ADDENDA

ASHRAE Addendum u to
ASHRAE Guideline 36-2018

High Performance Sequences of Operation for HVAC Systems

Approved by ASHRAE on March 30, 2021.

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FOREWORD

Addendum u 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.

Note: In this addendum, changes to the current guideline are indicated in the text by underlining (for additions) and strikethrough (for deletions) unless the instructions specifically mention some other means of indicating the changes.

Addendum u to Guideline 36-2018

Revise Section 5.16.14 as shown (I-P and SI Units).

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. A~~n~~ 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 and separate minimum outdoor air damper.

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.

~~**If there is a return fan, keep Section 0 and delete Sections** Error! Reference source not found. **and 0 and separate minimum outdoor air damper.**~~

~~**If there are relief dampers or relief fans and a separate minimum outdoor air damper, keep Section** Error! Reference source not found. **and delete Sections 0 and 0.**~~

~~**If there are relief dampers or relief fans and a single common damper for minimum outdoor air and economizer functions, keep Section 0 and delete Sections 0 and** Error! Reference source not found..~~

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 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		

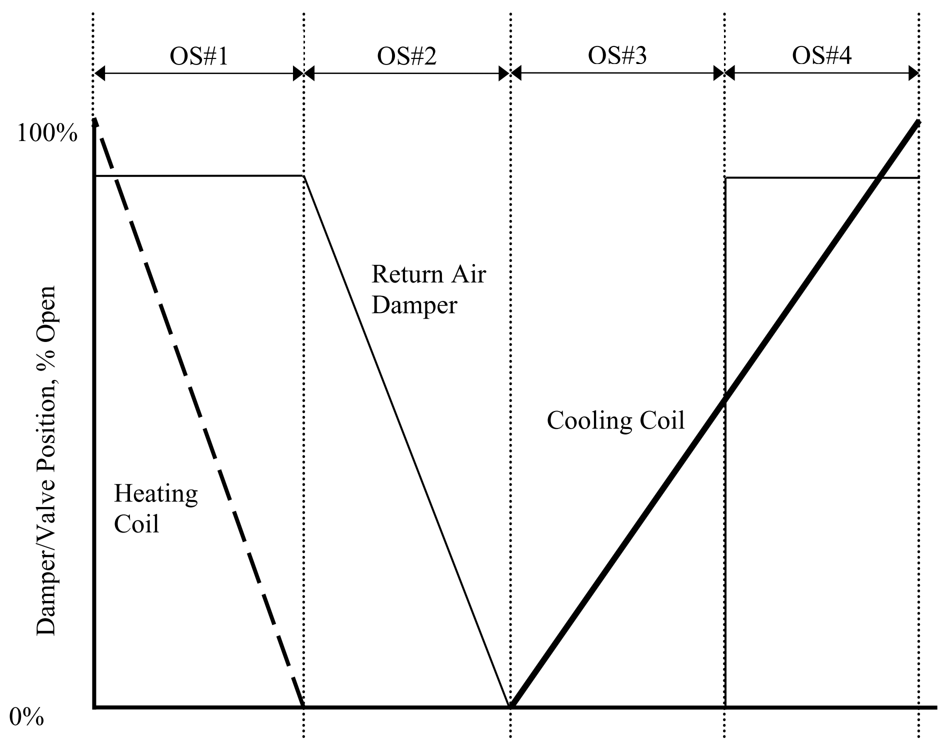

Figure 5.16.14.2 VAV AHU operating states.

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		

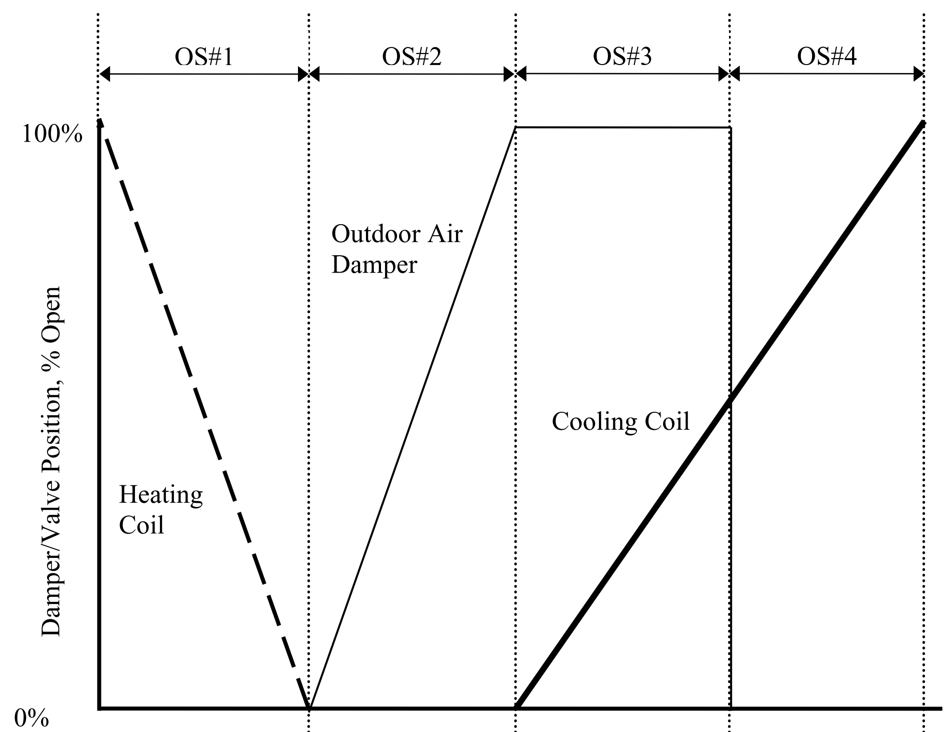

Figure 5.16.14.3 VAV AHU operating states.

5.16.14.4 For units with relief dampers or relief fans and a single common damper for 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.~~2~~ 4 and Figure 5.16.14.~~2~~4.

Table 5.16.14.~~2~~ 4 VAV AHU Operating States

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

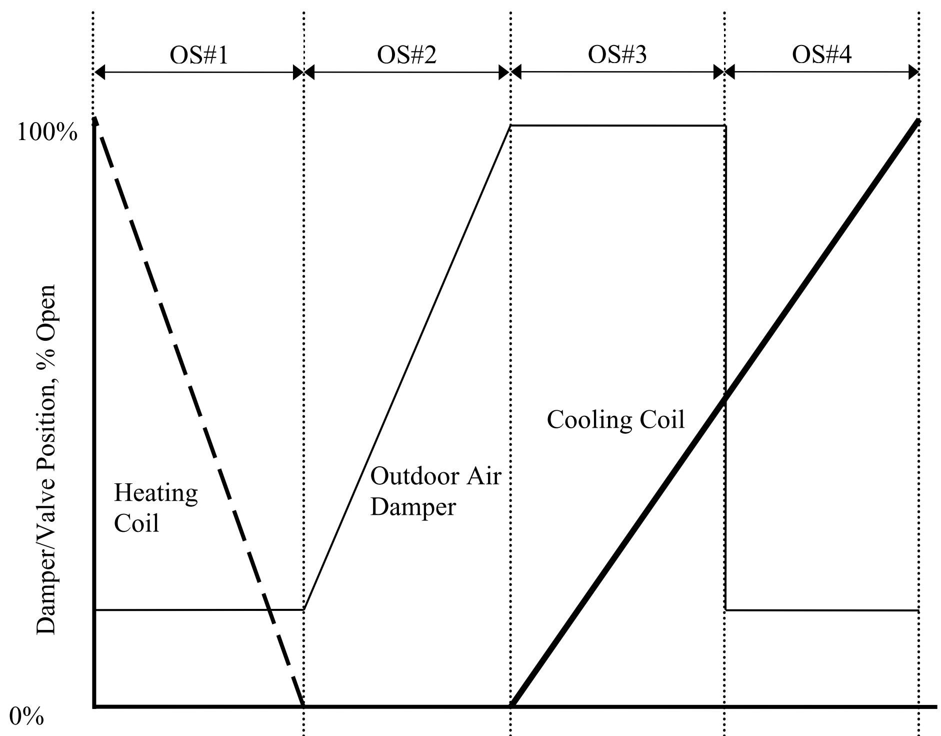

Figure 5.16.14.~~2~~ 4 VAV AHU operating states.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or zone group mode (occupied, warm-up, 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 ~~5.16.14.6~~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 warm-up.

~~5.16.14.3~~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 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~~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 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~~5.16.14.7 The internal variables shown in Table 5.16.14.~~5~~ 7 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.~~5~~ 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)
$_{SAT}$	Temperature error threshold for SAT sensor	1°C (2°F)
$_{RAT}$	Temperature error threshold for RAT sensor	1°C (2°F)
$_{MAT}$	Temperature error threshold for MAT sensor	3°C (5°F)
$_{OAT}$	Temperature error threshold for OAT sensor	1°C (2°F) if local sensor @ unit. 3°C (5°F) if global sensor.
$_{F}$	Airflow error threshold	30%
$_{VFDSPD}$	VFD speed error threshold	5%
$_{DSP}$	Duct static pressure error threshold	25 Pa (0.1”)
$_{CCET}$	Cooling coil entering temperature sensor error. Equal to $_{MAT}$ or dedicated sensor error	Varies, see Description
$_{CCLT}$	Cooling coil leaving temperature sensor error. Equal to $_{SAT}$ or dedicated sensor error	
$_{HCET}$	Heating coil entering temperature sensor error; equal to $_{MAT}$ or dedicated sensor error	
$_{HCLT}$	Heating coil leaving temperature sensor error. Equal to $_{SAT}$ or dedicated sensor error	
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 ”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~~14.

~~5.16.14.6~~5.16.14.8 Table 5.16.14.~~6~~ 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.~~6~~ 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.~~6~~ 8 VAV AHU Fault Conditions

FC#1	**Equation**	$DSP_{AVG} < DSPSP -\ _{DSP}$ and $VFDSPD\ e\ 99\% -\ _{VFDSPD}$	**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**	$MAT_{AVG} +\ _{MAT} < \min[(RAT_{AVG} -\ _{RAT}),$ $(OAT_{AVG} -\ _{OAT})]$	**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**	$MAT_{AVG} - \ _{MAT} > \max[(RAT_{AVG} + \ _{RAT}), (OAT_{AVG} + \ _{OAT})]$	**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**	$SAT_{AVG} + \ _{SAT}$ d $MAT_{AVG} - \ _{MAT} + \Delta T_{SF}$	**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**	$\| RAT_{AVG} - OAT_{AVG} \|$ e ΔT_{MIN} and $\| \%OA - \%OA_{MIN} \| > \ _{F}$	**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 <u>(omit if no heating coil)</u>	**Equation**	$SAT_{AVG} < SATSP - \ _{SAT}$ and HC e 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**	$\mid SAT_{AVG} - \Delta T_{SF} - MAT_{AVG} \mid > \sqrt{{}_{SAT}^{2} + {}_{MAT}^{2}}$	**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**	$OAT_{AVG} - {}_{OAT} > SATSP - \Delta T_{SF} + {}_{SAT}$	**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**	$\mid MAT_{AVG} - OAT_{AVG} \mid > \sqrt{{}_{MAT}^{2} + {}_{OAT}^{2}}$	**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**	$OAT_{AVG} + {}_{OAT} < SATSP - \Delta T_{SF} - {}_{SAT}$	**Applies to OS #3**
	Description	OAT is too low for ~~100% OA~~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**	$SAT_{AVG} - {}_{SAT} - \Delta T_{SF}$ e $MAT_{AVG} + {}_{MAT}$	**Applies to OS #~~3,~~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**	$SAT_{AVG} > SATSP + \ _{SAT}$ and CC e 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**	$CCET_{AVG} - CCLT_{AVG}$ e $\sqrt{\ _{CCET}^{2} + \ _{CCLT}^{2} + \Delta T_{SF}^{*}}$ *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**	$HCLT_{AVG} - HCET_{AVG}$ e $\sqrt{\ _{HCET}^{2} + \ _{HCLT}^{2} + \Delta T_{SF}^{*}}$ *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.	

~~5.16.14.7~~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 %OAmin
7. FC#7: SAT too low in full heating
8. FC#14: Temperature drop across inactive cooling coil

b. In OS#2 (modulating economizer), the following fault conditions shall be evaluated:

1. FC#1: DSP too low with fan at full speed
2. FC#2: MAT too low; should be between RAT and OAT
3. FC#3: MAT too high; should be between RAT and OAT
4. FC#4: Too many changes in OS
5. FC#8: SAT and MAT should be approximately equal
6. FC#9: OAT too high for free cooling without mechanical cooling
7. FC#12: SAT too high; should be less than MAT
8. FC#14: Temperature drop across inactive cooling coil
9. FC#15: Temperature rise across inactive heating coil

c. In OS#3 (mechanical + 100% economizer cooling), the following fault conditions shall be evaluated:

1. FC#1: DSP too low with fan at full speed
2. FC#2: MAT too low; should be between RAT and OAT
3. FC#3: MAT too high; should be between RAT and OAT
4. FC#4: Too many changes in OS
5. FC#10: OAT and MAT should be approximately equal
6. FC#11: OAT too low for ~~100% OA~~mechanical cooling
7. FC#12: SAT too high; should be less than MAT
8. FC#13: SAT too high in full cooling
9. FC#15: Temperature rise across inactive heating coil

d. In OS#4 (mechanical Cooling, minimum OA), the following fault conditions shall be evaluated:

1. FC#1: DSP too low with fan at full speed

2. FC#2: MAT too low; should be between RAT and OAT
3. FC#3: MAT too high; should be between RAT and OAT
4. FC#4: Too many changes in OS
5. FC#6: OA fraction too low or too high; should equal %OAmin
6. FC#12: SAT too high; should be less than MAT
7. FC#13: SAT too high in full cooling
8. FC#15: Temperature rise across inactive heating coil

e. In OS#5 (other), the following fault conditions shall be evaluated:

1. FC#1: DSP too low with fan at full speed
2. FC#2: MAT too low; should be between RAT and OAT
3. FC#3: MAT too high; should be between RAT and OAT
4. FC#4: Too many changes in OS

~~5.16.14.8~~5.16.14.10 For each air handler, the operator shall be able to suppress the alarm for any fault condition.

~~5.16.14.9~~5.16.14.11 Evaluation of fault conditions shall be suspended under the following conditions:

a. When AHU is not operating

b. For a period of ModeDelay minutes following a change in mode (e.g., from warm-up to occupied) of any zone group served by the AHU

~~5.16.14.10~~5.16.14.12 Fault conditions that are not applicable to the current OS shall not be evaluated.

~~5.16.14.11~~5.16.14.14 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~~5.16.14.15 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~~5.16.14.16 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~~8.

Revise Paragraph 5.17.4.10 as follows:

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~~5.17.4.5.

Revise Section 5.17.4.5 as follows:

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**	$DSP_{\underline{AVG}} < DSPSP - {}_{DSP}$ and $VFDSPD$ e $99\% - {}_{VFDSPD}$
	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**	$SAT_{AVG} < SATSP - {}_{SAT}$ and HC e 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**	$RAT_{AVG} - SAT_{AVG}$ e $\sqrt{{}_{SAT}^{2} + {}_{RAT}^{2}} + \Delta T_{SF}$ 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

Revise Section 5.18.14 as follows:

5.18.14 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 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. A~~n~~ MAT sensor is required for many of these alarms to work, and an averaging sensor is strongly recommended for best accuracy. If a~~n~~ 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.

5.18.14.1 AFDD conditions are evaluated continuously and separately for each operating AHU.

5.18.14.2 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 5.18.~~13~~14.2 and Figure 5.18.~~13~~14.2.

Table 5.18.~~13~~14.2 SZVAV AHU Operating States

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

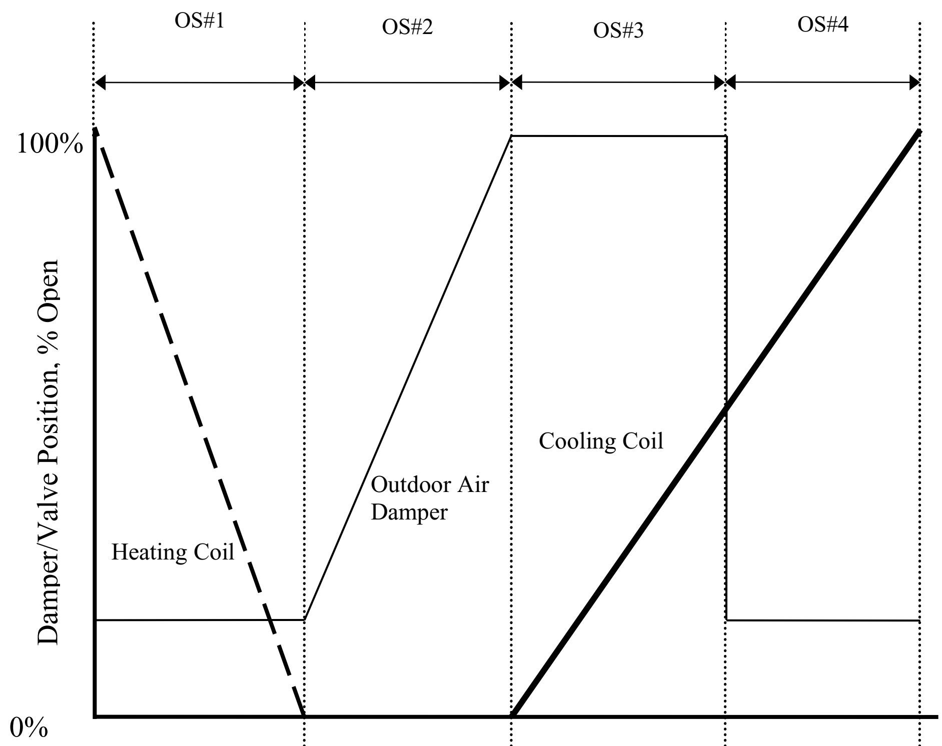

Figure 5.18.~~13~~14.2 SZVAV AHU operating states.

The OS is distinct from, and should not be confused with, the zone status (cooling, heating, deadband) or zone group mode (occupied, warm-up, etc.).
OS#1 through OS#4 (see Table ~~5.18.13.2~~5.18.14.2) represent normal operation during which a fault may nevertheless occur if so determined by the fault condition tests in Section 0~~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.

5.18.14.3 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 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 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.)

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

a. Five-minute rolling averages with 1-minute sampling of the following point values; operator shall have the ability to adjust the averaging window and sampling period for each point independently.

1. SATavg = rolling average of supply air temperature
2. MATavg = rolling average of mixed air temperature
3. RATavg = rolling average of return air temperature
4. OATavg = rolling average of outdoor air temperature
5. CCETavg = rolling average of cooling-coil entering temperature
6. CCLTavg = rolling average of cooling-coil leaving temperature
7. HCETavg = rolling average of heating-coil entering temperature
8. HCLTavg = rolling average of heating-coil leaving temperature
9. ” OS = number of changes in OS during the previous 60 minutes (moving window)

5.18.14.5 The internal variables shown in Table ~~5.18.13.5~~5.18.14.5 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~~14.5 SZVAV 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	
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

> *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 0~~5.18.13.12~~.*

5.18.14.6 Table 5.18.~~13~~14.6 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~~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.*

Table 5.18.~~13~~14.6 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**	$MAT_{AVG} + {}_{MAT} < \min[(RAT_{AVG} - {}_{RAT}), (OAT_{AVG} - {}_{OAT})]$	**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**	$MAT_{AVG} - {}_{MAT} > \min[(RAT_{AVG} + {}_{RAT}), (OAT_{AVG} + {}_{OAT})]$	**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**	$SAT_{AVG} + \ {}_{SAT}\ \mathrm{d}\ MAT_{AVG} - \ {}_{MAT} + \Delta T_{SF}$	**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**	$\mid RAT_{AVG} - OAT_{AVG} \mid \mathrm{e}\ \Delta T_{MIN}$ and $\mid RAT_{AVG} - MAT_{AVG} \mid > \mid OAT_{AVG} - MAT_{AVG} \mid$	**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 <u>(omit if no heating coil)</u>	**Equation**	$SAT_{AVG} < SATSP - \ {}_{SAT}$ and $HC\ \mathrm{e}\ 99\%$	**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**	$\mid SAT_{AVG} - \Delta T_{SF} - MAT_{AVG} \mid > \sqrt{{}_{SAT}^{2} + {}_{MAT}^{2}}$	**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**	$OAT_{AVG} + \ _{OAT} > SATSP - \Delta T_{SF} + \ _{SAT}$	**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**	$\mid MAT_{AVG} - OAT_{AVG} \mid > \sqrt{\ _{MAT}{}^{2} + \ _{OAT}{}^{2}}$	**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**	$OAT_{AVG} + \ _{OAT} < SAT_{SP} - \Delta T_{SF} - \ _{SAT}$	**Applies to OS #3**
	Description	OAT is too low for ~~100% OA~~<u>mechanical</u> 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**	$SAT_{AVG} - \ _{SAT} - \Delta T_{SF}$ e $MAT_{AVG} + \ _{MAT}$	**Applies to OS <u>#2</u>~~–#3,~~ #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**	$SAT_{AVG} > SAT_{SP}-C + \ _{SAT}$ and CC e 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**	$CCET_{AVG} - CCLT_{AVG}\ e \sqrt{{}_{CCET}^{2} + {}_{CCLT}^{2} +}\ \Delta T_{SF}^{*}$ *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**	$HCLT_{AVG} - HCET_{AVG}\ e \sqrt{{}_{HCET}^{2} + {}_{HCLT}^{2} +}\ \Delta T_{SF}^{*}$ *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	

5.18.14.7 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. If a~~n~~ 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 ~~100% OA~~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

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

5.18.14.9 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

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

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

5.18.14.12 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.

5.18.14.13 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 Table ~~5.18.13.6~~5.18.14.6.

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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.

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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.

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