Shaping Tomorrow's Built Environment Today

ASHRAE Guideline 36-2018

High-Performance Sequences of Operation for HVAC Systems

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High-Performance Sequences of Operation for HVAC Systems

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

- Reduced engineering time
- Reduced programming and commissioning time.
- Reduced energy consumption
  - 62.1
  - Title 24
- Improved indoor air quality
- Reduced system down- time by including AFDD
- A common set of terms to facilitate communication between specifiers, contractors, and operators.

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

Learning Objectives

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High-Performance Sequences of Operation for HVAC Systems

A Review of sequences, control diagrams and required IO Points for:

- Generic Ventilation & Thermal Zones
- Zone Groups
- VAV Terminal Unit—Cooling Only
- VAV Terminal Unit with Reheat
- Parallel Fan-Powered Terminal Unit—Constant-Volume Fan
- Parallel Fan-Powered Terminal Unit—Variable-Volume Fan
- Series Fan-Powered Terminal Unit—Constant-Volume Fan
- Series Fan-Powered Terminal Unit—Variable-Volume Fan
- Dual-Duct VAV Terminal Unit—Snap Acting Control
- Dual-Duct VAV Terminal Unit—Mixing Control with Inlet Airflow Sensors
- Dual-Duct VAV Terminal Unit—Mixing Control with Discharge Airflow Sensor
- Dual-Duct VAV Terminal Unit—Cold-Duct Minimum Control
- Air-Handling Unit System Modes
- Multiple-Zone VAV Air-Handling Unit
- Dual-Fan Dual-Duct Heating VAV Air-Handling Unit
- Single-Zone VAV Air-Handling Unit

Look at AFDD For AHU's and how Guideline 36 address barriers to entry for FDD

Assumptions: We all have a basic or general understanding / familiarity of control systems and terms

Set Points – Section 3

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General Observations

- General Move to Calculated or Dynamic Set Points over Static Set Points.
- IAQ is front and center
- Combines \ 62.1 and Title 24 into a single reference point

Examples

- Economizer min sp at min VFD Speed and min sp at VFD Max Speed, VS a single economizer minimum position.
- CO2 Setpoint Guidance
  - Title 24, CO2setpoint = 600ppm + Ambient OA ppm (Assumed 400ppm if no sensor in place)
  - 62.1, CO2setpoint = 0.9[Coa+8400EzM/(Rp+(RaAz /Pz))] (62.1, 3.1.1.3 assumes 400ppm OA)
- Max DAT = Ambient Temperature + 20 degF (ceiling supply systems)

Set Points – Section 3 Table 62.1, 3.1.1.3

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Informative Table 3.1.1.3 Default CO_2 Set Points per ASHRAE Standard 62.1

Occupancy Category	CO_2 Set Point, ppm	Occupancy Category	CO_2 Set Point, ppm
Correctional Facilities		**Office Buildings**	
Cell	965	Office space	894
Dayroom	1656	Reception areas	1656
Guard stations	1200	Telephone/data entry	1872
Booking/waiting	1200	Main entry/lobbies	1391
Educational Facilities		**Miscellaneous Spaces**	
Day care (through age 4)	1027	Bank vaults/safe deposit	805
Day care sickroom	716	Computer (not printing)	738
Classrooms (ages 5 to 8)	864	Pharmacy (preparation area)	820
Classrooms (ages 9+)	942	Photo studios	983
Lecture classroom	1305	Transportation waiting	1305
Lecture hall (fixed seats)	1305	**Public Assembly Spaces**	
Art classroom	837	Auditorium seating area	1872
Science laboratories	894	Place of religious worship	1872

5.1 – General Guidelines

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Items of note

- 5.1.5.1 OA sensors at AHU's are only valid when the fan is proven "On"
- 5.1.5.2 OA reading used for global sequences shall be the avg of all valid sensors, if there are 4 or more ignore the the highest and lowest reading.
- 5.1.81 PID Loop control, use only the P term for limiting loops (CO2, Zone Temperature, etc.)
- 5.1.8.2 Do not use the D term on any loops if possible.
- 5.1.9 Limit PID maximum change to 25%, make this a user modifiable variable.
- 5.1.12.4 Alarm Exit Hysteresis
  - Time based 5 seconds
  - Analog includes Value % (Default is 0%)
- 5.1.16 VAV Box Controllable Minimum
  - Option 1 – VAV stops moving damper when airflow is too low to low to register
  - Option 2 – Calculated Minimum
- 5.1.18 Damper and Valve Positions (Needed)
- 5.1.19 Hierarchical Alarm Suppression
  - 5.1.20 Time Based Suppression (Set Points)

5.1.14 Trim and Response

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A “request” is a call to reset a static pressure or temperature set point generated by downstream zones or air-handling systems. These requests are sent upstream to the plant or system that serves the zone or air handler that generated the request.

- Importance-Multiplier (default = 1)
- Request-Hours Accumulator
- System Run-Hours Total
- Cumulative%-Request-Hours

5.1.14 Trim and Response

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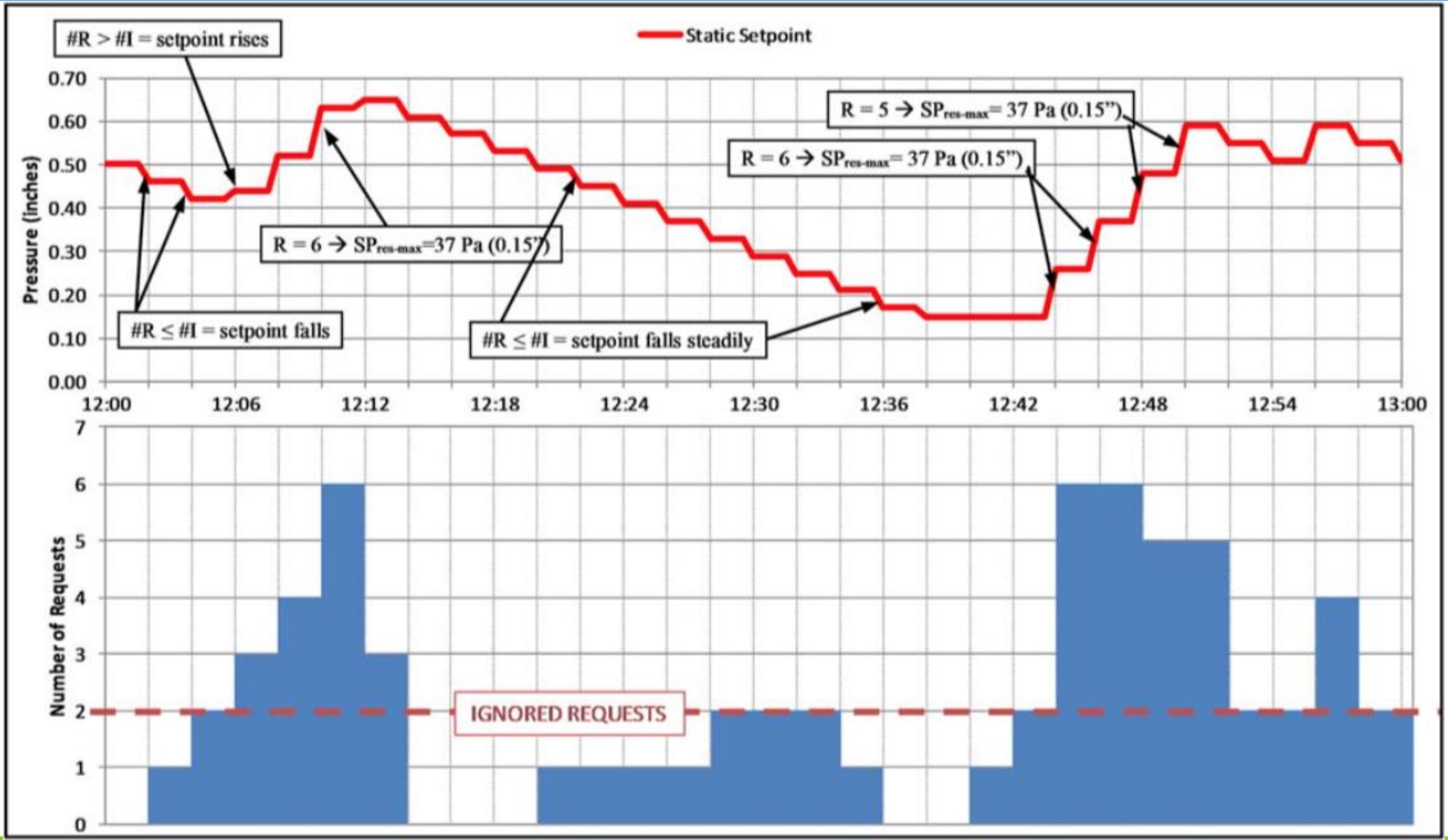

Informative Figure 5.1.14.4 Example sequence trend graph.

5.2 - Generic Ventilation

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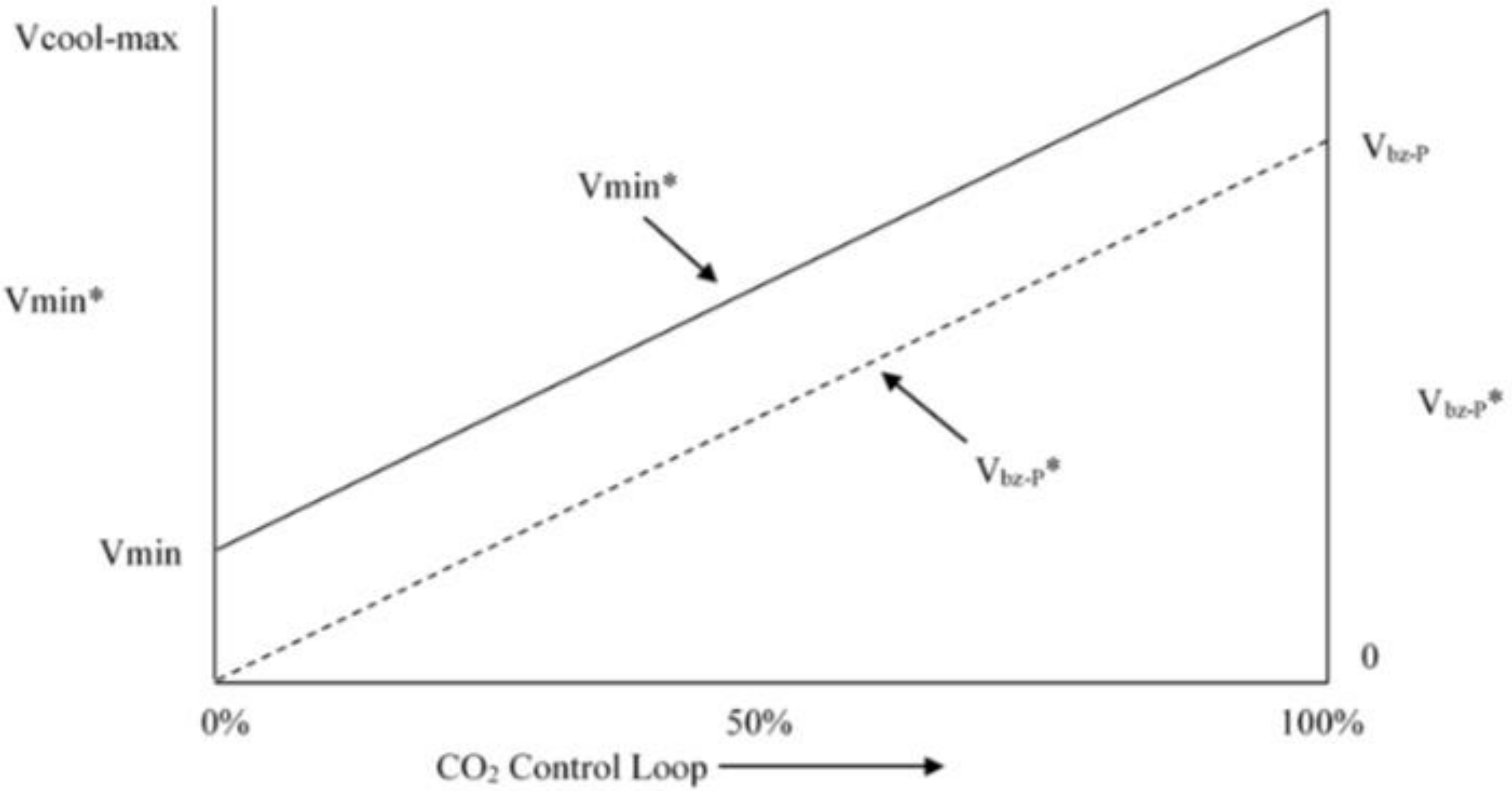
Zone Air Distribution Effectiveness Ez

- DAT =< ZT Then Ez = 1
- DAT > ZT Then Ez = 0.8
- Voz = (VbzA + VbzP)/Ez
  - VbzP = Population component
  - VbzA = Ventilation Floor, Default 0
- VbzP = 0
  - Window Switch = Open
  - Occupancy Sensor = Off

If Co2 Sensor is present

- Vmin = 0% at Set Point – 200ppm
- Vmin = 100% at Set Point
- Control Disabled if unoccupied or population = 0.



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5.2.2 – Time-Averaged Ventilation

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ASHRAE Standard 62.1 and California Title 24 allow for ventilation to be provided based on average conditions over a specific period of time. This time-averaging method allows for zone airflows to effectively be controlled to values below the VAV box controllable minimum value, which may reduce energy use and the risk of overcooling when the zone ventilation requirement is less than the VAV box controllable minimum.

- The time-averaged ventilation (TAV) ratio shall be deter- mined as TAVratio = Vspt/Vm
- The total cycle time (TCT) shall be 15 minutes (adjust- able)
- Open period. During the open period, the TAV airflow set point Vspt* shall be equal to Vm for a period of time OP, which is the larger of the following:
  - 1.5 minutes or
  - TCT multiplied by TAVratio
- Closed period. During the closed period, Vspt* shall be set to 0 for a period of time CP, where CP = TCT – OP. The VAV damper control loop shall be disabled with output set equal to 0 during the closed period.
- During TAV mode, each cycle shall consist of an open and closed period that alternate until Vspt is greater than Vm.

5.3 – Generic Thermal Zones

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Items of note

- 5.3.2 Set Points
  - Separate Occ / Unocc set points
  - Forced Deadband of 1 DegF minimum
- 5.3.2.6 Cooling Demand Limit & Set Point Adjustment
- 5.3.2.7 Heating Demand Limit & Set Point Adjustment
- 5.3.4 Control Loops
  - Separate Loops \ Disable when not active
  - P+I loops only

5.4 – Zone Groups

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Zone scheduling groups, or zone groups, are sets of zones served by a single air handler that operate together for ease of scheduling and/or in order to ensure sufficient load to maintain stable operation in the upstream equipment. A zone group is equivalent to an isolation area as defined in ASHRAE/IES Standard 90.1 2016, Section 6.4.3.3.4.

Items of note

- 5.4.1 Schedules by system
- 5.4.2 Each Zone should be capable of being individually scheduled.
- 5.4.5 Testing and CX switches for each zone
- 5.4.6 Operational Modes
  - Occupied
  - Warm-Up
  - Cooldown
  - Setback
  - Freeze Protection
  - Setup
  - Unoccupied

5.5 – VAV Terminal Unit – Cooling Only

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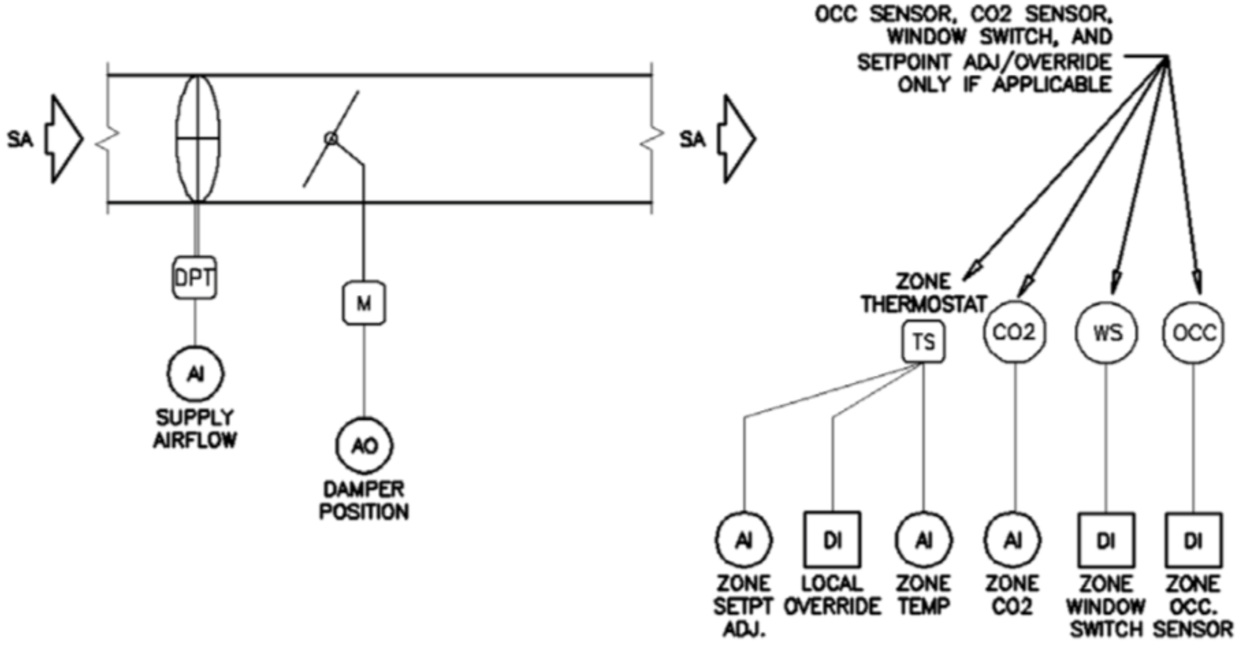
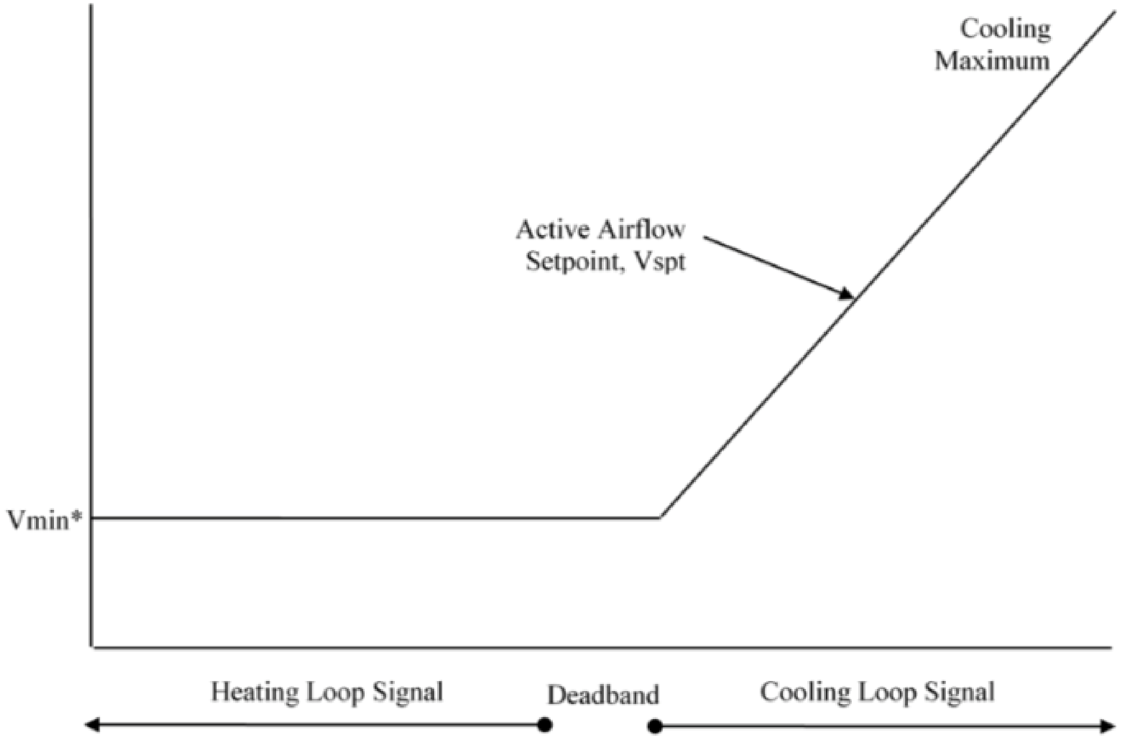


Figure A-1 VAV terminal unit, cooling only.



5.6 – VAV Terminal Unit with Reheat

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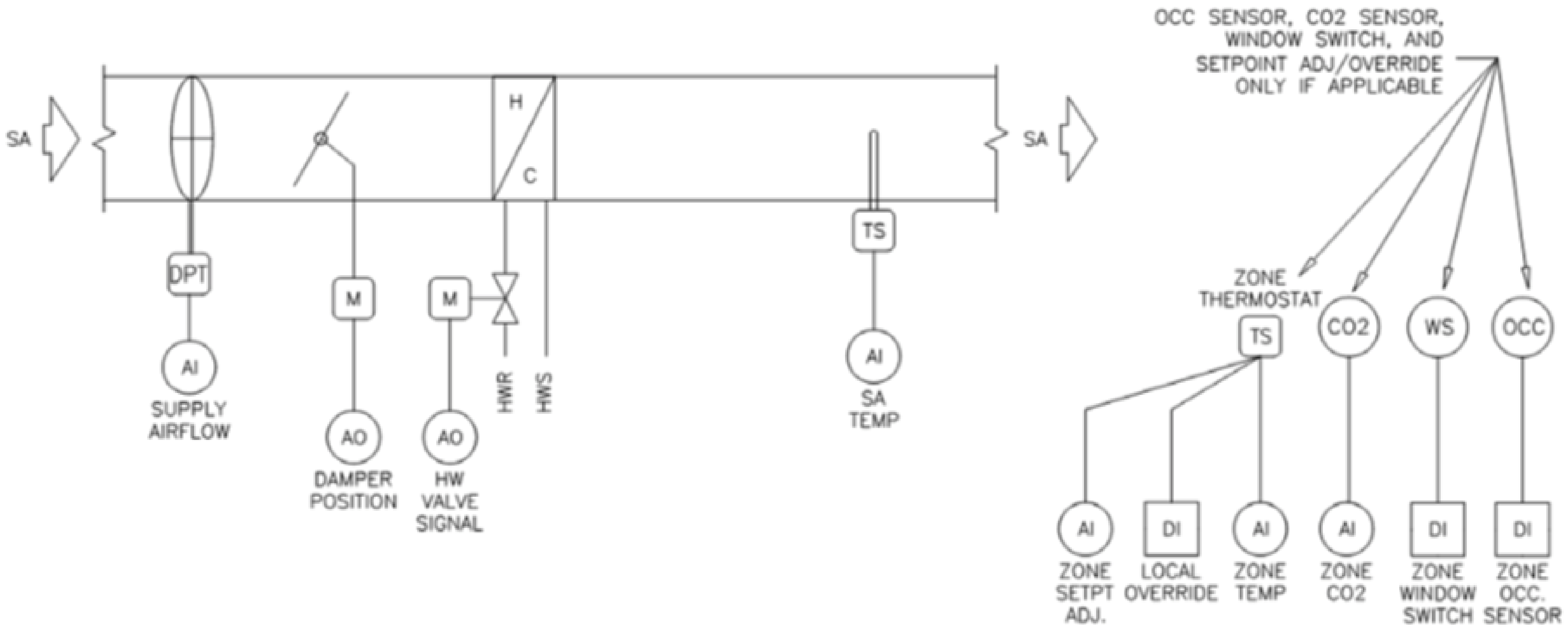

Figure A-2 VAV terminal unit with reheat.

5.6 – VAV Terminal Unit with Reheat

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4.2 VAV Terminal Unit with Reheat

Required?	Description	Type	Device
R	VAV box damper position	AO **OR** two DOs	Modulating actuator **OR** Floating actuator
R	Heating signal	AO **OR** two DOs	Modulating valve **OR** Floating actuator **OR** Modulating electric heating coil
R	Discharge airflow	AI	DP transducer connected to flow sensor
R	Discharge air temperature (DAT)	AI	Duct temperature sensor (probe or averaging at designer's discretion)
R	Zone temperature	AI	Room temperature sensor
A	Local override (if applicable)	DI	Zone thermostat override switch
A	Occupancy sensor (if applicable)	DI	Occupancy sensor
A	Window switch (if applicable)	DI	Window switch
A	Zone temperature set point adjustment (if applicable)	AI	Zone thermostat adjustment
A	Zone CO_2 level (if applicable)	AI	Room CO_2 sensor

5.6 – VAV Terminal Unit with Reheat

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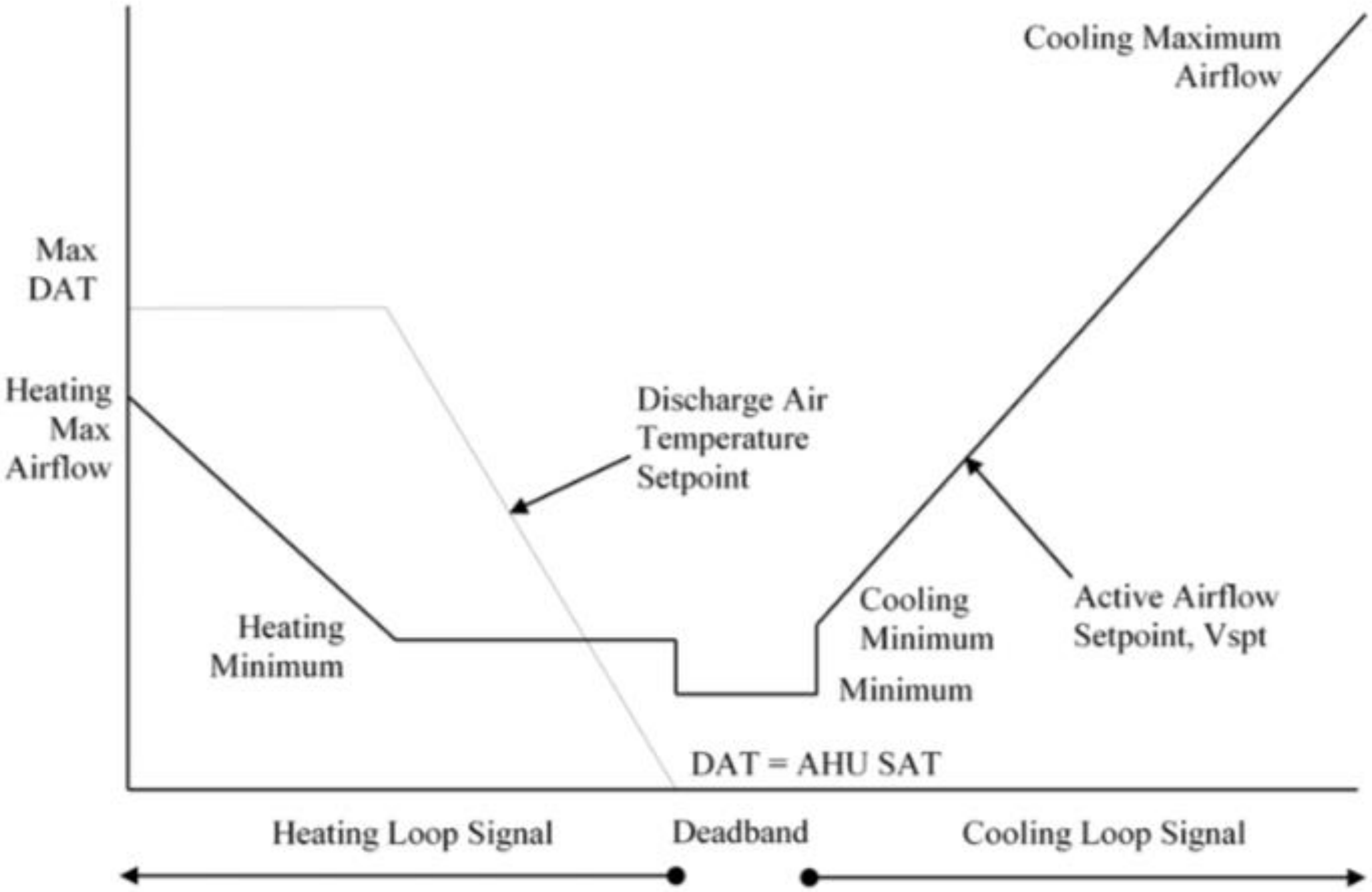

Figure 5.6.5 Control logic for VAV reheat zone.

5.6 – VAV Terminal Unit with Reheat

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Table 5.6.4 Set Points as a Function of Zone Group Mode

Set Point	Occupied	Cooldown	Setup	Warm-Up	Setback	Unoccupied
Cooling maximum	Vcool-max	Vcool-max	Vcool-max	0	0	0
Cooling minimum	Vmin*	0	0	0	0	0
Minimum	Vmin*	0	0	0	0	0
Heating minimum	Max (Vheat-min, Vmin*)	Vheat-min	0	Vheat-max	Vheat-max	0
Heating maximum	Max (Vheat-max, Vmin*)	Vheat-max	0	Vcool-max	Vcool-max	0

5.6 – VAV Terminal Unit with Reheat

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5.6.8 System Requests

5.6.8.1 Cooling SAT Reset Requests

a. If the zone temperature exceeds the zone's cooling set point by 3°C (5°F) for 2 minutes and after suppression period due to set point change per Section 5.1.19, send 3 requests.
b. Else if the zone temperature exceeds the zone's cooling set point by 2°C (3°F) for 2 minutes and after suppression period due to set point change per Section 5.1.19, send 2 requests.
c. Else if the cooling loop is greater than 95%, send 1 request until the cooling loop is less than 85%.
d. Else if the cooling loop is less than 95%, send 0 requests.

5.6.8.2 Static Pressure Reset Requests

a. If the measured airflow is less than 50% of set point while set point is greater than zero and the damper position is greater than 95% for 1 minute, send 3 requests.
b. Else if the measured airflow is less than 70% of set point while set point is greater than zero and the damper position is greater than 95% for 1 minute, send 2 requests.
c. Else if the damper position is greater than 95%, send 1 request until the damper position is less than 85%.
d. Else if the damper position is less than 95%, send 0 requests.

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

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

5.6.8.4 If There Is a Hot-Water Coil and Heating Hot-Water Plant, Heating Hot-Water Plant Requests. Send the heating hot-water plant that serves the zone a heating hot-water plant request as follows:

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

5.7 – Parallel Fan-Powered Terminal Unit – CV Fan

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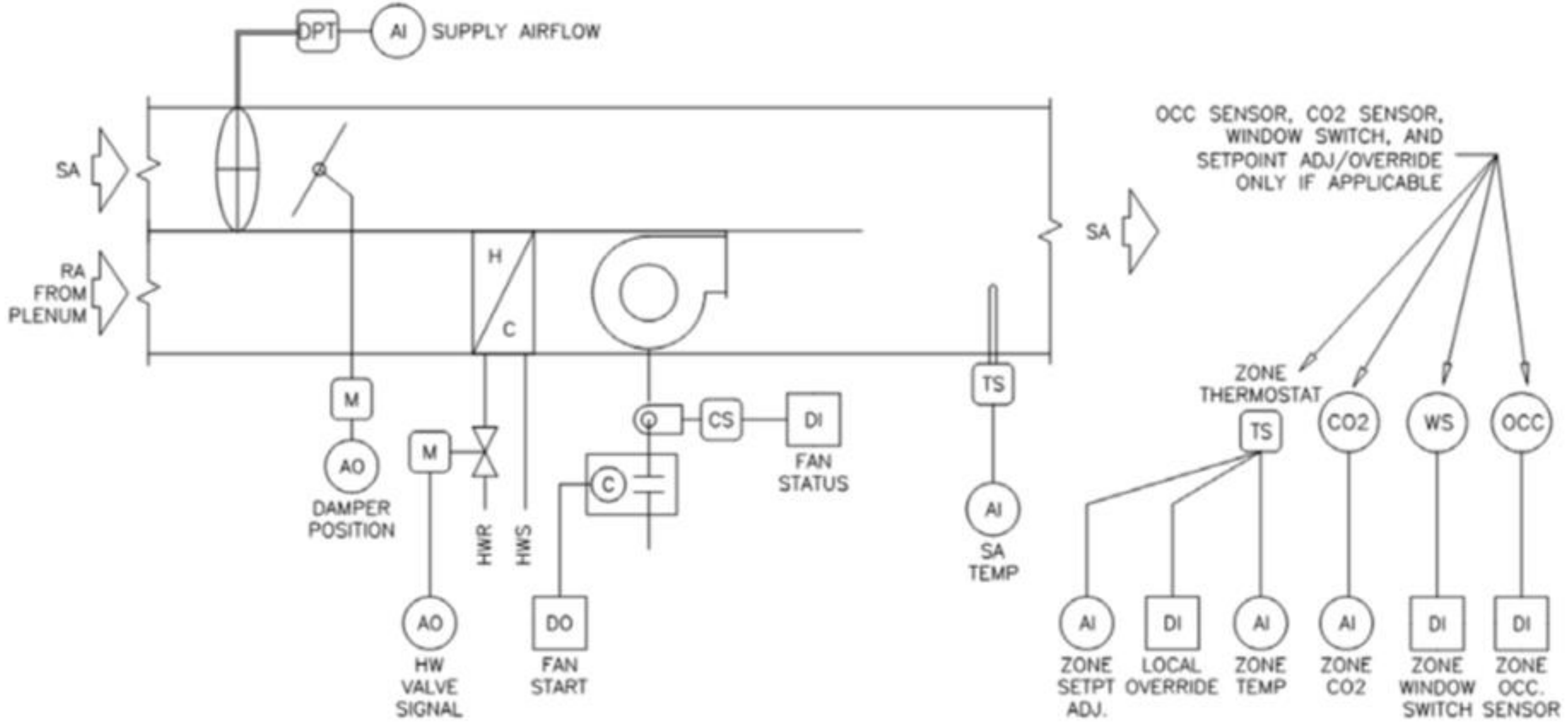

Figure A-3 Parallel fan-powered terminal unit, constant-volume fan.

5.7 – Parallel Fan-Powered Terminal Unit – CV Fan

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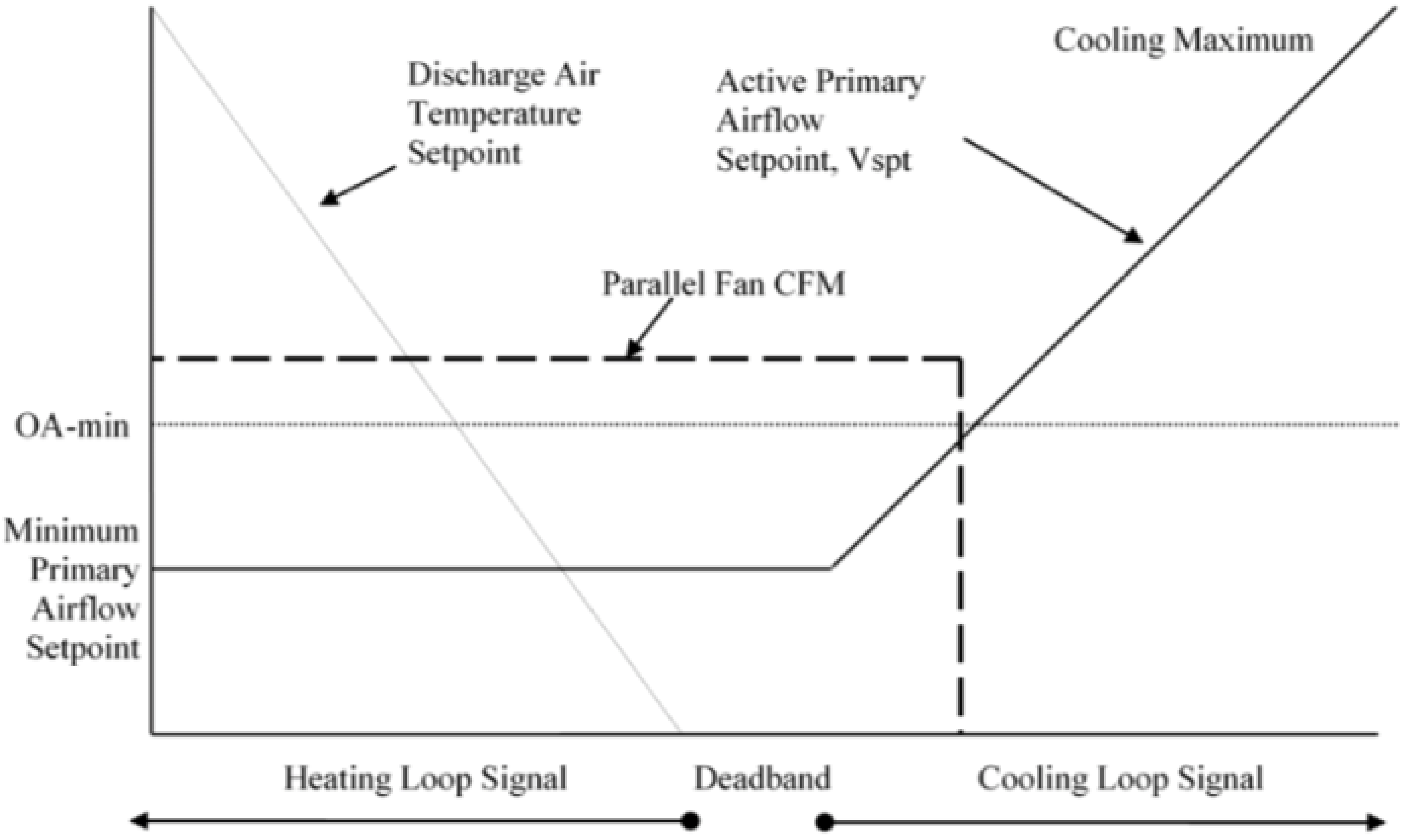

Figure 5.7.5-1 Control logic for constant-volume parallel fan-powered VAV zone (OA-min > Vmin).

5.7 – Parallel Fan-Powered Terminal Unit – CV Fan

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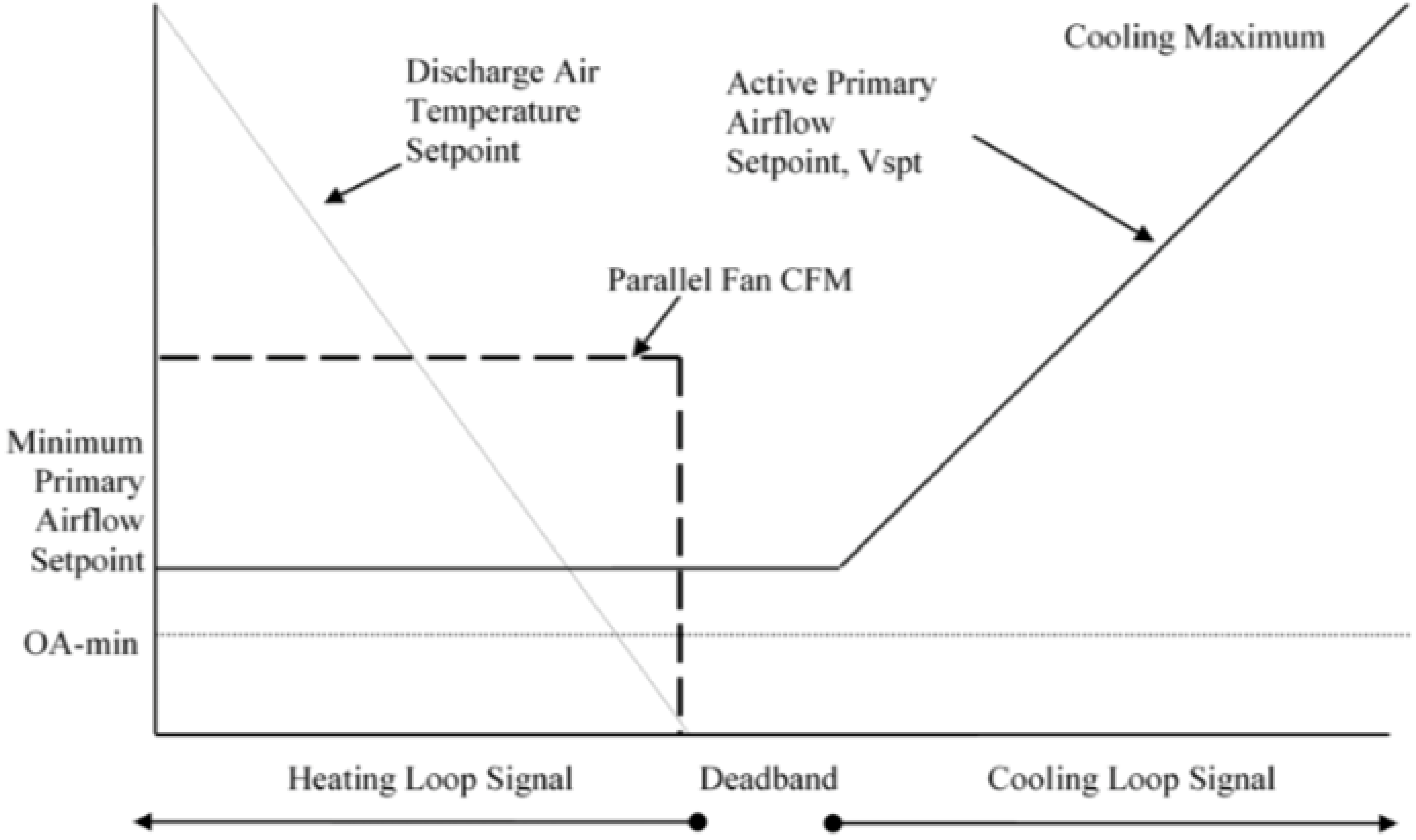

Figure 5.7.5-2 Control logic for constant-volume parallel fan-powered VAV zone (OA-min < Vmin).

5.8 – Parallel Fan-Powered Terminal Unit – V Fan

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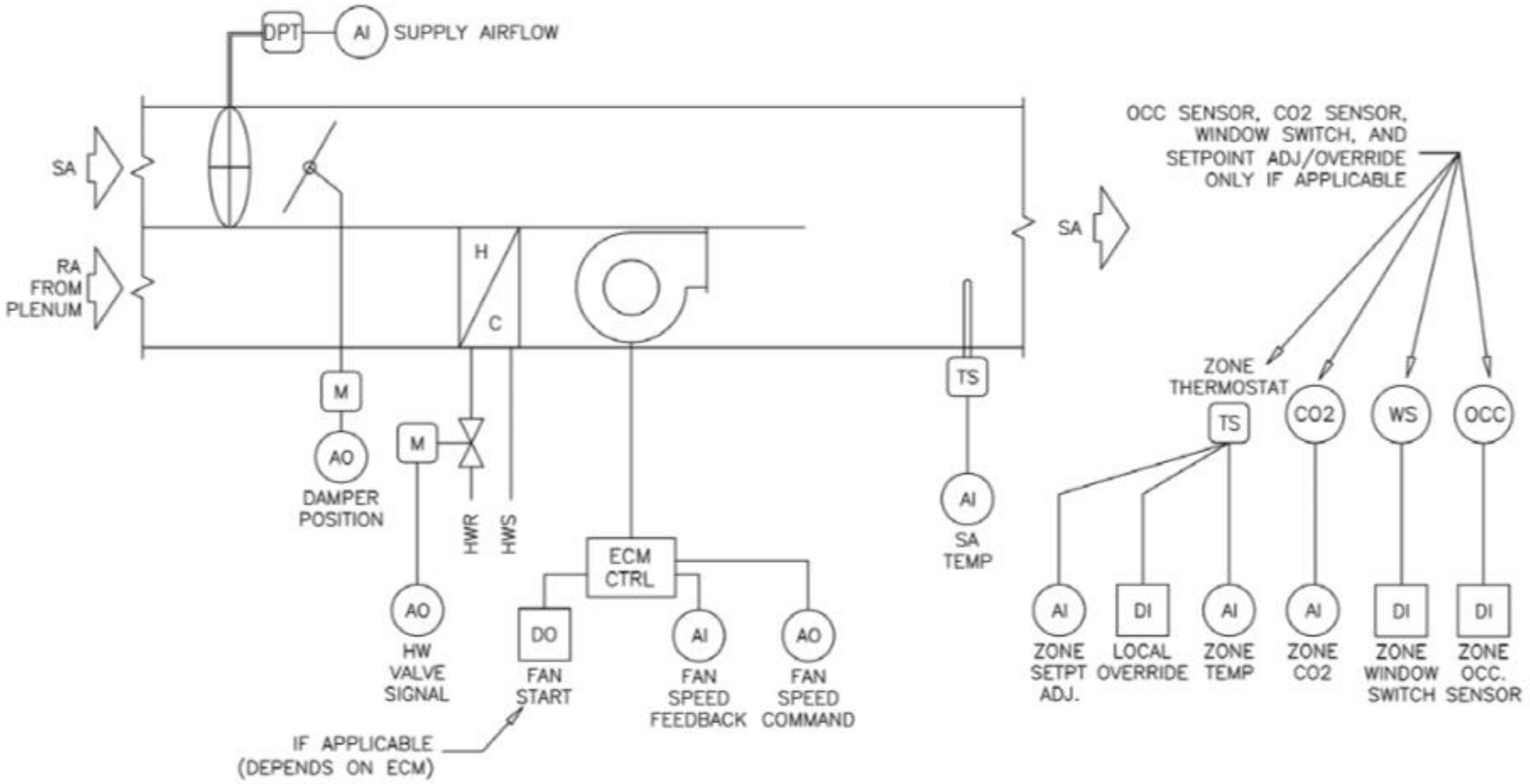

Figure A-4 Parallel fan-powered terminal unit, variable-volume fan.

5.8 – Parallel Fan-Powered Terminal Unit – V Fan

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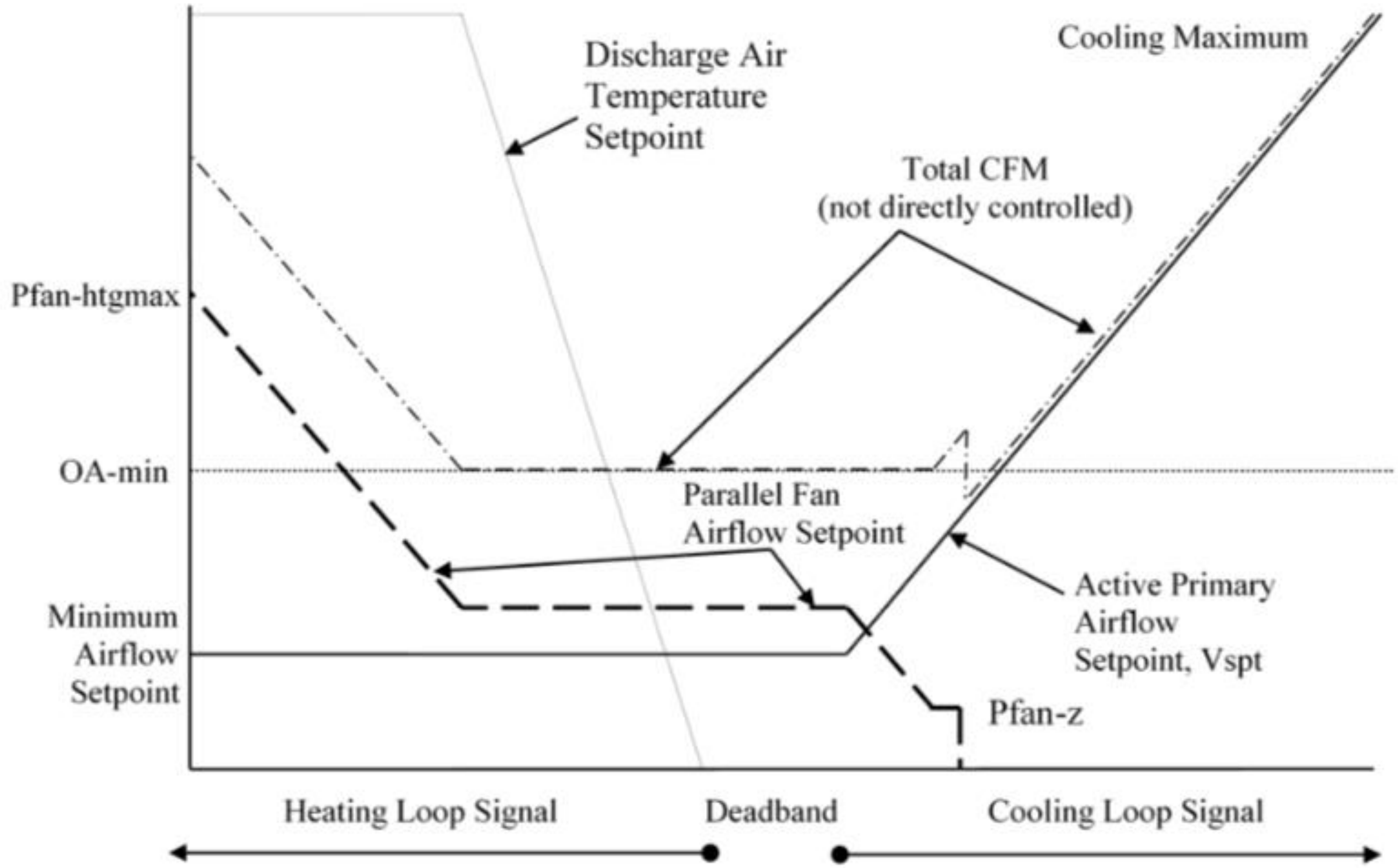

Figure 5.8.5 Control logic for variable-volume parallel fan-powered VAV zone.

5.9 – Series Fan-Powered Terminal Unit – CV Fan

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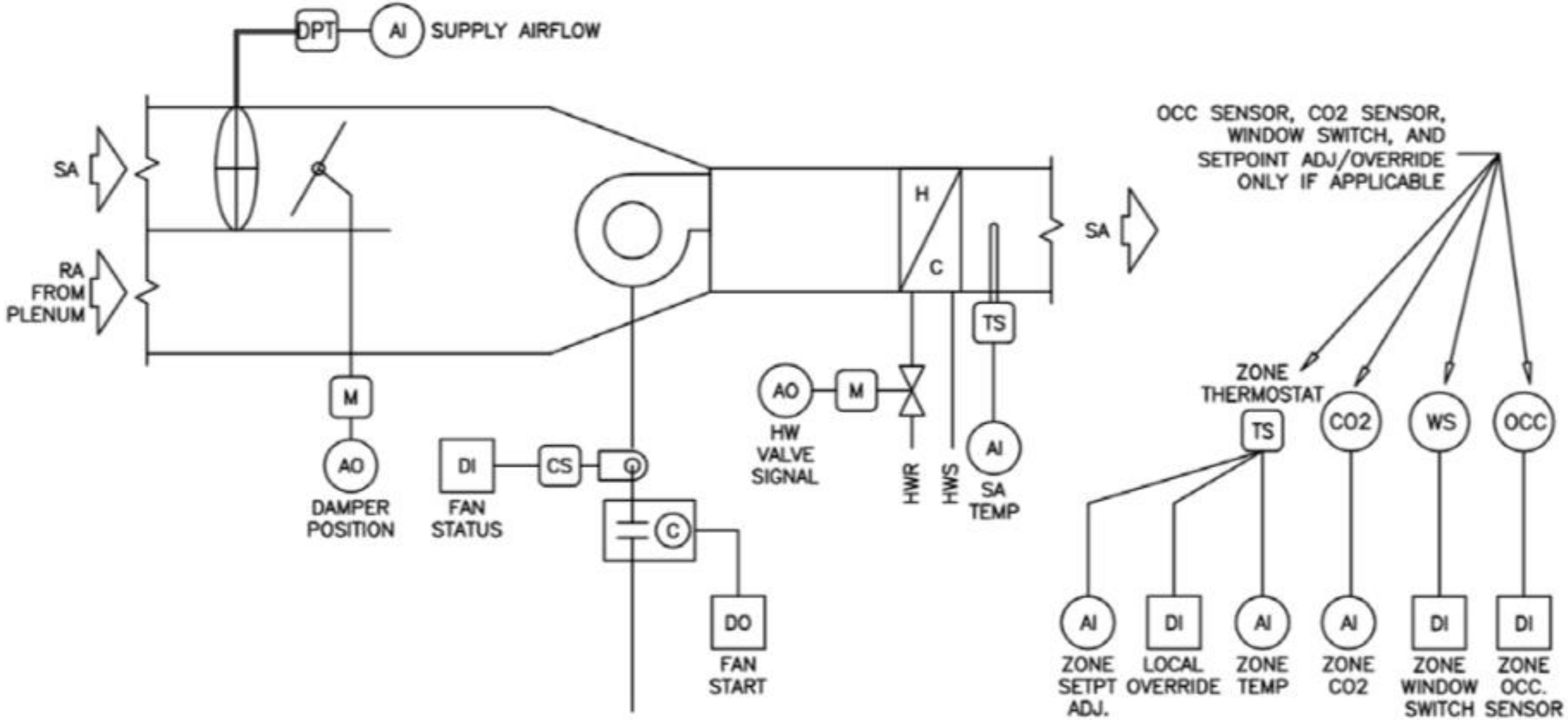

Figure A-5 Series fan-powered terminal unit, constant-volume fan.

5.9 – Series Fan-Powered Terminal Unit – CV Fan

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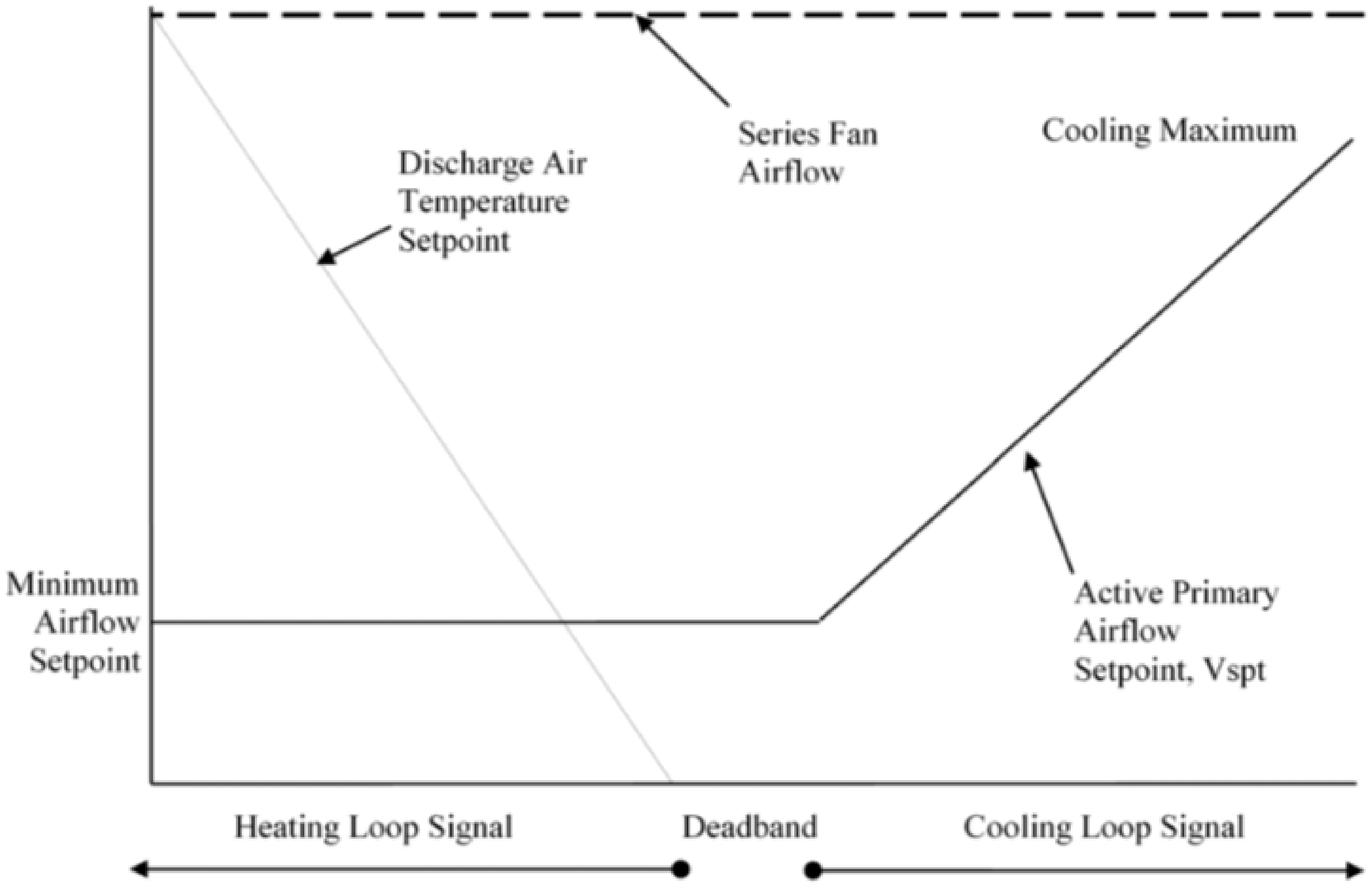

Figure 5.9.5 Control logic for constant-volume series fan-powered VAV zone.

5.10 – Series Fan-Powered Terminal Unit – V Fan

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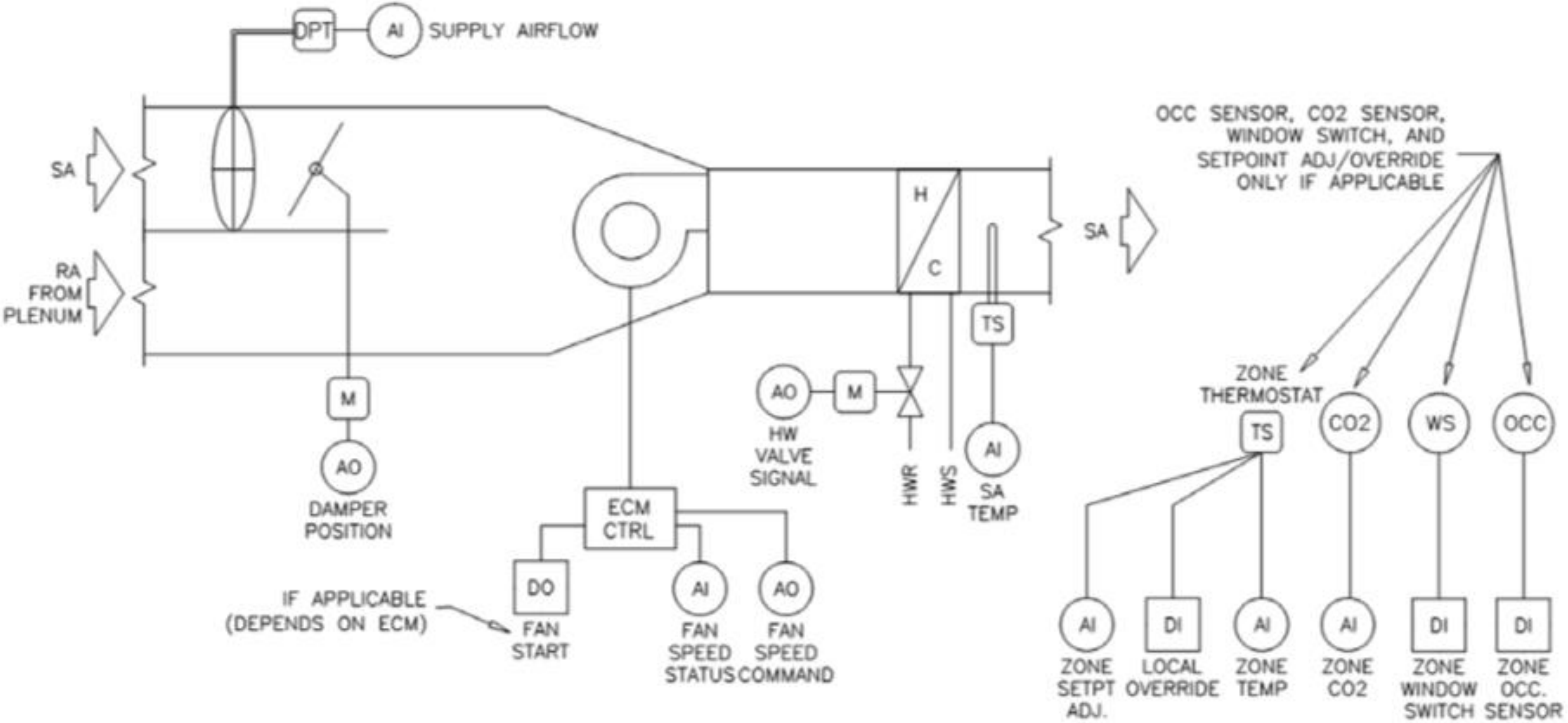

Figure A-6 Series fan-powered terminal unit, variable-volume fan.

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5.10 – Series Fan-Powered Terminal Unit – V Fan

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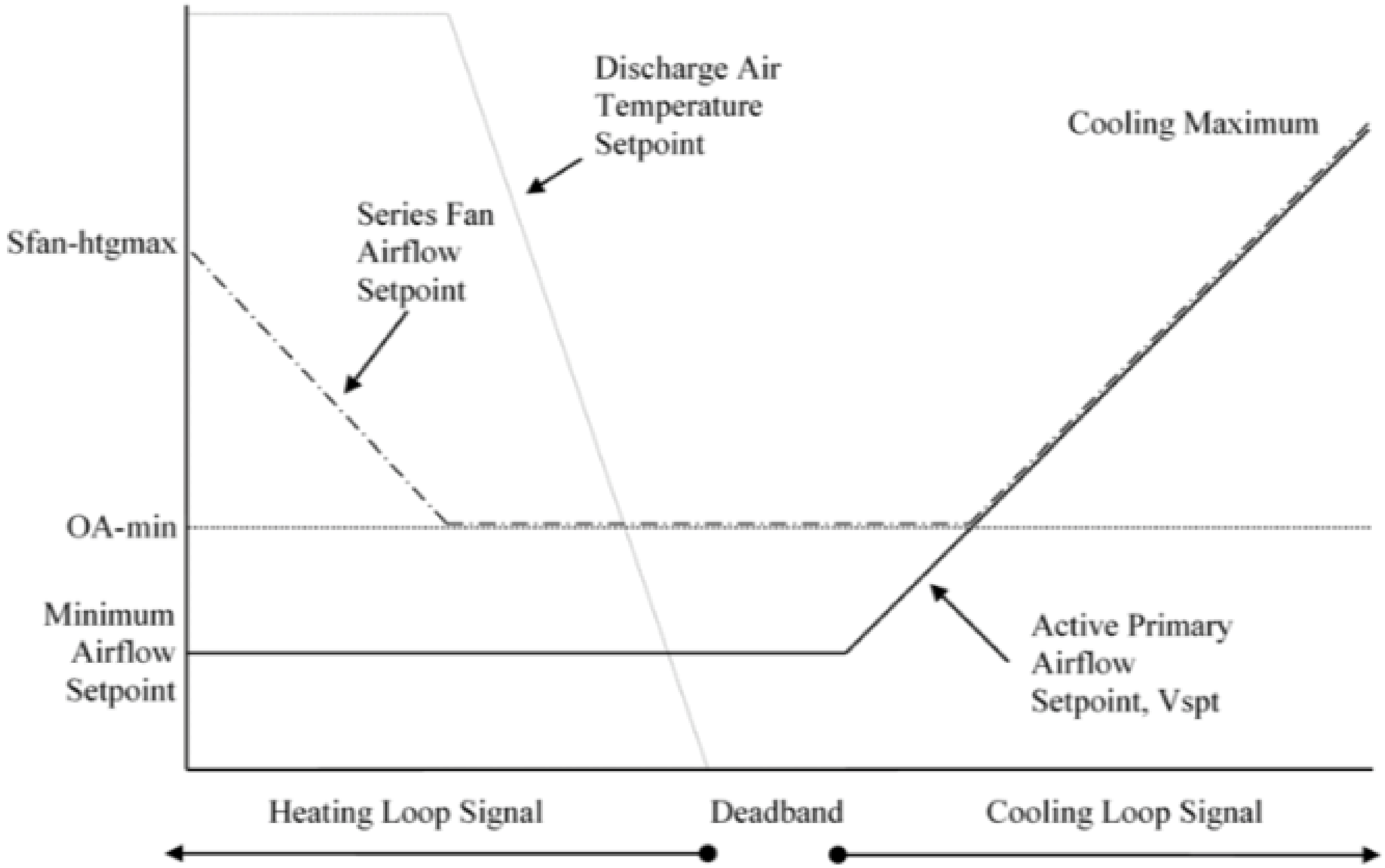

Figure 5.10.5 Control logic for variable-volume series fan-powered VAV zone.

5.11 – Dual-Duct VAV Terminal Unit Snap Acting Control

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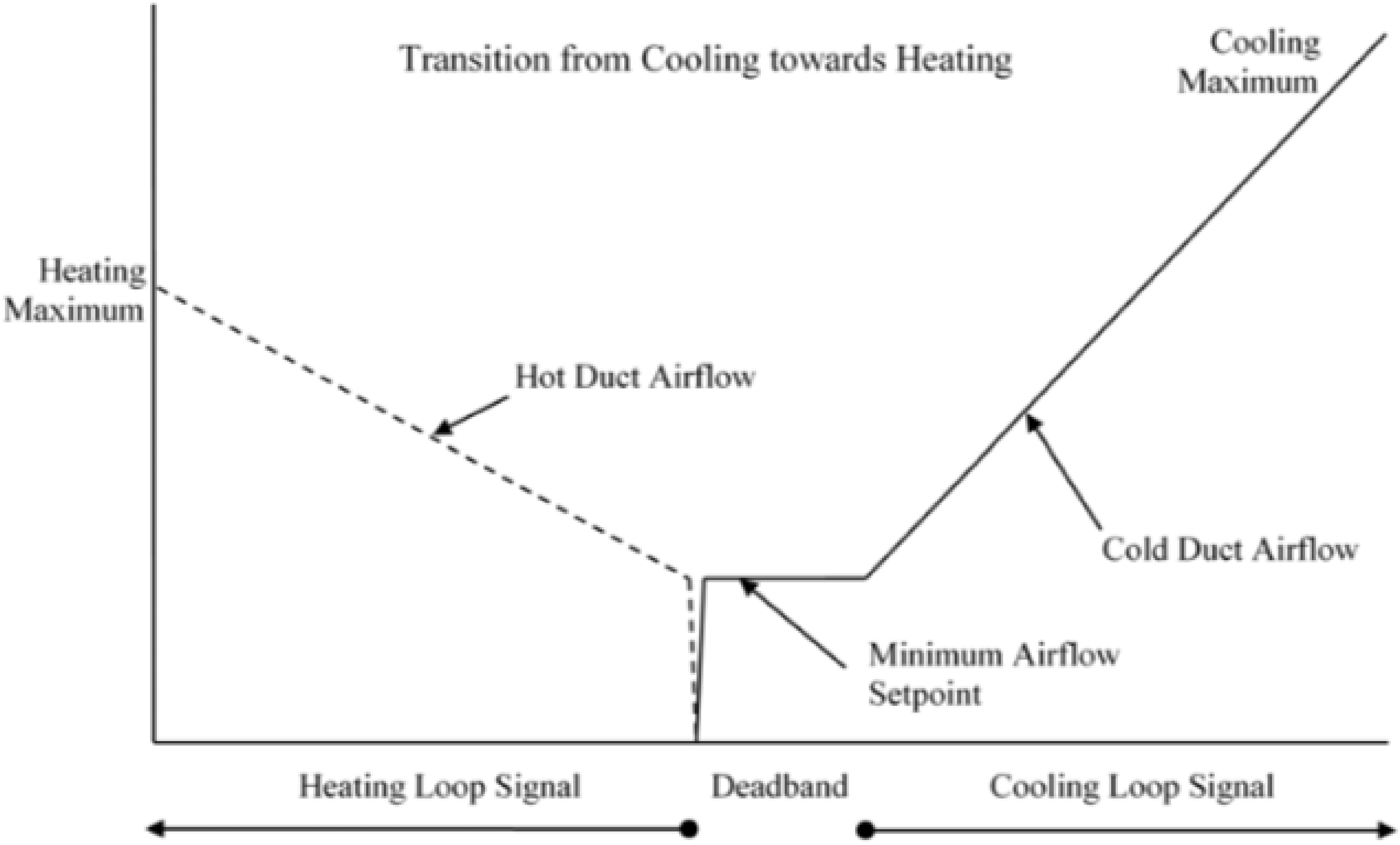

Figure 5.11.5-1 Control logic for snap-acting dual-duct VAV zone (transition to cooling).

5.11 – Dual-Duct VAV Terminal Unit Snap Acting Control

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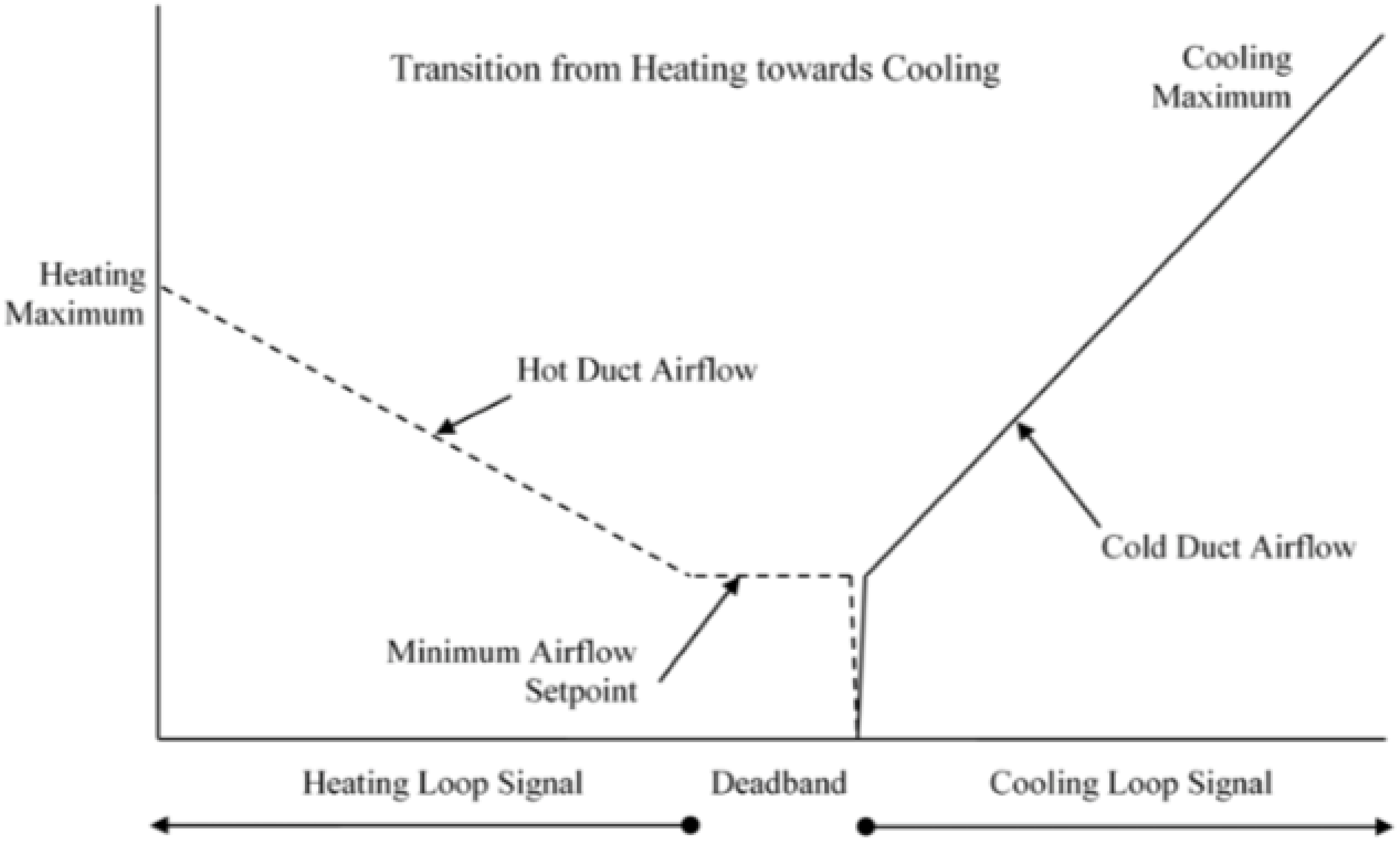

Figure 5.11.5-2 Control logic for snap-acting dual-duct VAV zone (transition to heating).

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

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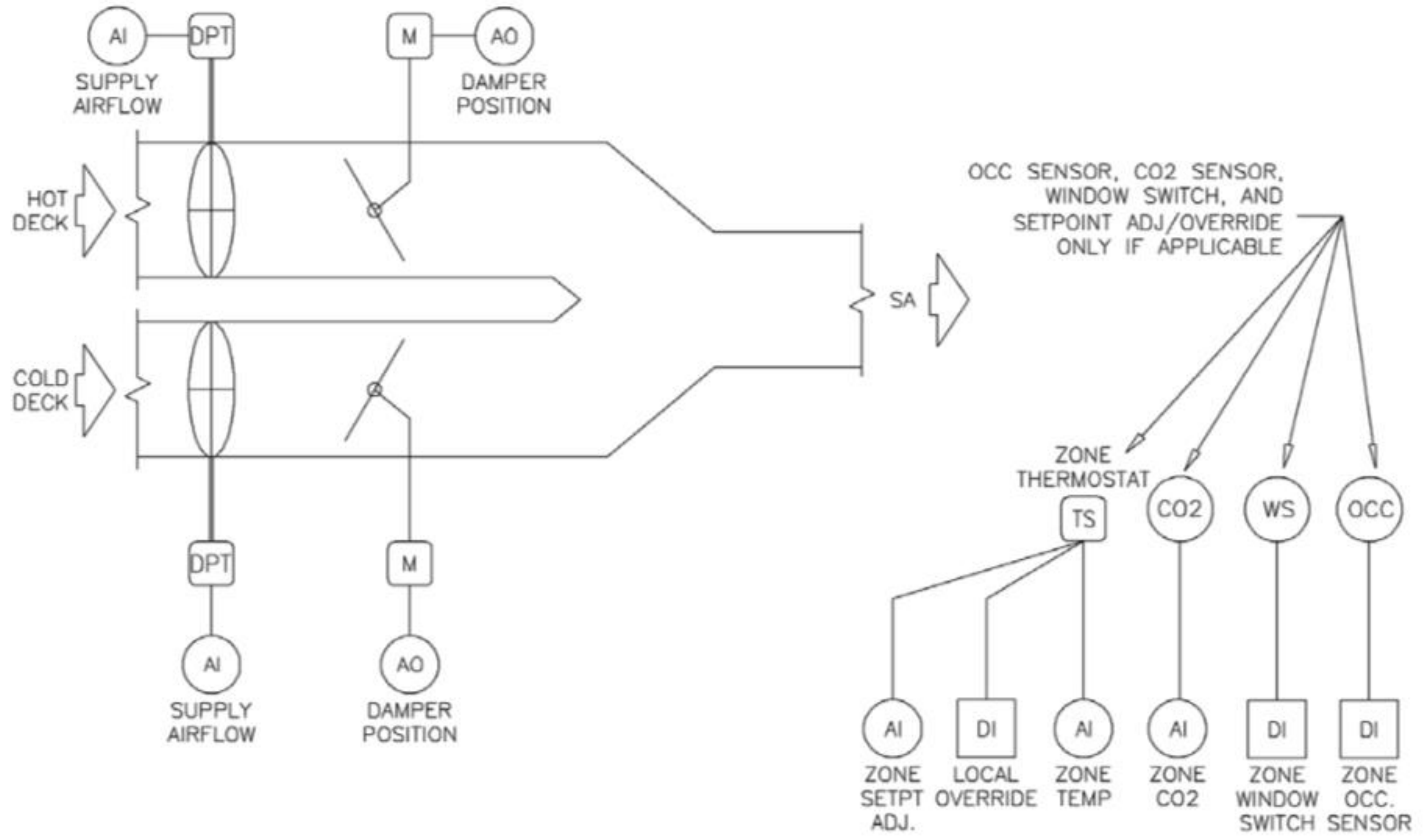

Figure A-7 Dual-duct terminal unit with inlet sensors.

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

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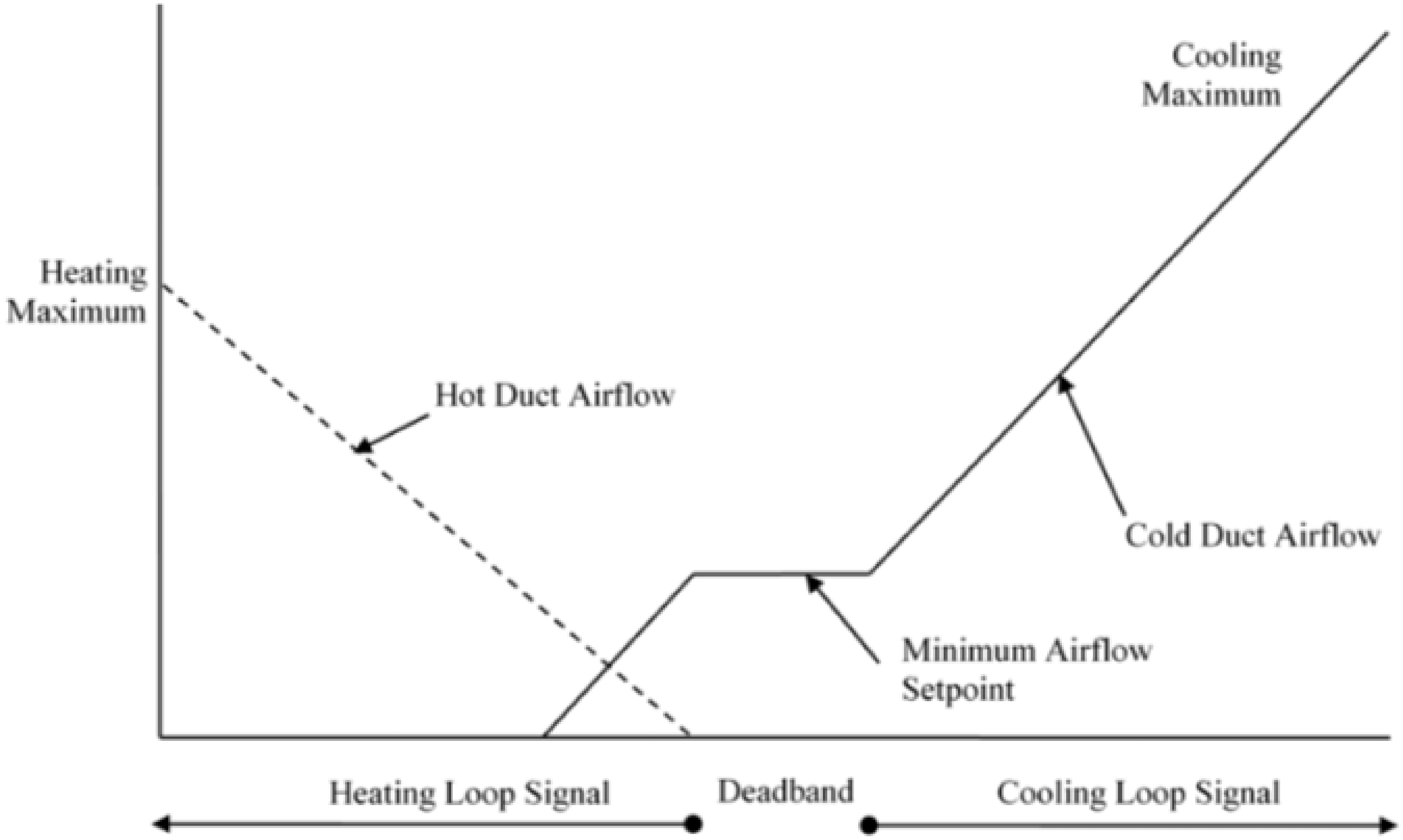

Figure 5.12.5 Control logic for mixing dual-duct VAV zone with inlet sensors.

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

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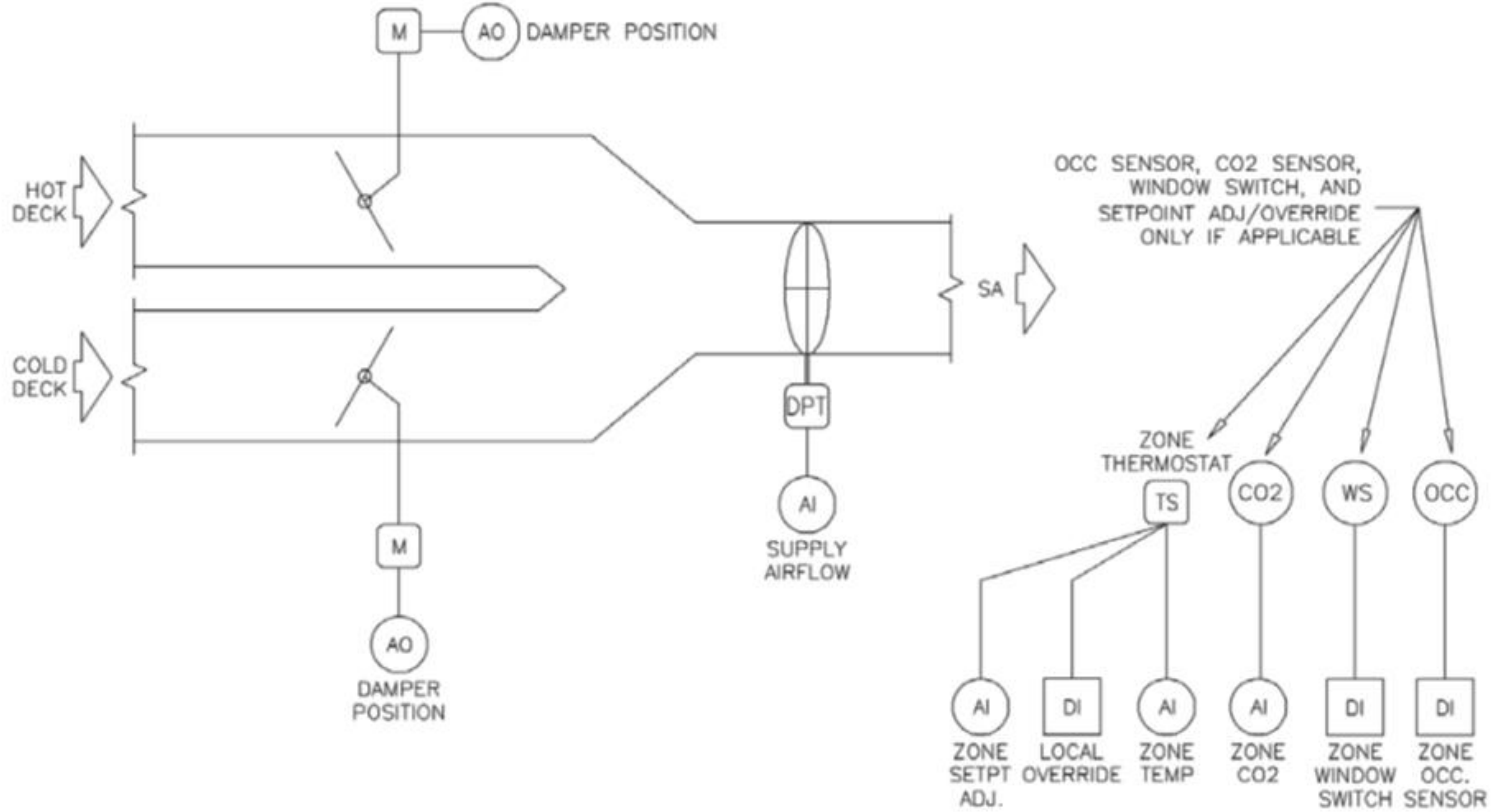

Figure A-8 Dual-Duct terminal unit with discharge sensor.

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

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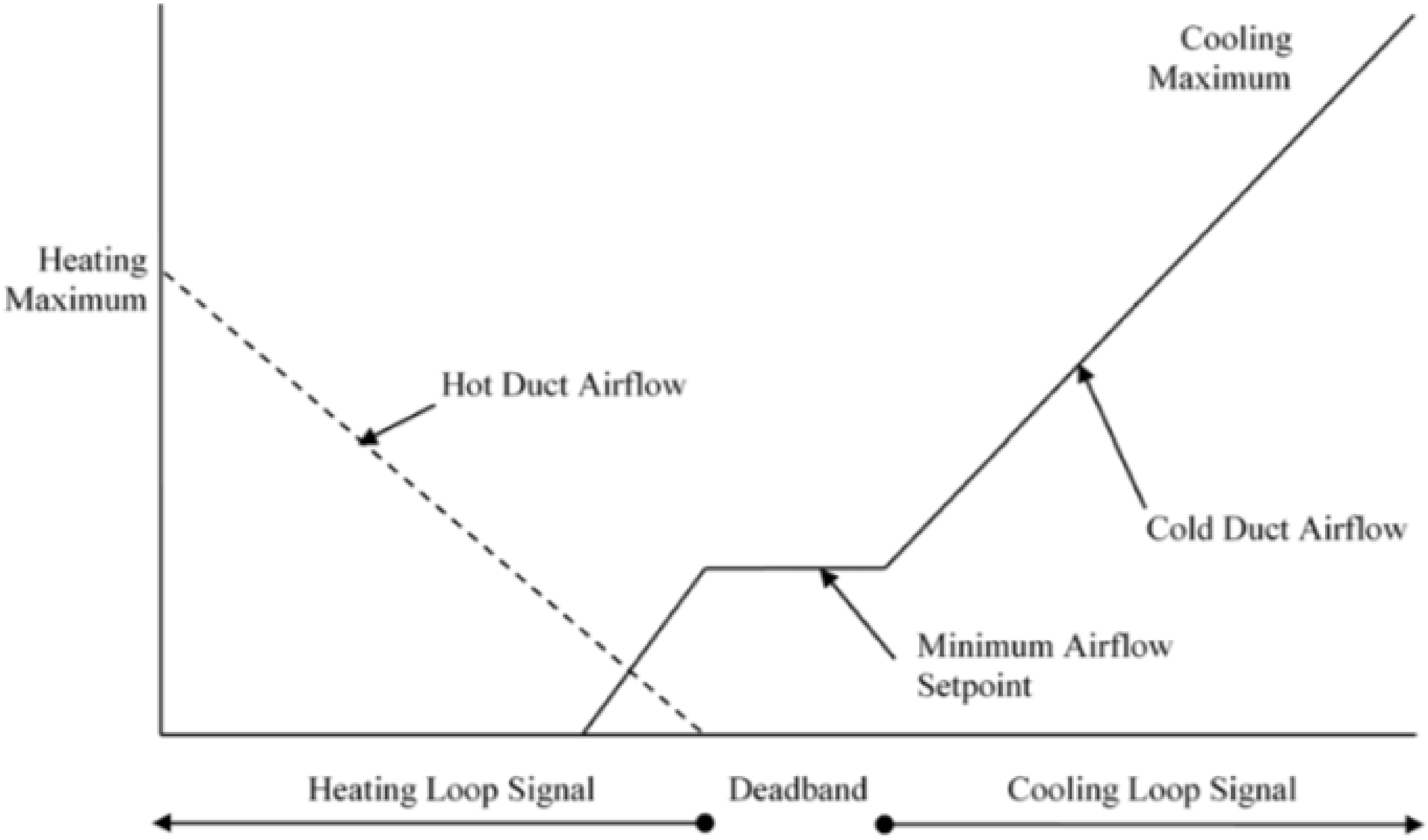

Figure 5.13.5 Control logic for mixing dual-duct VAV zone with discharge sensor.

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

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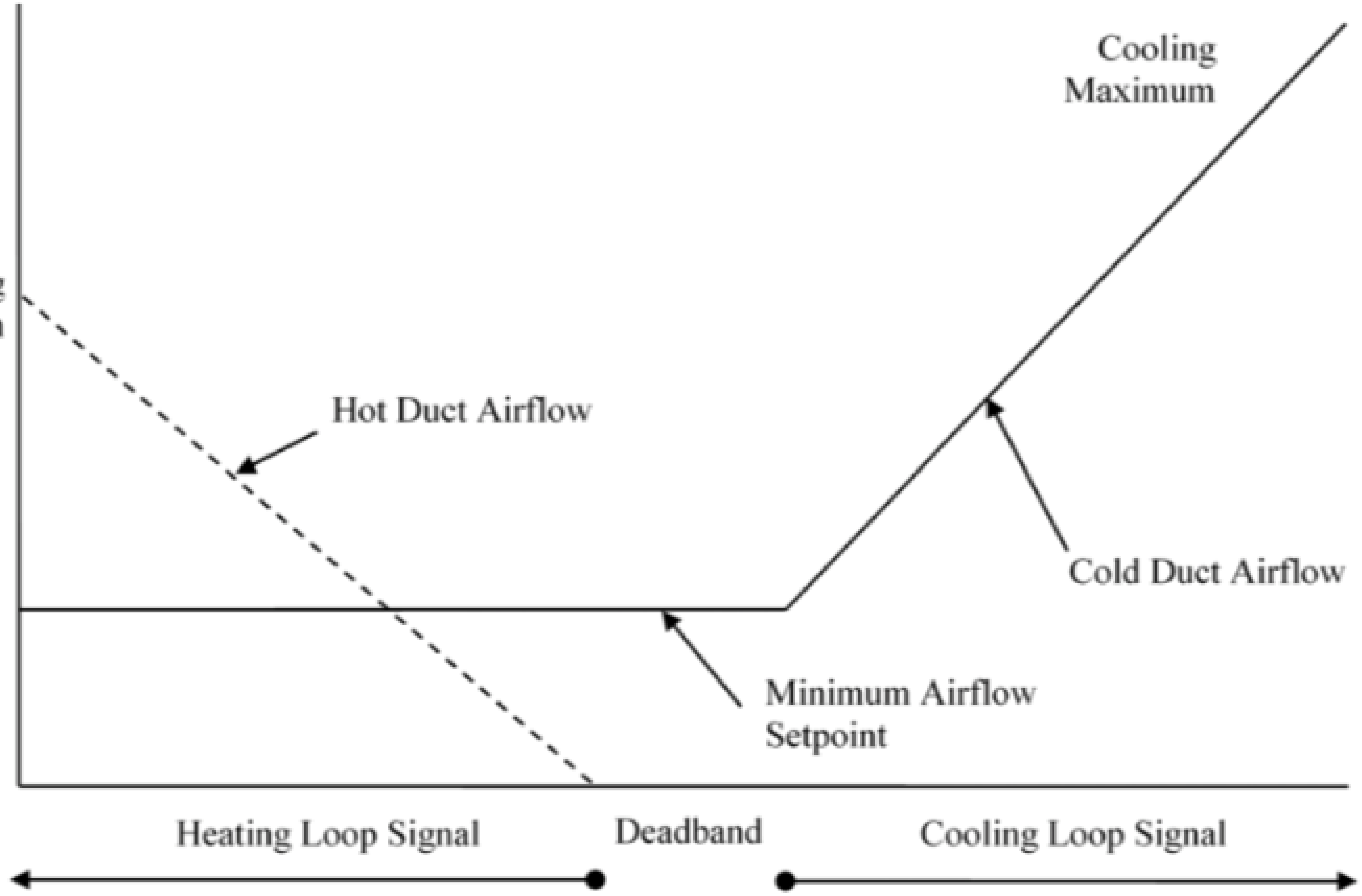

Figure 5.14.5 Control logic for mixing dual-duct VAV zone with cold-duct minimum.

5.15 – Air-Handling Unit System Modes

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Match the Modes used by the Zone level terminal units.

- Occupied
- Warm-Up
- Cooldown
- Setback
- Freeze Protection
- Setup
- Unoccupied

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5.16 – Multiple Zone VAV AHU

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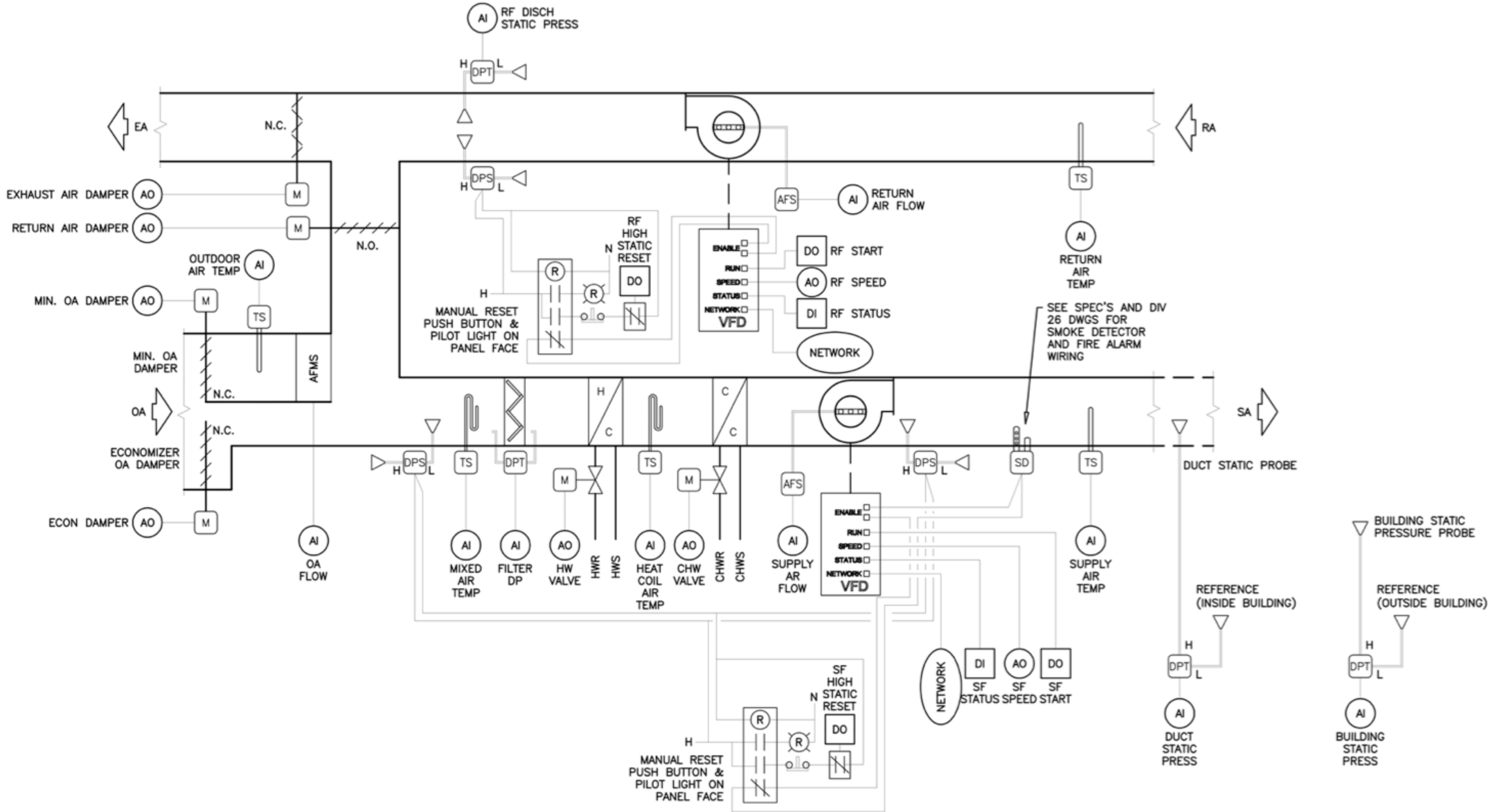

Figure A-9 Multiple-zone VAV air-handling unit with return fan and minimum OA measurement station.

5.16 – Multiple Zone VAV AHU

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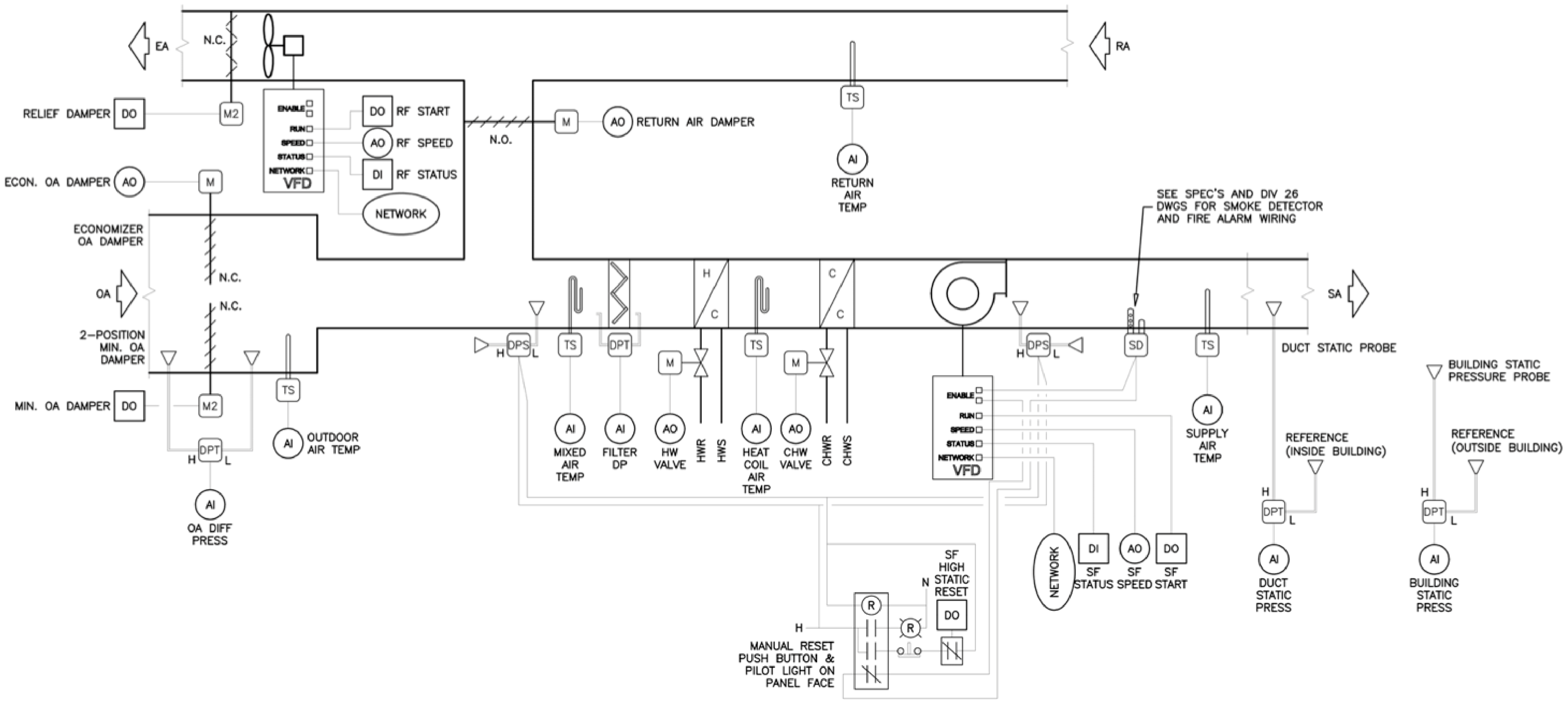

Figure A-10 Multiple-zone VAV air-handling unit with relief fan and differential pressure OA measurement.

5.16 – Multiple Zone VAV AHU

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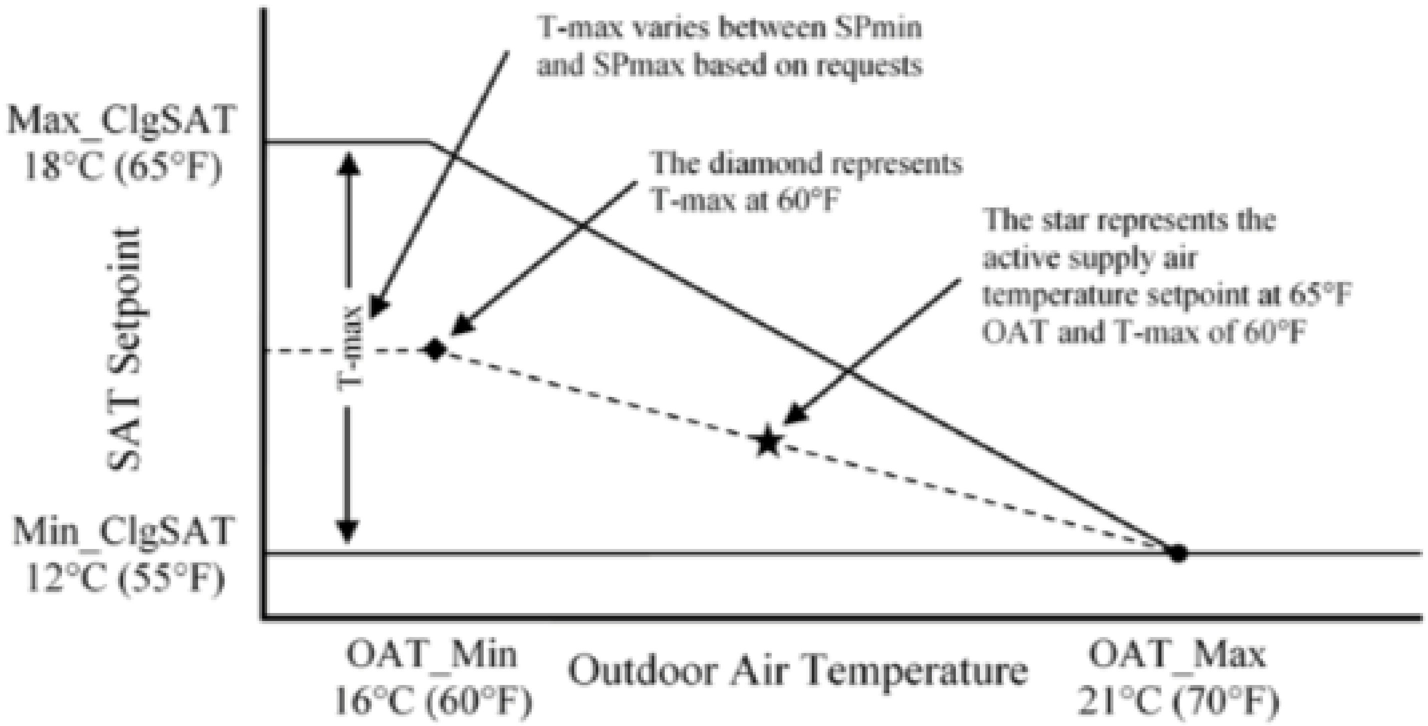

Figure 5.16.2.2 Example supply air temperature reset diagram.

5.16 – Multiple Zone VAV AHU

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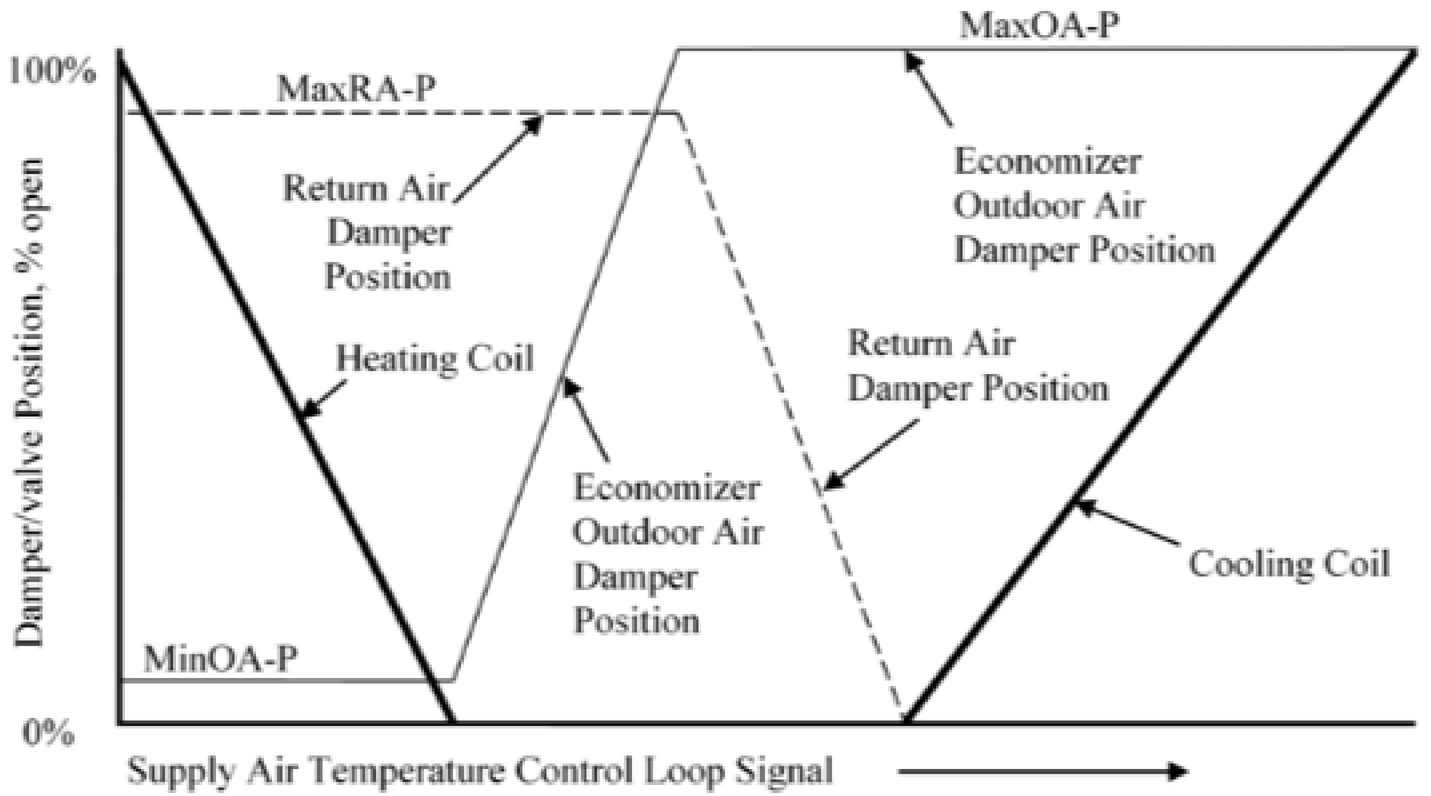

Figure 5.16.2.3-1 SAT loop mapping with relief damper or relief fan.

5.16 – Multiple Zone VAV AHU

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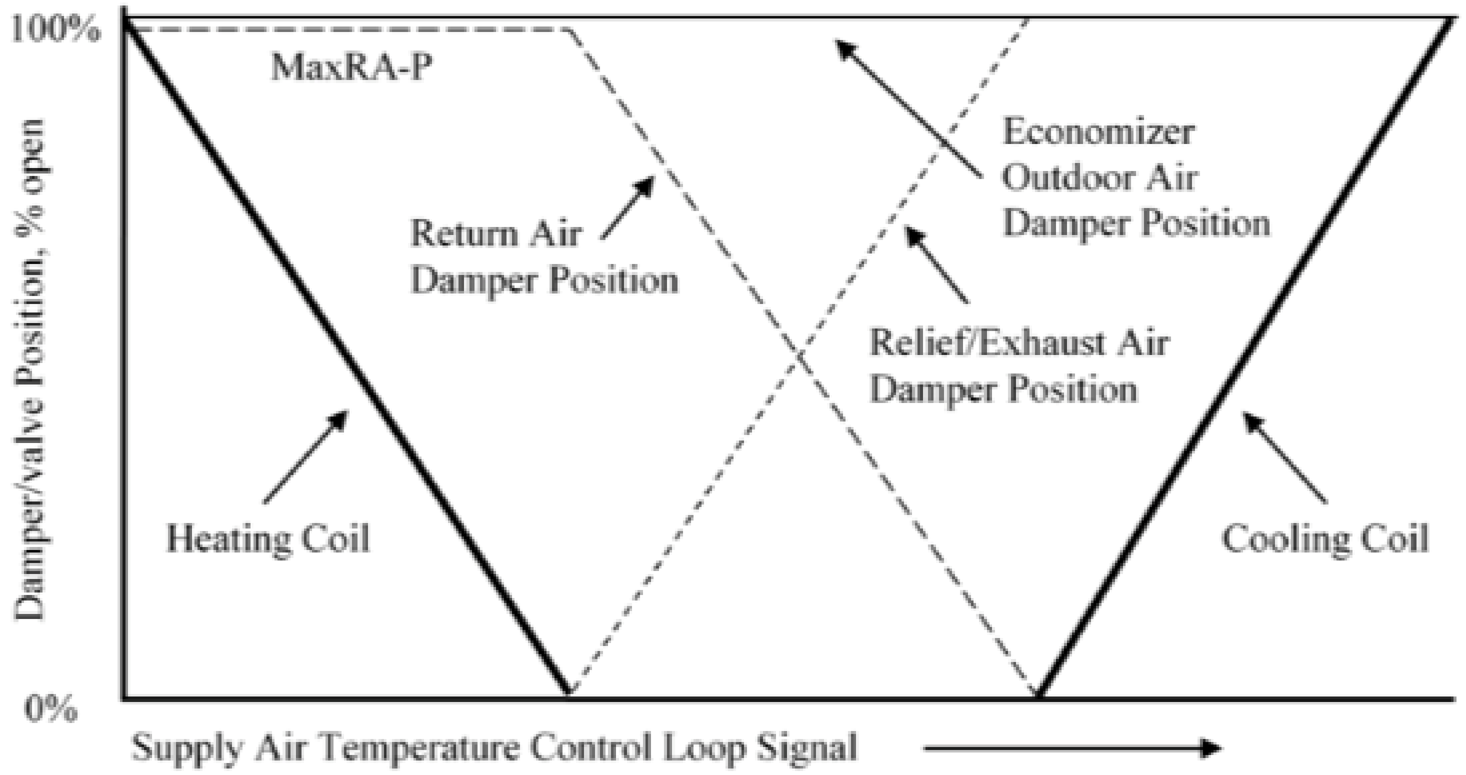

Figure 5.16.2.3-2 SAT loop mapping with return-fan control with airflow tracking.

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5.16 – Multiple Zone VAV AHU

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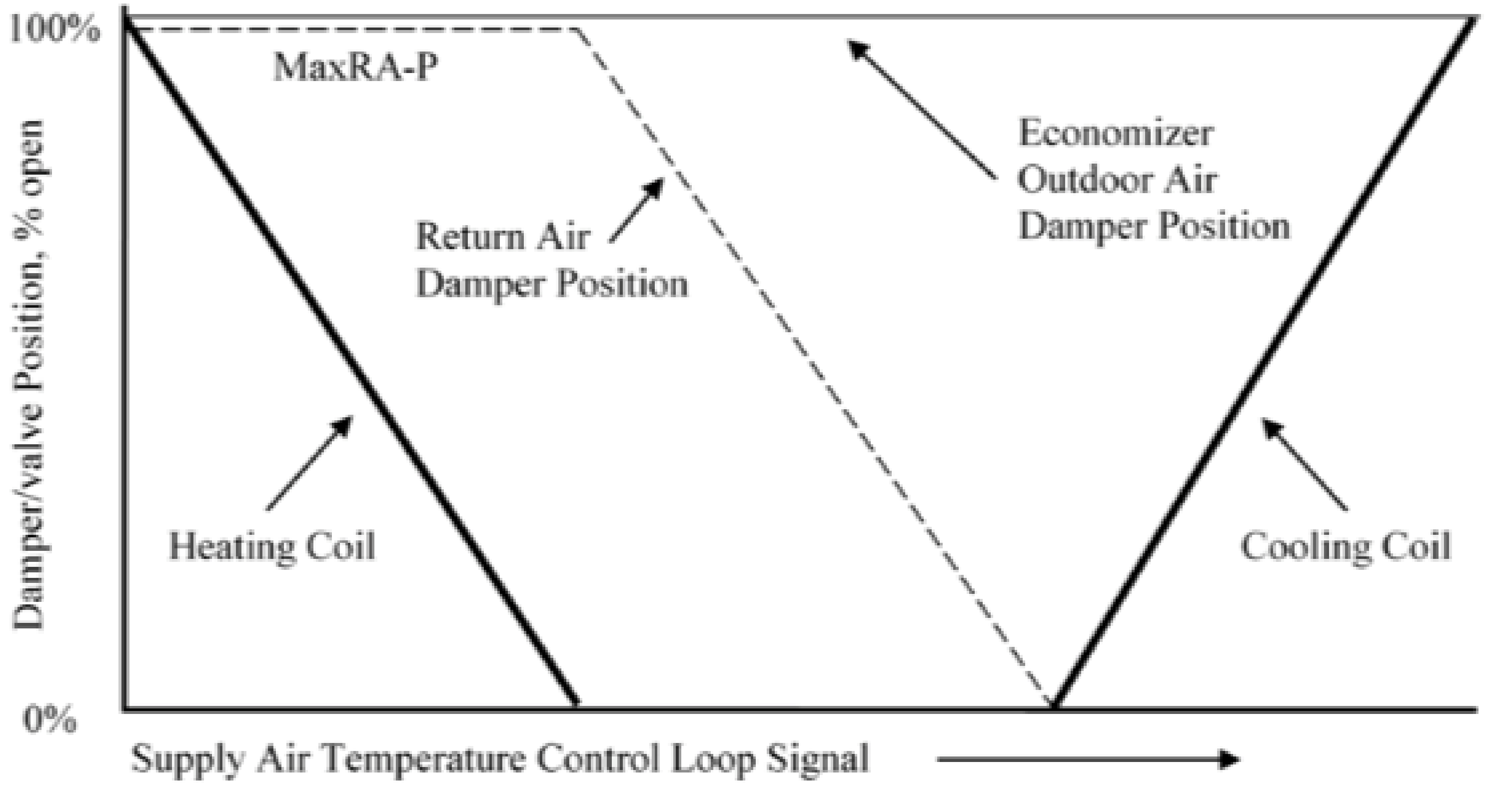

Figure 5.16.2.3-3 SAT loop mapping with return-fan control with direct building pressure controls.

5.16 – Multiple Zone VAV AHU

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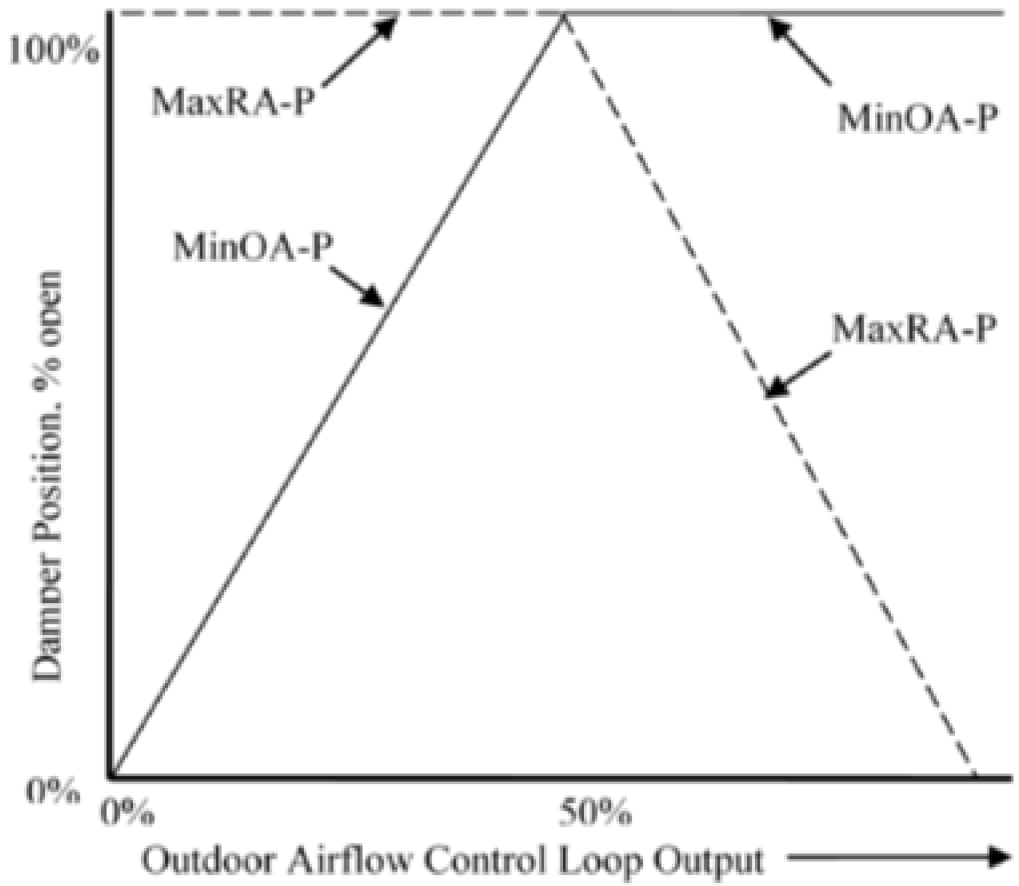

Figure 5.16.6.3 Minimum outdoor airflow control mapping with single damper.

5.16 – Multiple Zone VAV AHU

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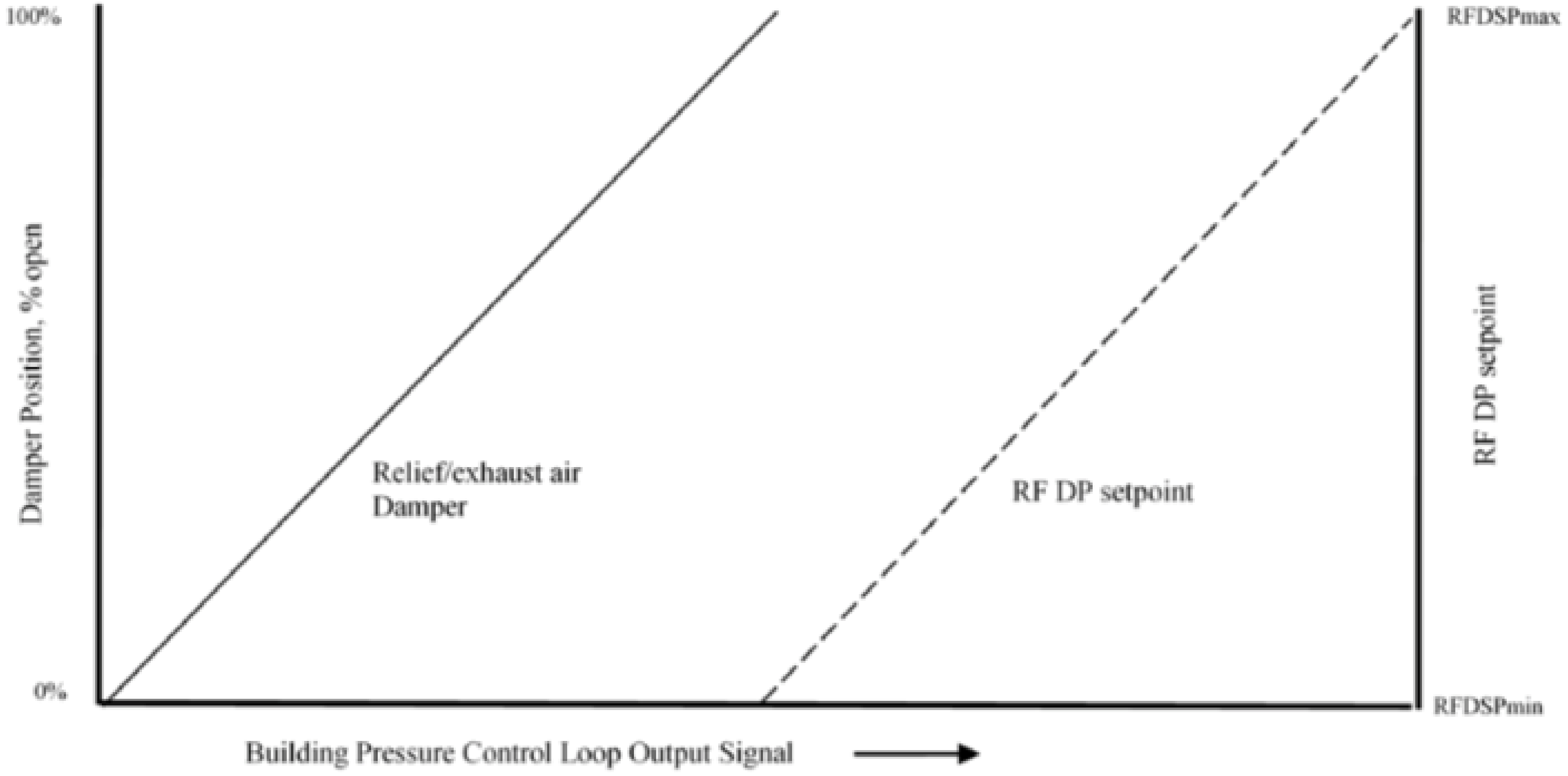

Figure 5.16.10.5 Exhaust damper position and return-fan DP reset

5.16 – Multiple Zone VAV AHU

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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		

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5.16 – Multiple Zone VAV AHU

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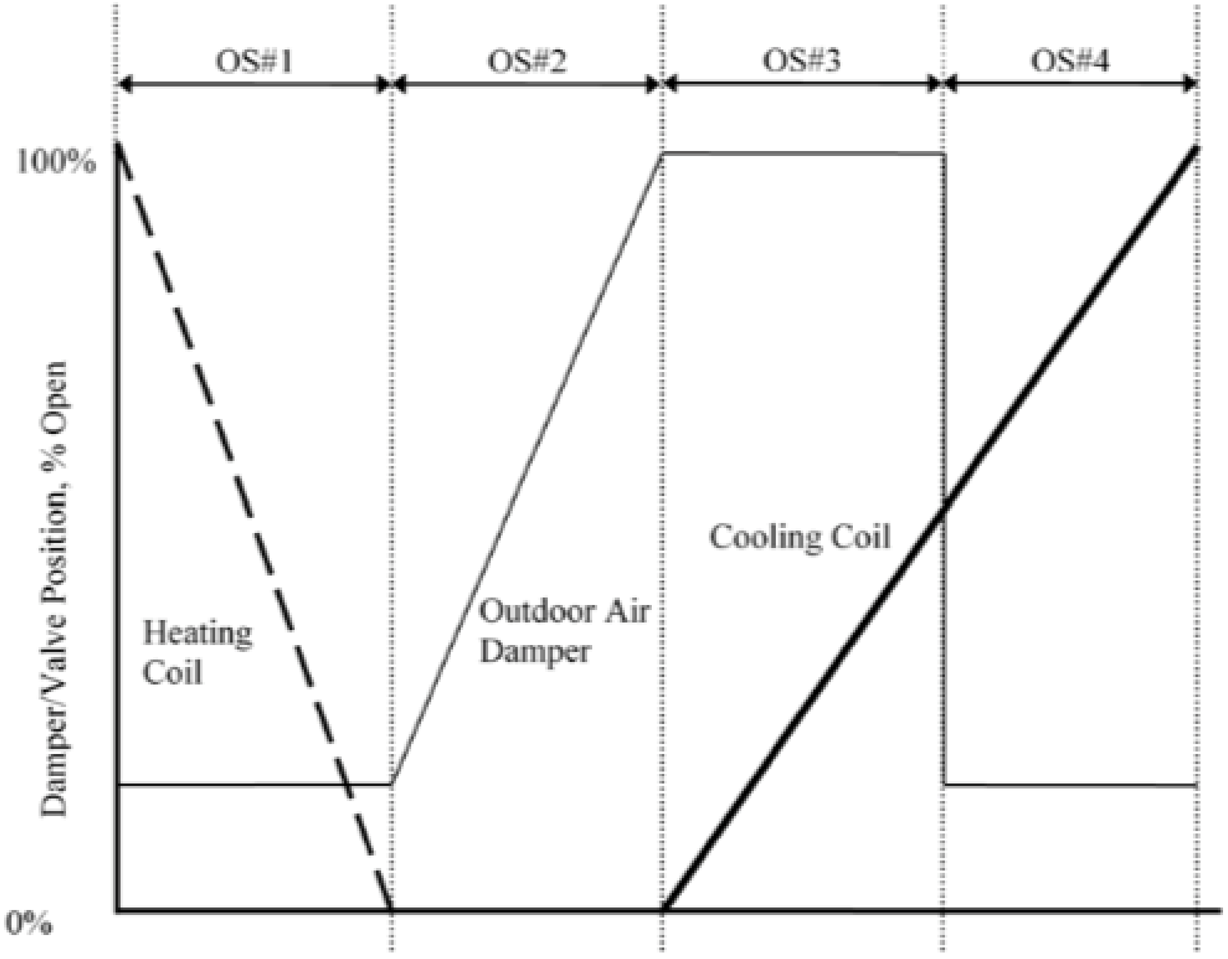

Figure 5.16.14.2 VAV AHU operating states.

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

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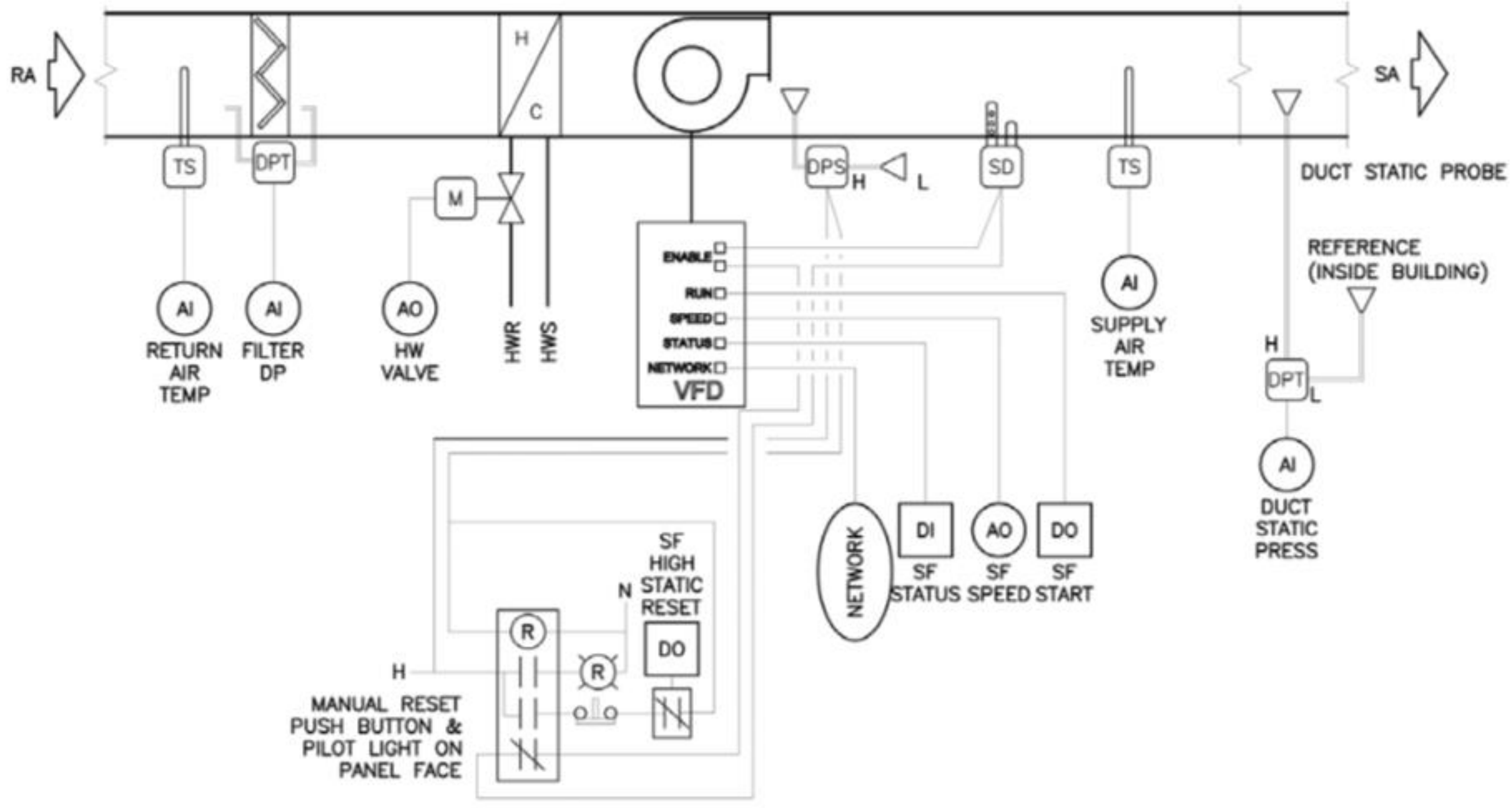

Figure A-11 Dual-fan dual-duct heating VAV air-handling unit.

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

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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)

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)

5.18 – Single-Zone VAV Air-Handling Unit

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High-Performance Sequences of Operation for HVAC Systems

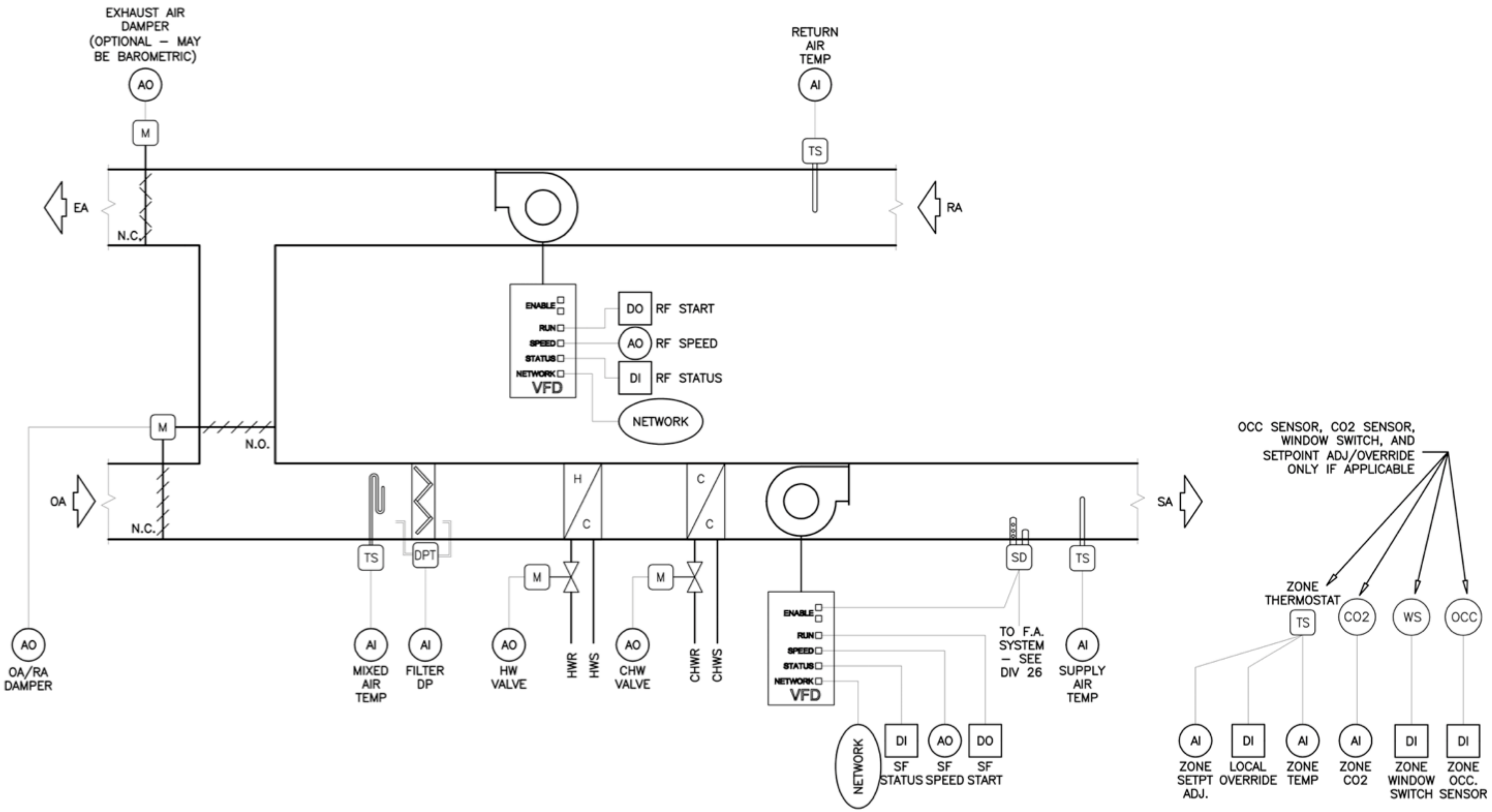

Figure A-12 SZVAV AHU (return-fan option).

5.18 – Single-Zone VAV Air-Handling Unit

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High-Performance Sequences of Operation for HVAC Systems

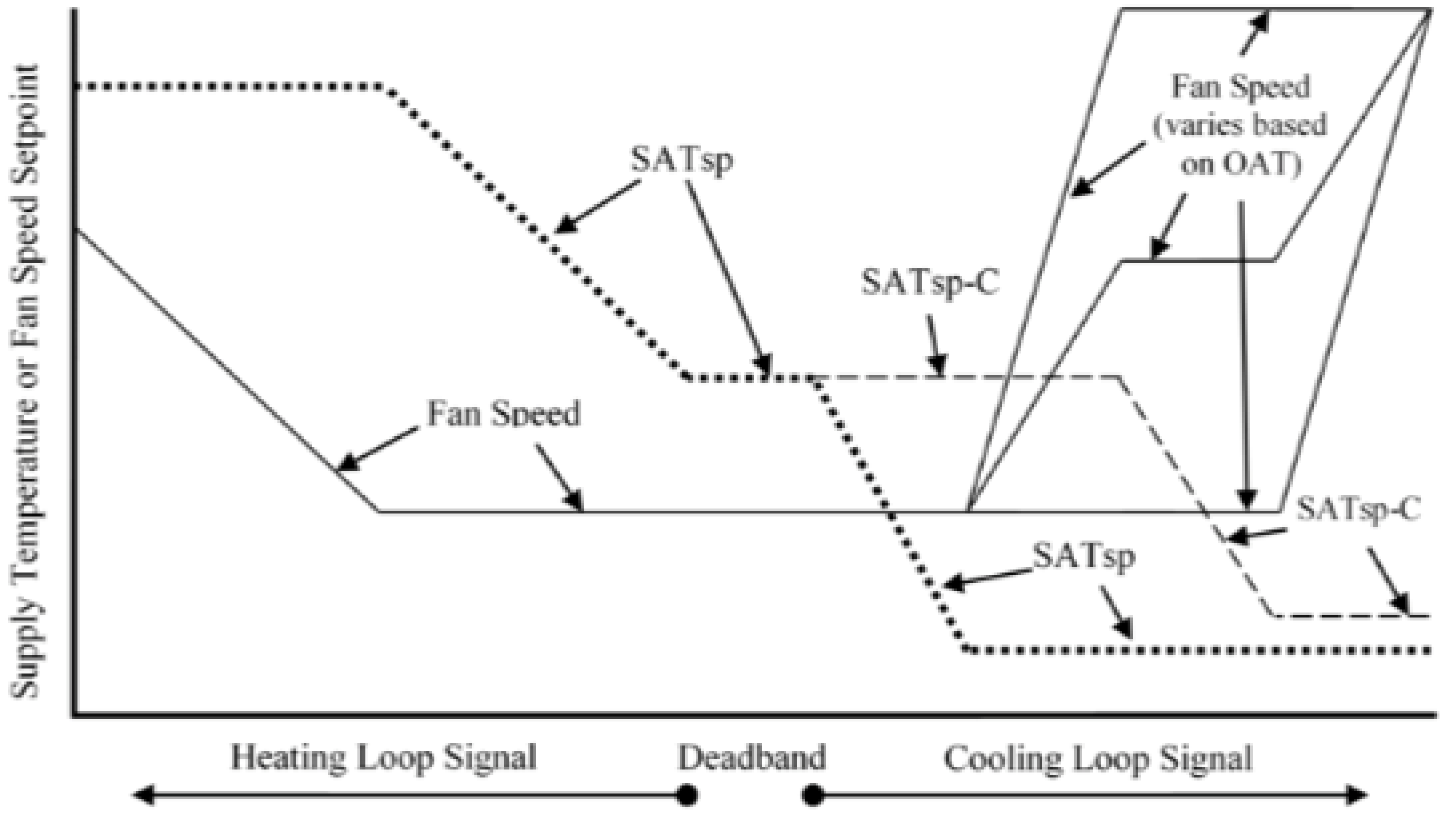

Figure 5.18.4.5-1 Control diagram for SZVAV AHU.

5.18 – Single-Zone VAV Air-Handling Unit

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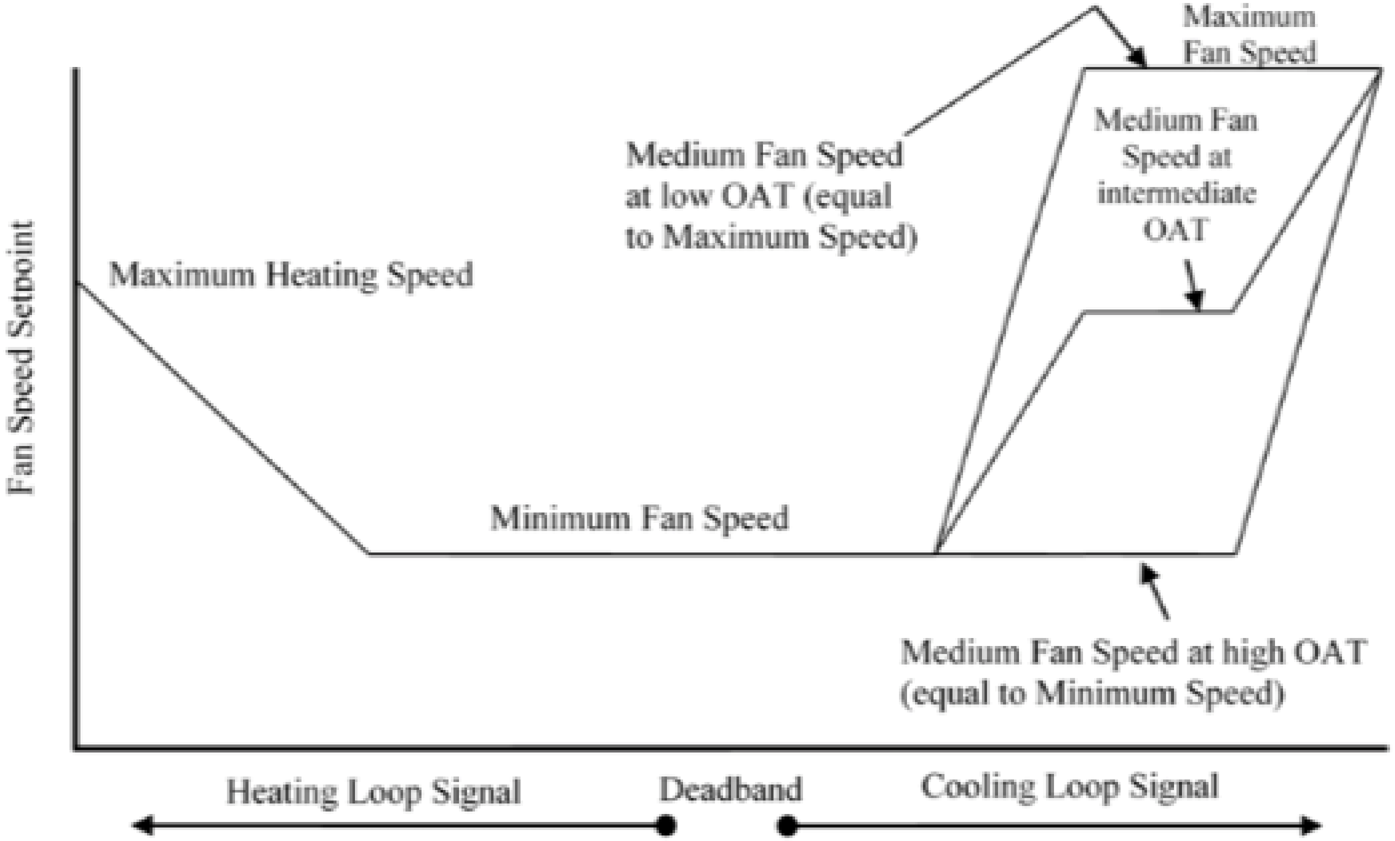

Figure 5.18.4.5-2 Control diagram for SZVAV AHU—fan speed.

5.18 – Single-Zone VAV Air-Handling Unit

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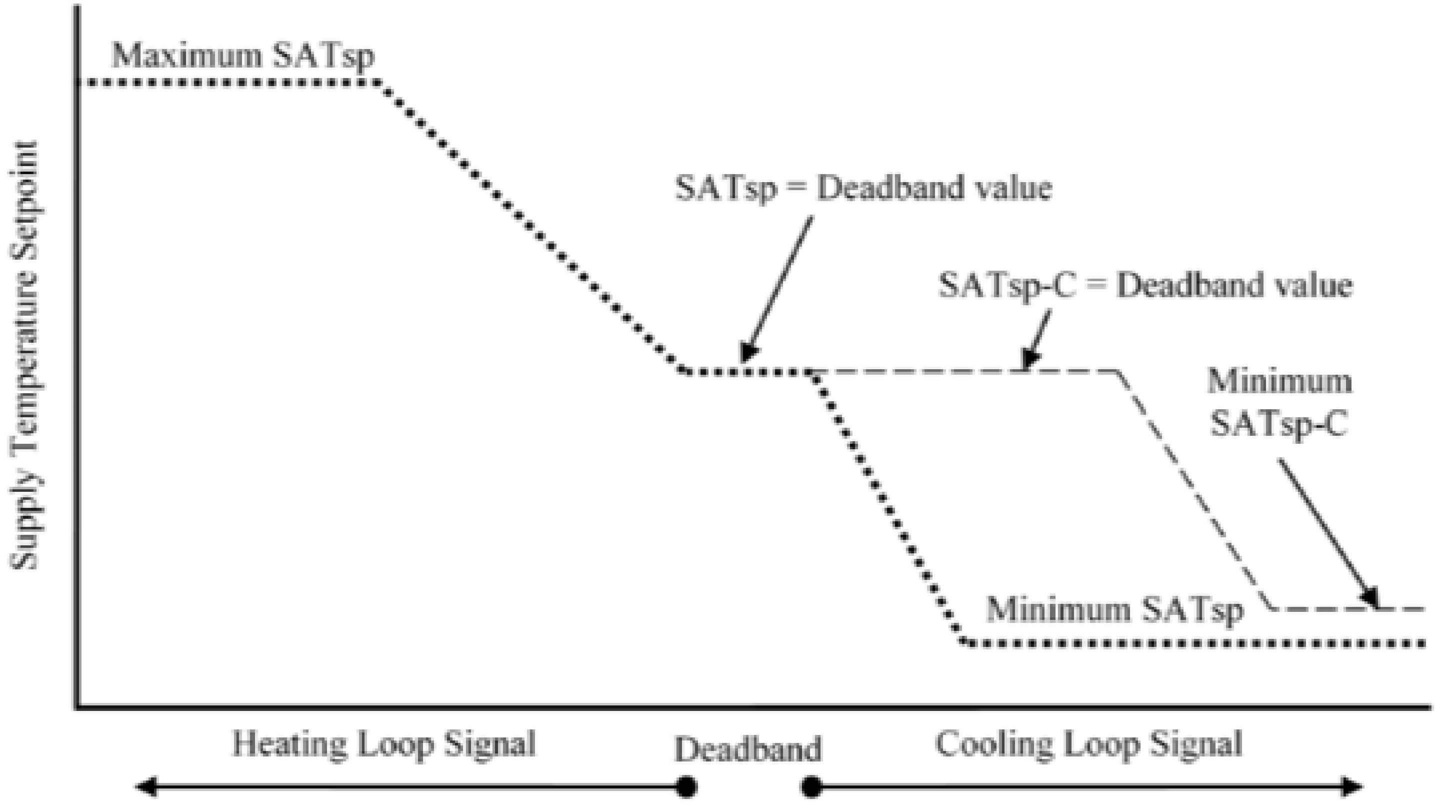

Figure 5.18.4.5-3 Control diagram for SZVAV AHU—supply air temperature.

5.18 – Single-Zone VAV Air-Handling Unit

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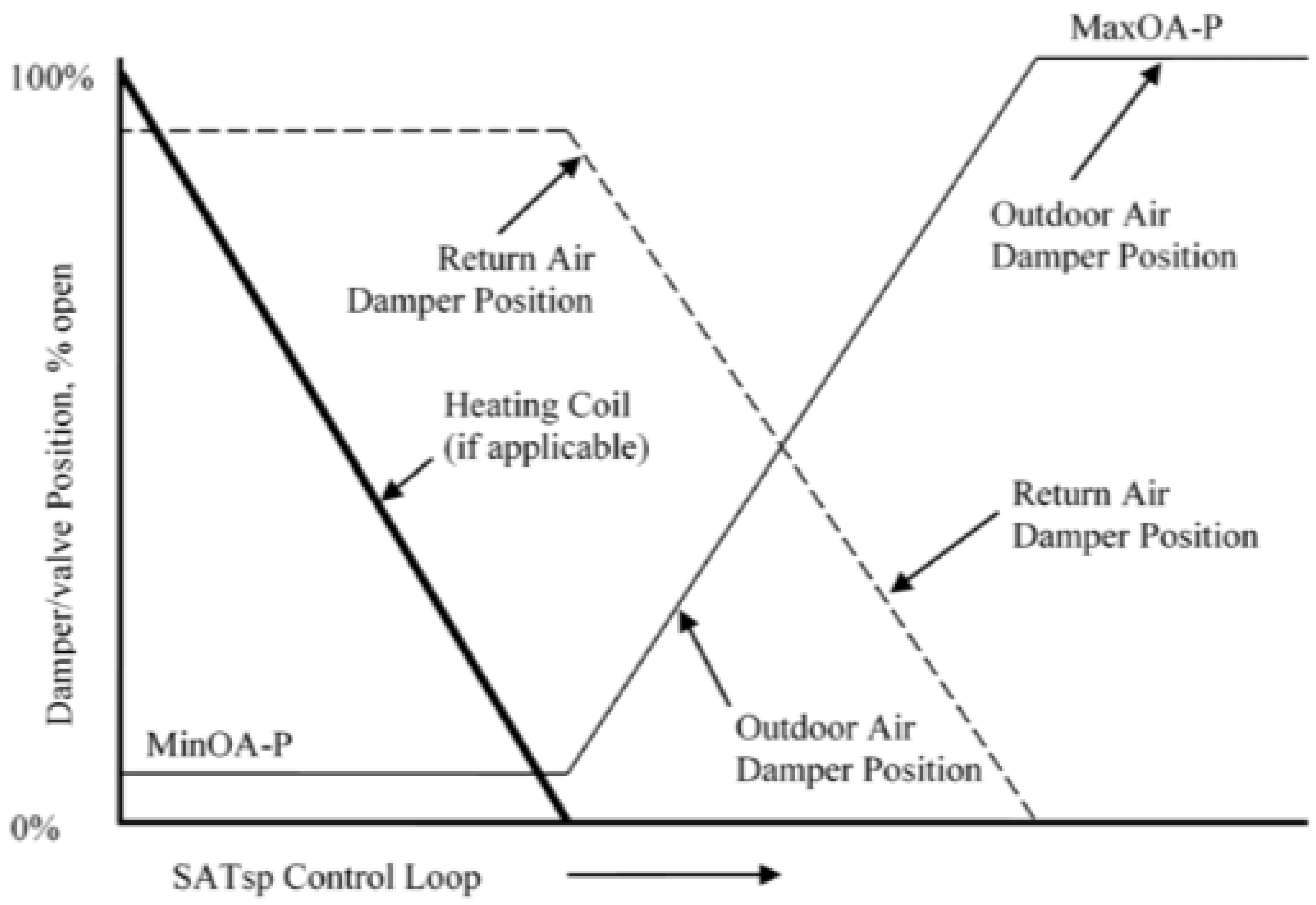

Figure 5.18.5.2 SZVAV AHU supply air temperature loop mapping.

5.18 – Single-Zone VAV Air-Handling Unit

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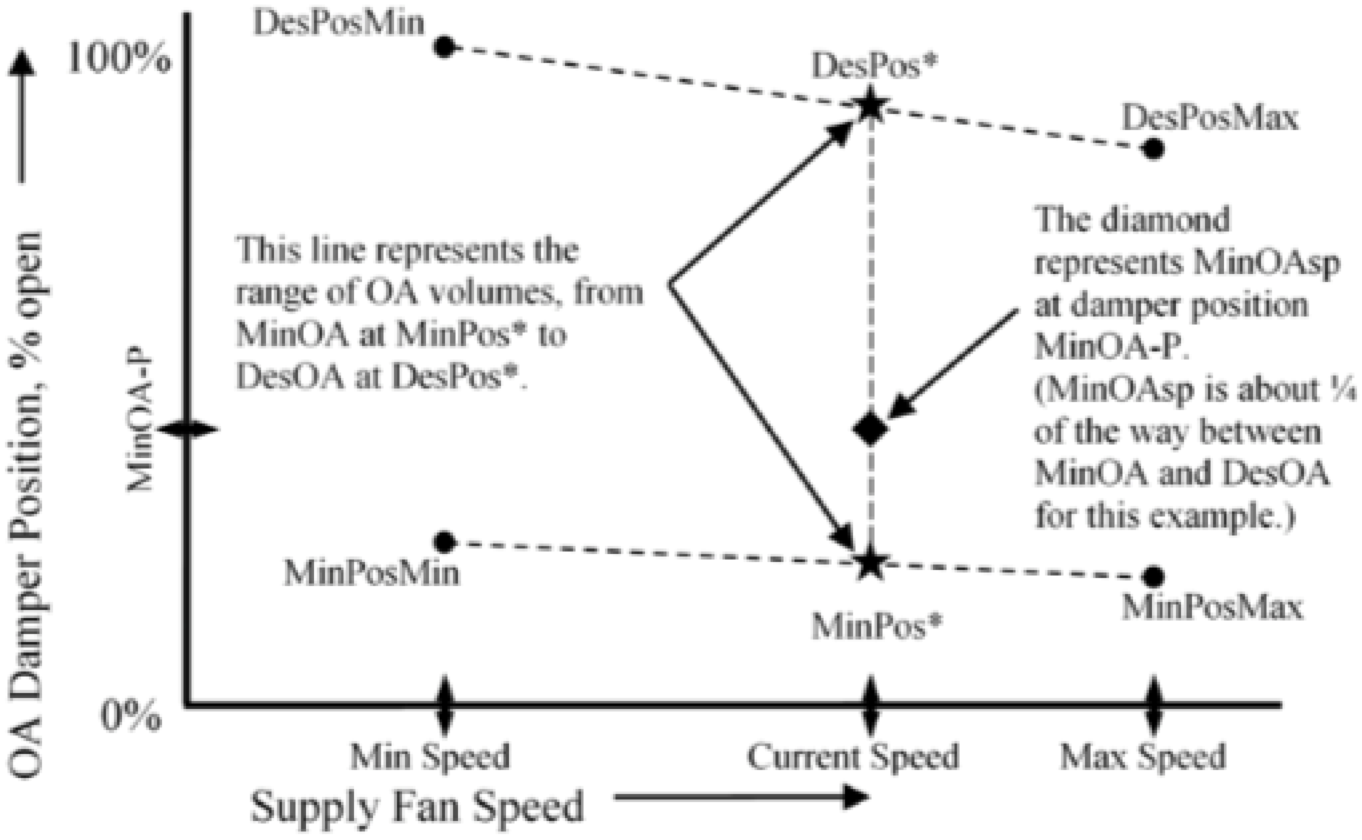

Figure 5.18.6.2 SZVAV AHU minimum outdoor air control.

5.18 – Single-Zone VAV Air-Handling Unit

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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		

5.18 – Single-Zone VAV Air-Handling Unit

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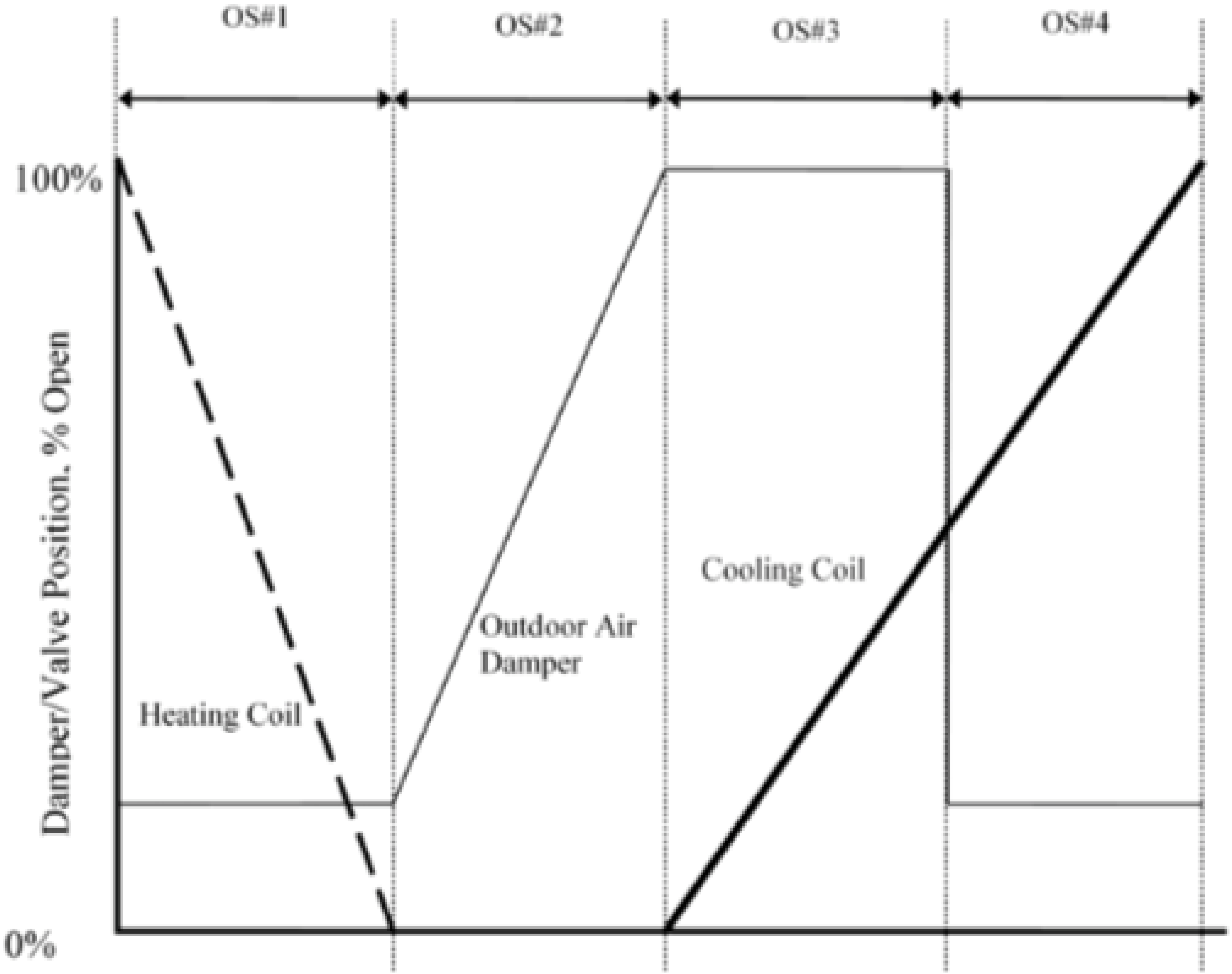

Figure 5.18.13.2 SZVAV AHU operating states.

5.18 – Single-Zone VAV Air-Handling Unit T&R

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High-Performance Sequences of Operation for HVAC Systems

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)

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)

5.18 – Single-Zone VAV Air-Handling Unit T&R

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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.

5.18 – Single-Zone VAV Air-Handling Unit AFDD

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Required IO

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.)

Required Calculated Variables

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 – Single-Zone VAV Air-Handling Unit AFDD

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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

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5.18 – Single-Zone VAV Air-Handling Unit AFDD

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High-Performance Sequences of Operation for HVAC Systems

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.

5.18 – Single-Zone VAV Air-Handling Unit AFDD

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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	

5.18 – Single-Zone VAV Air-Handling Unit AFDD

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FC#6	**Equation**	$\lvert RATavg - OATavg \rvert \geq \Delta Tmin$ **AND** $\lvert RATavg - MATavg \rvert > \lvert OATavg - MATavg \rvert$	**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**	$SATavg < SATSP - \varepsilon SAT$ **AND** $HC \geq 99\%$	**Applies to OS#1**
	Description	SAT too low in full heating	
	Possible Diagnosis	• SAT sensor error • Cooling-coil valve leaking or stuck open • Heating-coil valve stuck closed or actuator failure • Fouled or undersized heating coil • HW temperature too low or HW unavailable • Gas or electric heat is unavailable • DX cooling is stuck ON • Leaking or stuck economizer damper or actuator	
FC#8 (omit if no MAT sensor)	**Equation**	$\lvert SATavg - \Delta TSF - MATavg \rvert > \sqrt{\varepsilon SAT^2 + \varepsilon MAT^2}$	**Applies to OS#2**
	Description	SAT and MAT should be approximately equal	
	Possible Diagnosis	• SAT sensor error • MAT sensor error • Cooling-coil valve leaking or stuck open • DX cooling stuck on • Heating-coil valve leaking or stuck open • Gas or electric heat stuck ON	

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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	

5.18 – Single-Zone VAV Air-Handling Unit AFDD

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FC#13	**Equation**	SATavg > SATSP-C + εSAT **AND** CC ≥ 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	

AFDD – Barriers to Entry

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Setup & Data Pipeline

- Upgrade Equipment
- Configure Trends
- Install Jace
- Contextualize Data

Continuous Data Verification

- Collecting Data
- Database Management
- Managing BAS Connectivity
- Rule Generation
- Patching

Verify Reports

Making Changes / Improvements

Measure & Verify Changes

Questions

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Thank You

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