TITLE 24, PART 6 | 2028 CODE CYCLE

Welcome to the Statewide CASE Team’s Utility Sponsored Stakeholder Meeting

Topic: Reducing Maximum Airflow During Deadband Operation for Variable Air Volume HVAC Systems

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CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

Background – Low Airflows in Multizone Systems

Title 24 requires VAV systems be capable of operating with low airflows – even for high outside air systems

- Section 140.4(d) of Title 24 requires that for multizone VAV systems, zones with reheating shall set the airflow in deadband to be no more than the required outdoor airflow.
- Section 140.4(a)3(F) says that parallel fan-powered box used to comply with Section 140.4(a)3Aiii shall be set to no greater than the minimum ventilation rate when the zone is in deadband or in heating mode.
- Section 120.1(d)4 requires demand control ventilation for most classrooms and office conference rooms.
- Section 120.1(d)5 requires the use of occupied standby controls, which covers most office spaces. This means when the ventilation zone is unoccupied for more than 20 minutes, airflow goes to zero.

With DCV and occupied standby controls, airflow is often less than the sum of the minimum airflows

Background – Lower occupant densities

DCV and unoccupied standby come into effect for more hours than many think.

- Many office workers are on hybrid schedules and only in their office a few days a week.
- Office occupancy schedules often go late into the night to accommodate cleaners and others working late. Most of the offices will be in occupied standby mode.
- School occupancy schedules typically go to 6:00 p.m. or later for after-school activities, but most students have left.
- Some systems have override controls that let the occupants of a single zone change its status to occupied. In that case, that zone will often need mechanical cooling to return from setback.

Background – The Problem

Packaged VAV Systems (PVAVs) often do not provide mechanical cooling at airflows less than 50% of design. Some do not even turn fans below 50%.

- For low outdoor air buildings like offices, if many zones are in deadband or heating, mechanical cooling is not available for zones that need it.
- In schools, many classrooms are empty in the afternoon, and if properly set, DCV values are very low. Again, if there are only one or two classrooms that need mechanical cooling, they will not get it.

When occupants are uncomfortable, building operators have two choices:

1. Build a bypass duct to allow the needed air to flow without going to the zones.
2. Increase the VAV minimum airflows, which drives up reheating, especially in zones with few occupants.

How ASHRAE 90.1 addressed the problem

Addendum u to ASHRAE 90.1-2022 requires multizone equipment to be able to turn down airflow to the greater of 15% of design airflow or the design minimum outdoor air rate.

6.5.3.2 Fan Control

6.5.3.2.1 Supply Fan Airflow Control. Each cooling *system* listed in Table 6.5.3.2.1 shall be designed to vary the supply fan airflow as a function of load and shall comply with the following requirements:

…

b. All other units, including multiple-zone *VAV* DX cooling units and chilled-water units that *control* the *space* temperature by modulating the airflow to the *space*, shall have modulating fan control. Minimum ~~speed~~ supply fan airflow shall not exceed ~~50%~~ the greater of 15% of design airflow or the *design minimum outdoor air rate* ~~full speed~~. ~~At minimum speed, the fan system shall draw no more than 30% of the power at full fan speed.~~ Low or minimum ~~speed~~ airflow shall be used during periods of low cooling load and *ventilation*-only operation. *Mechanical cooling*, economizer, and *ventilation* shall not limit the unit from operating at minimum supply fan airflow.

How manufacturers might meet the requirement

- Low coil face velocity changes heat transfer behavior, making the evaporator much more sensitive at the air side
- Very low evaporator load requires precise refrigerant control, especially in multi-circuit DX coils
- Refrigerant distribution becomes harder to balance across all circuits as mass flow drops
- Superheat control becomes more sensitive because pressure drop through the distributor and feeders matters more
- Compressor, fan, and expansion device must all turn down together to maintain stable mechanical cooling

Challenges of low airflow in DX systems

- Low coil face velocity changes heat transfer behavior, making the evaporator much more sensitive at the air side
- Very low evaporator load requires precise refrigerant control, especially in multi-circuit DX coils
- Refrigerant distribution becomes harder to balance across all circuits as mass flow drops
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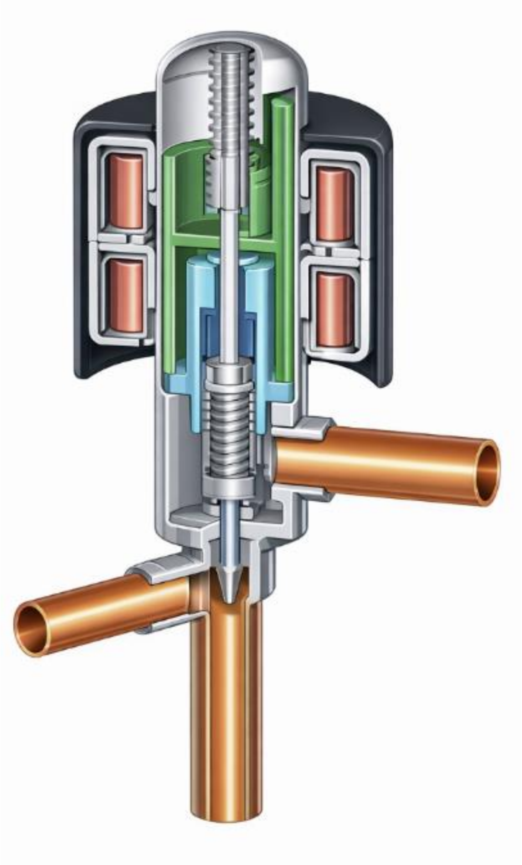
How manufacturers might meet the requirement

Variable-speed compressor

- Use a variable-speed compressor combined with single-speed compressors that allow turndown to low load when only the variable-speed compressor is operating.
- Use electronic expansion valves with external equalization for accurate low-load superheat control
- Optimize the nozzle, distributor, and feeder tube design for stable low-flow refrigerant distribution
- Coordinate compressor speed, valve position, and airflow together as one integrated control strategy



How manufacturers might meet the requirement

Non-Variable Speed Solutions

- Use mixed-size compressors with one small compressor for low-load operation.
- Design the coil circuiting for stable operation at low airflows, not just peak conditions that are rarely required by increasing refrigerant pressure drop to prevent maldistribution.
- Use a face damper to limit the exposed part of the coil face to 33% to 50% of the area during low load operation to allow higher airflow over the exposed face.
- Use hot gas bypass to put a false load on the coil (very inefficient)

Incremental Cost

- The CBECC prototype medium office is 51,000 ft^2 with three 50-ton PVAV systems.
- Assumed the most expensive path – adding a variable-speed compressor.
- Cost data is not readily available, as pricing for large AHUs is typically not publicly available, but we did find public pricing on the GSA website for one manufacturer. For a 28-ton unit, the variable-speed was $9,000 more than a standard unit.
- We made the following conservative assumptions:
  - For a 50-ton unit, the Statewide CASE Team multiplied the cost by two (now $18,000/unit)
  - A contractor will pay 25 percent more than the GSA (now $22,500/unit)
  - The contractor will mark up the cost to the customer by 40 percent (now $31,500/unit)
- With three units, the incremental first cost is $94,500.
- For acceptance testing, additional 8 hours of technician time at $250/hour was added.

Modeling and Savings Assumptions

For both the current state and proposed measure modeling, the CBECC Medium Office model were modified in the same manner:

- Design airflow was set to 1 cfm/ft^2.
- Occupant density was reduced to reflect the new reality of hybrid work-from-home. Lighting and plug loads were reduced for the same reason.
- Fan maximum static pressure was slightly reduced to better reflect the Fan Power Budget in Section 140.4.
- Supply air temperature reset was reduced from a maximum of 60F to 58F to better reflect operating realities.

There are two differences between the current state model and the proposed measure model:

- For the proposed measure, the low-stage airflow was set to 25%. This will be remodeled with a variable-speed system that can turn down to 15% for the final CASE Report.
- The VAV box minimum flow was left at 30% for the current state model and reduced to 15% for the proposed model.

We assumed for new construction, the measure applies to 50% of buildings that use an air-to-water heat pump (AWHP), and all the savings are electricity. For alterations, we assumed 80% of medium offices use a PVAV system with a gas boiler. We calculated that savings by taking the hourly heating output of the AWHP and calculating the gas input of a 90 E_t boiler.

Multi-zone Turndown Measure Description

1. All new central station air handlers or rooftop units (RTUs) of a multizone system must be capable of and configured to provide mechanical cooling down to the greater of the sum of the minimum outdoor air requirements in section 120.1(c)3 or 15% of design airflow. This applies to alterations as well, which will enable operating the building per the requirements of Title 24, including demand control ventilation, occupied standby, and zone deadband airflow.

2. The acceptance test has been modified to prove the mechanical cooling will operate at the greater of the sum of the minimum outdoor air requirements in section 120.1(c)3 or 15% of design airflow.

- The measure does NOT change the existing requirements for flow during deadband, DCV, or occupied standby.

- Within the existing requirements of Title 24, designers are free to choose how the multizone system operates.

Detailed Changes to Title 24, Part 6

Section 140.4 – PRESCRIPTIVE REQUIREMENTS FOR SPACE CONDITIONING SYSTEMS

…

(m) Fan and mechanical cooling control. Each cooling system listed in Table 140.4-I shall be designed to vary the indoor fan airflow as a function of load and shall comply with the following requirements:

…

3. Multiple-zone VAV DX cooling systems and chilled water systems shall be configured to be able to reduce airflow from the supply fan to the larger of 15 percent of design airflow or the minimum outdoor airflow required in Section 120.1(c)3. The system shall be capable of providing mechanical cooling at that airflow.

Exception to Section 140.4(m)3: *Group R occupancies and common or public use areas that serve group R occupancies*

Detailed Changes to Reference Appendix NA7

***NA7.5.6* Supply Fan Variable Flow Controls**

NA7.5.6.1 Construction Inspection

Prior to Functional Testing, verify and document the following:

(a) Supply fan includes device(s) for modulating airflow, such as variable speed drive

or electrically commutated motor.

(b) For multiple zone systems:

1. Discharge static pressure sensors are either factory calibrated or field calibrated.

2. The static pressure location, setpoint, and reset control meets the requirements of §140.4(c)2A and §140.4(c)2B.

3. The central fan(s) and compressor(s) are capable of and configured to meet the requirements of §140.4(m)3

Exception to NA7.5.6.1(b)3: Systems serving *Group R occupancies and common or public use areas.*

Detailed Changes to Reference Appendix NA7

***NA7.5.6* Supply Fan Variable Flow Controls**

…

NA7.5.6.2 Functional Testing

Step 1: Simulate demand for full design airflow. Verify and document the following:

(a) Supply fan controls modulate to increase capacity.

(b) For multiple zone systems, supply fan maintains discharge static pressure within +/-10 percent of the current operating setpoint.

(c) Supply fan controls stabilize within a 5 minute period.

Detailed Changes to Reference Appendix NA7

***NA7.5.6* Supply Fan Variable Flow Controls**

NA7.5.6.2 Functional Testing

Step 2A: For multiple zone systems that do not serve *Group R occupancies and common or public use areas,* sSimulate demand for reduced or minimum airflow. Verify and document the following:

d) Close the outdoor air dampers.

e) Close and turn off or reduce the maximum airflow of enough air terminal dampers such that the full airflow of the remaining air terminals is not more than the greater 15 percent of the system design airflow or the minimum outdoor airflow required in Section 120.1(c)3.

f) Reduce the temperature setpoint in those zones enough to engage mechanical cooling.

g) Supply fan controls modulate to decrease airflow to the greater of 15 percent of the system design airflow or the minimum outdoor airflow required in Section 120.1(c)3.

h) Confirm that mechanical cooling is operating by showing a temperature drop of not less than 5ºF between the return and supply air.

i) Current operating setpoint has decreased (for systems with DDC to the zone level).

j) fan maintains discharge static pressure within +/-10 percent of the current operating setpoint.

k) Supply fan controls stabilize within a 5 minute period.

Detailed Changes to Reference Appendix NA7

***NA7.5.6* Supply Fan Variable Flow Controls**

NA7.5.6.2 Functional Testing

Step 2B: For all other systems, sSimulate demand for reduced or minimum airflow. Verify and document the following:

(d) Supply fan controls modulate to decrease capacity.

(e) Current operating setpoint has decreased (for systems with DDC to the zone level).

(f) For multiple zone systems, supply fan maintains discharge static pressure within +/-10 percent of the current operating setpoint.

(g) Supply fan controls stabilize within a 5 minute period.

Step 3: Restore the system to the correct operating conditions.

Proposed Changes to the Alternative Calculation Manual

- Will apply to System 5 – PVAV and System 15 – PVAVAWHP.
- Require the user to enter the minimum airflow at which mechanical cooling will be enabled in their selected equipment.
- The sum of the minimum VAV airflows for the proposed design will be set to the minimum that was entered.
- The AHJ will confirm the minimum airflow at which mechanical cooling is enabled for the selected equipment.

Note: This is different than shown in the Draft CASE Report, as the team now believes that proposed language would be redundant.

Compliance Verification

- Key Aspects of Compliance Verification
- Revisions to Compliance Software

Compliance improvement

- A review of twenty plan sets of buildings with multi-zone VAV system revealed a widespread lack of compliance with Section 140.4(d)2(A)ii.
- Many designers are setting their minimum zone airflows to values higher than the design outdoor airflow. 30% of peak airflow is typical.

2. Zones served by variable air-volume systems that are designed and controlled to reduce, to a minimum, the volume of reheated, recooled, or mixed air are allowed only if the controls meet all of the following requirements:

   A. For each zone with direct digital controls (DDC):

      i. The volume of primary air that is reheated, recooled, or mixed air supply shall not exceed the larger of:

         a. 50 percent of the peak primary airflow; or

         b. The design zone outdoor airflow rate as specified by Section 120.1(c)3.

      ii. The volume of primary air in the deadband shall not exceed the design zone outdoor airflow rate as specified by Section 120.1(c)3.

K. TERMINAL BOX CONTROLS

This table is used to demonstrate compliance with prescriptive zone control requirements in 140.4(d) & 170.2(c)4B.

01	02	03	04	05	06	07	08	09	10	11	12
		Design			Deadband Compliance			Reheated, Recooled, Mixed Air Compliance			
Zone/System/VAV Box Name or Item Tag	Zonal Control Strategy per 140.4(d)	Peak Primary Airflow CFM	Primary Air in Deadband CFM	Reheated Recooled Mixed Airflow CFM	Outside Air CFM	30% of Peak Primary Airflow CFM	Max Deadband Airflow CFM	50% of Peak Primary Airflow	1st Stage Modulates <=95 °F and Maintains DB Rate?	2nd Stage Modulates from DB Flow to Heating Max Flow?	Complies
(N) VAV-14	No Reheat, Recool, Mixing										Yes
(E) VAV-3	VAV with DDC @ zone	1000	300	500	300		300	500	Yes	Yes	Yes

04		05		06		07
System Name	(E) VAV-3	System Design OA CFM Airflow[1]	75	System Design Transfer Air CFM	0	Air Filtration per 120.1(c) 141.0(b)2 and 160.2(c)21[2]
						NA: Not system type specified in footnote 2

Cost-Effectiveness: New Construction and Alterations

Table 6: 30-Year Cost-Effectiveness Summary Per Square Foot – New Construction and Additions

Climate Zone	Benefits LSC Savings + Other PV Savings (2029 PV$)	Costs Total Incremental PV Costs (2029 PV$)	Benefit-to-Cost Ratio
1	10.19	1.87	5.45
2	10.72	1.87	5.74
3	12.88	1.87	6.89
4	9.75	1.87	5.22
5	12.34	1.87	6.60
6	14.07	1.87	7.53
7	14.13	1.87	7.56
8	12.79	1.87	6.85
9	10.78	1.87	5.77
10	10.74	1.87	5.75
11	9.41	1.87	5.04
12	9.57	1.87	5.12
13	9.35	1.87	5.00
14	7.50	1.87	4.01
15	7.52	1.87	4.02
16	6.68	1.87	3.58

First Year Energy Savings – New Construction

Table 4: Energy and Energy Cost Savings – Per Square Foot Medium Office

Climate Zone	First Year Electricity Savings (kWh)	First Year Peak Demand Reduction (kW)	First Year Natural Gas Savings (kBtu)	First Year Source Energy Savings (kBtu)	Total 30-Year LSC Savings (2029 PV$)
1	1.22	(0.06)	0	1.76	10.19
2	1.26	0.02	0	1.91	10.72
3	1.49	0.06	0	2.33	12.88
4	1.13	0.09	0	1.76	9.75
5	1.41	0.13	0	2.18	12.34
6	1.62	0.04	0	2.52	14.07
7	1.60	0.02	0	2.56	14.13
8	1.43	(0.01)	0	2.30	12.79
9	1.24	(0.01)	0	2.00	10.78
10	1.21	(0.04)	0	2.01	10.74
11	1.11	(0.02)	0	1.69	9.41
12	1.14	(0.11)	0	1.66	9.57
13	1.09	(0.06)	0	1.81	9.35
14	0.87	0.05	0	1.33	7.50
15	0.86	(0.05)	0	1.60	7.52
16	0.72	0.14	0	1.15	6.68

The increase in peak demand is an artifact of modeling a two-stage compressor. We expect this to be corrected when we remodel with a variable-speed compressor.

Thirty- Year Energy Savings – Alterations

Table 5: 2029 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – Alterations – Medium Office

Climate Zone	30-Year LSC Electricity Savings (2029 PV$)	30-Year LSC Natural Gas Savings (2029 PV$)	Total 30-Year LSC Savings (2029 PV$)
1	7.85	0.79	8.63
2	8.67	0.69	9.36
3	11.38	0.44	11.82
4	8.20	0.54	8.74
5	10.84	0.51	11.34
6	13.83	0.07	13.90
7	14.02	0.03	14.05
8	12.40	0.13	12.54
9	10.26	0.18	10.44
10	10.01	0.25	10.26
11	7.75	0.60	8.34
12	8.54	0.38	8.92
13	8.07	0.43	8.50
14	6.61	0.33	6.94
15	7.24	0.08	7.32
16	5.46	0.47	5.93

Thirty- Year Energy Savings – Alterations

Table 5: 2029 PV LSC Savings Over 30-Year Period of Analysis – Per Square Foot – Alterations – Medium Office

Climate Zone	30-Year LSC Electricity Savings (2029 PV$)	30-Year LSC Natural Gas Savings (2029 PV$)	Total 30-Year LSC Savings (2029 PV$)
1	7.85	0.79	8.63
2	8.67	0.69	9.36
3	11.38	0.44	11.82
4	8.20	0.54	8.74
5	10.84	0.51	11.34
6	13.83	0.07	13.90
7	14.02	0.03	14.05
8	12.40	0.13	12.54
9	10.26	0.18	10.44
10	10.01	0.25	10.26
11	7.75	0.60	8.34
12	8.54	0.38	8.92
13	8.07	0.43	8.50
14	6.61	0.33	6.94
15	7.24	0.08	7.32
16	5.46	0.47	5.93

Thank You

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