only plants where the remote DP sensor(s) is hardwired to the plant controller. Delete otherwise.

- 5.20.6.8. 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.
- 5.20.6.9. 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.

Retain the following three sections for primary-only plants where the remote DP sensor(s) is not hardwired to the plant controller, but a local DP sensor is hardwired to the plant controller. Delete otherwise.

- 5.20.6.10. 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.
- 5.20.6.11. 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.
- 5.20.6.12. 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.

Retain the following two sections for primary-secondary plants and primary-only plants where primary pump speed is not controlled to maintain differential pressure. Delete otherwise.

- 5.20.6.13. The number of operating primary chilled water pumps shall match the number of operating chillers.
- 5.20.6.14. See Section 5.20.4 for primary chilled water pump staging sequence relative to chiller stage-up and stage-down events.

Retain the following section for primary-only plants and primary-secondary plants with variable speed primary pumps that are intended to operate at a fixed speed. Delete otherwise.

- 5.20.6.15. 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.

Retain the following section for variable primary-variable secondary plants with primary and secondary loop flow meters. Delete otherwise.

- 5.20.6.16. 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.

Retain the following section for variable primary-variable secondary plants with a flow meter in the decoupler. Delete otherwise.

- 5.20.6.17. 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.

Retain the following two sections for variable primary-variable secondary plants without flow meters from which to deduce decoupler flow. Delete otherwise.

- 5.20.6.18. 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.
- If ΔT exceeds 2°F, send 2 requests until ΔT is less than 1.2°F.
 - Else if ΔT exceeds 1°F, send 1 request until ΔT is less than 0.2°F.
 - 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.

Retain the following section where the primary loop does not have a single CHWST sensor that measures the combined supply flow of all chillers. See schematics in Informative Appendix A for examples.

- 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.

- 5.20.6.19. 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
SP ₀	100%
SP _{min}	CH-MinPriPumpSpdStage
SP _{max}	100%
T _d	15 minutes
T	2 minutes
I	0
R	Primary Pump Speed Reset Requests
SP _{trim}	-2%
SP _{res}	+3%
SP _{res-max}	+6%

Delete Section 5.20.7. for Primary-only plants. Where multiple secondary loops with differing configurations exist, create a unique copy of Section 5.20.7 for each.

5.20.7. Secondary Chilled Water Pumps

- 5.20.7.1. Secondary CHW pumps shall be lead/lag controlled per Section 5.1.15.3.

- 5.20.7.2. 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.

Keep the following section if the plant has one or more sets of secondary loop pumps serving downstream control valves. Delete if all secondary loop loads are served by coil pumps.

5.20.7.3. Pumps serving multiple coils

- a. Secondary CHW pumps shall be staged as a function of SCHWFR, the ratio of current chilled water flow, $FLOW_S$, to design flow, and the number of pumps, N-SCHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$SCHWFR = \frac{FLOW_S}{SCHWF_{design}}$$

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:

$$SCHWFR > \frac{\text{Number of Operating Pumps}}{N} - .03$$

2. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{SCHWFR} < \frac{\text{Number of Operating Pumps} - 1}{N} - .03$$

Keep the following two sections if the remote DP sensor(s) is hardwired to the secondary pump controller. Delete otherwise.

- 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.

Keep the following three sections if the remote DP sensor(s) is not hardwired to the secondary pump controller, but a local DP sensor is hardwired to the secondary pump controller. Delete otherwise.

- 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.

Keep the following section for plants with coil pumps. Delete otherwise.

5.20.7.4. Coil Pumps

Retain the following section where coil pumps can turn down to 20% of design speed or less. This is true of all variable speed drive driven pumps. Delete otherwise.

- 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.

Retain the following two sections where coil pumps cannot turn down to 20% of design speed or less. This is true of some ECM driven pumps, though not all. Delete otherwise.

- 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:

$$\text{PumpSpeedMin} * \frac{(\text{Number of operating pumps} + 1)}{\text{Number of operating pumps}} + 10\%$$

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.

Keep the following section for Primary-only chilled water plants with a minimum flow bypass valve. Delete otherwise.

5.20.8. Chilled Water Minimum Flow Bypass Valve

Retain the following section for Primary-only plants with parallel chillers.

- 5.20.8.1. 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.

Retain the following section for Primary-only plants with series chillers.

- 5.20.8.2. 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.

Retain the following section for plants that stage a chiller on while staging another off during any stage change.

- 5.20.8.3. 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 5.20.4 for timing of setpoint change to this transitionary value.
- 5.20.8.4. 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.

Delete Section 5.20.9. for air-cooled plants. Retain otherwise.

5.20.9. Condenser Water Pumps

Retain the following section for plants with headered condenser water pumps. Delete otherwise.

- 5.20.9.1. Condenser water pumps shall be lead/lag controlled per Section 5.1.15.3.

Retain the following section for plants with headered condenser water pumps and a waterside economizer. Delete otherwise.

- 5.20.9.2. 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.

Retain the following section for plants with headered condenser water pumps and no waterside economizer. Delete otherwise.

- 5.20.9.3. 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.

Retain the following section for plants with dedicated condenser water pumps. Delete otherwise.

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.

- 5.20.9.4. 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.

Delete the following section if the plant has variable speed condenser water pumps or a waterside economizer. Retain otherwise.

- 5.20.9.5. The number of operating condenser water pumps shall match the number of operating chillers.

Delete the following two sections if the plant does not have variable speed condenser water pumps. Retain otherwise.

Where headered condenser water pumps are unequally sized, list the pump tags of the required pumps for each stage in the “CWP_s On” column below.

- 5.20.9.6. 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	CWP _s 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.

- 5.20.9.7. Condenser water pump speed setpoint for a given stage shall be Cw-DesPumpSpdStage unless reset per Head Pressure Control logic in Section 5.20.10.

- 5.20.9.8. See Section 5.20.4 for lag condenser water pump on/off staging timing.

Delete Section 0 for air-cooled plants or water-cooled plants where head pressure control is not required. Retain otherwise.

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).

5.20.10. Head Pressure Control

- 5.20.10.1. 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.

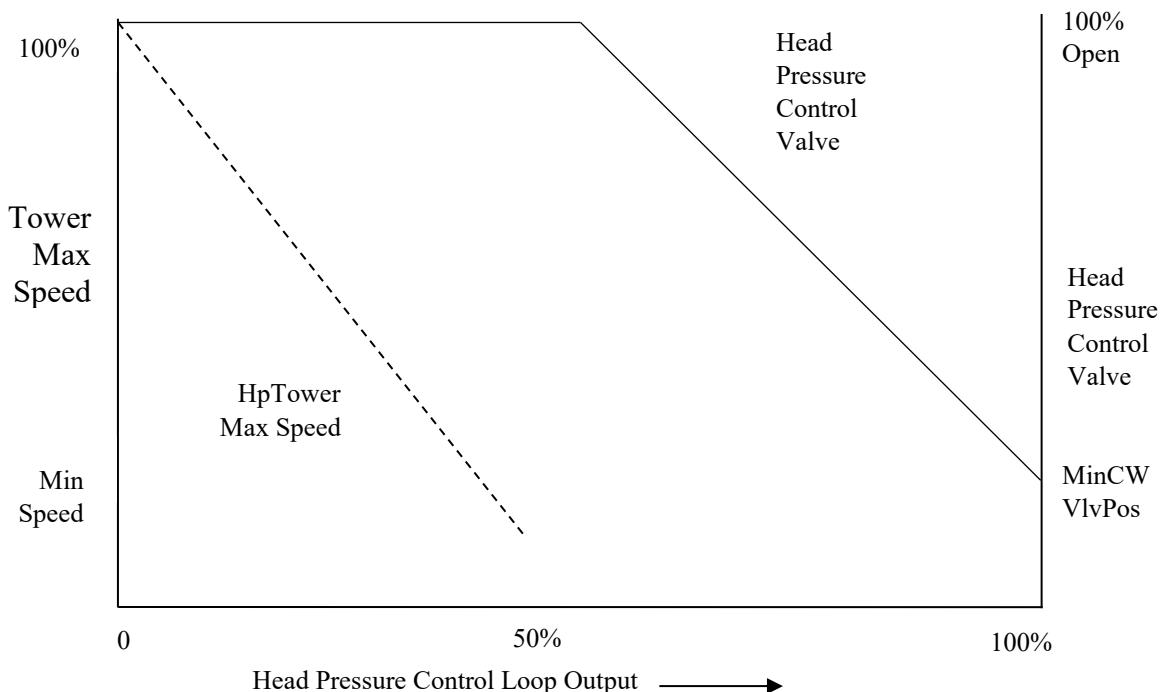
Note that the above BAS loop maintaining LIFTminX, if required, relies on the chiller's sensors, not common loop sensors. If hardwired sensors are available, they should be used; otherwise use network points through the chiller interface.

- 5.20.10.2. 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 5.20.4.

Retain the following section for plants with fixed speed condenser water pumps. Delete otherwise. Note: Such plants are assumed not to have a waterside economizer.

- 5.20.10.3. For each chiller, map loop output as follows:

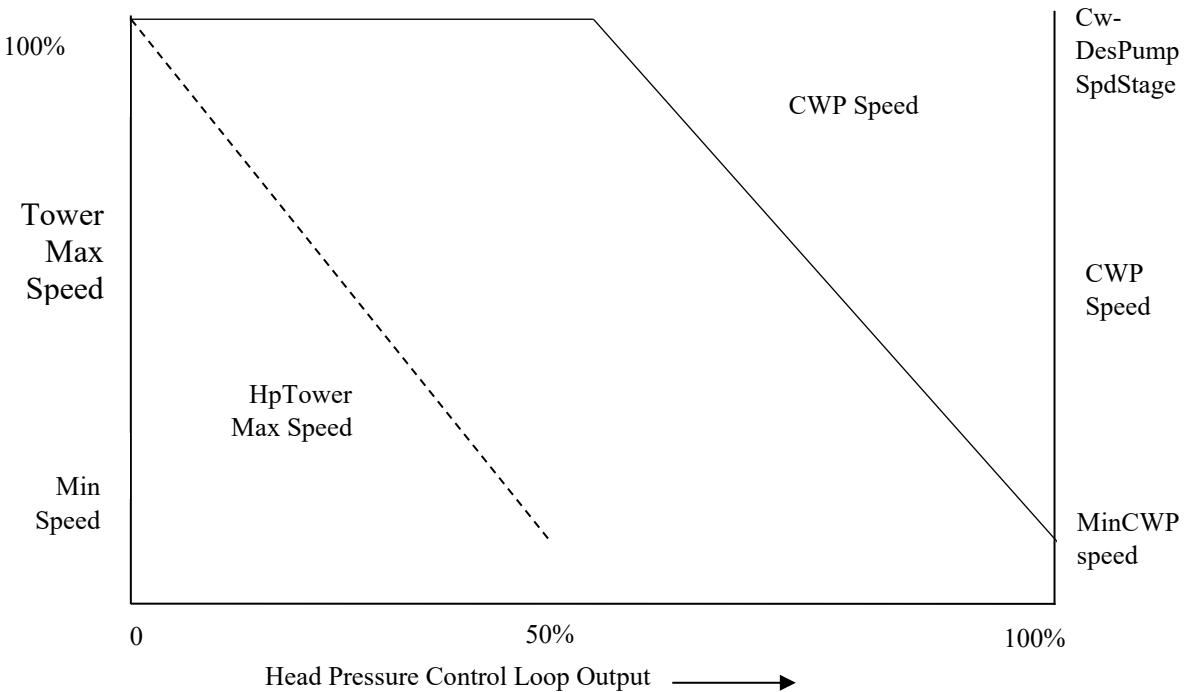
- From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.
- From 50-100%, the loop output shall reset head pressure control valve position from 100% open to MinCWVlvPos.



Retain the following section if the plant has variable speed condenser water pumps and no waterside economizer. Delete otherwise.

5.20.10.4. For each chiller, map loop output as follows:

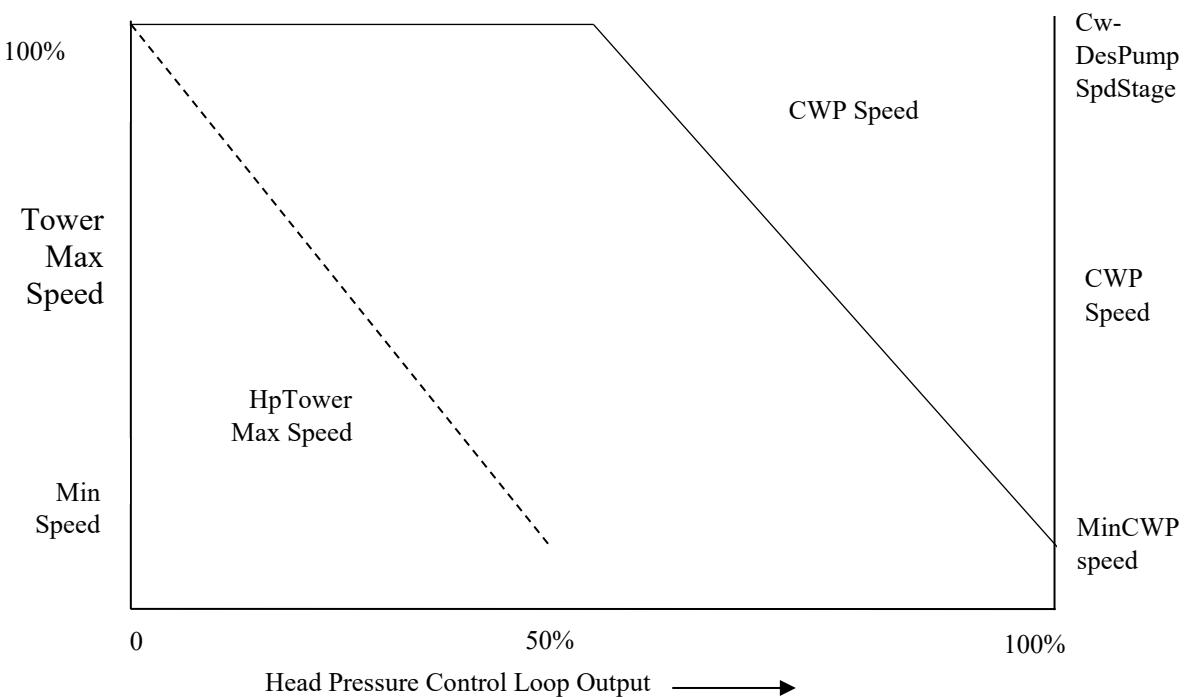
- From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.
- From 50-100%, the loop output shall reset condenser water pump speed from Cw-DesPumpSpdStage to MinCWPspeed. Where condenser water pumps are dedicated, speed reset shall be independent for each chiller.



Retain the following two sections if the plant has a waterside economizer. Delete otherwise. Note: Such plants are assumed to have headered condenser water pumps.

5.20.10.5. For each chiller, when the WSE is disabled, map loop output as follows:

- From 0-50%, the loop output shall reset maximum cooling tower speed point, HpTowerMaxSpd, from 100% to minimum speed.
- 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.

- 5.20.10.6. 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.

Retain the following section for plants with headered condenser water pumps. Delete otherwise.

- 5.20.10.7. When the head pressure control loop is disabled per Section 5.20.4.17, the CW isolation/head pressure control valve shall be closed.

The following section is required for most non-chemical water treatment systems, and recommended for some chemical treatment systems, to ensure condenser water is properly treated. Delete if not required. Always delete for air-cooled plants.

5.20.11. Water Treatment Override

- 5.20.11.1. 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:

Retain the following sentence if there are chiller condenser isolation valves. Delete otherwise.

- a. Open all chiller condenser isolation valves.

Retain the following if there are tower isolation valves. Delete otherwise.

- 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.

Retain Section 5.20.12 for water-cooled plants. Delete otherwise.

5.20.12. Cooling Towers

Retain the following section for plants that have tower isolation valves. Delete otherwise.

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.

5.20.12.1. Tower Staging

- a. Tower cells shall be lead/lag controlled per Section 5.1.15.3.

The table needs to be edited for each plant based on the condenser water flow per stage, number of towers in the plant, and tower minimum flow requirements.

- 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 5.20.4.
- 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.

5.20.12.2. Fan Control

Use the following CWRT Control Sequence for plants with dynamic load profiles, i.e., those for which PLR may change by more than approximately 25% in any hour. Examples include plants primarily serving a few large air handlers with similar schedules and plants serving intermittent process loads. Delete otherwise.

a. Condenser Water Return Temperature (CWRT) Control

1. Tower fan control is in part dictated by plant part load ratio, PLR_{plant} , which is the ratio of current plant required capacity, $Q_{required}$, 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.

Retain the following qualifier for plants with waterside economizers. Delete otherwise.

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.

$$CWRTsp = CHWSTsp + LIFTtarget$$

$$LIFTtarget = \text{Max}(LIFTmin, \text{Min}(LIFTmax, A * PLR_{plant} + B))$$

$$A = 1.1 * (LIFTmax - LIFTmin)$$

$$B = LIFTmax - A$$

- i. Where chillers have different $LIFTminX$ values, $LIFTmin$ in the above equation shall reset dynamically to equal the highest $LIFTminX$ of enabled chillers.

Retain the following sentence for parallel chiller plants only. Delete otherwise.

- ii. Where chillers have different $LIFTmaxX$ values, $LIFTmax$ in the above equations shall reset dynamically to equal the lowest $LIFTmaxX$ of enabled chillers.

Retain the following sentence for series chiller plants only. Delete otherwise.

- iii. $LIFTmax$ 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).

Use the following two sections when the plant is close coupled, i.e., the pipe length from the chillers to cooling towers does not exceed approximately 100 feet. Delete otherwise.

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.

Use the following three sections when the plant is not close coupled, i.e., the pipe length from the chillers to cooling towers exceeds approximately 100 feet. Delete otherwise.

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

- i. Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or

Retain the following sentence if tower speed is controlled to maintain CWRT at setpoint. Delete otherwise.

- ii. Tower fans have been at minimum speed for 5 minutes and CWRT drops below setpoint minus 1°F.

Retain the following sentence if tower speed is controlled to maintain CWST at setpoint. Delete otherwise.

- iii. Tower fans have been at minimum speed for 5 minutes and CWST drops below setpoint minus 1°F.

12. Enable the tower fans if

- i. They have been off for at least 1 minute, and

Retain the following sentence if tower speed is controlled to maintain CWRT at setpoint. Delete otherwise.

- ii. CWRT rises above setpoint by 1°F, and

Retain the following sentence if tower speed is controlled to maintain CWST at setpoint. Delete otherwise.

- iii. CWST rises above setpoint by 1°F, and
 - iv. 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.

Use the following CWST Control Sequence for plants with stable load profiles (i.e., those for which PLR_{plant} is expected to change by less than approximately 25% during any hour) and where network interfaces or power meters are available to read equipment power. Examples include campus central plants, plants serving buildings with many air systems and a variety of schedules and load profiles, and plants with a large, stable base load. Delete otherwise.

- b. Condenser Water Supply Temperature (CWST) Control
 - 1. CWSTdes in the subsequent logic shall be the lowest CWSTdesX of all chillers.

Retain the following qualifier for plants with waterside economizers. Delete otherwise.

- 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, Q_{actual} , 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 ($FLOW_P$), as shown in the equation below.

$$Q_{actual} = \frac{FLOW_P(CHWRT - CHWST)}{24} \text{ [tons]}$$

- 5. Combined chiller and tower fan efficiency, Eff_{Ch+T} , is calculated based on the combined power draw of all tower fans as read from tower VFD interfaces (kW_{Towers}), the combined power draw of all chillers as read from the chiller interfaces or power meters (kW_{Ch}), and instantaneous plant output (Q_{actual}). Eff_{Ch+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 5.20.5.2.a) plus 5 minutes, execute the following reset:
 - i. 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.

- ii. 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:

- (a) CWSTsp had reset down in the previous time interval and EffCh+T is now less than at the previous setpoint change.
 - (b) CWSTsp had reset up in the previous time interval and EffCh+T is now greater than at the previous setpoint change.
- iii. Else, if CWST is no more than 0.5°F below present setpoint, reset CWSTsp up by 1°F.
- iv. 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 $LIFTminX - 2^{\circ}\text{F}$. 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
 - i. Any enabled chiller's HpTowerMaxSpd has equaled tower minimum speed for 5 minutes, or
 - ii. 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

- i. They have been off for at least 1 minute, and
 - ii. CWST rises above setpoint by 1°F, and
 - iii. 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.

Retain the following section for plants with a waterside economizer. Delete otherwise.

- c. WSE Mode
 1. When the WSE is enabled and chiller(s) are running (i.e., integrated operation):
 - i. Fan speed shall be equal to WseTower-MaxSpeed.
 - ii. 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.
 - iii. 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.

- i. 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.
- ii. 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.

Keep the following section where 2-position tower bypass control valves are needed to prevent tower freezing if the plant needs to operate in freezing weather. Delete otherwise.

5.20.12.3. Cooling Tower Bypass Valves

- a. If any condenser water pump is on, all tower fans are off, and CWST from the tower falls below 40°F 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).

Retain the following section for water-cooled plants. Delete otherwise.

5.20.13. Tower Make-up Water

- 5.20.13.1. Make-up water valve shall cycle based on tower water fill level sensor. The valve shall open when water level falls below T-level-min-fill. It shall close when the water level goes above T-level-max-fill.

5.20.14. Emergency Chiller Off

Retain the following section for plants with waterside economizers. Delete otherwise.

- 5.20.14.1. 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.

Retain the following section for plants without waterside economizers. Delete otherwise.

- 5.20.14.2. 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.

Keep the following Section for water-cooled plants where basin heaters and heat trace are used in freezing climates. Delete otherwise.

5.20.15. Freeze Protection

Retain the following two sections for cold climate water-cooled plants with tower basin heaters and basin temperature sensors. Delete otherwise.

5.20.15.1. 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.

Retain the following two sections for cold climate water-cooled plants with outdoor piping and piping heat trace. Delete otherwise.

5.20.15.2. 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.

5.20.16. Performance Monitoring

- 5.20.16.1. 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.

- 5.20.16.2. 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).

Retain the following calculation for primary-only plants and primary-secondary plants with both a primary circuit flow meter and primary loop CHWST and CHWRT sensors. Delete otherwise.

- 5.20.16.3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, $FLOW_P$; chilled water return temperature upstream of the first HX or chiller, $CHWRT$; and primary loop chilled water supply temperature leaving the plant, $CHWST$.

$$Q_{Plant} = \frac{FLOW_P (CHWRT - CHWST)}{24} [\text{tons}]$$

Retain the following calculation for primary-secondary plants without both a primary circuit flow meter and primary loop CHWST and CHWRT sensors. Delete otherwise.

- 5.20.16.4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, $FLOW_S$; secondary chilled water return temperature, $SCHWRT$; and secondary chilled water supply temperature, $SCHWST$.

$$Q_{Plant} = \frac{FLOW_S (SCHWRT - SCHWST)}{24} [\text{tons}]$$

- 5.20.16.5. Equipment Load. Calculate load for each operating chiller and WSE heat exchanger (as applicable) using flowrate through the equipment, $FLOW_D$; chilled water return temperature entering the equipment, $CHWRT_D$; and chilled water supply temperature leaving the equipment, $CHWST_D$. Inputs to the below equation shall be determined per the following rules.

$$Q_D = \frac{FLOW_D (CHWRT_D - CHWST_D)}{24} [\text{tons}]$$

1. Where flow through each chiller is individually measured using a flow meter, $FLOW_D$ 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, $FLOW_D$ 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, $FLOW_D$ 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 $FLOW_D$ per manufacturer's pressure versus flow curves; otherwise, do not execute the above calculation for individual chillers.

Retain the following section for plants with waterside economizers where CHW flowrate through the heat exchanger is controlled by a modulating bypass valve. Delete otherwise.

5. For WSE heat exchangers controlled to differential pressure, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, HXF_{Design} ; design heat exchanger pressure drop, $HX_{DP-Design}$, and current HX pressure drop, HX_{DP-D} :

$$GPM_D = HXF_{Design} \left(\frac{HX_{DP-D}}{HX_{DP-Design}} \right)^{0.5}$$

Retain the following section for plants with a waterside economizer where CHW flowrate through the heat exchanger is controlled by a variable speed heat exchanger pump. Delete otherwise.

6. For WSE heat exchangers with side stream CHW pumps, heat exchanger flow rate shall be estimated based on design heat exchanger flowrate, HXF_{design} ; design heat exchanger pump speed, $HxPumpDesSpd$; and current HX pump speed, HX_{Sp-D} .

$$GPM_D = HF_{design} \left(\frac{HX_{Sp-D}}{HxPumpDesSpd} \right)$$

7. $CHWRT_D$ 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. $CHWST_D$ 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.
- 5.20.16.6. Calculate plant efficiency as total plant power divided by plant load. Calculate efficiency for each chiller as chiller power divided by chiller load.
- 5.20.16.7. 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)
CH-1															
CH-2															
Total Plant															

5.20.17. Alarms

- 5.20.17.1. 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.
- 5.20.17.2. 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.
- 5.20.17.3. Chiller alarm: level 2
- 5.20.17.4. Emergency off switch: Level 1

Retain the following alarm for water-cooled plants. Delete otherwise.

- 5.20.17.5. 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.

5.20.17.6. 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.

Retain the following two alarms for cold climate water-cooled plants with tower basin heaters and basin temperature sensors. Delete otherwise.

5.20.17.7. 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.

Retain the following two alarms for cold climate water-cooled plants with outdoor piping and heat trace. Delete otherwise.

5.20.17.8. 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.

Retain the following two alarms for plants with two-position valves with end switch status monitoring. Delete otherwise.

5.20.17.9. 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.

Retain the following alarm for plants with modulating valves with analog position feedback. Delete otherwise.

5.20.17.10. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2

Retain the following alarm for water-cooled plants with cooling tower basin heaters. Delete otherwise.

5.20.17.11. 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

5.20.17.12. 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.

5.20.18. 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.

5.20.18.1. AFDD conditions are evaluated continuously for the plant.

5.20.18.2. 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.

Edit the table below. Delete rows and columns that do not apply.

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 CWP (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 or 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

5.20.18.3. The following points must be available to the AFDD routines for the chilled water plant:

Retain the following two variables for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

- a. DP = Chilled water loop differential pressure (each loop, where applicable)
- b. DPSP = Chilled water loop differential pressure setpoint (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

- c. FLOW_P = Primary chilled water flow

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

- d. FLOW_S = Secondary chilled water flow

Retain the following two variables for Primary-only chilled water plants with a minimum flow bypass valve. Delete otherwise.

- e. MFBPV = Chilled water minimum flow bypass valve command; $0\% \leq MFBPV \leq 100\%$
- f. CHW-MinFlowSP = Effective minimum chilled water flow setpoint (MinFlowRatio multiplied by the sum of CHW-DesFlowX of enabled chillers).

Retain the following two variables for water-cooled plants. Delete otherwise.

- g. SpeedCT = Cooling tower speed command; $0\% \leq SpeedCT \leq 100\%$
- h. Status_{CWP} = Lead condenser water pump status
- i. Status_{PCHWP} = Lead primary chilled water pump status

Retain the following variable for primary-secondary plants. Delete otherwise.

- j. Status_{SCHWP} = Lead secondary chilled water pump status

Retain the following variable for plants with waterside economizers where CHW flow through the WSE is controlled by a variable speed HX pump. Delete otherwise.

- k. Status_{WSEHXP} = 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

Retain the following two variables for water-cooled plants. Delete otherwise.

- 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

Retain the following two variables for plants with waterside economizers. Delete otherwise.

- q. CHWRT_{BeforeWSE} = Chilled water return temperature before the waterside economizer
- r. CHWRT_{AfterWSE} = Chilled water return temperature after the waterside economizer
- s. CHWST_{CH-x} = CH-x chilled water supply temperature (each chiller)
- t. CHWRT_{CH-x} = CH-x chilled water return temperature (each chiller)

Retain the following two variables for water-cooled plants. Delete otherwise.

- u. CWSTCH-x = CH-x condenser water supply temperature (each chiller)
- v. CWRTH-x = CH-x condenser water return temperature (each chiller)

Retain the following two variables for plants with waterside economizers. Delete otherwise.

- w. CWRT_{HX} = Waterside economizer condenser water return temperature
- x. DAHX = Design heat exchanger approach
- y. RefrigEvapTempCH-x = CH-x refrigerant evaporating temperature (each chiller)

Retain the following variable for water-cooled plants. Delete otherwise.

- z. RefrigCondTempCH-x = CH-x refrigerant condensing temperature (each chiller)
- aa. CHW-ISOCH-x = CH-x chilled water isolation valve commanded position (each chiller)

Retain the following variable for water-cooled plants with headered CW pumps. Delete otherwise.

- 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)

Retain the following variable for plants with waterside economizers where CHW flow through the WSE is controlled by a modulating diverting valve. Delete otherwise.

- cc. WSE-HX-CHW-DIV = Waterside economizer chilled water diverting valve commanded position; 0% ≤ WSE-HX-CHW-DIV ≤ 100%

Retain the following variable for plants with waterside economizers. Delete otherwise.

- dd. WSE-HX-CW-ISO = Waterside economizer condenser water isolation valve commanded position; open/closed

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

- ee. PGAUGE = Chilled water system gauge pressure

The chiller chilled water supply temperature, chiller condenser water return temperature, refrigerant evaporating and condensing temperature points are listed as optional in 4.10.1 because they are typically networked points that are read via a chiller network interface rather than through hardwired connections. Where a chiller network interface or specific points are not available, omit the associated fault conditions.

5.20.18.4. 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. CHWST_{Avg} = rolling average of the common chilled water supply temperature
 - 2. CHWRT_{Avg} = rolling average of the common chilled water return temperature

Retain the following two variables for plants with waterside economizers. Delete otherwise.

- 3. CHWRT_{BEFOREWSE, Avg} = rolling average of the chilled water return temperature before the waterside economizer

4. CHWRT_{AFTERWSE, AVG} = rolling average of the chilled water return temperature after the waterside economizer

Retain the following four variables for water-cooled plants. Delete otherwise.

5. CWST_{AVG} = rolling average of the common condenser water supply temperature
6. CWRT_{AVG} = rolling average of the common condenser water return temperature
7. CWST_{CH-x, AVG} = rolling average of CH-x condenser water supply temperature (each chiller)
8. CWRT_{CH-x, AVG} = rolling average of CH-x condenser water return temperature (each chiller)
9. CHWST_{CH-x, AVG} = rolling average of CH-x chilled water supply temperature (each chiller)
10. CHWRT_{CH-x, AVG} = rolling average of CH-x chilled water return temperature (each chiller)

Retain the following variable for plants with waterside economizers. Delete otherwise.

11. CWRT_{HX, AVG} = rolling average of the waterside economizer heat exchanger condenser water return temperature

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

12. P_{GAUGE, AVG} = rolling average of chilled water system gauge pressure

Retain the following variable for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

13. DP_{Avg} = rolling average of loop differential pressure (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

14. FLOW_{P, AVG} = rolling average of primary chilled water flow

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

15. FLOW_{S, AVG} = rolling average of secondary chilled water flow

Retain the following variable for water-cooled plants. Delete otherwise.

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)

Retain the following section for plants with parallel chillers and headered primary chilled water pumps. Delete otherwise.

1. For plants with parallel chillers and headered primary chilled water pumps: 1 if CHW-ISO_{CH-x} > 0, 0 if CHW-ISO_{CH-x} = 0

Retain the following section for plants with parallel chillers and dedicated primary chilled water pumps. Delete otherwise.

2. For plants with parallel chillers and dedicated primary chilled water pumps: 1 if Status_{PCHWP} = On, 0 if Status_{PCHWP} = Off.

Retain the following section for plants with series chillers. Delete otherwise.

3. For plants with series chillers: 1 if $\text{CHW-ISO}_{\text{CH-X}} < 100$, 0 if $\text{CHW-ISO}_{\text{CH-X}} = 100$ (each chiller)
-

Retain the following variable for water-cooled plants. Delete otherwise.

- c. CW-FlowCH-X (each chiller)
-

Retain the following section for plants with headered condenser water pumps and modulating condenser water isolation valves. Delete otherwise.

1. For plants with headered condenser water pumps and if condenser water isolation valve is modulating: 1 if $\text{CW-ISO}_{\text{CH-X}} > 0\%$ open, 0 if $\text{CW-ISO}_{\text{CH-X}} = 0\%$ open (each chiller)
-

Retain the following section for plants with headered condenser water pumps and two-position condenser water isolation valves. Delete otherwise.

2. For plants with headered condenser water pumps and if condenser water isolation valve is two-position: 1 if $\text{CW-ISO}_{\text{CH-X}} = \text{open}$, 0 if $\text{CW-ISO}_{\text{CH-X}} = \text{closed}$ (each chiller)
-

Retain the following section for plants with dedicated condenser water pumps. Delete otherwise.

3. For plants with dedicated condenser pumps: 1 if $\text{Status}_{\text{CWP}} = \text{on}$, 0 if $\text{Status}_{\text{CWP}} = \text{off}$
 - d. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)
 - e. $\Delta Stage$ = 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)
-

5.20.18.5. 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
$\varepsilon_{\text{CHWT}}$	Temperature error threshold for chilled water temperature sensors	2°F
Retain the following variable for water-cooled plants. Delete otherwise.		
ε_{CWT}	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.		

Variable Name	Description	Default Value
ε_{DP}	Differential pressure error threshold for DP sensor	2 psi
Retain the following variable for plants with a flow meter. Delete otherwise.		
ε_{FM}	Flow error threshold for flow meter	20 gpm
ε_{VFDSPD}	VFD speed error threshold	5%
Retain the following variable for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
ε_{MFBVP}	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.		
Approach _{COND}	Condenser approach threshold	4°F
Approach _{EVAP}	Evaporator approach threshold	3°F
CHStarts _{MAX}	Maximum number of chiller starts during the previous 60 minutes (moving window)	2
ΔOS_{MAX}	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	2
$\Delta Stage_{MAX}$	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 5.20.18.12.

- 5.20.18.6. 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.

Edit the table below. Remove fault conditions that do not apply.

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	$DP_{AVG} > \varepsilon_{DSP}$ and $Status_{CHWP} = Off$	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	$FLOW_{P, AVG} > \varepsilon_{FM}$ and $Status_{PCHWP} = Off$	Applies to OS #1
	Description	Primary chilled water flow is too high with the chilled 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	$FLOW_{S, AVG} > \varepsilon_{FM}$ and $Status_{SCHWP} = Off$	Applies to OS #1
	Description	Secondary chilled water flow is too high with the chilled 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	$DP_{AVG} < DPSP - \varepsilon_{DP}$ and $Speed_{CHWP} \geq 99\% - \varepsilon_{VFDSPD}$	Applies to OS #2 – #5
	Description	Chilled water loop differential pressure is too low with chilled 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 CHWST is too high Primary flow is higher than the design evaporator flow of the operating chillers	

Retain the following fault condition for primary-only plants with a minimum flow bypass valve. Delete otherwise.

FC#5	Equation	$\text{FLOW}_{P, \text{AVG}} < \text{CHW-MinFlowSp} - \varepsilon_{FM}$ and $\text{MFBPV} \geq 99\% - \varepsilon_{MFBPV}$	Applies to OS #2, #3, #5
	Description	Primary chilled water flow is too low with the minimum flow bypass valve fully open.	
	Possible Diagnosis	Problem with minimum flow bypass valve Problem with chiller CHW isolation valves Minimum loop differential pressure setpoint too low	

FC#6	Equation	$\text{CHWST}_{\text{AVG}} - \varepsilon_{CHWT} \geq \text{CHWST}_{\text{SP}}$	Applies to OS #2 – #5
	Description	Chilled water supply temperature is too high	
	Possible Diagnosis	Mechanical problem with chillers Primary flow is higher than the design evaporator flow of the operating chillers	

Retain the following fault condition for plants where system gauge pressure is monitored. Delete otherwise.

FC#7	Equation	$\text{CHW-P}_{\text{GAUGE, AVG}} < 0.9 * \text{CHW-ETPreChargePress}$	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	$\text{Approach}_{\text{COND}} \geq \text{RefrigCondTemp}_{\text{CH-x, AVG}} - \text{CWRT}_{\text{CH-x, AVG}}$	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	$\text{Approach}_{\text{EVAP}} \geq \text{CHWST}_{\text{CH-x, AVG}} - \text{RefrigEvapTemp}_{\text{CH-x, AVG}}$	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	

Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.			
FC#10	Equation	$\left \frac{\sum(\text{CHW-Flow}_{\text{CH-X}} * \text{CHWST}_{\text{CH-X}})}{\sum\text{CHW-Flow}_{\text{CH-X}}} - \text{CHWST}_{\text{AVG}} \right > \epsilon_{\text{CHWT}}$ <p style="text-align: center;">and</p> $\sum\text{CHW-Flow}_{\text{CH-X}} = 1$	Applies to OS #2, #5
	Description	Deviation between the active chiller chilled water supply temperature and the common chilled water supply temperature is too high.	
	Possible Diagnosis	A chilled water supply temperature sensor is out of calibration	
Retain the following fault condition for parallel chilled water plants with chiller network interfaces. Delete otherwise.			
FC#11	Equation	$\left \frac{\sum(\text{CHW-Flow}_{\text{CH-X}} * \text{CHWRT}_{\text{CH-X}})}{\sum\text{CHW-Flow}_{\text{CH-X}}} - \text{CHWRT}_{\text{AVG}} \right > \epsilon_{\text{CHWT}}$ <p style="text-align: center;">and</p> $\sum\text{CHW-Flow}_{\text{CH-X}} = 1$	Applies to OS #2, #5
	Description	Deviation between the active chiller chilled water return temperature and the common chilled water return temperature is too high.	
	Possible Diagnosis	A chilled water return temperature sensor is out of calibration	
Retain the following two fault conditions for water-cooled plants with chiller network interfaces. Delete otherwise.			
FC#12	Equation	$\left \frac{\sum(\text{CW-Flow}_{\text{CH-X}} * \text{CWST}_{\text{CH-X}})}{\sum\text{CW-Flow}_{\text{CH-X}}} - \text{CWST}_{\text{AVG}} \right > \epsilon_{\text{CWT}}$ <p style="text-align: center;">and</p> $\sum\text{CW-Flow}_{\text{CH-X}} = 1$	Applies to OS #2
	Description	Deviation between the active chiller condenser water supply temperature and the common condenser water supply temperature is too high.	
	Possible Diagnosis	A condenser water supply temperature sensor is out of calibration	
FC#13	Equation	$\left \frac{\sum(\text{CW-Flow}_{\text{CH-X}} * \text{CWRT}_{\text{CH-X}})}{\sum\text{CW-Flow}_{\text{CH-X}}} - \text{CWRT}_{\text{AVG}} \right > \epsilon_{\text{CWT}}$ <p style="text-align: center;">and</p> $\sum\text{CW-Flow}_{\text{CH-X}} = 1$	Applies to OS #2
	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.			

	Equation	$CWST_{AVG} - \varepsilon_{CWT} \geq DesCWST_{des}$ and $SpeedCT \geq 99\% - \varepsilon_{VFDSPD}$	Applies to OS #2, #3
FC#14	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	$ CWRT_{HX, AVG} - CWRT_{AVG} > \varepsilon_{CWT}$ and $\sum_{CH-X} CW-Flow = 0$ 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	$CWST_{AVG} - CHWRT_{AFTERWSE, AVG} > (1.5 * DA_{HX}) + \varepsilon_{CHWRT}$	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	$ CHWRT_{BeforeWSE} - CHWRT_{AfterWSE} > \varepsilon_{CHWRT}$ and $Status_{WSE-HX-P} = Off$ (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	$\Delta OS > \Delta OS_{MAX}$	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	$\Delta Starts_{CH-x} > \Delta CHStart_{MAX}$	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	$\Delta Stage > \Delta Stage_{MAX}$	Applies to OS #1 – #5
	Description	Too many stage changes	
	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	

5.20.18.7. 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:

Edit the list of operating states and associated fault conditions to match those in the operating state and fault condition tables above.

- 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

- 5.20.18.8. For each chiller, the operator shall be able to suppress the alarm for any Fault Condition.
- 5.20.18.9. 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.
- 5.20.18.10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.
- 5.20.18.11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.
- 5.20.18.12. 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.
- 5.20.18.13. 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 5.20.18.6.

5.21 Hot Water Plant

Retain the applicable variables from Sections 3.1.8 and 3.2.4. Delete variables that are not applicable.

- 5.21.1. See Section 3.1.8 for HWSTmax, HW-LOT, HW-MinFlowX, HW-DesFlowX, QbX, B-FiringMinX, PHWFdesign, and SHWFdesign. See Section 3.2.4 for HW-DPmax, LocalHW-DPmax, and B-MinPriPumpSpdStage.

5.21.2. Plant Enable/Disable

- 5.21.2.1. 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).
- 5.21.2.2. 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 $> I$ ($I = \text{Ignores}$ shall default to 0, adjustable), and
 - b. OAT $<$ HW-LOT, and
 - c. The Boiler plant enable schedule is active.
- 5.21.2.3. Disable the plant when it has been enabled for at least 15 minutes and:
 - a. Number of Heating Hot-Water Plant Requests $\leq I$ 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.

5.21.2.4. When the plant is enabled:

Retain the following sentence for plants with headered primary HW pumps. Delete otherwise.

- a. Open the HW isolation valve of the lead boiler.

Retain the following two sentences for primary-secondary plants. Delete otherwise.

- b. Stage on lead primary HW pump and secondary HW pump per Sections 5.21.6 and 5.21.7 respectively.
- c. Once the lead pumps have proven on, enable the lead boiler.

Retain the following two sentences for primary-only plants. Delete otherwise.

- d. Stage on lead primary HW pump per Section 5.21.6.
- e. Once the lead pump has proven on, enable the lead boiler.

5.21.2.5. When the plant is disabled:

- a. Shut off the enabled boiler(s).

Retain the following sentence for primary-only and primary-secondary plants with headered primary HW pumps. Delete otherwise.

- 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 5.21.6.

Retain the following sentence for primary-only and primary-secondary plants with dedicated primary HW pumps. Delete otherwise.

- c. For each enabled boiler with dedicated primary HW pumps, disable the operating primary HW pump(s) per Section 5.21.6.

Retain the following sentence for primary-secondary plants. Delete otherwise.

- d. Disable the operating secondary HW pump(s) per Section 5.21.7.

5.21.3. Boiler Staging

5.21.3.1. Boiler stages shall be defined as follows:

The following table is project specific and must indicate the boilers that are required to run in each stage. Where boilers are interchangeable and should be lead/lag alternated, that must be indicated with an “or” in the enabled boilers column.

For instance, in the example table below, if there is a pony boiler (B-1) and two identical larger boilers (B-2, B-3), there are 5 possible boiler capacity stages.

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

Retain the following section for plants with equally sized condensing or non-condensing boilers. Delete otherwise.

- 5.21.3.2. Interchangeable boilers indicated with “or” in the table above shall be lead/lag controlled per Section 5.1.15.3.

Retain the following section for plants with headered primary pumps and HW isolation valves. Delete otherwise.

- 5.21.3.3. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its HW isolation valve shall be closed.

Retain the following section for plants with dedicated primary pumps. Delete otherwise.

- 5.21.3.4. If a boiler is in alarm, the boiler shall be disabled and after 3 minutes, its dedicated primary pump shall be disabled.

Retain the following section for primary-only plants and primary-secondary plants without flow meters in all secondary loops (if more than one). Delete otherwise.

- 5.21.3.5. Boilers are staged in part based on required capacity, $Q_{required}$. $Q_{required}$ is calculated based on hot water return temperature ($HWRT$), active hot water supply temperature setpoint ($HWST_{SP}$), and measured flow through the primary circuit flow meter ($FLOW_P$), 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.

$$Q_{required} = 0.49 * FLOW_P (HWST_{SP} - HWRT) \left[\frac{\text{kbtu}}{\text{h}} \right]$$

Retain the following section for primary-secondary plants with flow meters in all secondary loops (if more than one). Delete otherwise.

- 5.21.3.6. Boilers are staged in part based on required capacity, $Q_{required}$. $Q_{required}$ is calculated based on secondary hot water return temperature ($SHWRT$), active hot water supply temperature setpoint ($HWST_{SP}$), and measured flow through the secondary circuit flow meter ($FLOW_S$), 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.

$$Q_{required} = 0.49 * FLOW_S (HWST_{SP} - SHWRT) \left[\frac{\text{kbtu}}{\text{h}} \right]$$

Retain the following section for plants with condensing boilers. Delete otherwise.

- 5.21.3.7. Boilers are staged in part based on the minimum output of a given stage, $B-STAGE_{MIN}$. Calculate $B-STAGE_{MIN}$ 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.

- 5.21.3.8. 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 5.1.15.5.b.1.iii or a hot water pump dedicated to that boiler is faulted per Section 5.1.15.5.b.1.i; otherwise the stage shall be deemed available.
- 5.21.3.9. Staging shall be executed per the conditions below subject to the following requirements:
- Each stage shall have a minimum runtime of 10 minutes.
 - Timers shall reset to zero at the completion of every stage change.

- c. Any unavailable stage (see Section 5.21.3.8) shall be skipped during staging events, but staging conditionals in the current stage shall be evaluated as per usual.

Retain the following section for hybrid plants. Delete otherwise.

1. Exceptions:
 - i. 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.
 - ii. 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.

Retain the following section for primary-secondary boiler plants where the primary loop does not have a single HWST sensor that measures the common supply temperature. Delete otherwise.

- 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.

Retain the following two sections for primary only condensing boiler plants. Delete otherwise.

- 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:
 - i. $Q_{required}$ exceeds 200% of $B-STAGE_{MIN}$ of the next available stage for 10 minutes
 - ii. Hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 5.21.8).
 3. **Failsafe Condition:** HW supply temperature is $10^{\circ}\text{F} < \text{setpoint}$ for 15 minutes.
- g. Stage down if all of the following are true:
 1. Either:
 - i. $Q_{required}$ falls below 110% of $B-STAGE_{MIN}$ of the current stage for 5 minutes; or
 - ii. 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. $Q_{required}$ is less than 80% of the design capacity, Q_{bX} , 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.

Retain the following two sections for variable primary/variable secondary condensing boiler plants. Delete otherwise.

- 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:
 - i. $Q_{required}$ exceeds 150% of $B-STAGE_{MIN}$ of the next available stage for 10 minutes
 - ii. Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 5.21.8).
 - 3. **Failsafe Condition:** HW supply temperature is $10^{\circ}\text{F} < \text{setpoint}$ for 15 minutes.
- i. Stage down if all of the following are true:
 - 1. Either:
 - i. $Q_{required}$ falls below 110% of $B-STAGE_{MIN}$ of the current stage for 5 minutes; or
 - ii. 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. $Q_{required}$ is less than 80% of the design capacity, Q_{bX} , 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.

Retain the following two sections for non-condensing boiler plants. Delete otherwise.

- 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:** $Q_{required}$ 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 $10^{\circ}\text{F} < \text{setpoint}$ for 15 minutes.
- k. Stage down if both of the following are true:
 1. $Q_{required}$ 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.

Retain the following four sections for hybrid boiler plants. Delete otherwise.

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:
 - i. $Q_{required}$ exceeds 150% of $B-STAGE_{MIN}$ of the next available stage for 10 minutes
 - ii. Primary hot water flowrate exceeds the minimum flow setpoint of the next available stage (see Section 5.21.8).
 3. **Failsafe Condition:** HW supply temperature is $10^{\circ}\text{F} < \text{setpoint}$ 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:
 - i. $Q_{required}$ falls below 110% of $B-STAGE_{MIN}$ of the current stage for 5 minutes; or
 - ii. 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. $Q_{required}$ 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: $Q_{required}$ 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 $10^{\circ}\text{F} < \text{setpoint}$ 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. $Q_{required}$ 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.

Retain the following two sections for plants with only condensing or only non-condensing boilers. Delete the following two sections for hybrid plants.

5.21.3.10. Whenever a lag boiler is enabled:

Retain the following section if a smaller boiler is staged off while a larger boiler is staged on during any stage change (e.g. for plants with pony boilers) and the plant has a minimum flow bypass valve. Delete otherwise.

- 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 5.21.8.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

Retain the following section if the plant has a minimum flow bypass valve. Delete otherwise. Delete the words "For any other stage change," if the preceding section is deleted.

- b. For any other stage change, reset the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 5.21.8.1.

A stabilization delay does not apply in this case since flowrate will already be at least the stage minimum per staging logic.

Retain the following sentence for plants with dedicated primary pumps. Delete otherwise.

- c. Start the next lag boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

- d. Open the next lag boiler's isolation valve.

Retain the following sentence for all other plants with headered primary pumps. Delete otherwise.

- 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.

Retain the following section if a smaller boiler is staged off while a large boiler is staged on during any stage change (e.g. for plants with pony boilers). Delete otherwise.

- 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 5.1.15.5.b.1.iii, then shut off the smaller boiler.

Retain the following sentence for plants with dedicated primary pumps. Delete otherwise.

2. After 3 minutes, turn off the smaller boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

3. After 3 minutes, close the smaller boiler's isolation valve.

Retain the following sentence for all other plants with headered primary pumps. Delete otherwise.

4. After 3 minutes, turn off the last lag primary pump and simultaneously close the smaller boiler's isolation valve.

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

5. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 5.21.8.1.

5.21.3.11. Whenever a lag boiler is disabled:

Retain the following section if a smaller boiler is staged on while a larger boiler is staged off during any stage change (e.g. for plants with pony boilers) and the plant has a minimum flow bypass valve. Delete otherwise. If deleting, remove the words "If staging down from any other stage," from Section 5.21.3.11.b below.

- a. For any stage change during which a smaller boiler is enabled and a larger boiler is disabled:

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

1. Slowly change the minimum flow bypass setpoint to that appropriate for the stage transition as indicated in Section 5.21.8.2. After new setpoint is achieved, wait 1 minute to allow loop to stabilize.

Retain the following sentence for plants with dedicated primary pumps. Delete otherwise.

2. Enable the smaller boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

3. Open the smaller boiler's isolation valve.

Retain the following sentence for all other plants with headered primary pumps. Delete otherwise.

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 5.1.15.5.b.1.iii, then shut off the larger boiler.
- b. If staging down from any other stage, disable the last stage boiler.

Retain the following sentence for plants with dedicated primary pumps. Delete otherwise.

- c. After 3 minutes, turn off the disabled boiler's primary pump.

Retain the following sentence for primary-only plants with headered variable speed primary pumps. Delete otherwise.

- d. After 3 minutes, close the disabled boiler's isolation valve.

Retain the following sentence for all other plants with headered primary pumps. Delete otherwise.

- e. After 3 minutes, turn off the last lag primary pump and simultaneously close the disabled boiler's isolation valve.

Retain the following sentence if the plant has a minimum flow bypass valve. Delete otherwise.

- f. Change the minimum flow bypass setpoint to that appropriate for the new stage as indicated in Section 5.21.8.1.

Retain sections 5.21.3.12 through 5.21.3.17 for hybrid boiler plants. Delete otherwise.

Note: Staging logic below assumes no unequally sized boilers within either the condensing boiler group or non-condensing boiler group, though the condensing boilers may be smaller than the non-condensing boilers or vice versa.

- 5.21.3.12. Whenever a lag condensing boiler is enabled:

Retain the following sentence for plants with dedicated primary pumps in the condensing boiler loop. Delete otherwise.

- a. Start the next lag condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the condensing boiler loop. Delete otherwise.

- 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.

- 5.21.3.13. Whenever the first non-condensing boiler is enabled:

- a. Reset the non-condensing boiler hot water supply temperature setpoint per Section 5.21.4.3.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

- 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.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop. Delete otherwise.

- 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.

- 5.21.3.14. Whenever any other non-condensing boiler is enabled:

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop. Delete otherwise.

- a. Start the next lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop.
Delete otherwise.

- 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.

5.21.3.15. Whenever any non-condensing boiler other than the lead non-condensing boiler is disabled:
a. Disable the non-condensing boiler.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop.
Delete otherwise.

- b. After 3 minutes, turn off the lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop.
Delete otherwise.

- c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler's isolation valve.

5.21.3.16. 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 5.21.4.2.

Retain the following sentence for plants with dedicated primary pumps in the non-condensing boiler loop.
Delete otherwise.

- b. After 3 minutes, turn off the lag non-condensing boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the non-condensing boiler loop.
Delete otherwise.

- c. After 3 minutes, turn off the last lag non-condensing loop primary pump and simultaneously close the boiler's isolation valve.

5.21.3.17. Whenever a lag condensing boiler is disabled:
a. Disable the condensing boiler.

Retain the following sentence for plants with dedicated primary pumps in the condensing boiler loop. Delete otherwise.

- b. After 3 minutes, turn off the lag boiler's primary pump.

Retain the following sentence for plants with headered primary pumps in the condensing boiler loop. Delete otherwise.

- c. After 3 minutes, turn off the last lag primary pump and simultaneously close the boiler's isolation valve.

5.21.4. Hot Water Supply Temperature Reset

5.21.4.1. 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

SP_0	SP_{max}
SP_{min}	90°F for condensing and hybrid boiler plants; 155°F for non-condensing plants
SP_{max}	HWSTmax
T_d	10 minutes
T	5 minutes
I	2
R	Hot-Water Reset Requests
SP_{trim}	-2°F
SP_{res}	+3°F
$SP_{res-max}$	+7°F

Hot water supply temperature is reset downwards under low load conditions to minimize piping heat losses, improve controllability, and maximize condensing operation.

SP_{min} must be higher for non-condensing boiler plants to avoid condensing operation. 155°F should be sufficient for most plants, though SP_{min} 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 SP_{min} is reset from 90°F to 155°F based on whether non-condensing boilers are in operation or not in subsequent logic.

Retain the following two sections for hybrid boiler plants. Delete otherwise.

- 5.21.4.2. When only condensing boilers are enabled, condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.
- 5.21.4.3. Whenever any non-condensing boilers are enabled:
 - a. Non-condensing boiler setpoint shall be the Plant hot water supply temperature setpoint.
 - b. SP_{min} 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 SP_{min} 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 SP_{min} . 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.

Retain Section 5.21.5 for plants with non-condensing boilers. Delete otherwise.

- 5.21.5. Non-Condensing Boiler Condensation Control

Retain the following two sections for Primary-only plants. Delete otherwise.

- 5.21.5.1. 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.
- 5.21.5.2. Minimum bypass valve condensation control loop shall be enabled whenever any non-condensing boiler is enabled. Loop shall be disabled otherwise.

Retain the following two sections for Primary-secondary plants with constant speed primary pumps and variable speed secondary pumps. Delete otherwise.

- 5.21.5.3. 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.
- 5.21.5.4. 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.

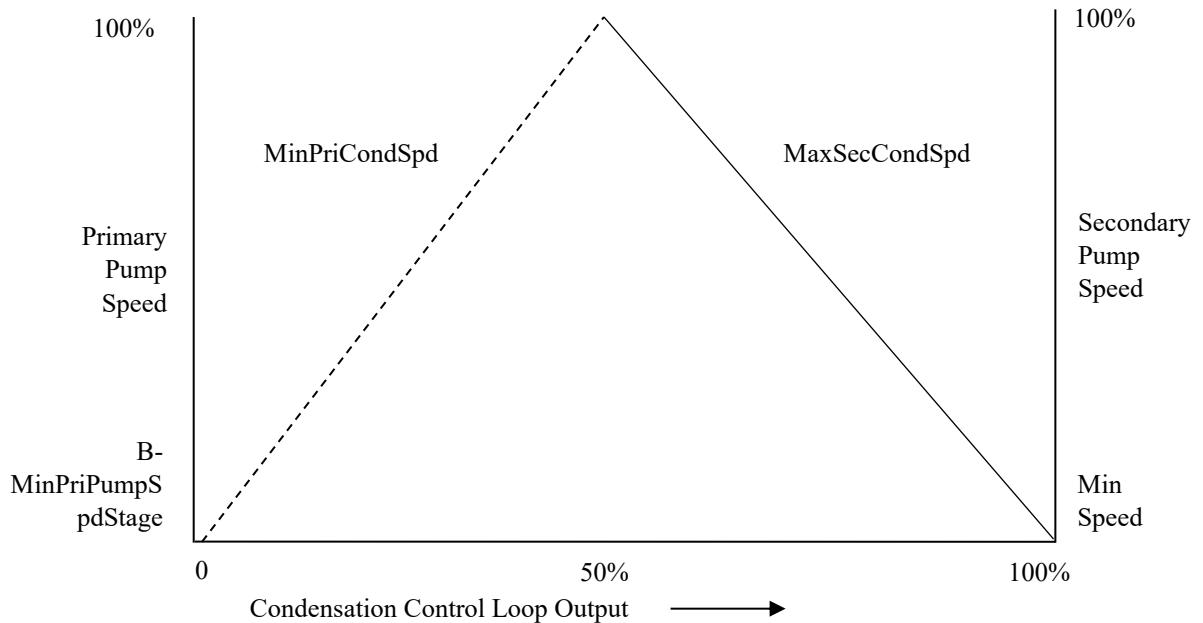
The above two sections assume that secondary pump VFDs are provided for condensation control instead of 3-way thermostatic mixing valves. Limiting secondary pump speed increases the ratio of primary recirculation to secondary return entering the boiler(s), which elevates boiler entering temperature much 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.

Retain the following two sections for Primary-secondary plants with variable speed primary pumps. Delete otherwise.

- 5.21.5.5. 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.
- 5.21.5.6. 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.

- 5.21.5.7. Refer to pump speed control logic for use of condensation control variables.

Retain the following section for Primary-secondary plants with constant speed primary pumps and constant speed secondary pumps. Delete otherwise.

- 5.21.5.8. A thermostatic mixing valve shall maintain boiler entering temperature above 135°F.

Where multiple primary loops with differing configurations exist, e.g. in a hybrid plant, create a unique copy of Section 5.21.6 for each.

5.21.6. Primary Hot Water Pumps

Retain the following two sections for plants with headered primary hot water pumps. Delete otherwise.

- 5.21.6.1. Primary hot water pumps shall be lead/lag controlled per Section 5.1.15.3.
- 5.21.6.2. 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.

Retain the following section for plants with dedicated primary hot water pumps. Delete otherwise.

- 5.21.6.3. 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.

Retain the following section for primary-only plants with headered variable speed pumps using differential pressure pump speed control. Delete otherwise.

- 5.21.6.4. HW pumps shall be staged as a function of the ratio of current hot water flow, $FLOW_P$, to design flow, $PHWF_{design}$, and the number of pumps, $N-PHWP$, that operate at design conditions. Pumps are assumed to be equally sized.

$$HWFR = \frac{FLOW_P}{PHWF_{design}}$$

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:

$$HWFR > \frac{\text{Number of Operating Pumps}}{N} - .03$$

- b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$\text{HWFR} < \frac{\text{Number of Operating Pumps} - 1}{N} - .03$$

Retain the following two sections for Primary-only plants with variable speed primary pumps where the control DP sensor(s) is hardwired to the plant controller. Delete otherwise.

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.

- 5.21.6.5. 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%.
 - 5.21.6.6. 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.

Retain the following three sections for primary-only plants with variable speed primary pumps where the remote DP sensor(s) is not hardwired to the plant controller, but a local DP sensor is hardwired to the plant controller. Delete otherwise.

- 5.21.6.7. 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.
 - 5.21.6.8. 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%.
 - 5.21.6.9. 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.

Retain the following two sections for all plants other than primary-only plants with headered variable speed primary pumps. Delete otherwise.

- 5.21.6.10. Primary pumps shall be staged with the boilers, i.e. the number of pumps shall match the number of boilers.
 - 5.21.6.11. See Section 5.21.3 for primary hot water pump staging sequence relative to boiler stage-up and stage-down events.
-

Retain the following section for primary-secondary plants with variable speed primary pumps and primary and secondary loop flow meters. Delete otherwise.

- 5.21.6.12. 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.

Retain the following section for primary-secondary plants with variable speed primary pumps and a flow meter in the decoupler. Delete otherwise.

- 5.21.6.13. 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%.

Retain the following three sections for primary-secondary plants with variable speed primary pumps and a secondary loop supply temperature sensor, but no flow meters from which to deduce decoupler flow. Delete otherwise.

- 5.21.6.14. 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.
- If ΔT exceeds 2°F, send 2 requests until ΔT is less than 1.2°F.
 - Else if ΔT exceeds 1°F, send 1 request until ΔT is less than 0.2°F.
 - 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.

Retain the following section where the primary loop does not have a single HWST sensor that measures the common supply temperature of all boilers. Delete otherwise.

- 5.21.6.15. 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.

- 5.21.6.16. 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
SP ₀	100%
SP _{min}	B-MinPriPumpSpdStage
SP _{max}	100%
T _d	15 minutes

T	2 minutes
I	0
R	Primary Pump Speed Reset Requests
SP _{trim}	-2%
SP _{res}	+3%
SP _{res-max}	+6%

Retain the following section for plants with non-condensing boilers served by variable speed primary pumps. Delete otherwise.

- 5.21.6.17. 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.

Retain the following section for primary-secondary boiler plants. Delete otherwise. Where multiple secondary loops with differing configurations exist, create a unique copy of Section 5.21.7 for each.

5.21.7. Secondary Hot Water Pumps

- 5.21.7.1. Secondary HW pumps shall be lead/lag controlled per Section 5.1.15.3.
- 5.21.7.2. 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.

Retain the following section for variable speed secondary pumps serving a secondary loop with a flow meter. Delete otherwise.

- 5.21.7.3. Secondary HW pumps shall be staged as a function of SHWFR, the ratio of current hot water flow, $FLOW_s$, to design flow, and the number of pumps, N-SHWP, that operate at design conditions. Pumps are assumed to be equally sized.

$$SHWFR = \frac{FLOW_s}{SHWF_{design}}$$

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:

$$SHWFR > \frac{\text{Number of Operating Pumps}}{N} - .03$$

- b. Shut off the last lag pump whenever the following is true for 10 minutes:

$$SHWFR < \frac{\text{Number of Operating Pumps} - 1}{N} - .03$$

Retain the following section for variable speed secondary pumps serving a secondary loop without a flow meter. Delete otherwise.

- 5.21.7.4. 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.

Retain the following two sections for DP controlled variable speed pumps if the remote DP sensor(s) is hardwired to the secondary pump controller. Delete otherwise.

- 5.21.7.5. 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%.
- 5.21.7.6. 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 converted to heat so reductions in HW pump energy are made up by the boilers.

Retain the following three sections for DP controlled variable speed pumps if the remote DP sensor is not hardwired to the secondary pump controller, but a local DP sensor is hardwired to the secondary pump controller. Delete otherwise.

- 5.21.7.7. 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.
- 5.21.7.8. 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%.
- 5.21.7.9. 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.

Retain the following section for plants with variable speed secondary pumps and non-condensing boilers. Delete otherwise.

- 5.21.7.10. 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.

Retain the following section for constant speed secondary pumps. Delete otherwise.

- 5.21.7.11. 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 5.21.5.

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.

Keep the following section for Primary-only hot water plants with a minimum flow bypass valve. Delete otherwise.

5.21.8. Minimum Flow Bypass Valve

- 5.21.8.1. 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:
- For the boilers operating in the stage, identify the boiler with the highest ratio, MinFlowRatio, of HW-MinFlowX to HW-DesFlowX.
 - 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.

Retain the following section for plants that stage a boiler on while staging another off during any stage change.

- 5.21.8.2. 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 5.21.2.4 for timing of setpoint change to this transitional value.

Retain the following section if the primary loop contains only condensing boilers. Delete otherwise.

- 5.21.8.3. 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.

Retain the following two sections if the primary loop contains any non-condensing boilers. Delete otherwise.

- 5.21.8.4. 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.

- 5.21.8.5. Minimum flow bypass valve position shall be the larger of MinFlowVlvPos and MinCondVlvPos defined in the Condensation Control Section.

- 5.21.8.6. 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.

5.21.9. Performance Monitoring

- 5.21.9.1. 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.

- 5.21.9.2. 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).

Retain the following calculation for primary-only plants and primary-secondary plants with both a primary circuit flow meter and primary loop HWST and HWRT sensors. Delete otherwise.

- 5.21.9.3. Total Plant Load. Calculate plant load using flowrate through the primary circuit, $FLOW_P$; primary hot water return temperature, $PHWRT$; and primary hot water supply temperature, $PHWST$.

$$Q_{actual} = 0.49 * FLOW_P(PHWST - PHWRT) \left[\frac{kbtu}{h} \right]$$

Retain the following calculation for primary-secondary plants without both a primary circuit flow meter and primary loop HWST and HWRT sensors. Delete otherwise.

- 5.21.9.4. Total Plant Load. Calculate plant load using flowrate through the secondary circuit, $FLOW_S$; secondary hot water return temperature, $SHWRT$; and secondary hot water supply temperature leaving the plant, $SHWST$.

$$Q_{actual} = 0.49 * FLOW_S(SHWST - SHWRT) \left[\frac{kbtu}{h} \right]$$

Retain the following section for all plants other than those with variable flow primary loops without flow meters. Delete otherwise.

- 5.21.9.5. Boiler Load. Calculate load for each operating boiler (as applicable) using flowrate through the boiler, $FLOW_B$; hot water return temperature entering the boiler, $HWRT_B$; and hot water supply temperature leaving the boiler, $HWST_B$. Inputs to the below equation shall be determined per the following rules.

$$Q_D = 0.49 * FLOW_B(HWST_B - HWRT_B) \left[\frac{kbtu}{h} \right]$$

Where flow through each boiler is individually measured using a flow meter, $FLOW_B$ shall be the flow measured by the boiler's associated flow meter.

Retain the following section for plants with parallel boilers where flowrate through each boiler is not measured, but flowrate through the primary circuit is measured. Delete otherwise.

- a. $FLOW_B$ shall be assumed proportional to design flow through all operating boilers in the circuit.

Retain the following section for plants with constant primary loop where neither flowrate through the boiler nor flowrate through the primary loop is measured. Delete otherwise.

- b. $FLOW_B$ shall be assumed equal to the design flowrate through the boiler for the current stage as determined during balancing.
- c. $HWRT_B$ 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. $HWST_B$ 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.

- 5.21.9.6. Calculate plant thermal efficiency as equal to measured plant load divided by measured gas consumption.

- 5.21.9.7. 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)
B-1															
B-2															
Total Plant															

5.21.10. Alarms

- 5.21.10.1. 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.
- 5.21.10.2. 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.
- 5.21.10.3. Boiler alarm: Level 2
- 5.21.10.4. 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
- 5.21.10.5. 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.

Retain the following two alarms for plants with two-position valves with end switch status monitoring. Delete otherwise.

- 5.21.10.6. 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.

Retain the following alarm for plants with modulating valves with analog position feedback. Delete otherwise.

- 5.21.10.7. Valve alarm is indicated by the analog position feedback being different from the output command by more than 10% for 90 seconds: Level 2
- 5.21.10.8. 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.

5.21.11. 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.

- 5.21.11.1. AFDD conditions are evaluated continuously for the plant.
- 5.21.11.2. 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

- 5.21.11.3. The following points must be available to the AFDD routines for the hot water plant:

Retain the following two variables for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

- a. DP = Hot water loop differential pressure (each loop, where applicable)
- b. DPSP = Hot water loop differential pressure setpoint (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

- c. FLOW_P = Primary hot water flow (each primary loop, where applicable)

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

- d. $FLOW_S$ = Secondary hot water flow (each secondary loop, where applicable)

Retain the following two variables for primary-only plants with a minimum flow bypass valve. Delete otherwise.

- e. $MFBPV$ = Hot water minimum flow bypass valve command; $0\% \leq MFBPV \leq 100\%$
- f. $HW\text{-}MinFlowSP$ = Effective minimum hot water flow setpoint (equal to $MinFlowRatio$ multiplied by the sum of $HW\text{-}MinFlowX$ of operating boilers)

Retain the following variable for primary-secondary plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

- g. $Speed_{HWP}$ = Secondary hot water pump speed command; $0\% \leq Speed_{HWP} \leq 100\%$

Retain the following variable for primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

- h. $Speed_{HWP}$ = Hot water pump speed command; $0\% \leq Speed_{HWP} \leq 100\%$
- i. $Status_{PHWP}$ = Lead primary hot water pump status (each primary loop, where applicable)

Retain the following variable for primary-secondary plants. Delete otherwise.

- j. $Status_{SHWP}$ = 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)

Retain the following variable for plants headered primary pumps. Delete otherwise.

- n. $HWISO_{B-x}$ = B-x hot water isolation valve commanded position (each boiler)

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

- o. P_{GAUGE} = Hot water system gauge pressure
- 5.21.11.4. 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. $HWST_{AVG}$ = rolling average of the common hot water supply temperature (each primary loop, where applicable)
 - 2. $HWRT_{AVG}$ = rolling average of the average boiler entering water return temperature.

Retain the following variable for plants where system gauge pressure is monitored. Delete otherwise.

- 3. $P_{GAUGE, AVG}$ = rolling average of hot water system gauge pressure

Retain the following variable for primary-secondary plants and primary-only plants where pump speed is controlled to maintain differential pressure. Delete otherwise.

- 4. DP_{AVG} = rolling average of loop differential pressure (each loop, where applicable)

Retain the following variable if there is a flow meter in the primary loop. Delete otherwise.

5. $\text{FLOW}_{P,\text{AVG}}$ = rolling average of primary hot water flow (each loop, where applicable)

Retain the following variable if there is a flow meter in the secondary loop. Delete otherwise.

6. $\text{FLOW}_{S,\text{AVG}}$ = rolling average of secondary hot water flow (each loop, where applicable)
7. HWST_{B-x} = rolling average of B-x hot water supply temperature (each boiler)
8. HWRT_{B-x} = rolling average of B-x hot water return temperature (each boiler)
- b. HWFlow_{B-x} (each boiler)

Retain the following section for plants with headered primary pumps. Delete otherwise.

1. For plants with headered primary hot water pumps: 1 if HWISO_{B-x} = open, 0 if HWISO_{B-x} = closed

Retain the following section for plants with dedicated primary pumps. Delete otherwise.

2. For plants with dedicated primary hot water pumps: 1 if Status_{PHWP} = on, 0 if Status_{PHWP} = off
- c. ΔOS = number of changes in Operating State during the previous 60 minutes (moving window)
- d. $\Delta Stage$ = number of hot water plant stage changes during the previous 60 minutes (moving window)
- e. Starts_{B-x} = number of B-x starts in the last 60 mins (each boiler)

- 5.21.11.5. 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
ε_{HWT}	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.		
ε_{DP}	Differential pressure error threshold for DP sensor	2 psi
ε_{FM}	Flow error threshold for flow meter	20 gpm
Retain the following variable for plants with variable speed pumps. Delete otherwise.		
ε_{VFDSPD}	VFD speed error threshold	5%

Variable Name	Description	Default Value
Retain the following variable for primary-only plants with a minimum flow bypass valve. Delete otherwise.		
ϵ_{MFBVP}	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
BStarts _{MAX}	Maximum number of boiler starts during the previous 60 minutes (moving window)	2
ΔOS_{MAX}	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	2
$\Delta Stage_{MAX}$	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 5.21.11.12.

- 5.21.11.6. 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.

Edit the table below. Remove fault conditions that do not apply.

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	$DP_{AVG} > \epsilon_{DSP}$ and $Status_{HWP} = \text{Off}$
	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	$\text{FLOW}_{P, \text{AVG}} > \varepsilon_{FM}$ and $\text{StatusPHWP} = \text{Off}$	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	$\text{FLOW}_{S, \text{AVG}} > \varepsilon_{FM}$ and $\text{StatusSHWP} = \text{Off}$	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	$\text{DP}_{\text{AVG}} < \text{DPSP} - \varepsilon_{DP}$ and $\text{Speed}_{HWP} \geq 99\% - \varepsilon_{VFDSPD}$	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	$\text{FLOW}_{P, \text{AVG}} < \text{HW-MinFlowSp} - \varepsilon_{FM}$ and $\text{MFBPV} \geq 99\% - \varepsilon_{MFBPV}$	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	$HWST_{AVG} + \epsilon_{HWT} < HWST_{SP}$	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	$P_{GAUGE, AVG} < 0.9 * ETPreChargePress$	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	$HWRT_{AVG} - \epsilon_{HWT} > CondTemp$	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	$HWRT_{AVG} + \epsilon_{HWT} < CondTemp$	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	$ \left(\sum(HW\text{-Flow}_{B-X} * HWST_{B-X}) / \sum HW\text{-Flow}_{B-X}\right) - HWST_{AVG} > \epsilon_{HWT}$	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	$ \sum(\text{HW-Flow}_{B-X} * \text{HWRT}_{B-X}) / \sum\text{HW-Flow}_{B-X} - \text{HWRT}_{AVG} > \varepsilon_{HWT}$	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	$\Delta OS > \Delta OS_{MAX}$	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	$\Delta Starts_{B-x} > \Delta BStart_{MAX}$	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	$\Delta Stage > \Delta Stage_{MAX}$	Applies to OS #1 – #3
	Description	Too many stage changes	
	Possible Diagnosis	Staging thresholds and/or delays need to be adjusted	

5.21.11.7. 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:

Edit the list of operating states and associated fault conditions to match those in the operating state and fault condition tables above.

- In OS #1 (Disabled), the following Fault Conditions shall be evaluated:
 - FC#1: Differential pressure is too high with the hot water pumps off
 - FC#2: Primary hot water flow is too high with the primary hot water pumps off
 - FC#3: Secondary hot water flow is too high with the associated secondary hot water pumps off
 - FC#7: Hot water system gauge pressure is too low
 - FC#10: Too many changes in operating state
 - FC#12: Too many stage changes
- In OS#2 (One boiler enabled), the following Fault Conditions shall be evaluated:
 - FC#4: Hot water loop differential pressure is too low with hot water pump(s) at full speed.
 - FC#5: Primary hot water flow is too low with the minimum flow bypass valve fully open.
 - 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
- 5.21.11.8. For each boiler, the operator shall be able to suppress the alarm for any Fault Condition.
- 5.21.11.9. 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 is in maintenance mode.
 - c. For a period of StageDelay minutes following a change in plant stage.
- 5.21.11.10. Fault Conditions that are not applicable to the current Operating State shall not be evaluated.
- 5.21.11.11. A Fault Condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.
- 5.21.11.12. 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.
- 5.21.11.13. 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 5.21.11.6.

5.22 Fan Coil Unit

- 5.22.1. See “Generic Thermal Zones” (Section 5.3) for setpoints, loops, control modes, alarms, etc.
- 5.22.2. See Section 3.1.7 for Cool_SAT, Heat_SAT, and DP100.

5.22.3. See Section 3.2.3 for MinSpeed, DeadbandSpeed, MaxHeatSpeed, and MaxCoolSpeed.

5.22.4. Supply Fan Speed and Supply Air Temperature Control

- 5.22.4.1. The supply fan shall run whenever the unit is in any mode other than Unoccupied Mode.
- 5.22.4.2. Provide a ramp function to prevent changes in fan speed of more than 10% per minute.
- 5.22.4.3. 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.

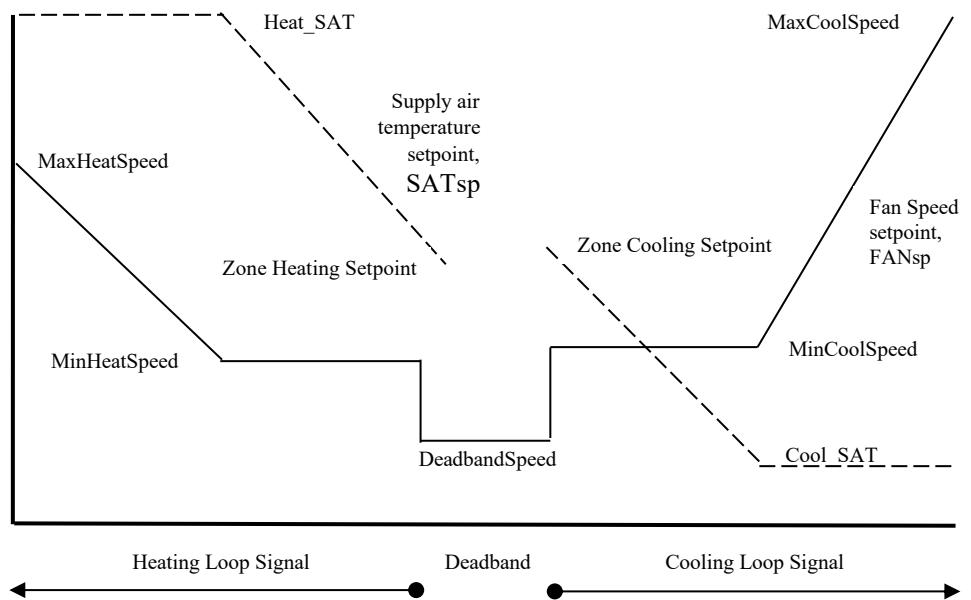


Figure 5.20.4.3 Control diagram for FCU.

- 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

5.22.5. Alarms

- 5.22.5.1. Maintenance interval alarm when fan has operated for more than 1500 hours: Level 4. Reset interval counter when alarm is acknowledged.
- 5.22.5.2. 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
- 5.22.5.3. 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 3.2.3 for MaxCoolSpeed and Section 3.1.7 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.

Automatic Fault Detection and Diagnostics (AFDD) is a sophisticated system for detecting and diagnosing fan-coil 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.

5.22.6. Automatic Fault Detection and Diagnostics

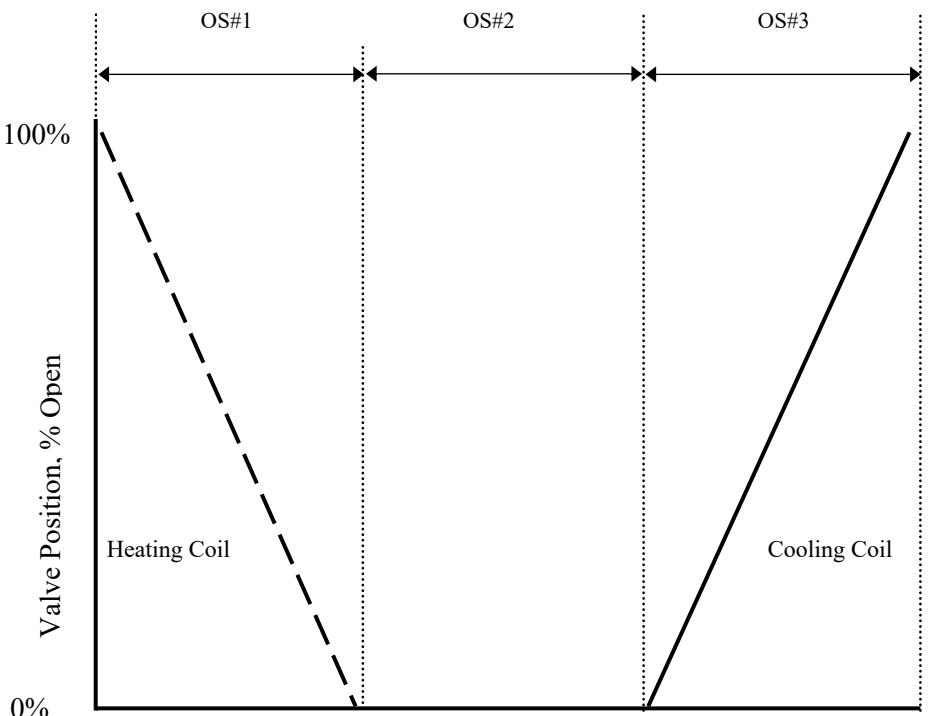
The AFDD routines for FCUs continually assess FCU performance by comparing the values of BAS inputs and outputs to a subset of potential fault conditions. The subset of potential fault conditions that is assessed at any point depends on the OS of the AHU, as determined by the position of the cooling 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.

- 5.22.6.1. AFDD conditions are evaluated continuously and separately for each operating FCU.
- 5.22.6.2. 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 5.18.13.6. 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.

5.22.6.3. 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; $0\% \leq HC \leq 100\%$
 - e. CC = cooling-coil valve position command; $0\% \leq CC \leq 100\%$
 - f. FS = fan-speed command; $0\% \leq FS \leq 100\%$
- 5.22.6.4. 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. SAT_{avg} = rolling average of supply air temperature
 2. RAT_{avg} = rolling average of return air temperature (if fitted)
 3. ΔOS = number of changes in OS during the previous 60 minutes (moving window)
- 5.22.6.5. 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
ΔT_{SF}	Temperature rise across supply fan	0.5°C (1°F)
ε_{SAT}	Temperature error threshold for SAT sensor	1°C (2°F)
ε_{RAT}	Temperature error threshold for RAT sensor	1°C (2°F)
ΔOS_{max}	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 5.18.13.12.

5.22.6.6. 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	$\Delta OS > \Delta OS_{MAX}$	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	$SAT_{AVG} < SAT_{SP} - \varepsilon_{SAT}$ 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	$SAT_{AVG} > SAT_{SP} + \varepsilon_{SAT}$ 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	$SAT_{AVG} - RAT \geq \sqrt{\varepsilon_{RAT}^2 + \varepsilon_{SAT}^2 + \Delta T_{SF}}$	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	$SAT_{AVG} - RAT \leq \sqrt{\varepsilon_{RAT}^2 + \varepsilon_{SAT}^2 + \Delta T_{SF}}$	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	

- 5.22.6.7. 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
- 5.22.6.8. For each FCU, the operator shall be able to suppress the alarm for any fault condition.
- 5.22.6.9. 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.
- 5.22.6.10. Fault conditions that are not applicable to the current OS shall not be evaluated.
- 5.22.6.11. A fault condition that evaluates as true must do so continuously for AlarmDelay minutes before it is reported to the operator.
- 5.22.6.12. 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.
- 5.22.6.13. 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.
- 5.22.7. 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.

Central plant sequences are not part of the initial scope of Guideline 36, but control logic for plant requests are being included for future use, when central plant sequences are added.

Typically, the chiller or heating hot-water plant will start when there is at least one request for 5 minutes, and stop when there are no requests for 5 minutes, after a minimum run-time has elapsed.

Chilled-water and hot-water reset requests are used in T&R loops to control supply water temperature and/or pump DP setpoints based on zone and FCU demands.

5.22.8. Plant Requests

5.22.8.1. If There Is a Chilled-Water Coil, Chilled-Water Reset Requests

- 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.

- If the supply air temperature is 10°F greater than setpoint for 5 minutes, send 3 requests,
- Else if the supply air temperature is 5°F greater than setpoint for 5 minutes, send 2 requests,
- Else if the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 85%.
- Else if the CHW valve position is less than 95%, send 0 requests.

5.22.8.2. If There Is a Chilled-Water Coil, Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

- If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.
- Else if the CHW valve position is less than 95%, send 0 requests.

5.22.8.3. If There Is a Hot-Water Coil, Hot-Water Reset Requests

- 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.

- If the supply air temperature is 17°C (30°F) less than SATsp for 5 minutes, send 3 requests.
- Else if the supply air temperature is 8°C (15°F) less than SATsp for 5 minutes, send 2 requests.
- Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
- Else if the HW valve position is less than 95%, send 0 requests.

5.22.8.4. 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:

- If the HW valve position is greater than 95%, send 1 request until the HW valve position is less than 10%.
- Else if the HW valve position is less than 95%, send 0 requests.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX A CONTROL DIAGRAMS

Appendix A provides control diagrams for a selection of the equipment configurations described in this guideline. These diagrams may be used in drawings where appropriate, but they are not intended to represent all of the possible equipment configurations that are supported by these sequences. The designer should edit these diagrams as required for the project.

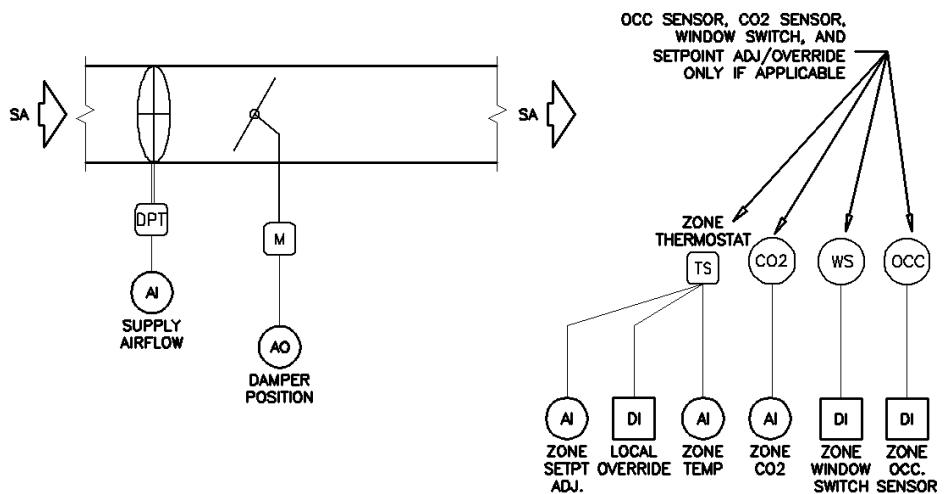


Figure A-1 VAV terminal unit, cooling only.

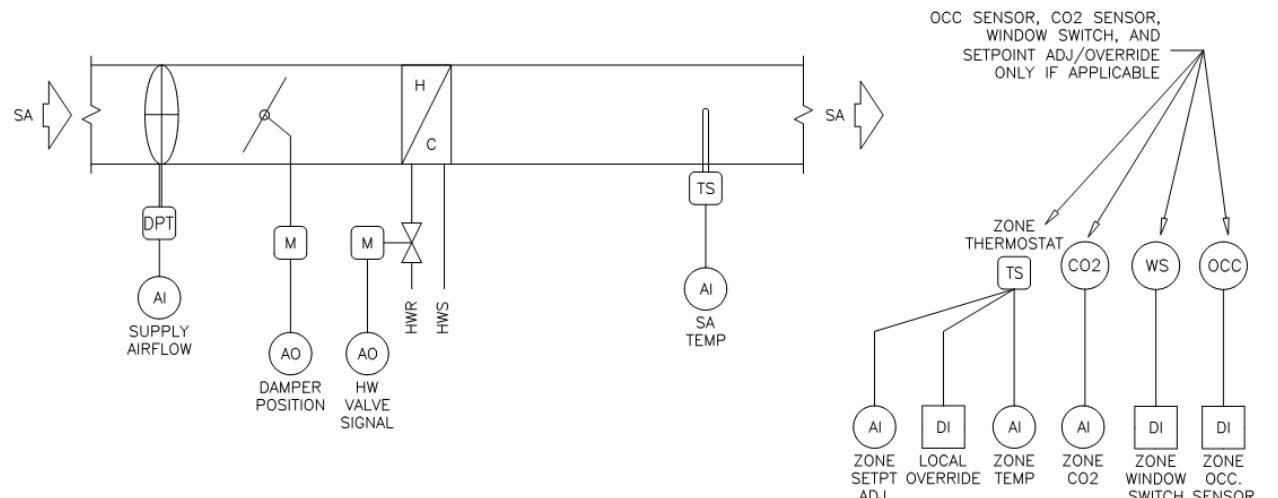
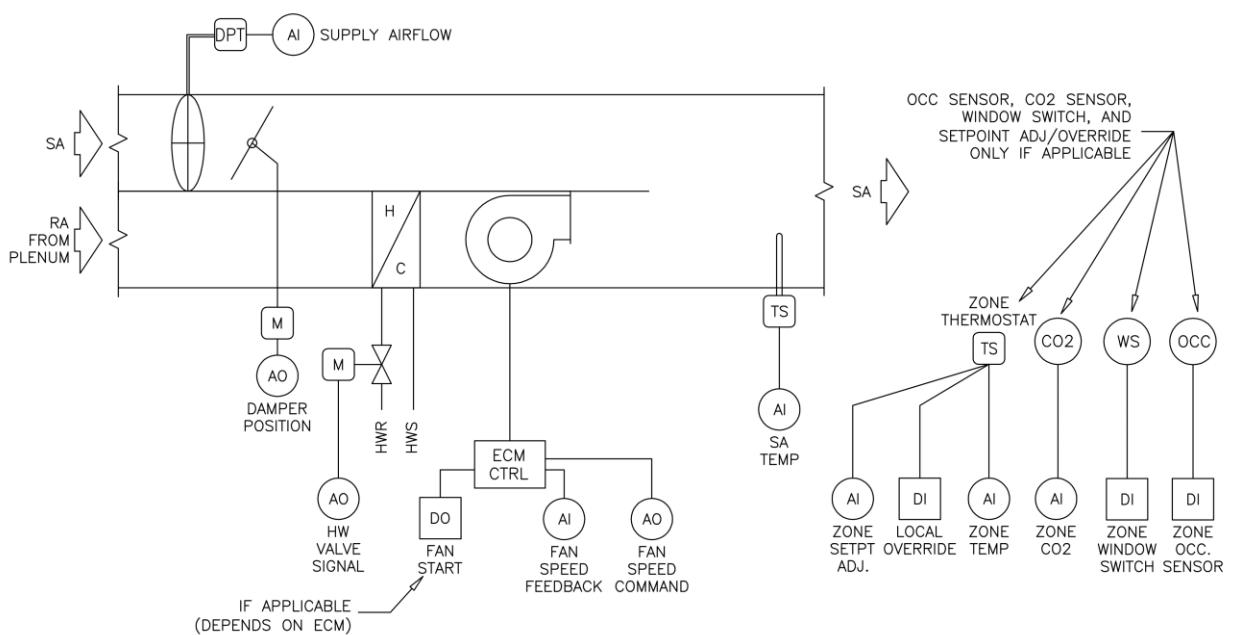
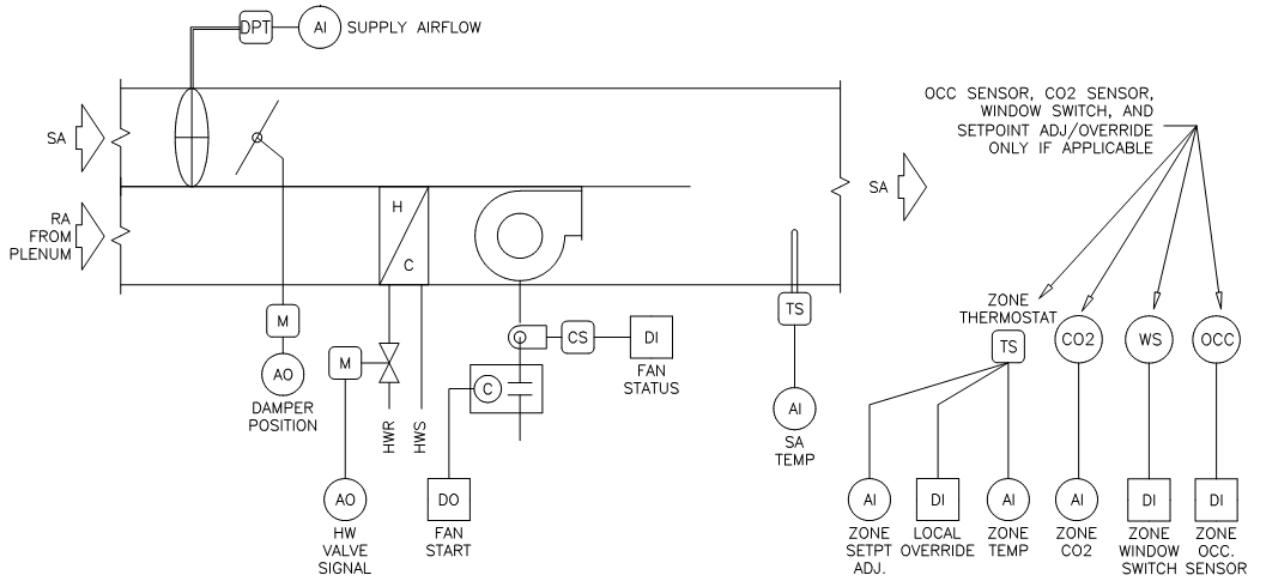


Figure A-2 VAV Terminal unit with reheat.



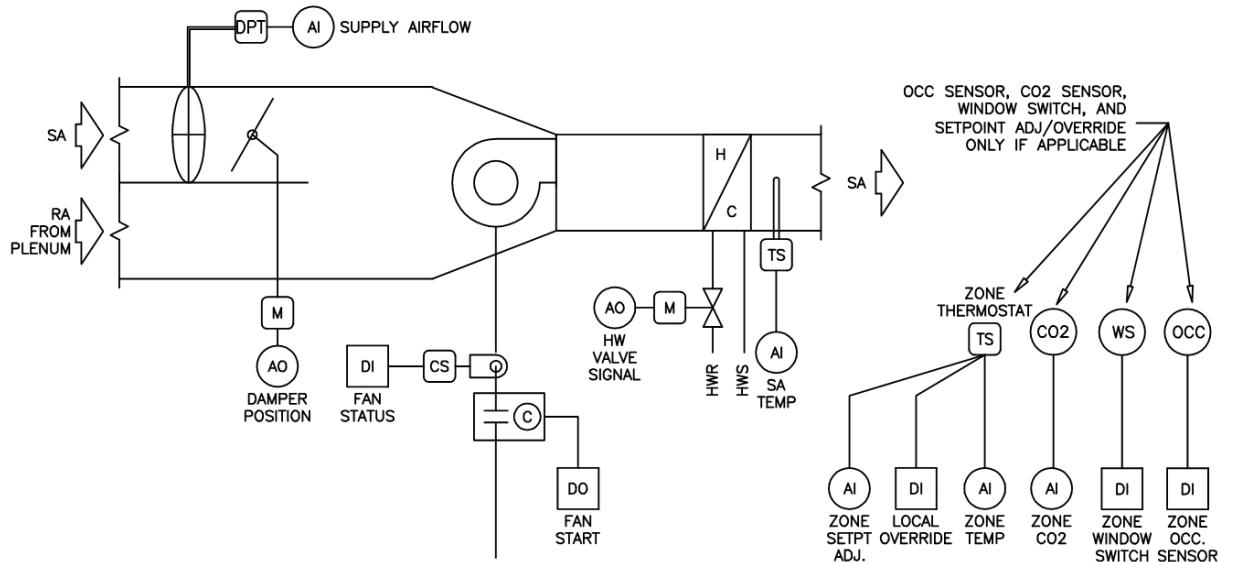


Figure A-5 Series fan-powered terminal unit, constant volume fan.

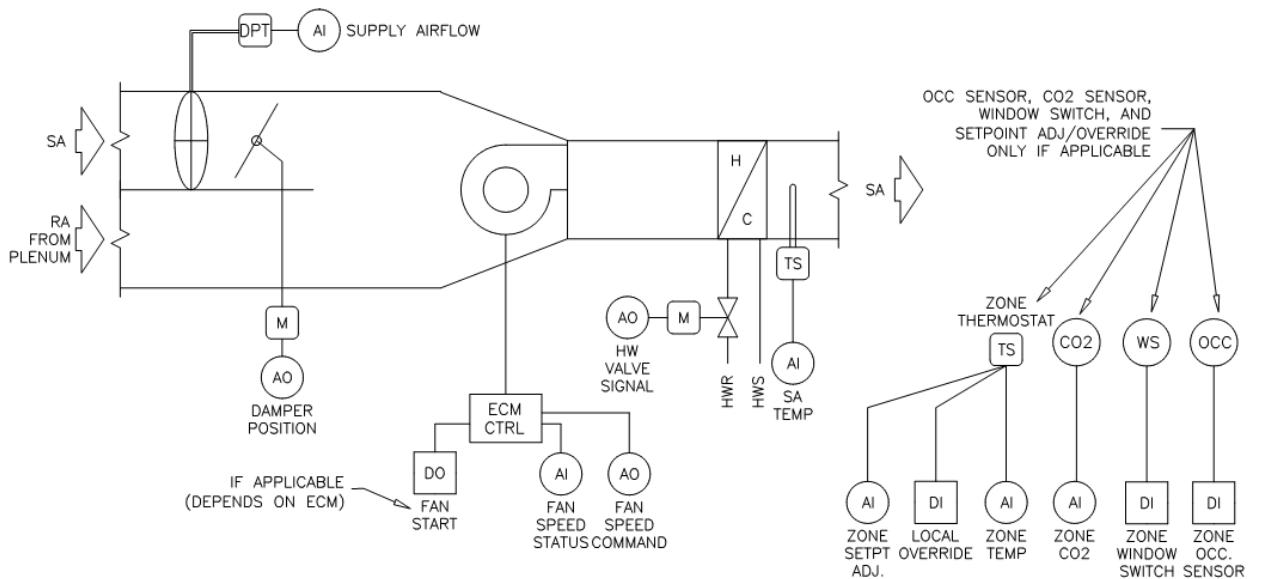


Figure A-6 Series fan-powered terminal unit, variable volume fan.

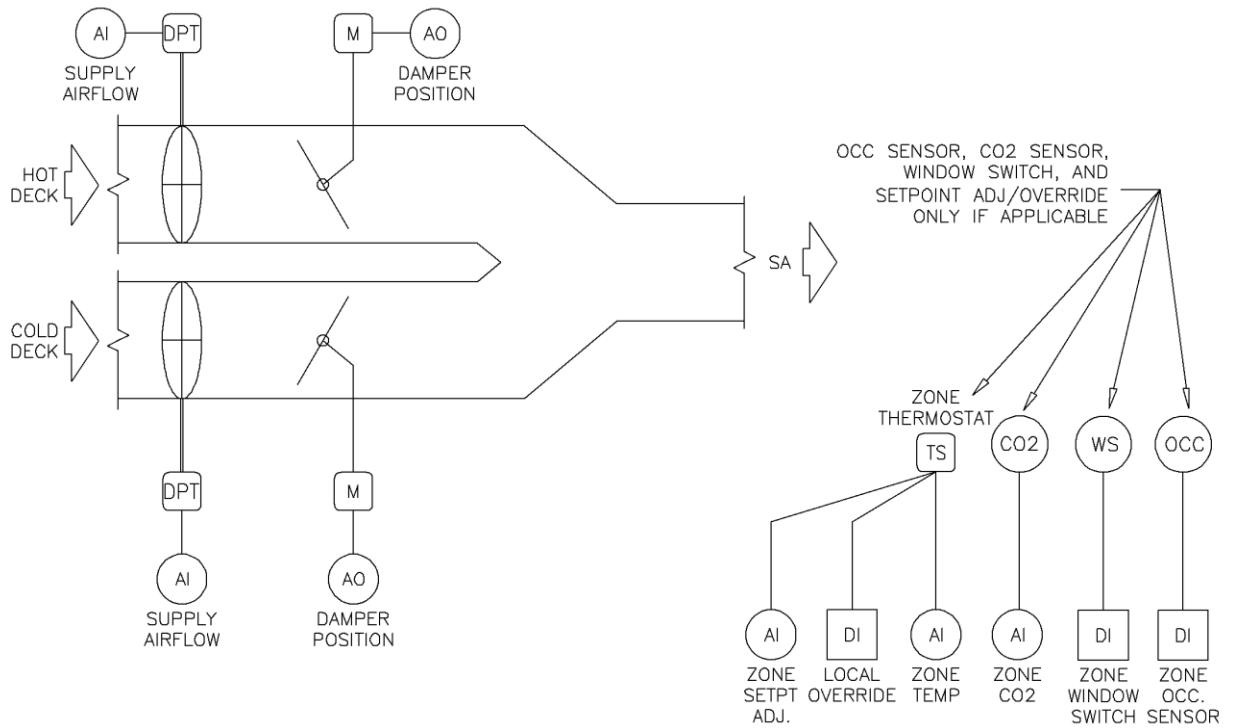


Figure A-7 Dual duct terminal unit with inlet sensors.

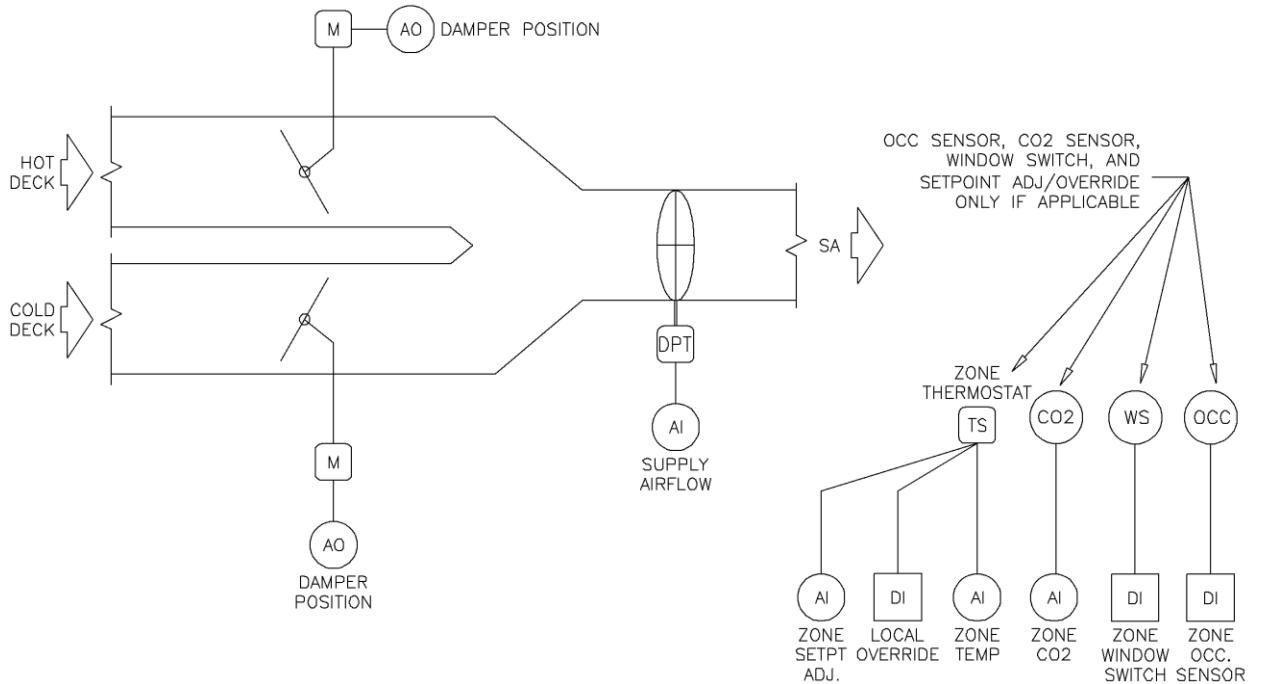


Figure A-8 Dual duct terminal unit with discharge sensor.

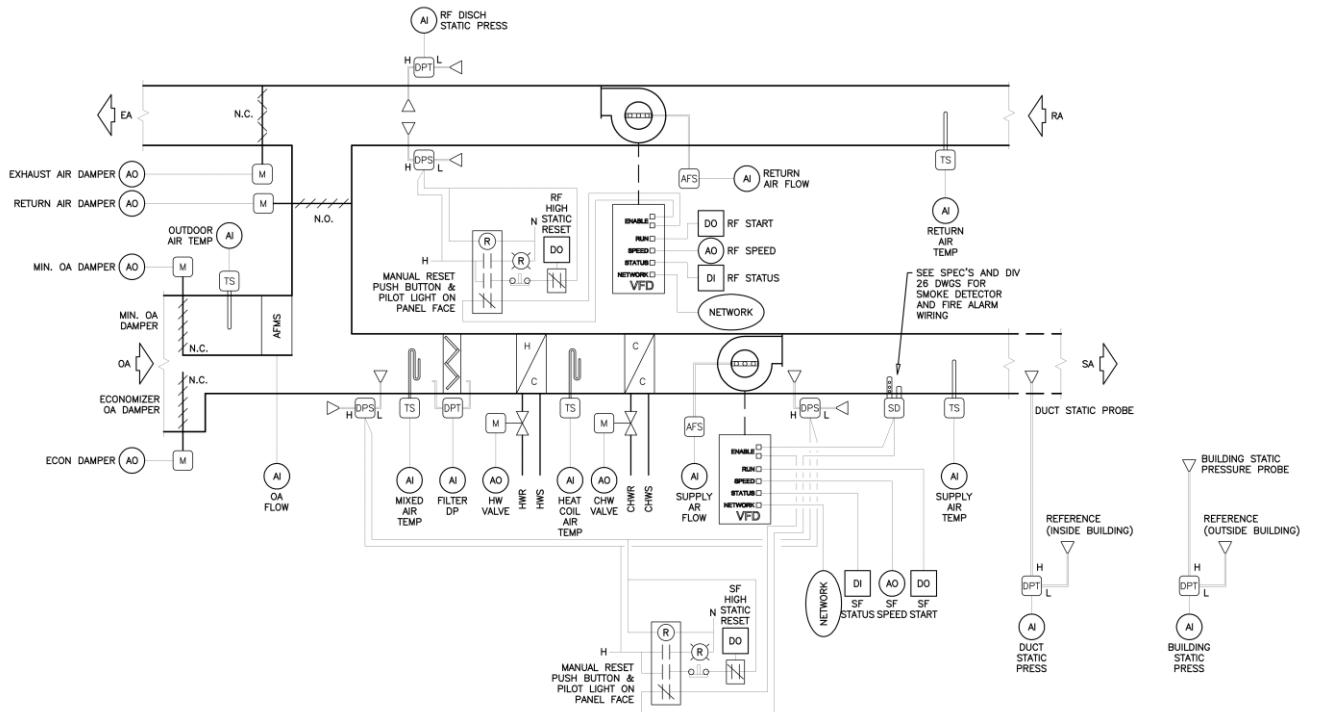


Figure A-9 Multiple zone VAV air handling unit with return fan and OA measurement station.

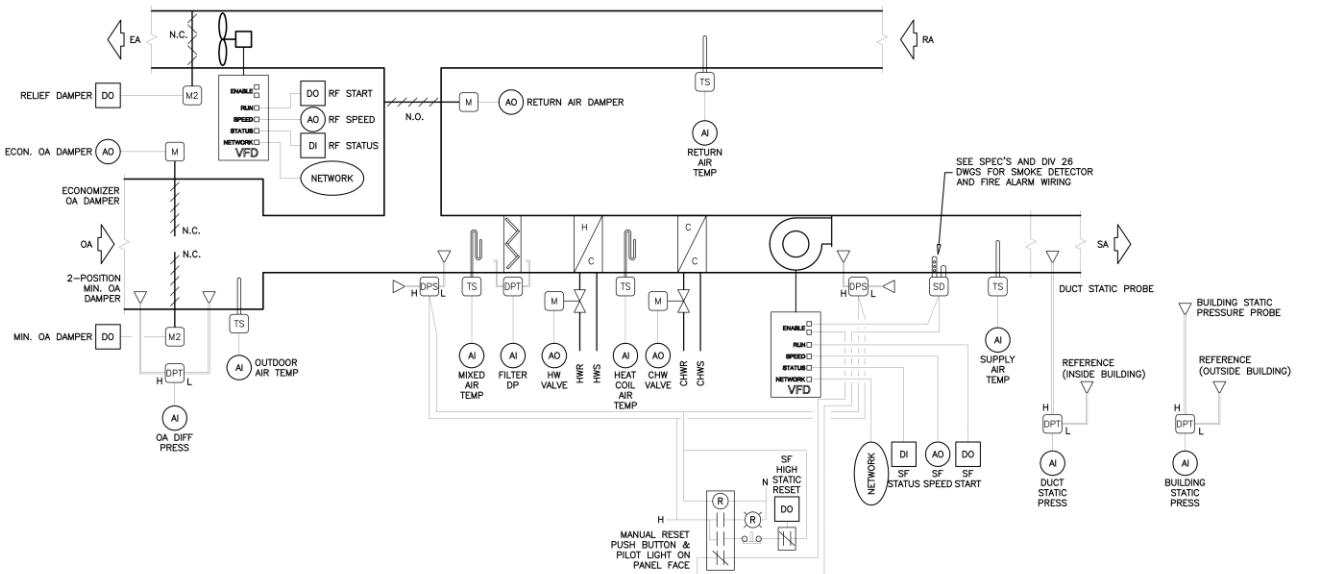


Figure A-10 Multiple zone VAV air handling unit with relief fan & differential pressure OA measurement.

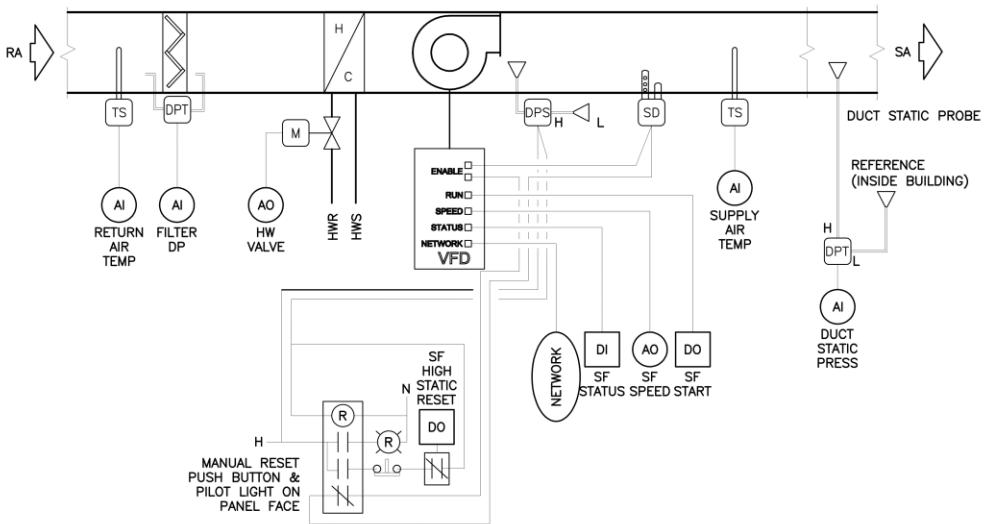


Figure A-11 Dual fan dual duct heating VAV air handling unit.

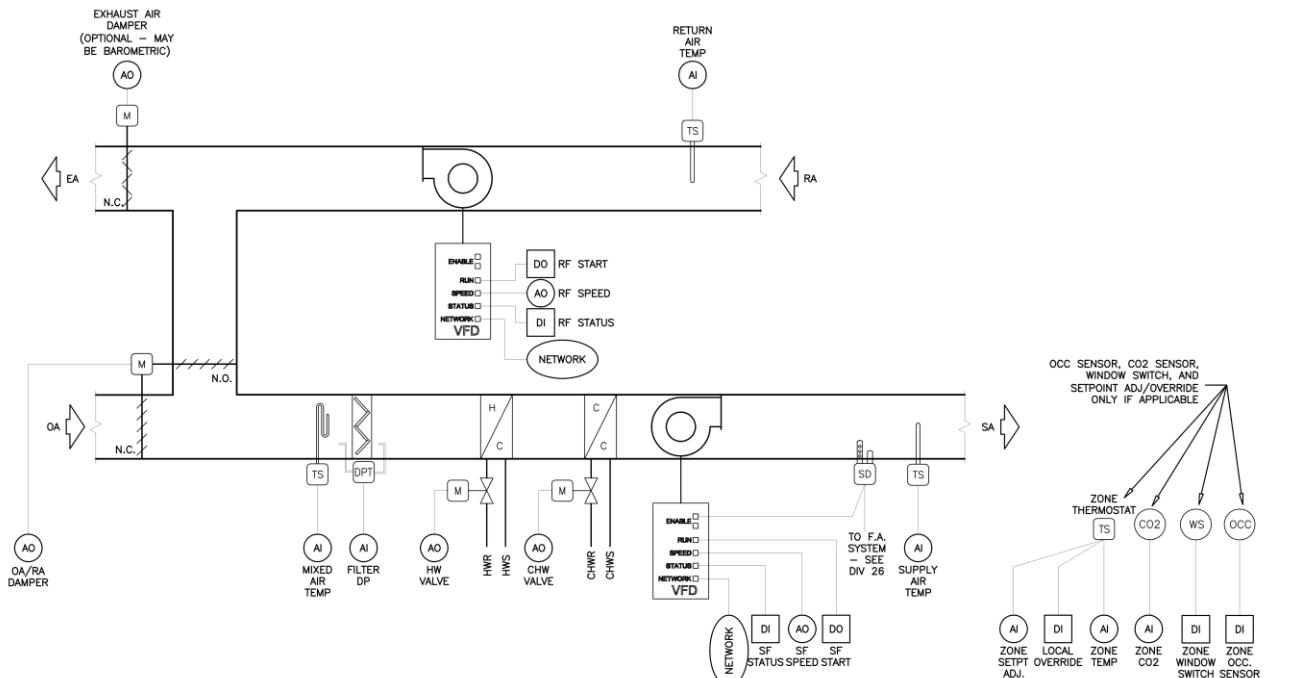


Figure A-12 Single zone VAV air handling unit (return fan option).

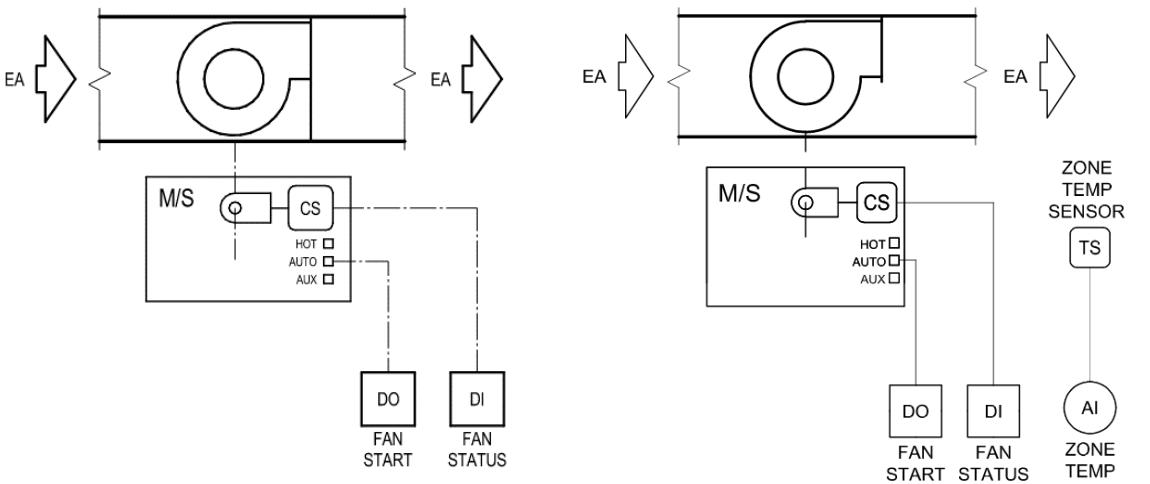


Figure A-13 Constant speed exhaust fan with or without zone temperature sensor.

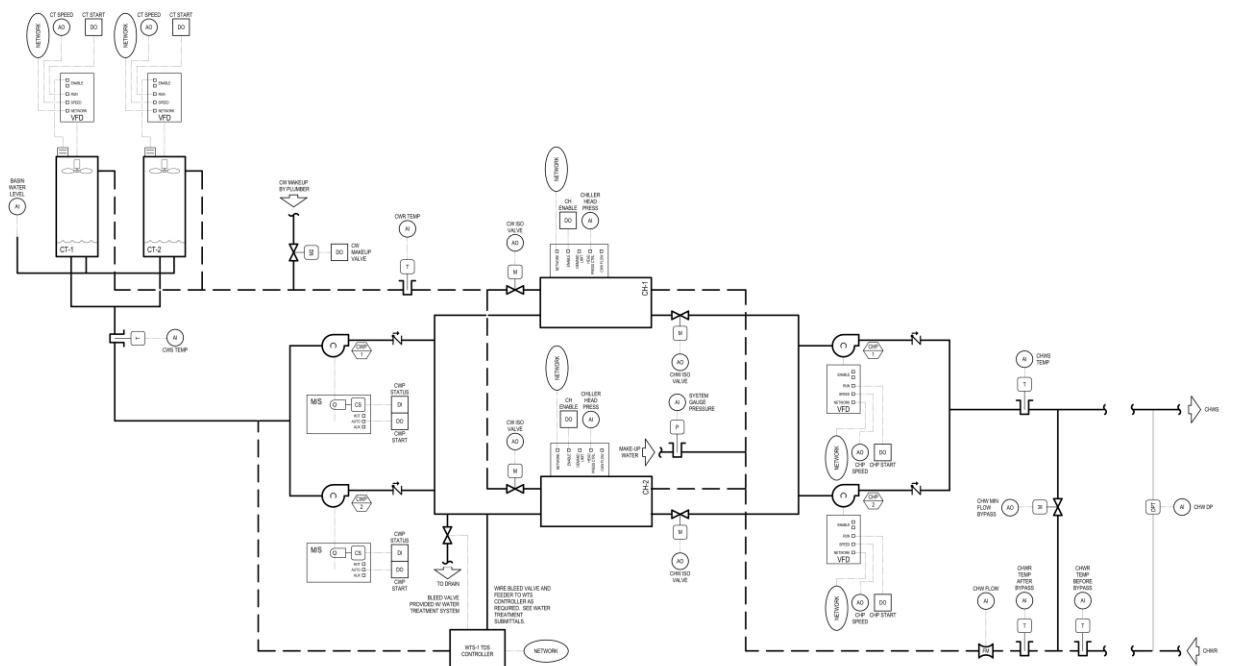


Figure A-14 Chilled water plant with parallel chillers, variable primary distribution, constant speed CW pumps, and headered pumps.

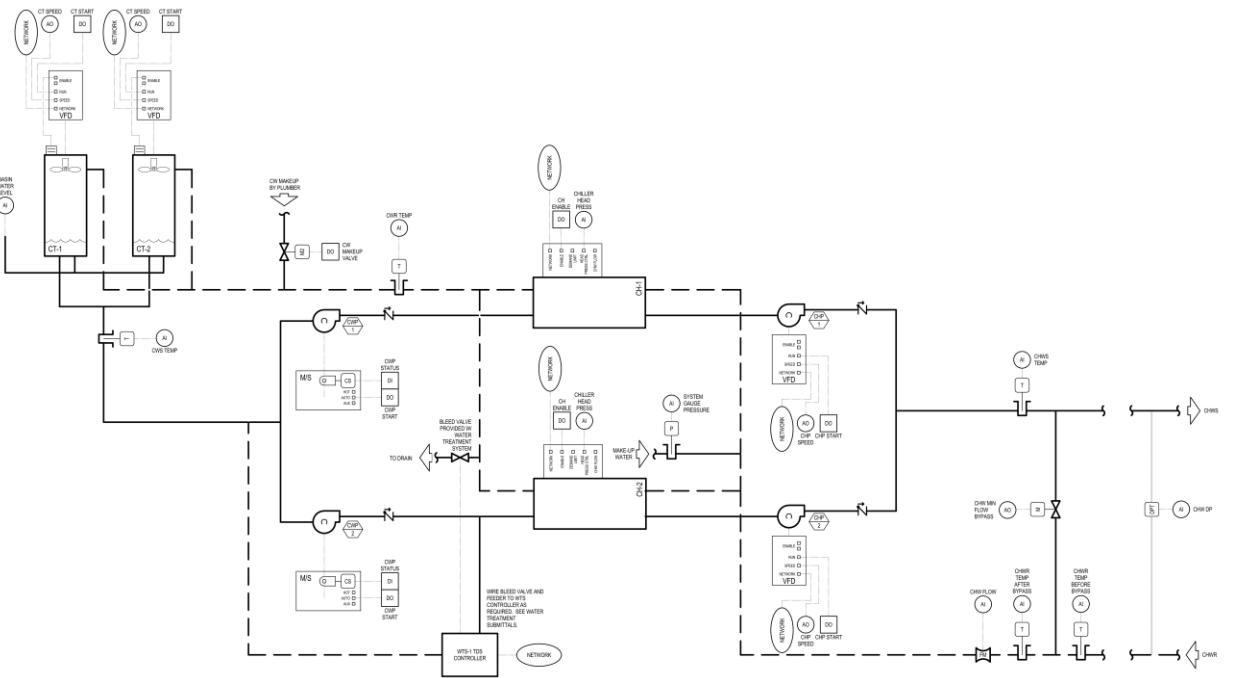


Figure A-15 Chilled water plant with parallel chillers, variable primary distribution, constant speed CW pumps, and dedicated pumps.

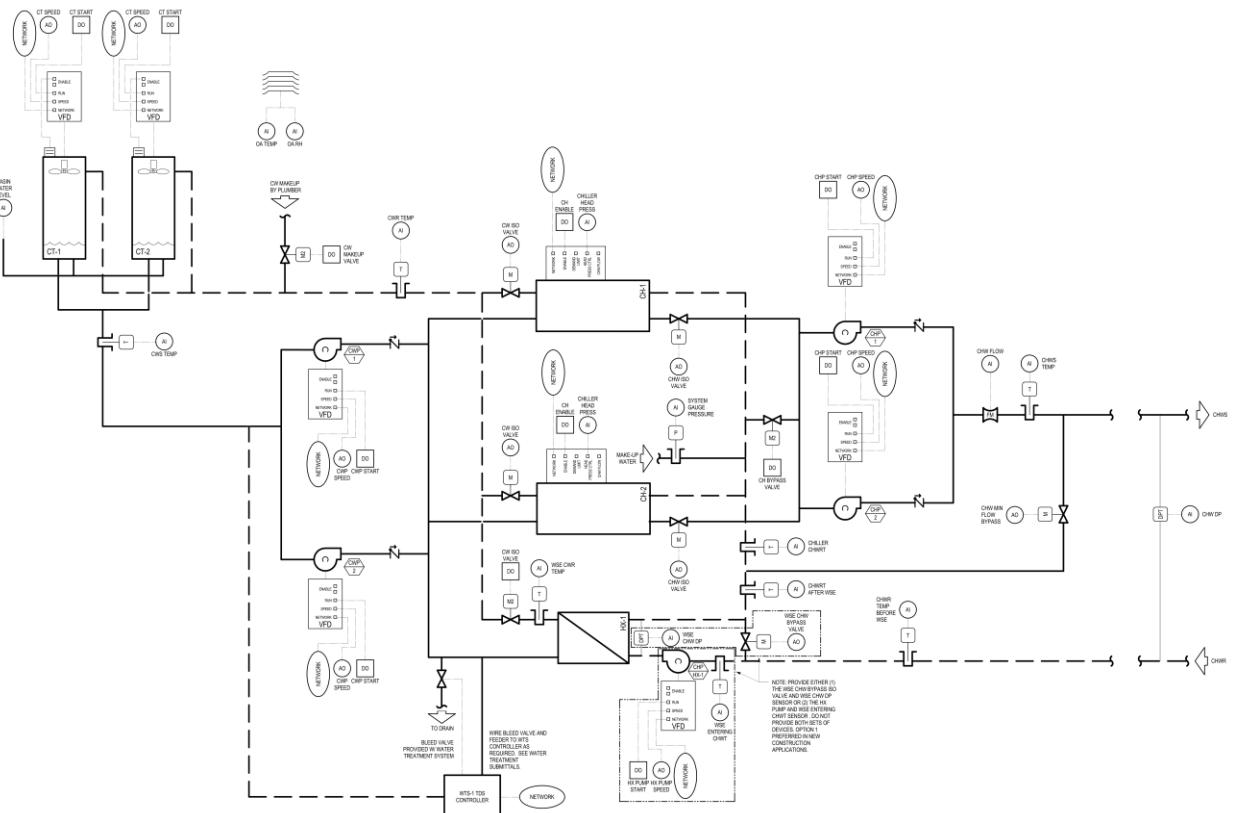


Figure A-16 Chilled water plant with parallel chillers and WSE, variable primary distribution, variable speed CW pumps, and headered pumps.

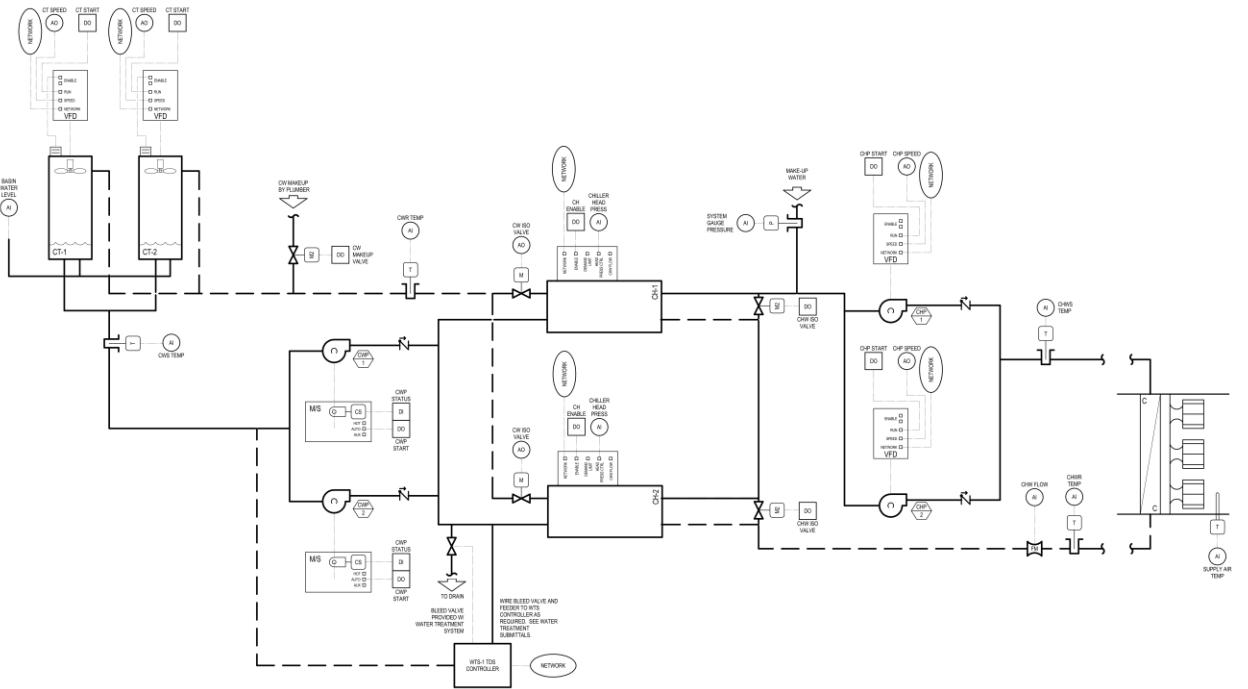


Figure A-17 Chilled water plant with series chillers, constant primary distribution, constant speed CW pumps, and headered pumps.

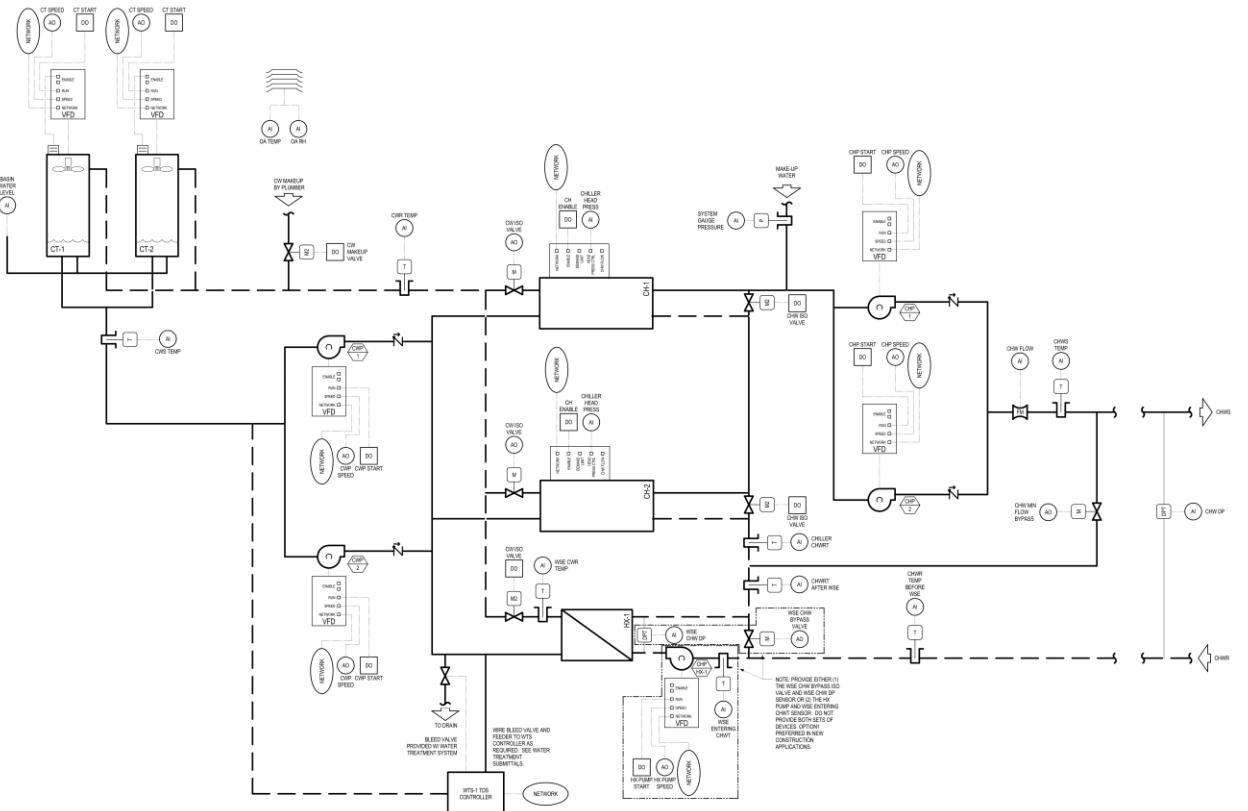
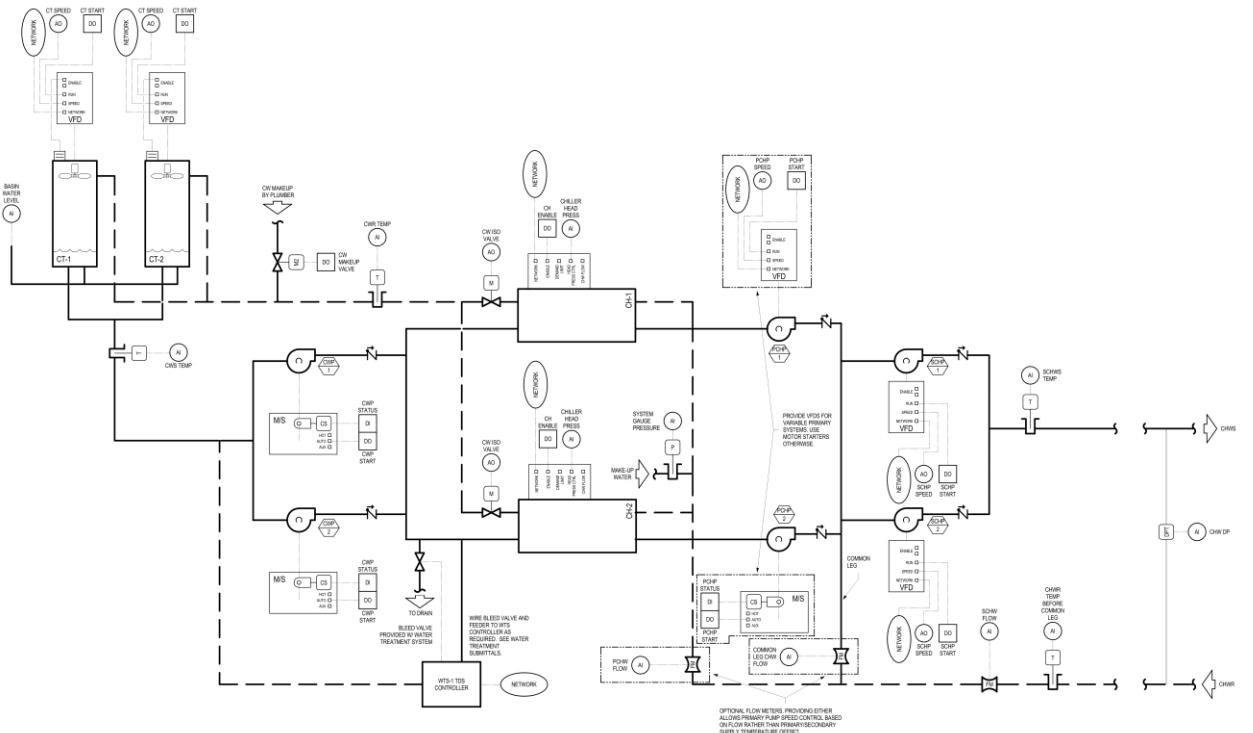


Figure A-18 Chilled water plant with series chillers and WSE, variable primary distribution, variable speed CW pumps, and headered pumps.



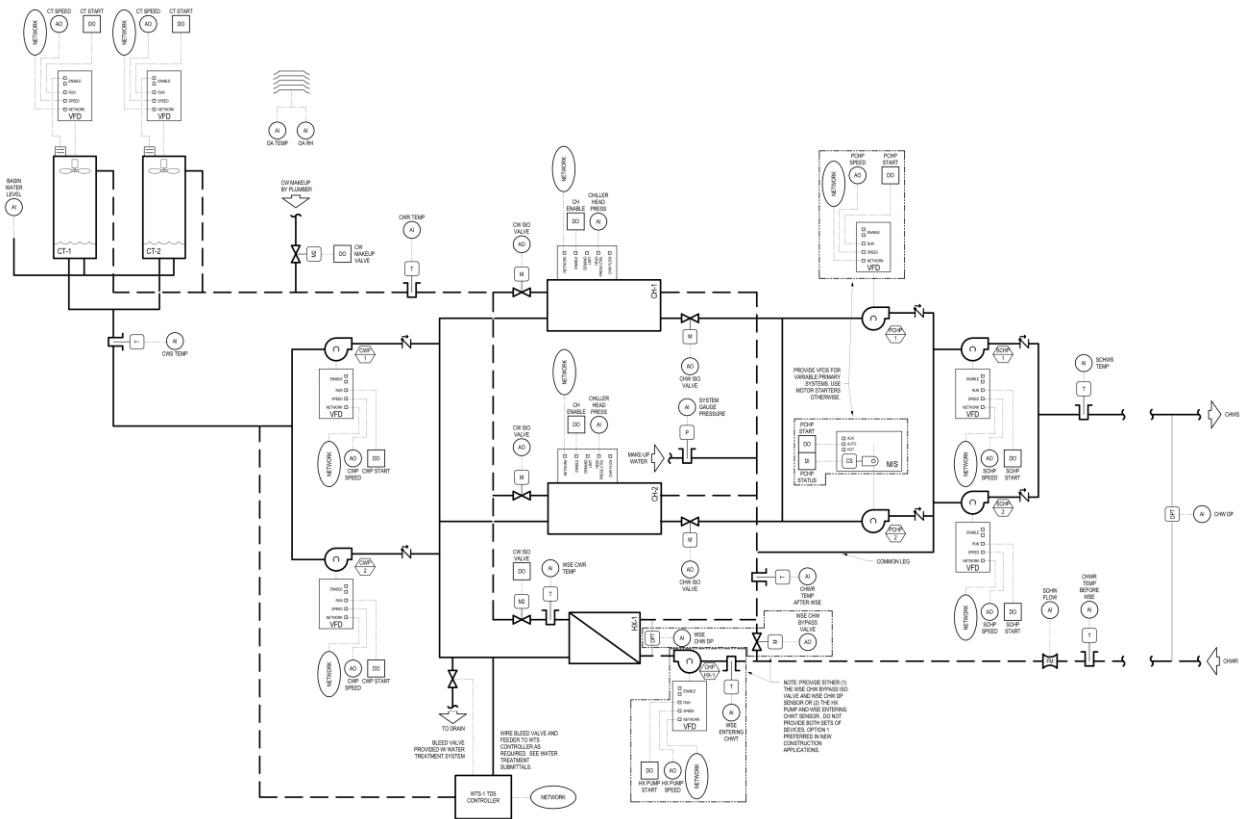


Figure A-21 Chilled water plant with parallel chillers and WSE, primary-secondary distribution, variable speed CW pumps, and headered pumps.

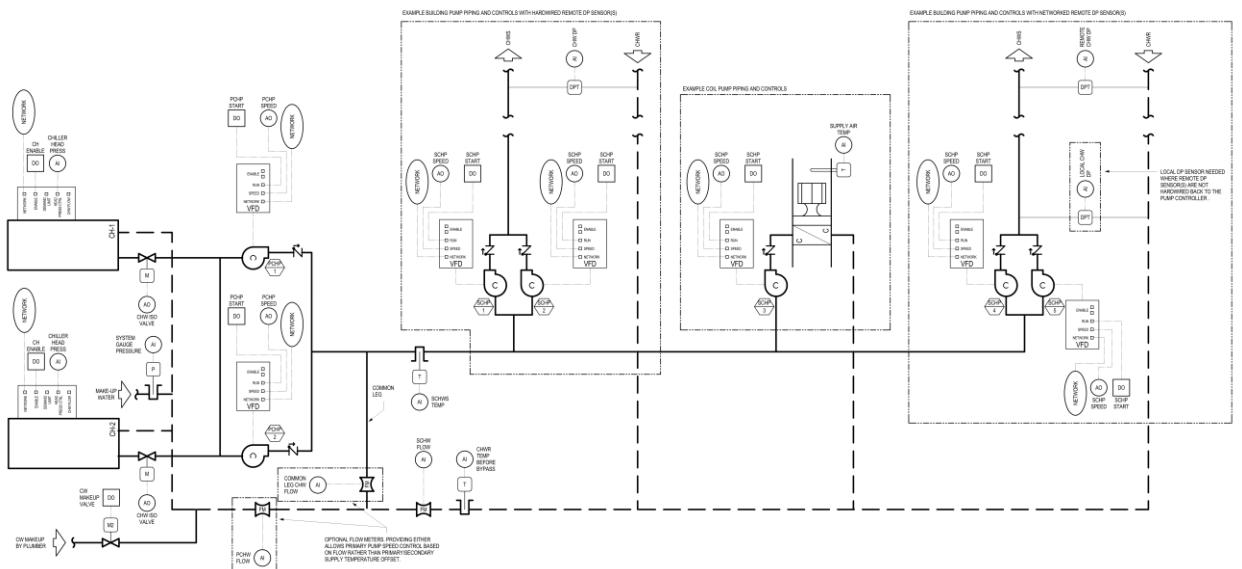


Figure A-22 Chilled water plant with parallel chillers, primary-distributed secondary distribution (CHW side only).

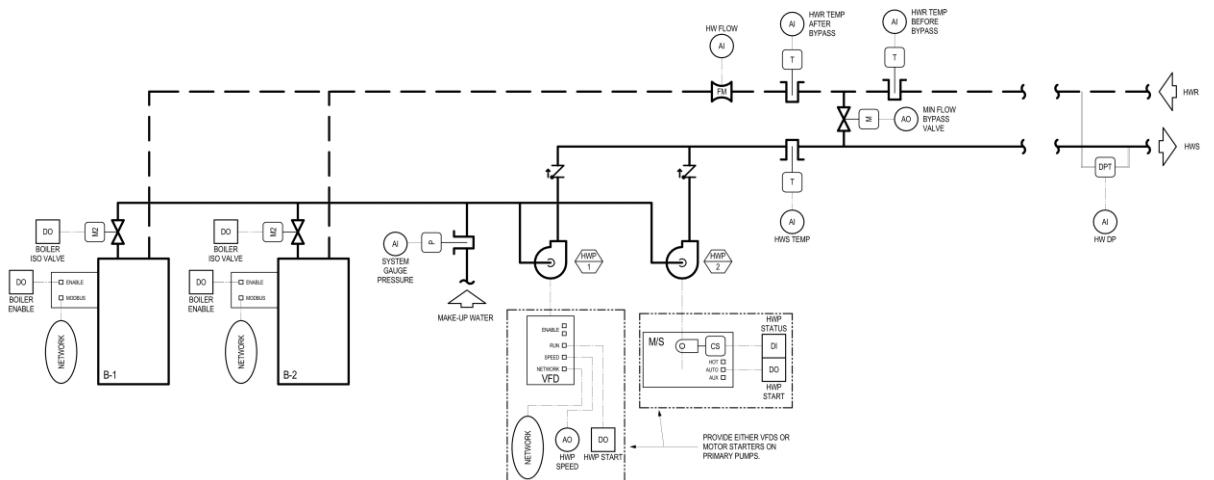


Figure A-23 Hot water plant with condensing boilers, variable primary distribution, and headered pumps.

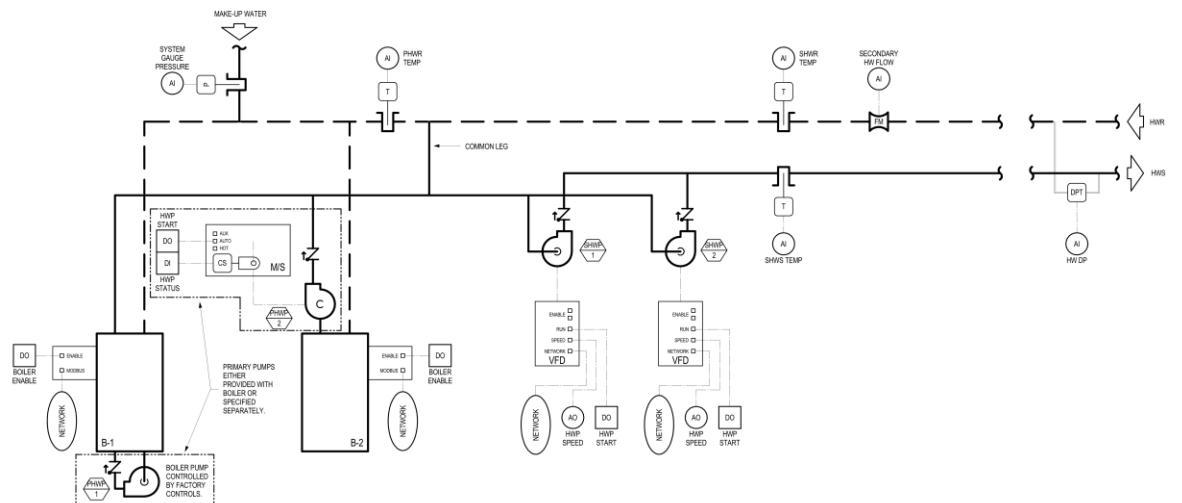


Figure A-24 Hot water plant with non-condensing boilers, primary-secondary distribution, and dedicated primary pumps.

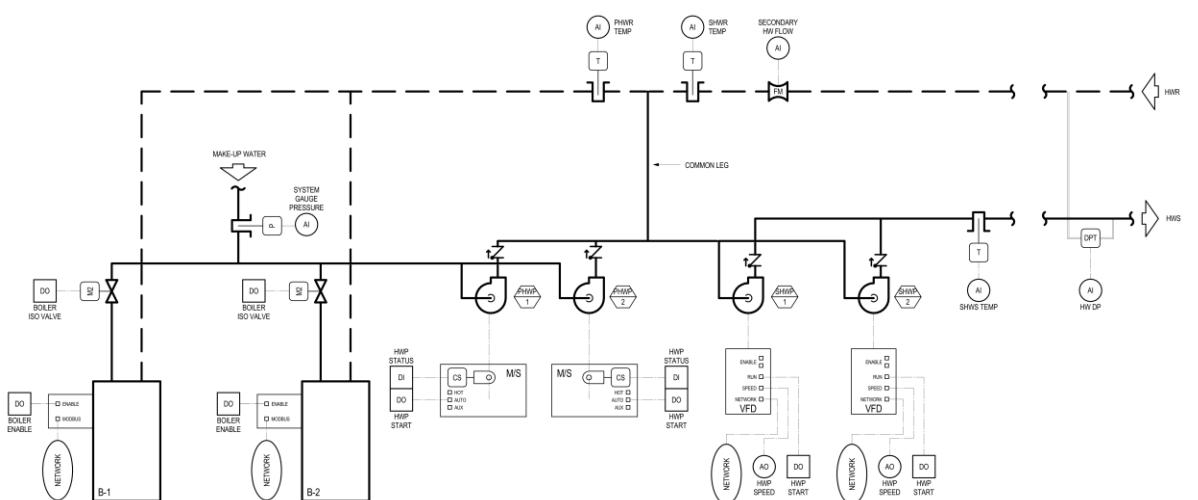


Figure A-25 Hot water plant with non-condensing boilers, primary-secondary distribution, and headered primary pumps.

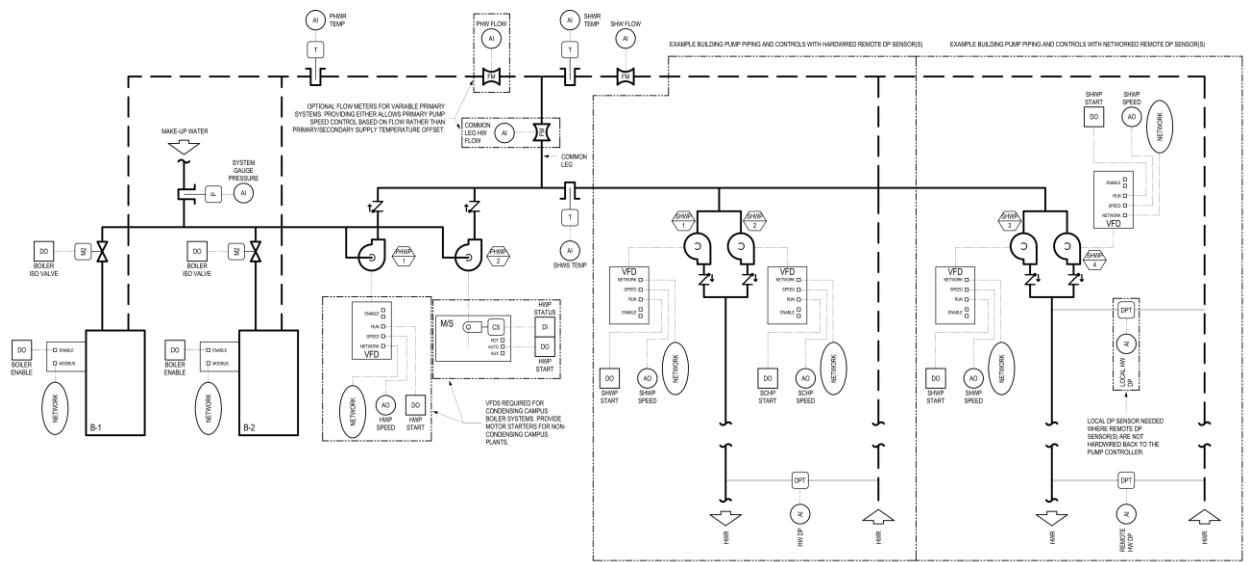


Figure A-26 Hot water plant with non-condensing or condensing boilers, primary-distributed secondary distribution, and headered primary pumps.

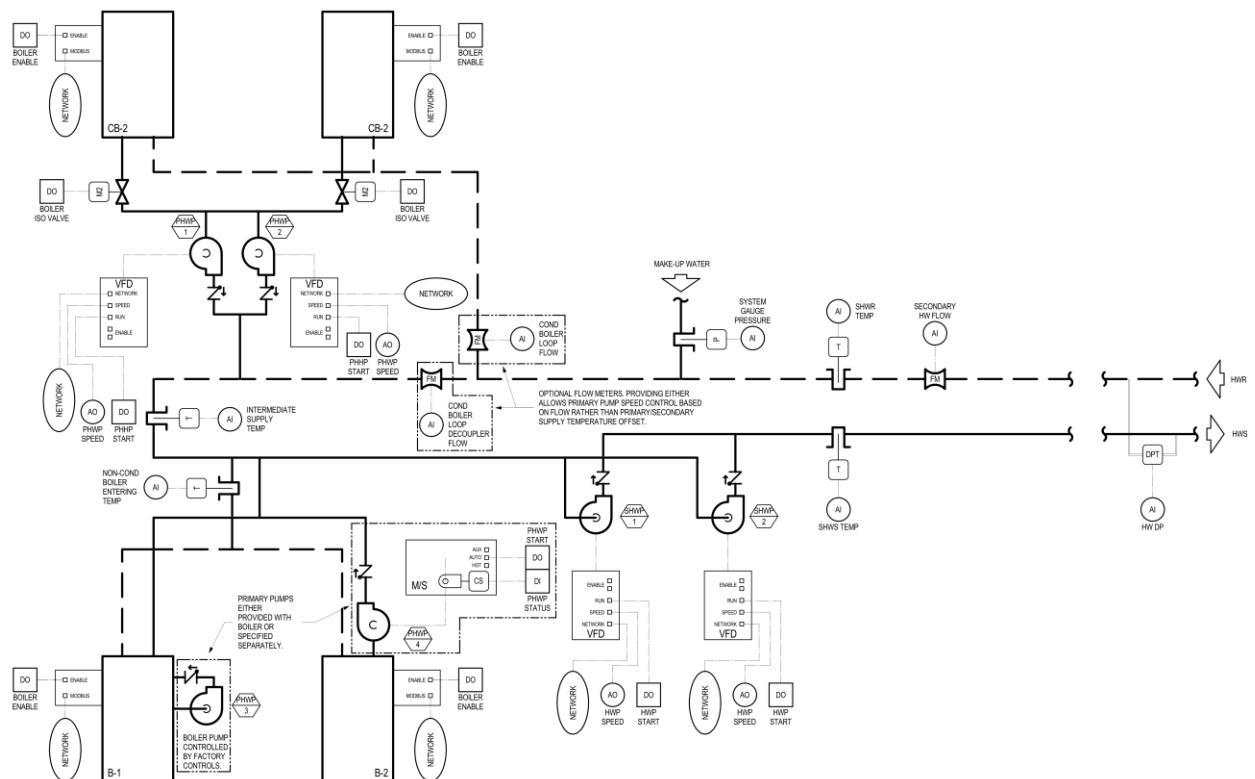


Figure A-27 Hot water plant with non-condensing and condensing boilers (hybrid plant) and separate non-condensing and condensing primary loops.

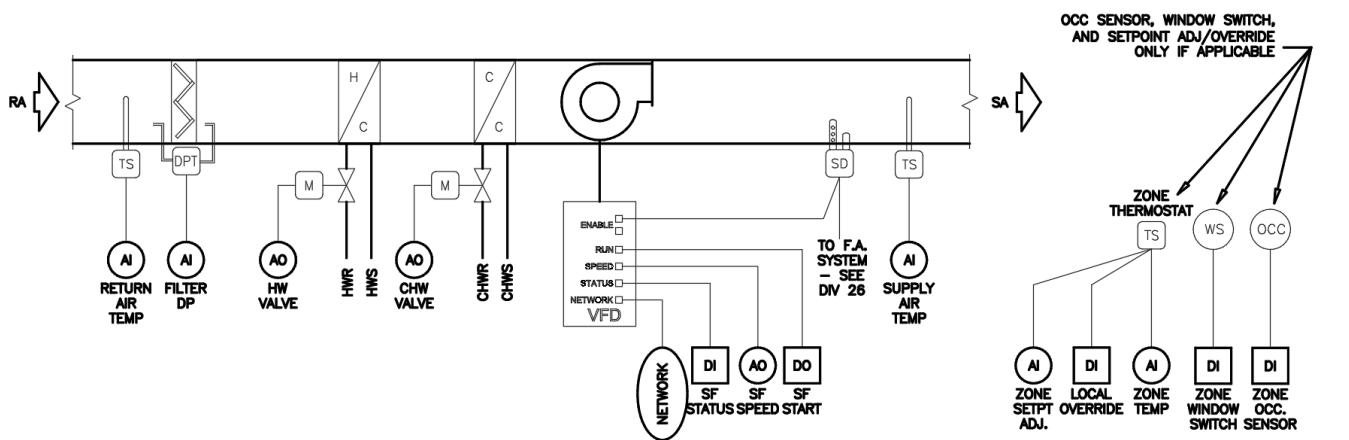


Figure A-28 Fan Coil Unit with variable volume fan, heating, and cooling coils .

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX B ABBREVIATIONS AND ACRONYMS

AFDD	automatic fault detection and diagnostics
AFMS	airflow measuring station
AHU	air-handling unit
AI	analog input
AO	analog output
BAS	building automation system
BI	binary input
BO	binary output
CC	cooling coil
CCET	cooling-coil entering temperature
CCLT	cooling-coil leaving temperature
CHW	chilled water
CxA	commissioning authority
DAT	discharge air temperature
DCV	demand-controlled ventilation
DD	dual duct
DFDD	dual fan dual duct
DI	digital input
DO	digital output
DP	differential pressure
DSP	duct static pressure
DSPSP	duct static pressure setpoint
DX	direct expansion
ECM	electronically commutated motor
FC	fault condition
FCU	fan coil unit
FS	fan speed
FSD	fire/smoke damper
HC	heating coil
HCET	heating-coil entering temperature
HCLT	heating -coil leaving temperature
HOA	hand-OFF-auto
HVAC	heating, ventilating, and air conditioning
HW	hot water
MA	mixed air
MAT	mixed air temperature
OA	outdoor air
OAT	outdoor air temperature
OS	operating state
PID	proportional-integral-derivative

RA	return air
RAT	return air temperature
SA	supply air
SAT	supply air temperature
SATSP	supply air temperature setpoint
SZ	single-zone
SZAV	single-zone variable-air-volume
T&R	Trim & Respond
TAB	testing, adjusting, and balancing
VAV	variable-air volume
VFD	variable-frequency drive

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX C ADDENDA DESCRIPTION

ASHRAE Guideline 36-2021 incorporates ASHRAE Guideline 36-2018 and Addenda a, b, c, d, e, f, g, h, i, j, l, o, p, q, r, s, t, u, v, w, x, y, and z to ASHRAE Guideline 36-2018. Table C-1 lists each addendum and describes the way in which the standard is affected by the change. It also lists the ASHRAE approval dates for each addendum.

Table C-1 Addenda Description Table

Addendum	Section(s) Affected	Description of Change	ASHRAE Approval Date
a	5.1.16	Moves Section 5.1.16 under Section 3 and assign the task of determining the controllable minimums to the appropriate knowledgeable control contractor. Deletes Option 1 because it is not reliable. Improves explanation of how to determine the minimum controllable velocity pressure using multiple sources, including an informative reference to ASHRAE Standard 195.	August 16, 2019
b	5.1.14.4; Table 5.1.14.3; Figure 5.1.14.4	Replaces the current version of control for Trim & Respond (Section 5.1.14) so that trimming does not occur each timestep.	August 16, 2019
c	5.1.13.2	Revises VFD minimum speed read/write to reduce network traffic and reduce write cycles to nonvolatile memory in VFDs.	August 16, 2019
d	3.2.2.5; 5.2.2, 5.6.3, 5.6.6	Updates description of the minimum heating airflow setpoint Vheat-min for consistency among variables (Section 3.2.2.5). Revises damper control paragraph under Time-Averaged Ventilation (Section 5.2.2). Adds missing reference to Vheat-min (Section 5.6.3). Adds missing damper control sequence to VAV Terminal Units with Reheat (Section 5.6.6). Addresses various issues in the affected sections. (Refer to Addendum d for details).	August 16, 2019
e	3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4, 3.1.2.5, 3.1.2.6, 3.1.2.7; 5.2.1.3, 5.2.1.4, 5.16.3.1	Implements changes made by Addendum f to Standard 62.1-2016 and Addendum au to Standard 90.1-2016 to allow minimum rates to be calculated automatically from zone occupant-based and area-based ventilation rates. Contains clarifications and bug fixes regarding Vbz-A* and Vbz-P*, which were not properly referenced in Section 5.16.3.1.	August 16, 2019
f	3.2.1.5; 5.16.11, 5.16.11.1, 5.16.11.2, 5.16.11.3, 5.16.11.4 (new)	Addresses two issues related to AHU return fan speed logic in Section 5.16.11.2 by assuming the amount of air needed for pressurization is proportional to the area-component of the ventilation rate. (Refer to Addendum f for more detailed description).	January 27, 2020
g	3.1.4.4, 3.1.5.2, 3.1.6.3; 4.8; 5.1.12.3, 5.1.12.5, 5.1.12.6, 5.1.12.7, 5.3.6.1, 5.5.7, 5.6.6, 5.7.6, 5.8.6, 5.9.6, 5.10.6, 5.11.6, 5.12.6,	Removes option to make all alarms configurable as latching or nonlatching. Removes generic entry delays. Moved entry delays to each alarm instance. Updates post-exit suppression timer initiation point from alarm entry to alarm exit. Removes resets for exit deadband and postexit suppression delays upon alarm acknowledgement. Reduces alarm levels for zone high/low zone temperature alarms from Levels 2 and 3 to Levels 3 and 4. Reduces alarm levels for low primary airflow alarms from Levels 2 and 3 to Levels 3 and 4.	January 27, 2020

Table C-1 Addenda Description Table

Addendum	Section(s) Affected	Description of Change	ASHRAE Approval Date
	5.13.6, 5.14.6, 5.16.13.3, 5.17.3.3, 5.17.3.4, 5.17.3.5, 5.18.12, 5.18.12.3	Reduces alarm levels for low discharge air temperature alarms from Levels 2 and 3 to Levels 3 and 4. Extends VAV airflow sensor calibration alarm delay from 10 to 30 minutes; adds an additional constant value threshold as a qualifier to initiate the alarm. Adds an additional constant-value threshold as a qualifier to initiate leaking damper alarms. Extends VAV low airflow alarm delays from 5 to 10 minutes. Adds filter high-limit differential pressure at design airflow (DP100) to the AHU sections for information provided by the designer. Adds additional qualifiers for filter differential pressure alarms to reduce nuisance alarms. Adds filter differential pressure point and alarm to single-zone VAV air-handling units. Addresses various issues in the affected sections. (Refer to Addendum g for details).	August 24, 2020
h	5.5 through 5.14; Figures 5.5.5 through 5.14.5	Updates airflow setpoint tables in Sections 5.5 through 5.14. Updates control logic Figures 5.5.5 through 5.14.5 to be consistent with updated airflow setpoint tables. Corrects Figure 5.13.5 for consistency with Section 5.13. Updates control logic descriptions in Sections 5.5 through 5.14 to match updated terms. For Dual Duct VAV Terminal Unit—Mixing Control with Discharge Airflow Sensor, removed hot duct static pressure reset requests based on airflow setpoint (Sections 5.13.8.4.1 and 5.13.8.4.2). For Dual Duct VAV Terminal Unit—Mixing Control with Discharge Airflow Sensor, changed the setpoint of the reverse-acting P-only maximum hot duct damper position limiting loop from Vheat-max to the heating maximum endpoint, which changes based on Zone Group Mode (Section 5.13.1.3[b]). Addresses various issues in the affected sections. (Refer to Addendum h for details).	August 24, 2020
i	5.10.5.1; Figure 5.10.5	Revises the way the variable-speed series fan is controlled.	January 27, 2020
j	3.1.1.2(b); 5.2.1.4	Revises the zone ventilation control logic in Sections 5.2.1.4 for projects that are to comply with the ventilation control requirements in the California Title 24 Building Energy Efficiency Standards, in order to make the logic consistent with changes to the 2019 version of Title 24. Section 3.1.1.2(b) is also revised to add an additional requirement for the designer to indicate which zones are to employ occupied-standby mode.	January 27, 2020
l	3.1.6.1, 3.1.6.2, 3.1.6.3, 3.2.2.1 through 3.2.2.4, 3.2.2.5 (new); 4.8; 5.18.6, 5.18.6.1, 5.18.6.2, 5.18.6.3 (new), 5.18.8 through 5.18.11	Adds option for using an airflow monitoring station for single zone air handling units. Renames variable S-R-DIFF to S-R-SPD-DIFF to avoid confusion with a variable with the same name and different unit of measurement used in the sequence for multiple zone VAV air handling units. Adds dynamic reset to return fan speed tracking offset, S-R-SPD-DIFF to reduce the excess outdoor air brought through the exhaust air damper when the minimum outdoor airflow setpoint, MinOA _{Sp} , is zero. Relocates ventilation setpoint determination from the “Information provided by (or in conjunction with) the Test & Balance Contractor” section to the “Information provided by the designer” section. Adds equations for determination of the minimum outdoor air damper position, MinOA-P, to avoid misinterpretation. Adds option for direct building pressure control with return fans.	August 24, 2020
o	4.9 (new); 5.18 (new); Figure A-13 (new)	Adds a sequence for general constant speed exhaust fans, which allows interlocked control based on Zone Group Mode or zone temperature regulation.	August 24, 2020

Table C-1 Addenda Description Table

Addendum	Section(s) Affected	Description of Change	ASHRAE Approval Date
p	3.1.3	Includes assignment of miscellaneous equipment (i.e., exhaust fans) to Zone Groups allowing for interlocking of equipment based on Zone Group Mode.	August 24, 2020
q	3.1.9 (new); 3.2.5 (new); 4.12 (new); 5.22 (new); Appendix A; Appendix B	Includes control sequences for 2-pipe heating, 2-pipe cooling, and 4-pipe heating/cooling fan-coil units (FCUs). It assumes the fan is variable speed but the sequences will still work with constant speed fans.	July 9, 2021
r	5.1.15, 5.16.9.1	Includes the lead/lag and lead/standby equipment rotation sequences developed as part of ASHRAE Research Project 1711: Advanced Sequences of Operation for HVAC Systems—Phase II Central Plants and Hydronic Systems.	February 24, 2021
s	5.16.2.3, 5.16.4.4, 5.16.5.3, 5.16.5.4, 5.16.6.3, 5.16.7, 5.16.10, 5.16.11.3, 5.16.11.5	Resolves the issues related to minimum outdoor airflow control for multiple zone air handling units with return fans. Provides clarification on building pressure control for return fans and adds informative text for the designer with respect to defining pressure zones.	February 24, 2021
t	5.16.9	Clarifies that a single building pressure loop should be used for each pressure zone. Provides direction on which building pressure sensor(s) to use as the control loop input and provides options for relief fans that do not share a common relief fan inlet plenum. Informative text is added to remove Stage 0 (barometric) relief if the return air pressure drop is high.	February 24, 2021
u	5.16.14, 5.17.4.5, 5.17.4.10, 5.18.14,	Includes edits to the automatic fault detection and diagnostics sections. AHU operating state tables and figures for return fan systems, which were previously missing, have been added. Fault Condition #1 has been updated to use DSPavg instead of DSP for consistency. A directive has been added to delete Fault Condition #7 if there is no heating coil. Fault Condition #12 has been expanded to include operating state, OS#2, as supply air temperature should be less than or equal to mixed air temperatures when in economizer.	March 30, 2021
v	3.1.4 (new); 5.16.9.1 (new); 5.16.10.1 (new)	Adds pressure zone group assignments to Section 3.1 Information Provided by the Designer. Pressure zone group assignments are added to provide direction on which relief/return fans and building pressure sensors to group together for direct building pressure control options.	February 24, 2021
w	5.2.1.4(d)(3)(vi), 5.18.8	Resolves inconsistencies between variable names used in Section 3.1.6.2 (Information Provided by Designer) and Section 5.2.1.4 for Single Zone Air Handling Units. Fixes a reference to MinoOAP* in Section 5.18.8.3 to ensure the sequence works regardless of minimum outdoor airflow control approach (with or without an airflow monitoring station) and adds an option for direct building pressure control with actuated relief dampers without fans.	February 24, 2021
x	(Refer to Addendum X)	Includes the CHW plant sequences and associated logic variables and hardwired control points developed as part of ASHRAE Research Project 1711: Advanced Sequences of Operation for HVAC Systems – Phase II Central Plants and Hydronic Systems. Corrects typos and minor language clarity issues.	July 9, 2021

Table C-1 Addenda Description Table

Addendum	Section(s) Affected (Refer to Addendum y)	Description of Change	ASHRAE Approval Date
y		Includes the HW plant sequences and associated logic variables and hardwired control points developed as part of ASHRAE Research Project 1711: Advanced Sequences of Operation for HVAC Systems – Phase II Central Plants and Hydronic Systems. Corrects typos and minor language clarity issues.	July 9, 2021
z	3.1.2.1; 5.5.3, 5.5.4, 5.5.5	Allows cooling-only terminal units to provide heating in occupied, warm-up, and setback modes if the air handling unit supply air temperature is greater than room temperature.	July 9, 2021

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

ASHRAE · 180 Technology Parkway NW · Peachtree Corners, GA 30092 · www.ashrae.org

About ASHRAE

Founded in 1894, ASHRAE is a global professional society committed to serve humanity by advancing the arts and sciences of heating, ventilation, air conditioning, refrigeration, and their allied fields.

As an industry leader in research, standards writing, publishing, certification, and continuing education, ASHRAE and its members are dedicated to promoting a healthy and sustainable built environment for all, through strategic partnerships with organizations in the HVAC&R community and across related industries.

To stay current with this and other ASHRAE Standards and Guidelines, visit www.ashrae.org/standards, and connect on LinkedIn, Facebook, Twitter, and YouTube.

Visit the ASHRAE Bookstore

ASHRAE offers its Standards and Guidelines in print, as immediately downloadable PDFs, and via ASHRAE Digital Collections, which provides online access with automatic updates as well as historical versions of publications. Selected Standards and Guidelines are also offered in redline versions that indicate the changes made between the active Standard or Guideline and its previous edition. For more information, visit the Standards and Guidelines section of the ASHRAE Bookstore at www.ashrae.org/bookstore.

IMPORTANT NOTICES ABOUT THIS GUIDELINE

To ensure that you have all of the approved addenda, errata, and interpretations for this Guideline, visit www.ashrae.org/standards to download them free of charge.

Addenda, errata, and interpretations for ASHRAE Standards and Guidelines are no longer distributed with copies of the Standards and Guidelines. ASHRAE provides these addenda, errata, and interpretations only in electronic form to promote more sustainable use of resources.