5.16.13.3 Filter pressure drop exceeds alarm limit: Level 4. The alarm limit shall vary with total airflow (if available; use fan speed if total airflow is not known) as follows:

$$DPx = DP100(x)^{1.4}$$

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 set point at 50% of design airflow would be $(0.5)^{1.4}$, or 38% of the design high-limit pressure drop.

5.16.13.4 High building pressure (more than 25 Pa [0.10 in. of water]): Level 3.

5.16.13.5 Low building pressure (less than 0 Pa [0.0 in. of water], i.e., negative): 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.

5.16.14.2 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 5.16.14.2 and Figure 5.16.14.2.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or zone group mode (occupied, warm-up, etc.).

OS#1 through OS#4 (see Table 5.16.14.2) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 5.16.14.6. 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 warm-up.

5.16.14.3 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 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.

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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 set point
g. DSPSP = duct static pressure set point
h. HC = heating-coil valve position command; 0% ≤ HC ≤ 100%
i. CC = cooling-coil valve position command; 0% ≤ CC ≤ 100%
j. FS = fan speed command; 0% ≤ FS ≤ 100%
k. CCET = cooling-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)
l. CCLT = cooling-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)
m. HCET = heating-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)
n. HCLT = heating-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

5.16.14.4 The following values must be continuously calculated by the AFDD routines for each AHU:

a. Five-minute rolling averages with 1-minute sampling time of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently.
   1. SATavg = rolling average of supply air temperature
   2. MATavg = rolling average of mixed air temperature
   3. RATavg = rolling average of return air temperature
   4. OATavg = rolling average of outdoor air temperature
   5. DSPavg = rolling average of duct static pressure
   6. CCETavg = rolling average of cooling-coil entering temperature
   7. CCLTavg = rolling average of cooling-coil leaving temperature
   8. HCETavg = rolling average of heating-coil entering temperature
   9. HCLTavg = rolling average of heating-coil leaving temperature

Table 5.16.4.2 VAV AHU Operating States

Operating State	Heating Valve Position	Cooling Valve Position	Outdoor Air Damper Position
#1: Heating	> 0	= 0	= min
#2: Free cooling, modulating OA	= 0	= 0	min < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= min
#5: Unknown or dehumidification	No other OS applies		

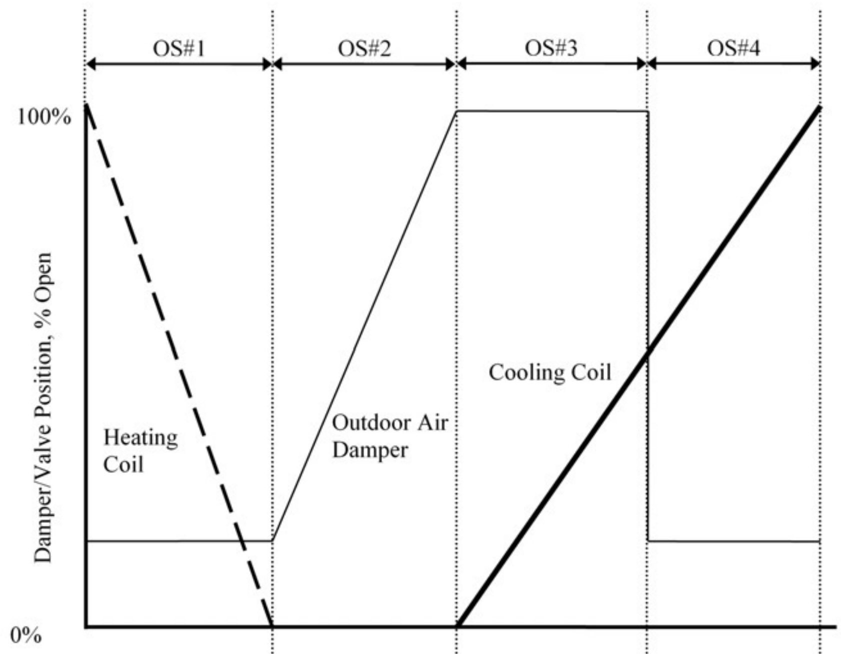

Figure 5.16.14.2 VAV AHU operating states.

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 set point (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)

5.16.14.5 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.

The purpose of $\Delta Tmin$ is to ensure that the mixing box/economizer damper tests are meaningful. These tests are based on the relationship between supply, return, and outdoor air. If RAT ≈ MAT, these tests will not be accurate and will produce false alarms.

The purpose of TestModeDelay is to ensure that normal fault reporting occurs after the testing and commissioning process is completed as prescribed in Section 5.16.14.12.

Table 5.16.14.5 VAV AHU AFDD Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	1°C (2°F)
ΔTmin	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10° F)
εSAT	Temperature error threshold for SAT sensor	1°C (2°F)
εRAT	Temperature error threshold for RAT sensor	1°C (2°F)
εMAT	Temperature error threshold for MAT sensor	3°C (5°F)
εOAT	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
εF	Airflow error threshold	30%
εVFDSPD	VFD speed error threshold	5%
εDSP	DSP error threshold	25 Pa (0.1”)
εCCET	CCET sensor error; equal to εMAT or dedicated sensor error	Varies; see description.
εCCLT	CCLT sensor error; equal to εSAT or dedicated sensor error	
εHCET	Heating-coil entering temperature sensor error; equal to εMAT or dedicated sensor error	
εHCLT	Heating-coil leaving temperature sensor error; equal to εSAT or dedicated sensor error	
ΔOSmax	Maximum number of changes in OS 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

5.16.14.6 Table 5.16.14.6 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 5.16.14.6 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.

5.16.14.7 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:

a. In OS#1 (heating), the following fault conditions shall be evaluated:
   1. FC#1: DSP too low with fan at full speed
   2. FC#2: MAT too low; should be between RAT and OAT
   3. FC#3: MAT too high; should be between RAT and OAT
   4. FC#4: Too many changes in OS
   5. FC#5: SAT too low; should be higher than MAT
   6. FC#6: OA fraction too low or too high; should equal %OAmin
   7. FC#7: SAT too low in full heating
   8. FC#14: Temperature drop across inactive cooling coil
b. In OS#2 (modulating economizer), the following fault conditions shall be evaluated:
   1. FC#1: DSP too low with fan at full speed
   2. FC#2: MAT too low; should be between RAT and OAT
   3. FC#3: MAT too high; should be between RAT and OAT
   4. FC#4: Too many changes in OS
   5. FC#8: SAT and MAT should be approximately equal
   6. FC#9: OAT too high for free cooling without mechanical cooling
   7. FC#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#1: DSP too low with fan at full speed
   2. FC#2: MAT too low; should be between RAT and OAT

Table 5.16.14.6 VAV AHU Fault Conditions

FC#1	**Equation**	$DSP < DSPSP - \varepsilon DSP$ **AND** $VFDSPD \geq 99\% - \varepsilon VFDSPD$	**Applies to OS#1 through OS#5**
	Description	Duct static pressure too low with fan at full speed	
	Possible Diagnosis	• Problem with VFD • Mechanical problem with fan • Fan undersized • SAT set point too high (too much zone demand)	
FC#2 (omit if no MAT sensor)	**Equation**	$MATavg + \varepsilon MAT < \min[(RATavg - \varepsilon RAT), (OATavg - \varepsilon OAT)]$	**Applies to OS#1 through OS#5**
	Description	MAT too low; should be between OAT and RAT	
	Possible Diagnosis	• RAT sensor error • MAT sensor error • OAT sensor error	
FC#3 (omit if no MAT sensor)	**Equation**	$MATavg - \varepsilon MAT > \max[(RATavg + \varepsilon RAT), (OATavg + \varepsilon OAT)]$	**Applies to OS#1 through OS#5**
	Description	MAT too high; should be between OAT and RAT	
	Possible Diagnosis	• RAT sensor error • MAT sensor error • OAT sensor error	
FC#4	**Equation**	$\Delta OS > \Delta OSmax$	**Applies to OS#1 through OS#5**
	Description	Too many changes in OS	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#5 (omit if no MAT sensor)	**Equation**	$SATavg + \varepsilon SAT \leq MATavg - \varepsilon MAT + \Delta TSF$	**Applies to OS#1**
	Description	SAT too low; should be higher than MAT	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve stuck closed or actuator failure • Fouled or undersized heating coil • HW temperature too low or HW unavailable • Gas or electric heat unavailable • DX cooling stuck ON	
FC#6	**Equation**	$\lvert RATavg - OATavg \rvert \geq \Delta Tmin$ **AND** $\lvert \%OA - \%OAmin \rvert > \varepsilon F$	**Applies to OS#1 and OS#4**
	Description	OA fraction too low or too high; should equal %OAmin	
	Possible Diagnosis	• RAT sensor error • MAT sensor error • OAT sensor error • Leaking or stuck economizer damper or actuator	
FC#7	**Equation**	$SATavg < SATSP - \varepsilon SAT$ **AND** $HC \geq 99\%$	**Applies to OS#1**
	Description	SAT too low in full heating	
	Possible Diagnosis	• SAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve stuck closed or actuator failure • Fouled or undersized heating coil • HW temperature too low or HW unavailable • Gas or electric heat unavailable • DX cooling stuck ON • Leaking or stuck economizer damper or actuator	
FC#8 (omit if no MAT sensor)	**Equation**	$\lvert SATavg - \Delta TSF - MATavg \rvert > \sqrt{\varepsilon SAT^2 + \varepsilon MAT^2}$	**Applies to OS#2**
	Description	SAT and MAT should be approximately equal	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve leaking or stuck open	

Table 5.16.14.6 VAV AHU Fault Conditions *(Continued)*

FC#9	**Equation**	$OATavg - \varepsilon OAT > SATSP - \Delta TSF + \varepsilon SAT$	**Applies to OS#2**
	Description	OAT too high for free cooling without additional mechanical cooling	
	Possible Diagnosis	• SAT sensor error • OAT sensor error • Cooling-coil valve leaking or stuck open	
FC#10 (omit if no MAT sensor)	**Equation**	$\lvert MATavg - OATavg \rvert > \sqrt{\varepsilon MAT2 + \varepsilon OAT^2}$	**Applies to OS#3**
	Description	OAT and MAT should be approximately equal	
	Possible Diagnosis	• MAT sensor error • OAT sensor error • Leaking or stuck economizer damper or actuator	
FC#11	**Equation**	$OATavg + \varepsilon OAT < SATSP - \Delta TSF - \varepsilon SAT$	**Applies to OS#3**
	Description	OAT too low for 100% OA cooling	
	Possible Diagnosis	• SAT sensor error • OAT sensor error • Heating-coil valve leaking or stuck open • Leaking or stuck economizer damper or actuator	
FC#12 (omit if no MAT sensor)	**Equation**	$SATavg - \varepsilon SAT - \Delta TSF \geq MATavg + \varepsilon MAT$	**Applies to OS#3 and OS#4**
	Description	SAT too high; should be less than MAT	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve stuck closed or actuator failure • Fouled or undersized cooling coil • CHW temperature too high or CHW unavailable • DX cooling unavailable • Gas or electric heat stuck ON • Heating-coil valve leaking or stuck open	
FC#13	**Equation**	$SATavg > SATSP + \varepsilon SAT$ **AND** $CC \geq 99\%$	**Applies to OS#3 and OS#4**
	Description	SAT too high in full cooling	
	Possible Diagnosis	• SAT sensor error • Cooling-coil valve stuck closed or actuator failure • Fouled or undersized cooling coil • CHW temperature too high or CHW unavailable • DX cooling unavailable • Gas or electric heat stuck ON • Heating-coil valve leaking or stuck open	
FC#14	**Equation**	$CCETavg - CCLTavg \geq \sqrt{\varepsilon CCET^2 + \varepsilon CCLT^2} + \Delta T_{SF}{}^*$ *Fan heat factor included or not, depending on location of sensors used for CCET and CCLT	**Applies to OS#1 and OS#2**
	Description	Temperature drop across inactive cooling coil	
	Possible Diagnosis	• CCET sensor error • CCLT sensor error • Cooling-coil valve stuck open or leaking • DX cooling stuck on	
FC#15	**Equation**	$HCLTavg - HCET_{avg} \geq \sqrt{\varepsilon HCET^2 + \varepsilon HCLT^2} + \Delta T_{SF}{}^*$ *Fan heat factor included or not, depending on location of sensors used for HCET and HCLT	**Applies to OS#2 through OS#4**
	Description	Temperature rise across inactive heating coil	
	Possible Diagnosis	• HCET sensor error • HCLT sensor error • Heating-coil valve stuck open or leaking.	

   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 100% OA
   7. FC#12: SAT too high; should be less than MAT
   8. FC#13: SAT too high in full cooling
   9. FC#15: Temperature rise across inactive heating coil

d. In OS#4 (mechanical Cooling, minimum OA), the following fault conditions shall be evaluated:
   1. FC#1: DSP too low with fan at full speed
   2. FC#2: MAT too low; should be between RAT and OAT
   3. FC#3: MAT too high; should be between RAT and OAT
   4. FC#4: Too many changes in OS
   5. FC#6: OA fraction too low or too high; should equal%OAmin
   6. FC#12: SAT too high; should be less than MAT
   7. FC#13: SAT too high in full cooling
   8. FC#15: Temperature rise across inactive heating coil

e. In OS#5 (other), the following fault conditions shall be evaluated:
   1. FC#1: DSP too low with fan at full speed
   2. FC#2: MAT too low; should be between RAT and OAT
   3. FC#3: MAT too high; should be between RAT and OAT
   4. FC#4: Too many changes in OS

5.16.14.8 For each air handler, the operator shall be able to suppress the alarm for any fault condition.

5.16.14.9 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 warm-up to occupied) of any zone group served by the AHU

5.16.14.10 Fault conditions that are not applicable to the current OS shall not be evaluated.

5.16.14.11 A fault condition that evaluates as TRUE must do so continuously for AlarmDelay minutes before it is reported to the operator.

5.16.14.12 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.

5.16.14.13 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 5.16.14.6.

5.16.15 Testing/Commissioning Overrides. Provide software switches that interlock to a CHW and hot-water plant level to

a. force HW valve full open if there is a hot-water coil,
b. force HW valve full closed if there is a hot-water coil,
c. force CHW valve full open, and
d. force CHW valve full closed.

Per Section 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 set points based on zone and AHU demands.

5.16.16 Plant Requests

5.16.16.1 Chilled-Water Reset Requests

a. If the supply air temperature exceeds the supply air temperature set point by 3°C (5°F) for 2 minutes, send 3 requests.
b. Else if the supply air temperature exceeds the supply air temperature set point 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.

5.16.16.2 Chiller Plant Requests. Send the chiller plant that serves the system a chiller plant request as follows:

a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.
b. Else if the CHW valve position is less than 95%, send 0 requests.

5.16.16.3 If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the supply air temperature is 17°C (30°F) less than set point for 5 minutes, send 3 requests.
b. Else if the supply air temperature is 8°C (15°F) less than set point 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.

5.16.16.4 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:

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.

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

5.17.1 Supply Fan Control

5.17.1.1 Supply Fan Start/Stop

a. Fan shall run when system is in the warm-up 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 paragraph 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 paragraph may also be deleted if there is a supply AFMS.

b. 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

a. **Static pressure set point.** Set point 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.

5.17.1.3 Static Pressure Control

a. Supply fan speed is controlled to maintain DSP at set point 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.).

Table 5.17.1.2 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)

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 Set Point

a. **During occupied mode (Table 5.17.2.2).** Set point 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.

b. **During warm-up and setback modes.** Set point shall be Max_HtgSAT.

5.17.2.3 Supply air temperature shall be maintained at set point 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 alarm limit: Level 4. The alarm limit shall vary with total airflow (if available; use fan speed if total airflow is not known) as follows:

$$DPx = DP100(x)^{1.4}$$

where DP100 is the high-limit pressure drop at design airflow (determine limit from filter manufacturer) and DPx is the high-limit at airflow rate x (expressed as a fraction). For instance, the set point at 50% of design airflow would be $(0.5)^{1.4}$, or 38% of the design high limit pressure drop.

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 set point
e. DSPSP = duct static pressure set point
f. HC = heating coil valve position command; 0% ≤ HC ≤ 100%
g. FS = fan speed command; 0% ≤ FS ≤ 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

a. SATavg = rolling average of supply air temperature
b. RATavg = rolling average of return air temperature
c. DSPavg = 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.

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.

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 warm-up to occupied) 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 5.16.14.6.

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.

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

Table 5.17.4.4 DFDD Heating AHU AFDD Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	1°C (2°F)
εSAT	Temperature error threshold for SAT sensor	1°C (2°F)
εRAT	Temperature error threshold for RAT sensor	1°C (2°F)
εVFDSPD	VFD speed error threshold	5%
εDSP	DSP error threshold	25 Pa (0.1in. of water)
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

Table 5.17.4.5 DFDD Heating AHU Fault Conditions

FC#1	**Equation**	DSP < DSPSP – εDSP **AND** VFDSPD ≥ 99% – εVFDSPD
	Description	DSP too low with fan at full speed
	Possible Diagnosis	• Problem with VFD • Mechanical problem with fan • Fan undersized • SAT set point too high (too much zone demand)
FC#2	**Equation**	SATavg < SATSP – εSAT **AND** HC ≥ 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**	$\mathrm{RATavg} - \mathrm{SATavg} \geq \sqrt{\varepsilon\mathrm{SAT}^2 + \varepsilon\mathrm{RAT}^2} + \Delta\mathrm{TSF}$ **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

5.17.6 Plant Requests

5.17.6.1 Hot-Water Reset Requests

a. If the supply air temperature is 17°C (30°F) less than set point for 5 minutes, send 3 requests.
b. Else if the supply air temperature is 8°C (15°F) less than set point 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.

5.17.6.2 Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the AHU a heating hot-water plant request as follows:

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.

5.18 Single-Zone VAV Air-Handling Unit

5.18.1 See “Generic Thermal Zones” (Section 5.3) for set points, loops, control modes, alarms, etc.

5.18.2 See Section 3.1.6 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 set points 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 set point that controls the economizer SATsp is lower than the minimum value of the set point 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 3.2.2.1.
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 set point is kept at the minimum, which will reduce supply air temperature and thus lower supply air temperature set point.

5.18.4.4 Minimum and maximum supply air temperature set points shall be as follows:

a. The Deadband values of SATsp and SATsp-C shall be the average of the zone heating set point and the zone cooling set point but shall be no lower than 21°C (70°F) and no higher than 24°C (75°F).

The deadband set point is intended to provide neutral temperature air when the zone state is deadband. The values of this set point are limited to avoid the situation where an extreme value for zone temperature set point forces unnecessary heating or cooling, e.g., a cold-aisle set point 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 set points 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 5.18.4.5-2 separates Figure 5.18.4.5-1 in two for clarity and to illustrate the relative set points. However, both fan speed and supply air temperature set points are reset simultaneously and by the same signal: the value of the heating loop or cooling loop.

a. For a heating-loop signal of 100% to 50%, fan speed is reset from MaxHeatSpeed to MinSpeed.
b. For a heating-loop signal of 50% to 0%, fan speed set point is MinSpeed.
c. In deadband, fan speed set point is MinSpeed.
d. For a cooling-loop signal of 0% to 25%, fan speed is MinSpeed.
e. For a cooling-loop signal of 25% to 50%, fan speed is reset from MinSpeed to MedSpeed.
f. For a cooling-loop signal of 50% to 75%, fan speed is MedSpeed.
g. For a cooling-loop signal of 75% to 100%, fan speed is reset from MedSpeed to MaxCoolSpeed.
h. For a heating-loop signal of 100% to 50%, SATsp is Heat_SAT.
i. For a heating-loop signal of 50% to 0%, SATsp is reset from Heat_SAT to the deadband value.
j. In deadband, SATsp is the deadband value.
k. For a cooling-loop signal of 0% to 25%, SATsp is reset from the deadband value to Cool_SAT minus 1°C (2°F), while SATsp-C is the deadband value.
l. For a cooling-loop signal of 25% to 50%, SATsp and SATsp-C are unchanged.
m. For a cooling-loop signal of 50% to 75%, SATsp remains at Cool_SAT minus 1°C (2°F), SATsp-C is reset from the deadband value to Cool_SAT.
n. For a cooling-loop signal of 75% to 100%, SATsp and SATsp-C are unchanged.

In cooling, the economizer is controlled to a lower set point than the cooling coil (i.e., SATsp < SATsp-C) so that a low-temperature excursion does not cause the economizer to close inadvertently while cooling with mechanical cooling.

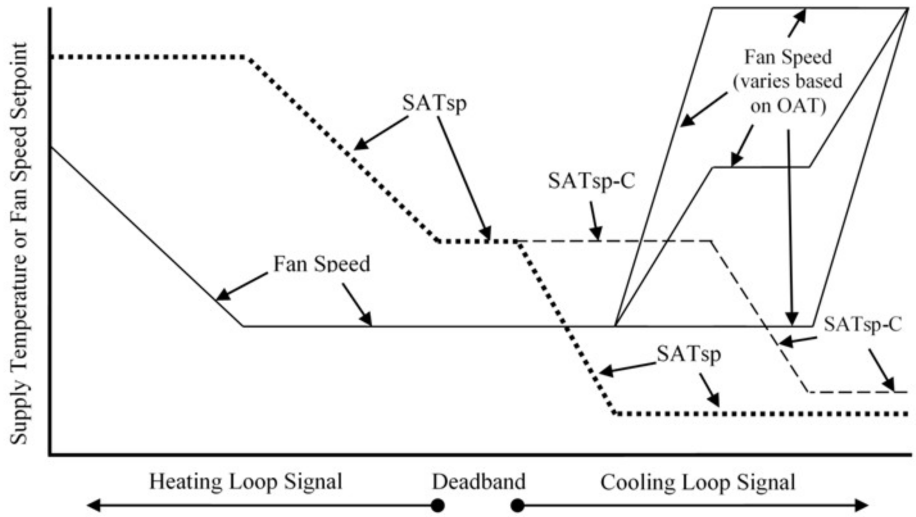

Figure 5.18.4.5-1 Control diagram for SZVAV AHU.

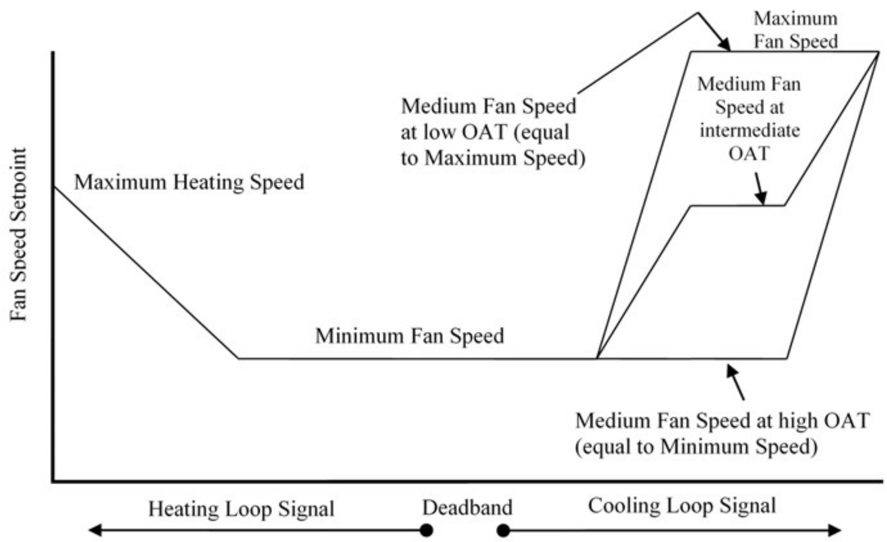

Figure 5.18.4.5-2 Control diagram for SZVAV AHU—fan speed.

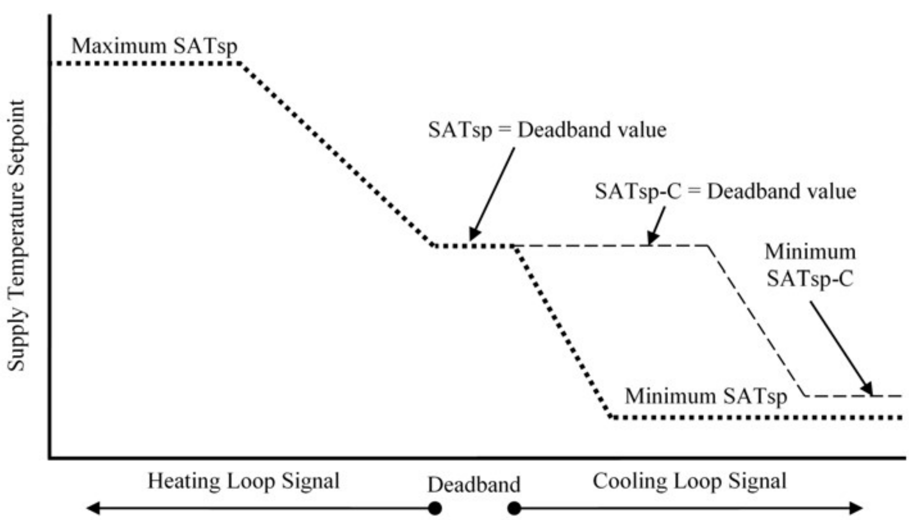

Figure 5.18.4.5-3 Control diagram for SZVAV AHU—supply air temperature.

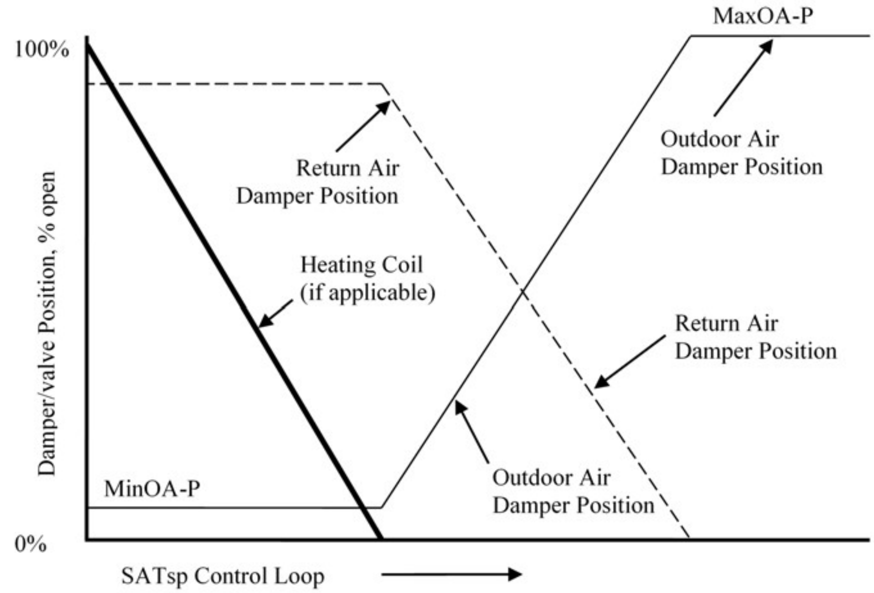

Figure 5.18.5.2 SZVAV AHU supply air temperature loop mapping.

5.18.5 Supply Air Temperature Control

5.18.5.1 There are two supply air temperature set points, SATsp and SATsp-C. Each set point 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.

a. Supply air temperature shall be controlled to SATsp by a control loop whose output is mapped to sequence the heating coil (if applicable) and economizer dampers as shown in the Figure 5.18.5.2. Outdoor air damper minimum MinOA-P and maximum MaxOA-P positions are limited for economizer lockout and to maintain minimum outdoor airflow rate as described in Sections 5.18.6 and 5.18.7.

These sequences assume that the heat source can be modulated and thus control SAT to a set point in heating. If this is not the case (e.g., because heating is by multistage furnace or electric coil), then the following will need to be modified to add appropriate staging logic.

b. The points of transition along the x-axis shown in Figure 5.18.5.2 are representative. Separate gains shall be provided for each section of the control map (heating coil, economizer) that are determined by the contractor to provide stable control. Alternatively, the contractor shall adjust the precise value of the x-axis thresholds shown in Figure 5.18.5.2 to provide stable control.

Dampers are complementary (rather than sequenced, as they are for multiple-zone VAV AHUs) to reduce equipment costs (avoiding multiple actuators) and to maintain a more-linear relationship between fan speed and outdoor air volume.

In order to make this relationship as linear as possible, the economizer should use parallel blade dampers.

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

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 DCV.

This logic assumes that there is no airflow measurement station or DP sensor across the outdoor air intake and controls OA volume directly via damper position set points. 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 and the control logic.

5.18.6.1 See Section 5.2 for calculation of zone minimum outdoor airflow set point.

5.18.6.2 Outdoor Air Damper Control

a. See Section 3.2.2.2 for minimum damper position set points.
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.

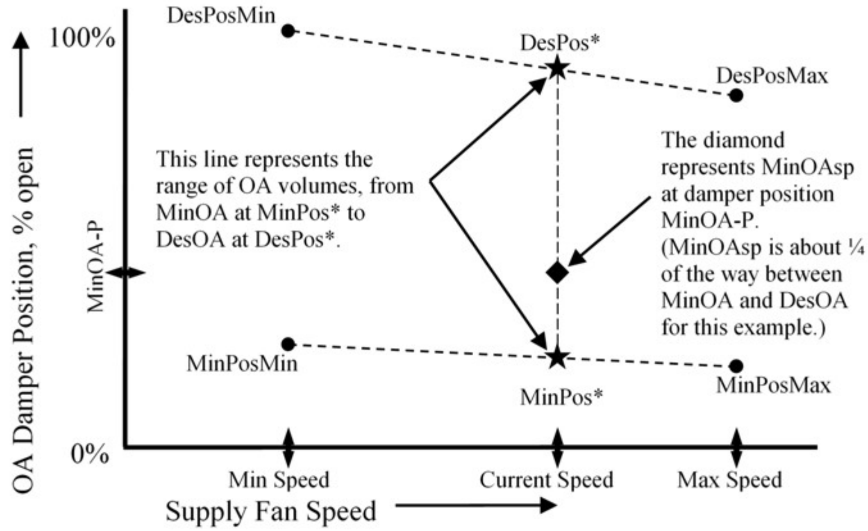

Figure 5.18.6.2 SZVAV AHU minimum outdoor air control.

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).

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 5.1.16.

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 5.18.5, "Supply Air Temperature Control," and Section 5.18.6, "Minimum Outdoor Air Control," for outdoor air damper minimum set point.

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 Section 5.18.9 and Section 5.18.10.**
- **For AHUs using actuated relief dampers with relief fan(s), use Section 5.18.9 and delete Section 5.18.8 and Section 5.18.10.**
- **For AHUs using a return fan, use Section 5.18.10 and delete Section 5.18.8 and Section 5.18.9.**
- **For AHUs using nonactuated barometric relief only, delete *all three* Sections 5.18.8, 5.18.9, and 5.18.10.**
- **A building pressure sensor is required for the option in Section 5.18.9. One is not required for Sections 5.18.8 or 5.18.10.**

5.18.8 Control of Actuated Relief Dampers without Fans

5.18.8.1 See Section 3.2.2.2 for relief-damper position set points.

5.18.8.2 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.

5.18.8.3 Relief-damper position shall be reset linearly from MinRelief to MaxRelief as the commanded economizer damper position goes from MinPos* to 100% open.

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

Exhaust damper may be barometric (no actuator). In that case, delete Sections 5.18.10.1 and 5.18.10.4.

5.18.10.1 Exhaust damper shall open whenever associated supply fan is proven ON.

5.18.10.2 Return fan shall run whenever associated supply fan is proven ON.

5.18.10.3 Return-fan speed shall be the same as supply-fan speed with a user adjustable offset S-R-DIFF.

5.18.10.4 Exhaust damper shall be closed when return fan is disabled.

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, or 5.18.10 should remain. If relief is barometric (without actuators) only, then all three 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:

a. 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.

b. 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.

c. 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.

a. 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 set point. 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 Standard 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

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	= min
#2: Free cooling, modulating OA	= 0	= 0	min < x < 100%
#3: Mechanical + economizer cooling	= 0	> 0	= 100%
#4: Mechanical cooling, minimum OA	= 0	> 0	= min
#5: Unknown or dehumidification	No other OS applies		

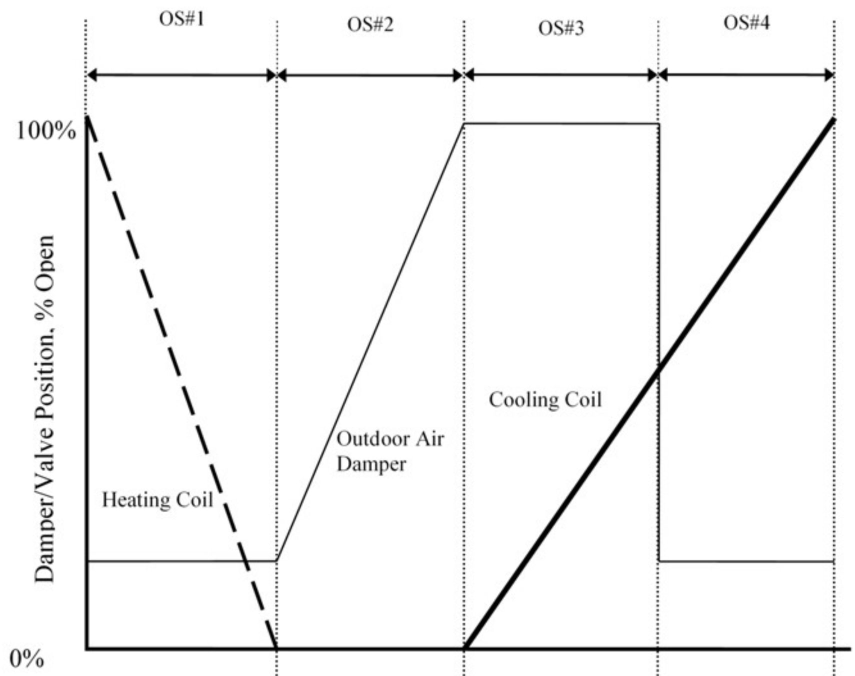

Figure 5.18.13.2 SZVAV AHU operating states.

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.

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.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or zone group mode (occupied, warm-up, 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 warm-up.

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.

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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 set point for heating coil and economizer control
g. SATsp-C = supply air temperature set point for cooling coil control
h. HC = heating-coil valve position command; 0% ≤ HC ≤ 100%
i. CC = cooling-coil valve position command; 0% ≤ CC ≤ 100%
j. FS = fan-speed command; 0% ≤ FS ≤ 100%
k. CCET = cooling-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose).
l. CCLT = cooling-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)
m. HCET = heating-coil entering temperature (Depending on the AHU configuration, this could be the MAT or a separate sensor for this specific purpose.)
n. HCLT = heating-coil leaving temperature (Depending on the AHU configuration, this could be the SAT or a separate sensor for this specific purpose.)

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. SATavg = rolling average of supply air temperature
   2. MATavg = rolling average of mixed air temperature
   3. RATavg = rolling average of return air temperature
   4. OATavg = rolling average of outdoor air temperature
   5. CCETavg = rolling average of cooling-coil entering temperature
   6. CCLTavg = rolling average of cooling-coil leaving temperature
   7. HCETavg = rolling average of heating-coil entering temperature
   8. HCLTavg = rolling average of heating-coil leaving temperature
   9. 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.

The purpose of ΔTmin is to ensure that the mixing box/economizer damper tests are meaningful. These tests are based on the relationship between supply, return, and outdoor air. If RAT ≈ MAT, these tests will not be accurate and will produce false alarms.

The purpose of TestModeDelay is to ensure that normal fault reporting occurs after the testing and commissioning process is completed as 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.

Table 5.18.13.5 SZVAV AHU Internal Variables

Variable Name	Description	Default Value
ΔTSF	Temperature rise across supply fan	0.5°C (1°F)
ΔTmin	Minimum difference between OAT and RAT to evaluate economizer error conditions (FC#6)	6°C (10°F)
εSAT	Temperature error threshold for SAT sensor	1°C (2°F)
εRAT	Temperature error threshold for RAT sensor	1°C (2°F)
εMAT	Temperature error threshold for MAT sensor	3°C (5°F)
εOAT	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
εCCET	Cooling coil entering temperature sensor error. Equal to εMAT or dedicated sensor error	Varies; see description.
εCCLT	Cooling coil leaving temperature sensor error. Equal to εSAT or dedicated sensor error	
εHCET	Heating coil entering temperature sensor error; equal to εMAT or dedicated sensor error	
εHCLT	Heating coil leaving temperature sensor error. Equal to εSAT or dedicated sensor error	
ΔOSmax	Maximum number of changes in Operating State during the previous 60 minutes (moving window)	7
ModeDelay	Time in minutes to suspend Fault Condition evaluation after a change in mode	30
AlarmDelay	Time in minutes that a Fault Condition must persist before triggering an alarm	30
TestModeDelay	Time in minutes that Test Mode is enabled	120

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.

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:

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#14: Temperature drop across inactive cooling coil
   7. 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 100% OA
   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.

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 set point.		**Applies to OS#1 through OS#5**
FC#2 (omit if no MAT sensor)	**Equation**	MATavg + εMAT < min[(RATavg – εRAT), (OATavg – εOAT)]	**Applies to OS#1 through OS#5**
	Description	MAT too low; should be between OAT and RAT	
	Possible Diagnosis	RAT sensor error	
		MAT sensor error	
		OAT sensor error	
FC#3 (omit if no MAT sensor)	**Equation**	MATavg – εMAT > min[(RATavg + εRAT), (OATavg + εOAT)]	**Applies to OS#1 through OS#5**
	Description	MAT too high; should be between OAT and RAT	
	Possible Diagnosis	• RAT sensor error • MAT sensor error • OAT sensor error	
FC#4	**Equation**	ΔOS > ΔOSmax	**Applies to OS#1 through OS#5**
	Description	Too many changes in OS	
	Possible Diagnosis	Unstable control due to poorly tuned loop or mechanical problem	
FC#5 (omit if no MAT sensor)	**Equation**	SATavg + εSAT ≤ MATavg – εMAT + ΔTSF	**Applies to OS#1**
	Description	SAT too low; should be higher than MAT	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve stuck closed or actuator failure • Fouled or undersized heating coil • HW temperature too low or HW unavailable • Gas or electric heat unavailable	
FC#6	**Equation**	|RATavg – OATavg| ≥ ΔTmin **AND** |RATavg – MATavg| > |OATavg – MATavg|	**Applies to OS#1 and OS#4**
	Description	OA fraction 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	**Equation**	SATavg < SATSP – εSAT **AND** HC ≥ 99%	**Applies to OS#1**
	Description	SAT too low in full heating	
	Possible Diagnosis	• SAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve stuck closed or actuator failure • Fouled or undersized heating coil • HW temperature too low or HW unavailable • Gas or electric heat is unavailable • DX cooling is stuck ON • Leaking or stuck economizer damper or actuator	
FC#8 (omit if no MAT sensor)	**Equation**	$\|SATavg – ΔTSF – MATavg\| > \sqrt{\varepsilon SAT^2 + \varepsilon MAT^2}$	**Applies to OS#2**
	Description	SAT and MAT should be approximately equal	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve leaking or stuck open • DX cooling stuck on • Heating-coil valve leaking or stuck open • Gas or electric heat stuck ON	

Table 5.18.13.6 SZVAV AHU Fault Conditions *(Continued)*

FC#9	**Equation**	$OATavg + \varepsilon OAT > SATSP - \Delta TSF + \varepsilon SAT$	**Applies to OS#2**
	Description	OAT too high for free cooling without additional mechanical cooling	
	Possible Diagnosis	• SAT sensor error • OAT sensor error • Cooling-coil valve leaking or stuck open • DX cooling stuck ON	
FC#10 (omit if no MAT sensor)	**Equation**	$\lvert MATavg - OATavg \rvert > \sqrt{\varepsilon MAT^2 + \varepsilon OAT^2}$	**Applies to OS#3**
	Description	OAT and MAT should be approximately equal	
	Possible Diagnosis	• MAT sensor error • OAT sensor error • Leaking or stuck economizer damper or actuator	
FC#11	**Equation**	$OATavg + \varepsilon OAT < SATSP - \Delta TSF - \varepsilon SAT$	**Applies to OS#3**
	Description	OAT too low for 100% OA cooling	
	Possible Diagnosis	• SAT sensor error • OAT sensor error • Heating-coil valve leaking or stuck open • Gas or electric heat stuck ON • Leaking or stuck economizer damper or actuator	
FC#12 (omit if no MAT sensor)	**Equation**	$SATavg - \varepsilon SAT - \Delta TSF \geq MATavg + \varepsilon MAT$	**Applies to OS#3 and OS#4**
	Description	SAT too high; should be less than MAT	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve stuck closed or actuator failure • Fouled or undersized cooling coil • CHW temperature too high or CHW unavailable • DX cooling unavailable • Gas or electric heat stuck ON • Heating-coil valve leaking or stuck open	
FC#13	**Equation**	$SATavg > SATSP\text{-}C + \varepsilon SAT$ **AND** $CC \geq 99\%$	**Applies to OS#3 and OS#4**
	Description	SAT too high in full cooling	
	Possible Diagnosis	• SAT sensor error • Cooling-coil valve stuck closed or actuator failure • Fouled or undersized cooling coil • CHW temperature too low or CHW unavailable • DX cooling unavailable • Gas or electric heat stuck ON • Heating-coil valve leaking or stuck open	
FC#14	**Equation**	$CCETavg - CCLTavg \geq \sqrt{\varepsilon CCET^2 + \varepsilon CCLT^2} + \Delta TSF^*$ *Fan heat factor included or not, depending on location of sensors used for CCET and CCLT	**Applies to OS#1 and OS#2**
	Description	Temperature drop across inactive cooling coil	
	Possible Diagnosis	• CCET sensor error • CCLT sensor error • Cooling-coil valve stuck open or leaking • DX cooling stuck ON	
FC#15	**Equation**	$HCLTavg - HCETavg \geq \sqrt{\varepsilon HCET^2 + \varepsilon HCLT^2} + \Delta TSF^*$ *Fan heat factor included or not, depending on location of sensors used for HCET and HCLT	**Applies to OS#2 through OS#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	

5.18.13.9 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 warm-up to occupied) 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 set points 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:

a. If the CHW valve position is greater than 95%, send 1 request until the CHW valve position is less than 10%.
b. Else if the CHW valve position is less than 95%, send 0 requests.

5.18.15.3 If There Is a Hot-Water Coil, Hot-Water Reset Requests

a. If the supply air temperature is 17°C (30°F) less than SATsp for 5 minutes, send 3 requests.
b. Else if the supply air temperature is 8°C (15°F) less than SATsp for 5 minutes, send 2 requests.
c. Else if HW valve position is greater than 95%, send 1 request until the HW valve position is less than 85%.
d. Else if the HW valve position is less than 95%, send 0 requests.

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:

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.