TRANE

Trane Engineers Newsletter Live

Trends in Small Rooftop Systems

Presenters: John Murphy, Eric Sturm and Jeanne Harshaw (host)

Trane program number: APP-CMC061-EN

Agenda

Trane *Engineers Newsletter Live* Series

Trends in Small Rooftop Systems

Abstract
A large number of buildings use small, packaged rooftop units for HVAC. This ENL will discuss several recent regulatory changes and technology advances that affect systems using this class of equipment.

Presenters: Trane engineers John Murphy and Eric Sturm

After viewing attendees will be able to:

1. Summarize recent changes to minimum efficiency requirements and regulations from ASHRAE Standard 90.1 and the Department of Energy.
2. Explain the various energy efficiency ratings used for small rooftop equipment (EER, SEER, and IEER).
3. Understand single-zone VAV control in rooftop units equipped with either modulated or staged/cycled heat.
4. Apply small rooftop units in multiple-zone VAV systems.
5. Employ energy-saving control strategies, such as demand-controlled ventilation, airside economizing, fan pressure optimization, and supply air temperature reset.

Agenda

- Efficiency regulations, standards, and codes
- Variable-speed compressors
- Modulating heat
- Variable-speed fan control
- Controls
- Summary (energy analysis)

Presenter biographies

Trends in Small Rooftop Systems

John Murphy | applications engineer | Trane

John has been with Trane since 1993. His primary responsibility as an applications engineer is to aid design engineers and Trane sales personnel in the proper design and application of HVAC systems. His main areas of expertise include energy efficiency, dehumidification, dedicated outdoor-air systems, air-to-air energy recovery, psychrometry, airside system control and ventilation. He is also a LEED Accredited Professional.

John is the author of numerous Trane application manuals and Engineers Newsletters, and is a frequent presenter on Trane's Engineers Newsletter Live series. He has authored several articles for the ASHRAE Journal, and was twice awarded "Article of the Year" award. He is an ASHRAE Fellow and has served on the "Moisture Management in Buildings" and "Mechanical Dehumidifiers" technical committees. He was a contributing author of the Advanced Energy Design Guide for K-12 Schools and the Advanced Energy Design Guide for Small Hospitals and Health Care Facilities, a technical reviewer for the ASHRAE Guide for Buildings in Hot and Humid Climates, and a presenter on the 2012 ASHRAE "Dedicated Outdoor Air Systems" webcast.

Eric Sturm | applications engineer | Trane

Eric joined Trane in 2006 after graduating from the University of Wisconsin – Platteville with a Bachelor of Science degree in mechanical engineering. Prior to joining the applications engineering team, he worked in the Customer Direct Services (C.D.S.) department as a marketing engineer and product manager for the TRACE™ 700 load design and energy simulation software application. As a C.D.S. marketing engineer he supported and trained customers globally. In his current role as an applications engineer,

Eric's areas of expertise include acoustics, airside systems, and standards and codes.
He is currently involved with ASHRAE at the local chapter as president-elect and nationally as member of the "Global Climate Change" and "Sound and Vibration" technical committees. In 2015, Eric was named recipient of the Young Engineers in ASHRAE Award of Individual Excellence for service to the La Crosse Area Chapter of ASHRAE.

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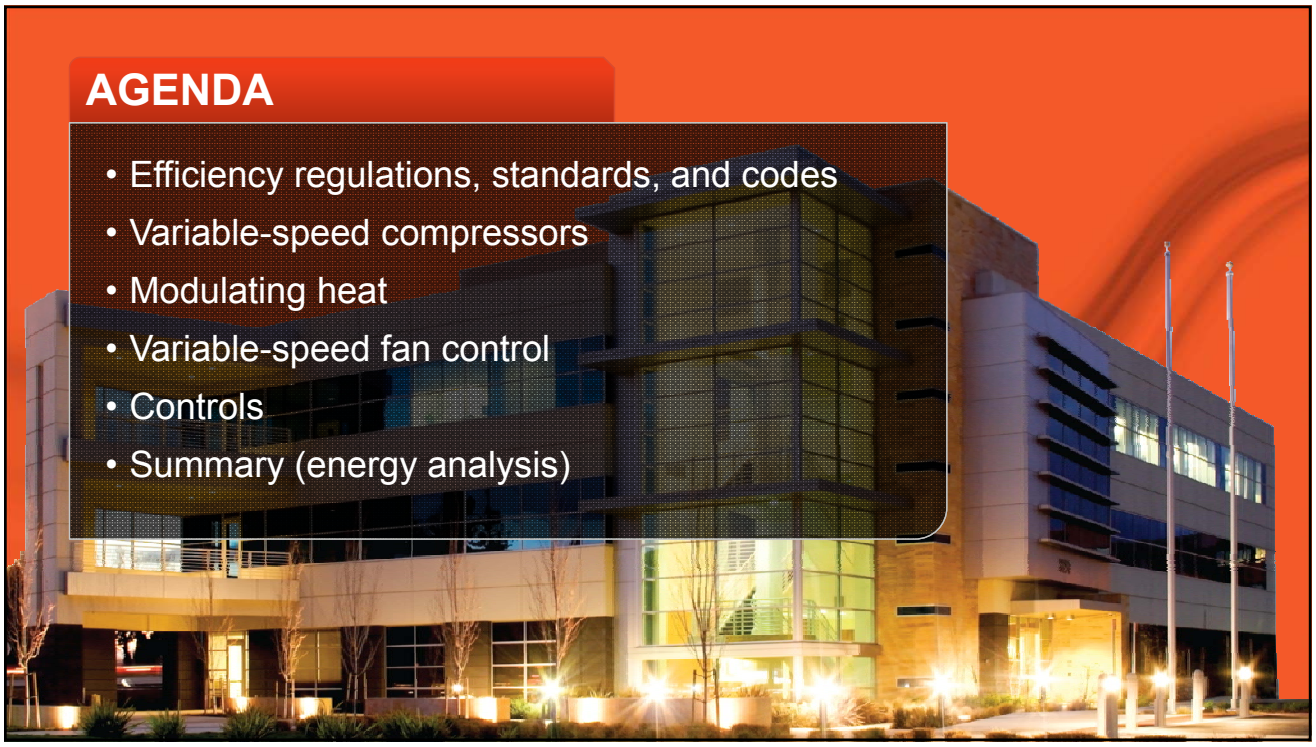
Learning objectives

- Summarize recent changes to minimum efficiency requirements and regulations from ASHRAE Standard 90.1 and the Department of Energy.
- Explain the various energy efficiency ratings used for small rooftop equipment (EER, SEER, and IEER).
- Understand single-zone VAV control in rooftop units equipped with either modulated or staged/cycled heat.
- Apply small rooftop units in multiple-zone VAV systems
- Employ energy-saving control strategies, such as demand-controlled ventilation, airside economizing, fan pressure optimization, and supply air temperature reset.

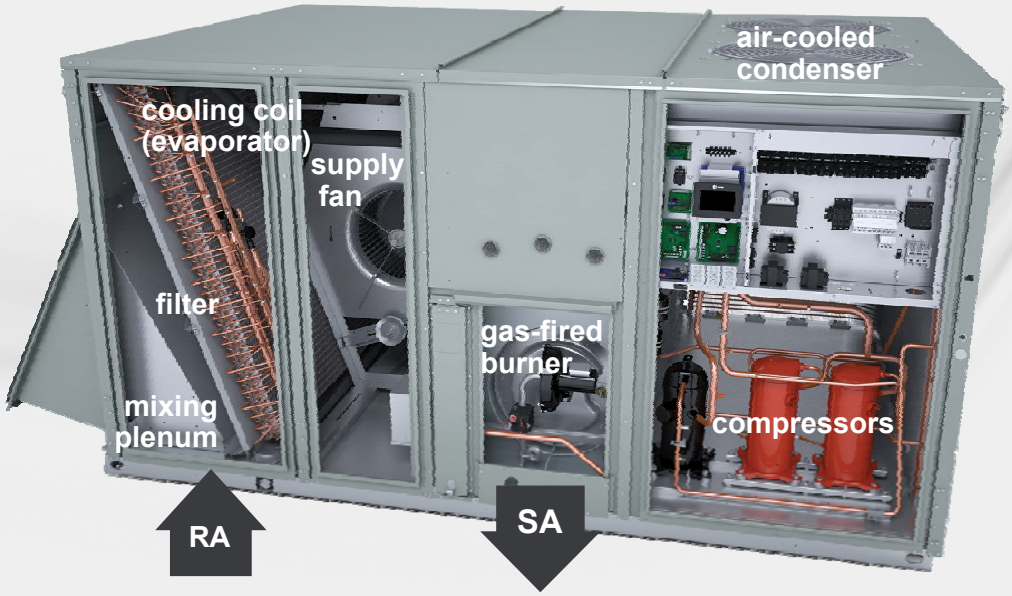


Today's Presenters

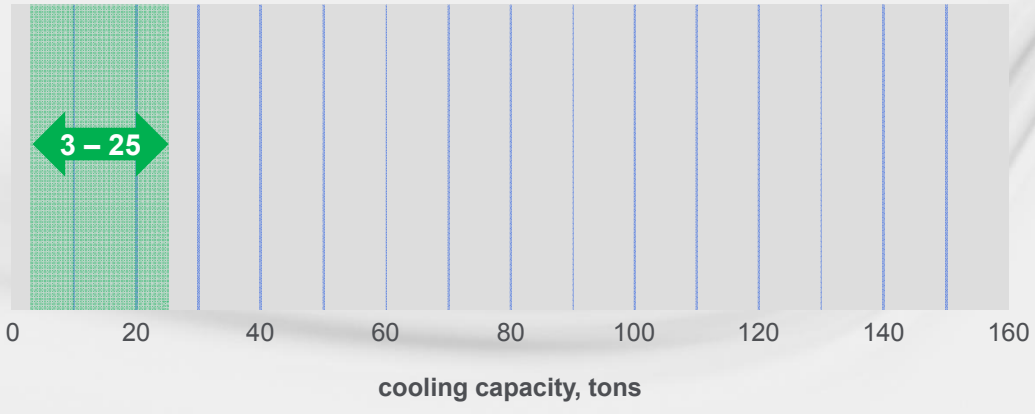
John Murphy
Applications Engineer

Eric Sturm
Applications Engineer

Packaged Rooftop Unit



"Small" Rooftop Systems



small rooftop systems

Advantages

- Packaging eases design, installation, and startup
- Low installed cost
- Maximizes usable floor space inside the building
- Maintenance done outside of the occupied space
- Equipment is easy to replace

small rooftop systems

Drawbacks

- Less flexibility
- Equipment located outside (aesthetics, maintenance)
- Space required for ductwork

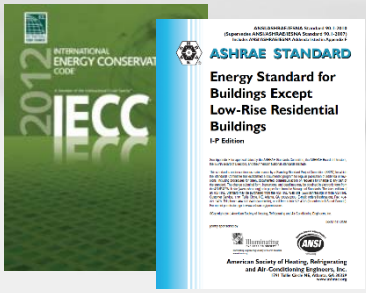
AGENDA

- **Efficiency regulations, standards, and codes**
- Variable-speed compressors
- Modulating heat
- Variable-speed fan control
- Controls
- Summary (energy analysis)

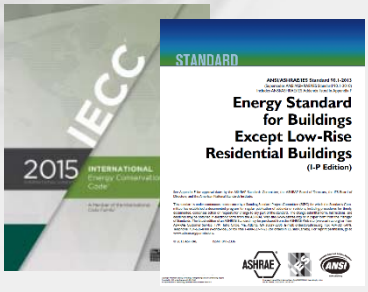
Minimum Efficiency Requirements

- ASHRAE Standard 90.1
- International Energy Conservation Code (IECC)
- U.S. Department of Energy

2012 IECC (90.1-2010)



2015 IECC (90.1-2013)



ASHRAE Standard 90.1-2004

Unitary Air Conditioners, Air-Cooled

Size	Sub-Category	Minimum Efficiency
< 65,000 Btu/hr	Split System	10.0 SEER (before 1/23/2006) 12.0 SEER (as of 1/23/2006)
	Single Package	9.7 SEER (before 1/23/2006) **12.0 SEER** (as of 1/23/2006)

Minimum efficiency requirements are developed in conjunction with the Air Conditioning, Heating, and Refrigeration Institute (AHRI)

addendum F to ASHRAE Standard 90.1-2004

Unitary Air Conditioners, Air-Cooled

Size	Sub-Category	Minimum Efficiency
< 65,000 Btu/hr	Split System	10.0 SEER (before 1/23/2006) ~~12.0 SEER~~ **13.0 SEER** (as of 1/23/2006)
	Single Package	9.7 SEER (before 1/23/2006) ~~12.0 SEER~~ **13.0 SEER** (as of 1/23/2006)

* Change made to coincide with U.S. DOE regulations

unitary air conditioners, air-cooled (< 65,000 Btu/hr)

New U.S. DOE Regulations

- Effective 1 January 2017
- Increase minimum cooling efficiency from 13 to 14 SEER
- Incorporated into 2016 version of ASHRAE 90.1

Size	Sub-Category	Minimum Efficiency
< 65,000 Btu/hr	Split System, 3 Phase	13.0 SEER
	Single Package, 3 Phase	**14.0 SEER**

Efficiency Ratings

EER (Energy Efficiency Ratio)

- Cooling output / Input power, at AHRI rating conditions

SEER (Seasonal Energy Efficiency Ratio)

- Season of cooling / Season of power

IEER (Integrated Energy Efficiency Ratio)

- Time-weighted efficiency calculation at 100%, 75%, 50%, and 25% load conditions

ASHRAE Standard 90.1-2010

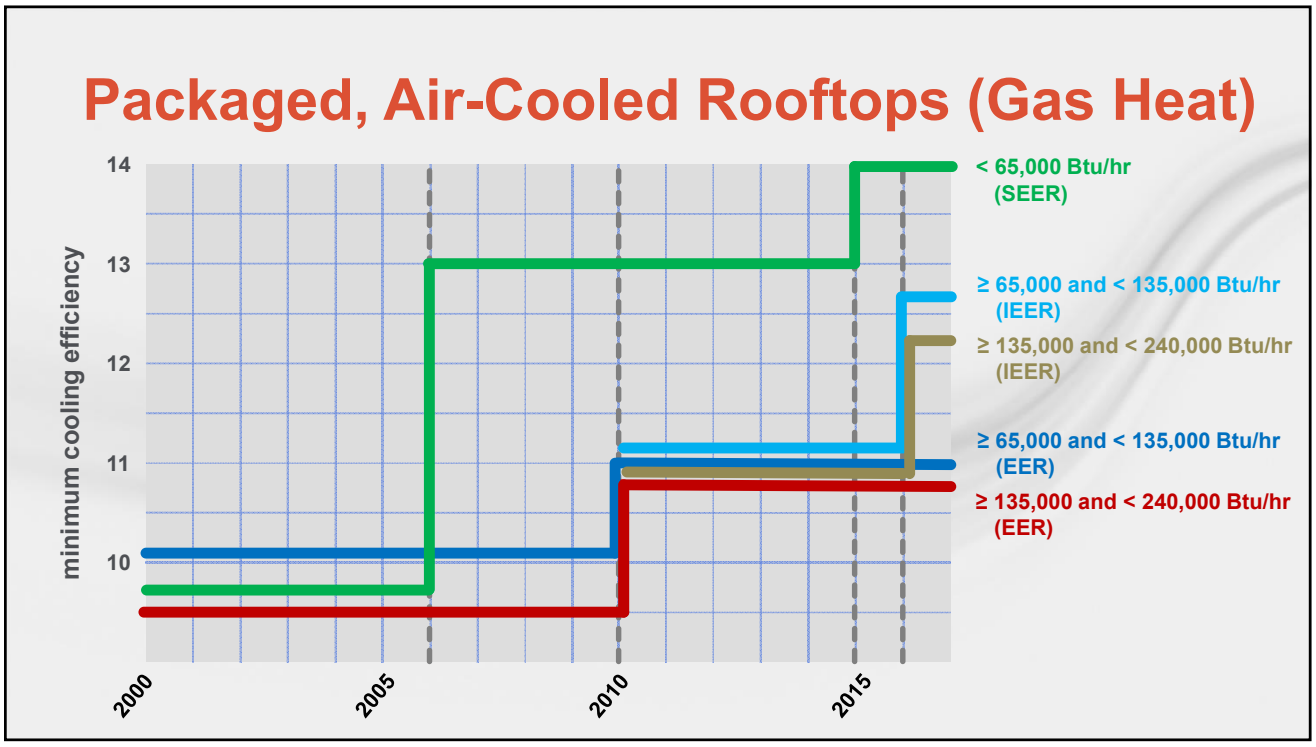
Unitary Air Conditioners, Air-Cooled

Size	Heating Type	Minimum Efficiency
≥ 65,000 Btu/hr and < 135,000 Btu/hr	Electric Resistance (or none)	11.2 EER and 11.4 IEER
	All Other	11.0 EER and 11.2 IEER
≥ 135,000 Btu/hr and < 240,000 Btu/hr	Electric Resistance (or none)	11.0 EER and 11.2 IEER
	All Other	10.8 EER and 11.0 IEER

air-cooled rooftop equipment (≥ 65,000 Btu/hr and < 760,000 Btu/hr)

Upcoming U.S. DOE Regulations

- Effective 1 January 2018
- Switching from minimum full-load cooling efficiency (EER) to a minimum IEER (using ASHRAE 90.1-2013 levels)


Packaged, Air-Cooled Rooftops (Gas Heat)
minimum cooling efficiency
14
13
12
11
10
2000
2005
2010
2015
< 65,000 Btu/hr (SEER)
≥ 65,000 and < 135,000 Btu/hr (IEER)
≥ 135,000 and < 240,000 Btu/hr (IEER)
≥ 65,000 and < 135,000 Btu/hr (EER)
≥ 135,000 and < 240,000 Btu/hr (EER)


AGENDA
• Efficiency regulations, standards, and codes
• Variable-speed compressors
• Modulating heat
• Variable-speed fan control
• Controls
• Summary (energy analysis)

Scroll Compressor

Stationary Scroll

Driven Scroll

Scroll Compressor

Scroll Compressor Capacity Modulation

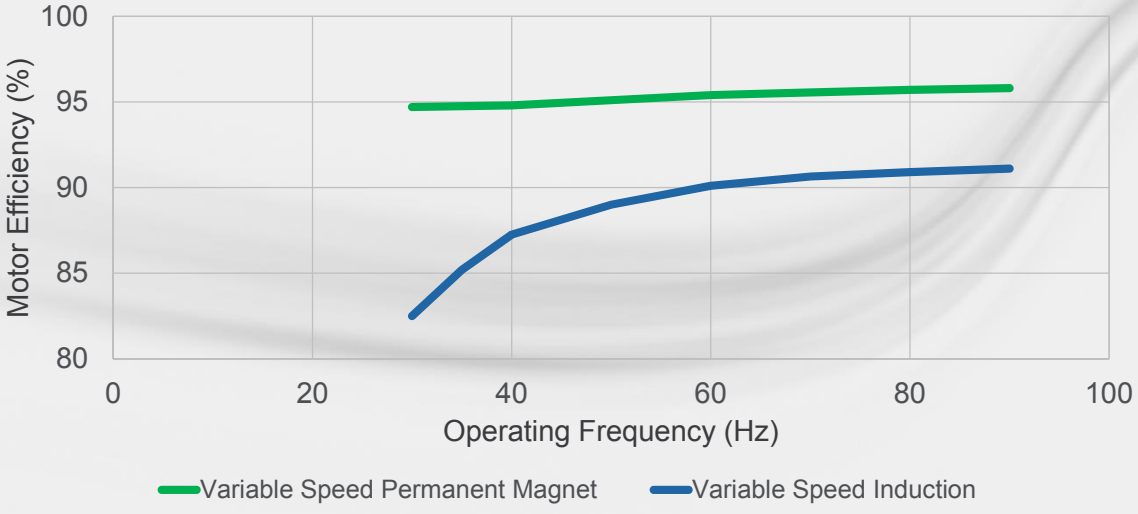
Compressor Operation

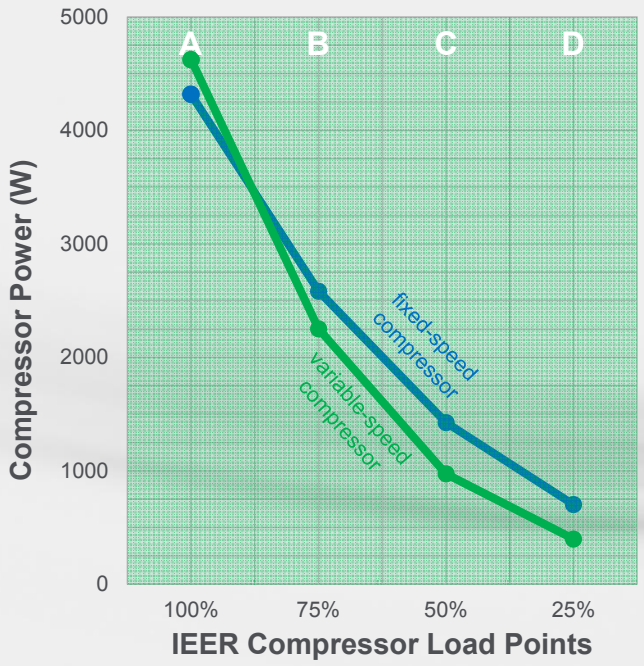
- On/off control
- Hot gas bypass
- Variable speed

Compressor Design

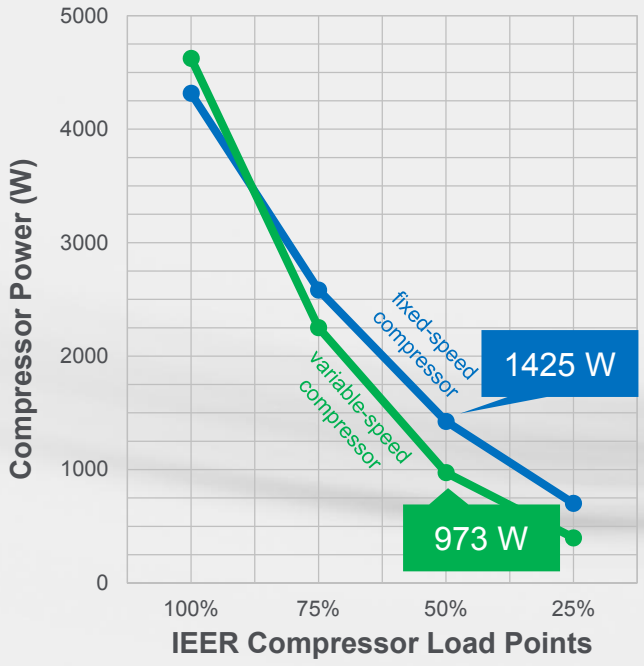
- Digital scroll
- Pocket unloading

Motor Efficiency

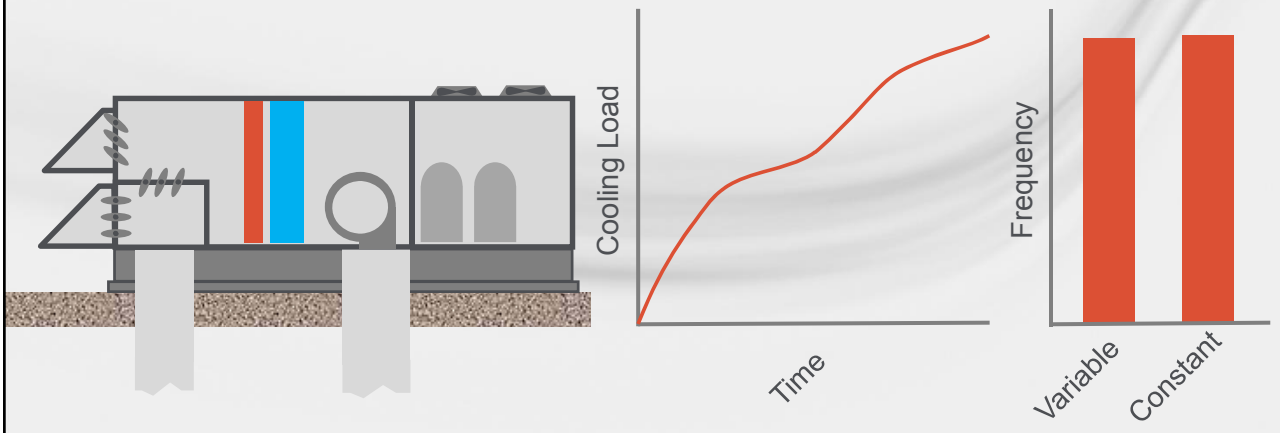




IEER Rating Conditions				
	A	B	C	D
Capacity	100%	75%	50%	25%
Condenser Entering Temperature	95.0°F	81.5°F	68.0°F	65.0°F
Weighting Factor	2.0%	61.7%	23.8%	12.5%



Variable and Fixed Speed Compressors, Paired



Variable Speed Compressors

Advantages

- Use results in better discharge air temperature control (+/- 2°F)
- Lower minimum speed, reduced compressor cycling
- Low speed oil injection reduces compression pocket losses

Drawbacks

- Increased complexity
- Higher cost

Microchannel Coils

Advantages

- Lighter weight
- Lower refrigerant charge
- Single material construction
- Fewer braze points

Drawbacks

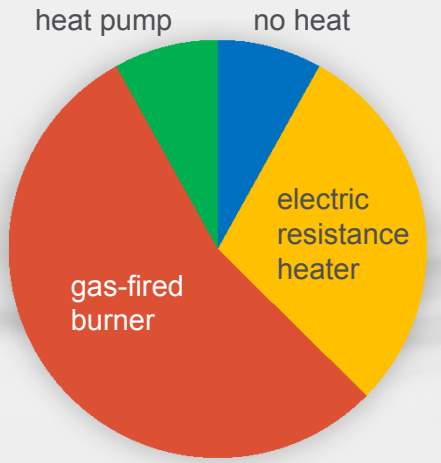
- Difficult to repair
- Sensitive to damage

AGENDA

- Efficiency regulations, standards, and codes
- Variable-speed compressors
- **Modulating heat**
- Variable-speed fan control
- Controls
- Summary (energy analysis)

small rooftop systems

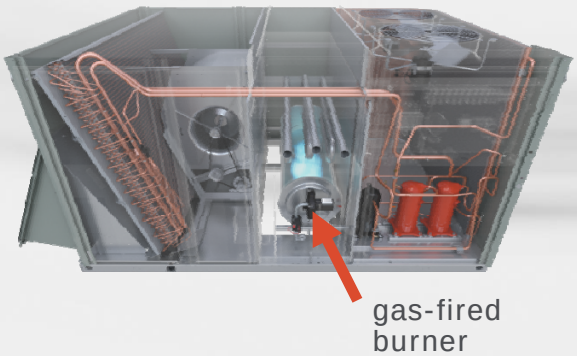
Heat Sources



small rooftop systems

Heat Source Trends

- Increased demand for modulating (rather than staged) gas-fired burners



small rooftop systems

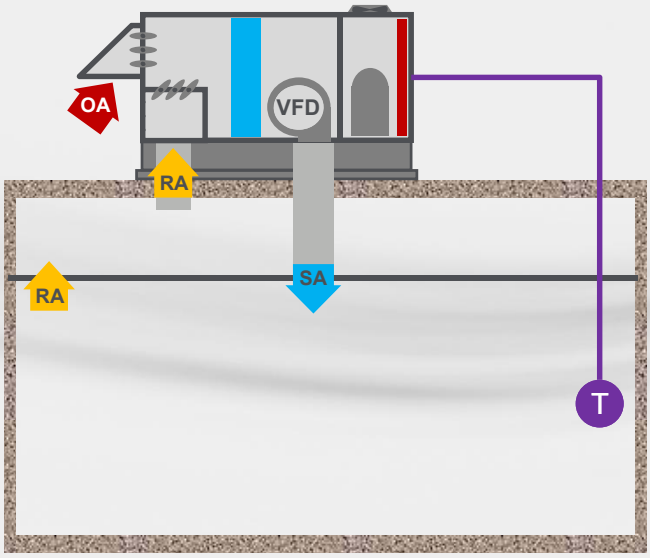
Heat Source Trends

- Increased use of heat pumps in buildings that generate electricity on site (photovoltaic, wind)

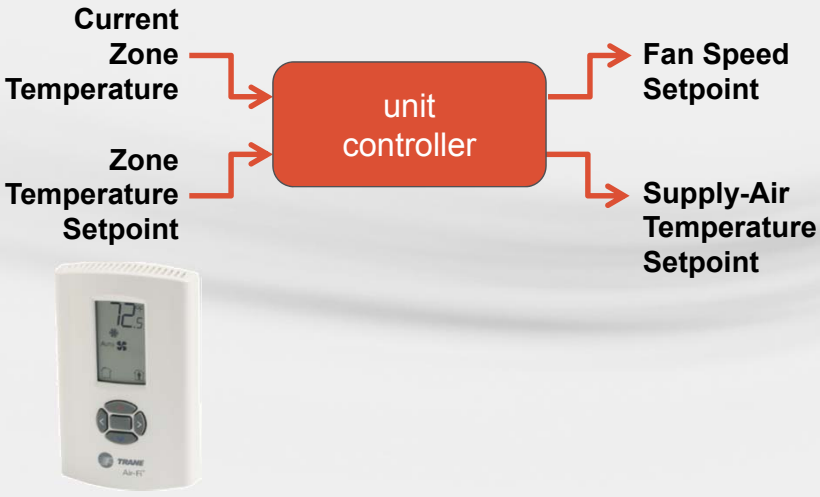
AGENDA

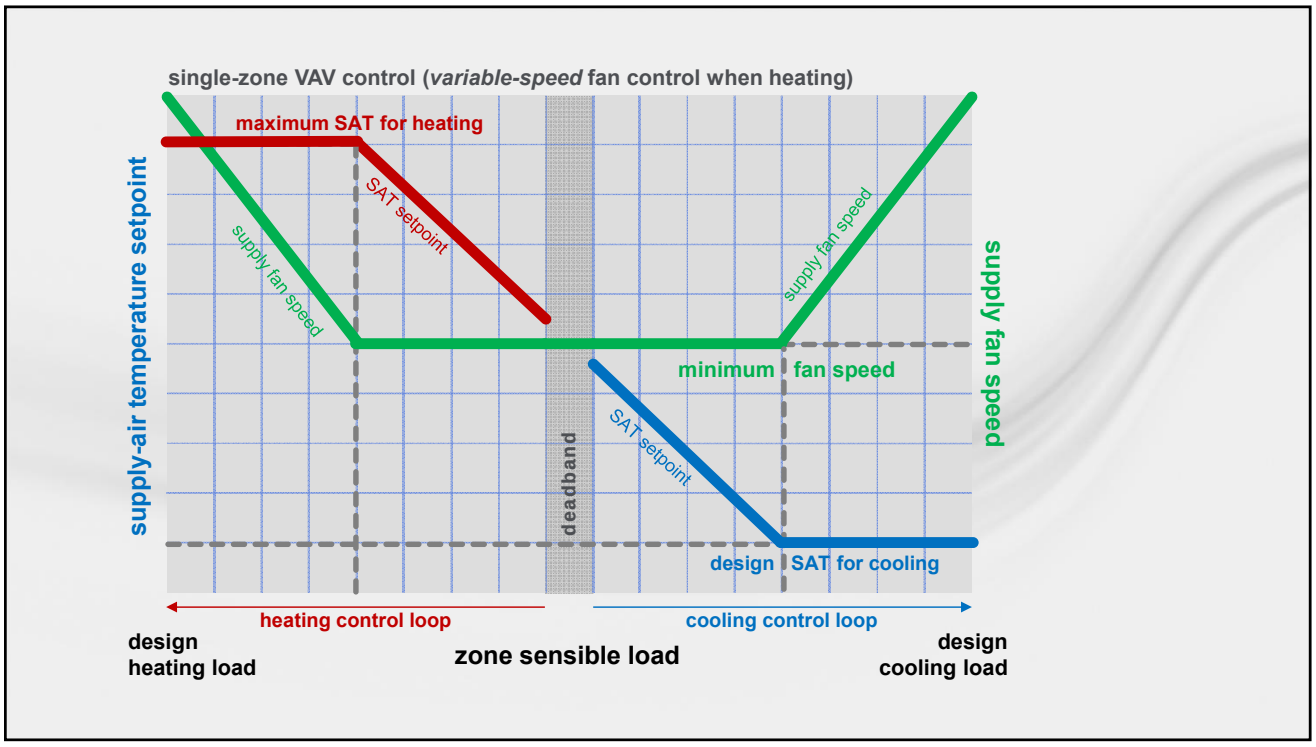
- Efficiency regulations, standards, and codes
- Variable-speed compressors
- Modulating heat
- **Variable-speed fan control**
- Controls
- Summary (energy analysis)

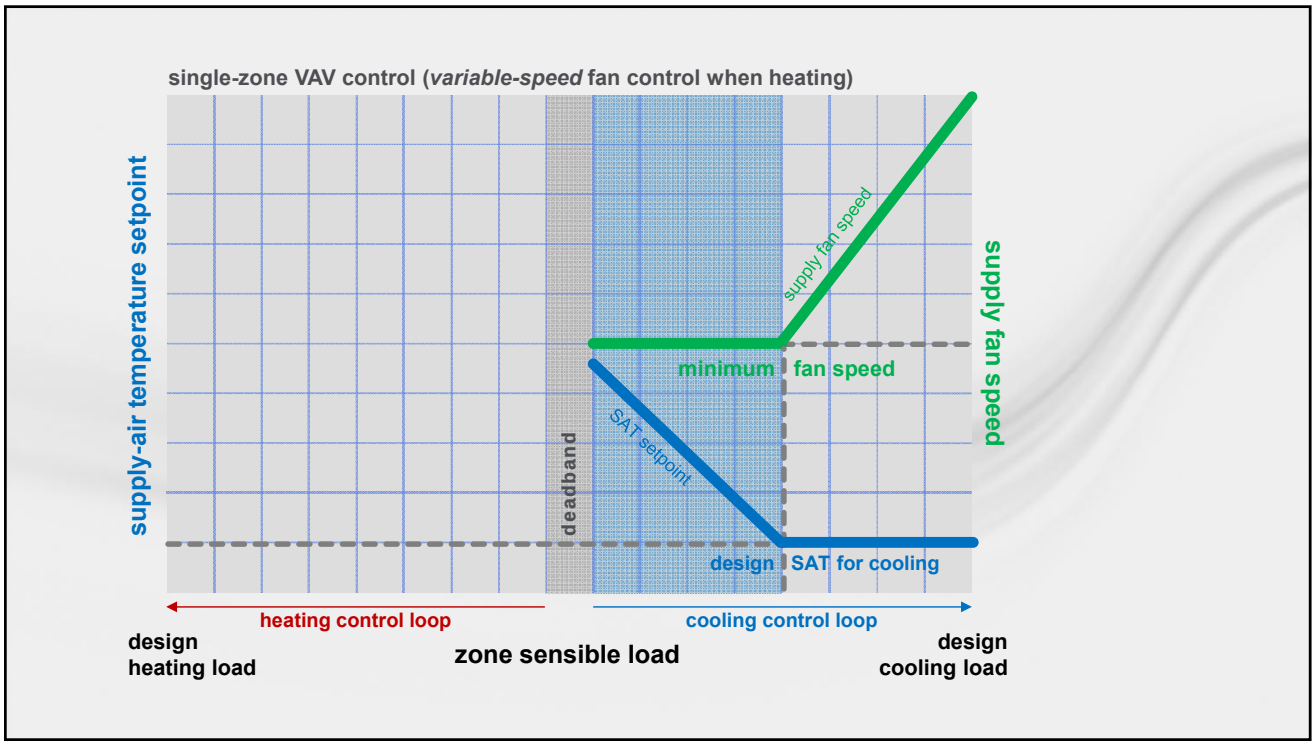
Single-Zone System



SZVAV Control Algorithms




single-zone VAV control (*variable-speed* fan control when heating)
maximum SAT for heating
SAT setpoint
supply fan speed
supply fan speed
minimum fan speed
SAT setpoint
deadband
design SAT for cooling
supply-air temperature setpoint
supply fan speed
heating control loop
cooling control loop
design heating load
zone sensible load
design cooling load


single-zone VAV control (*variable-speed* fan control when heating)
supply fan speed
minimum fan speed
SAT setpoint
deadband
design SAT for cooling
supply-air temperature setpoint
supply fan speed
heating control loop
cooling control loop
design heating load
zone sensible load
design cooling load

small rooftop systems

Humidity and SZVAV Systems

- Avoid oversizing equipment … especially oversizing supply airflow
- If necessary, some SZVAV rooftop units can be equipped with hot gas reheat also

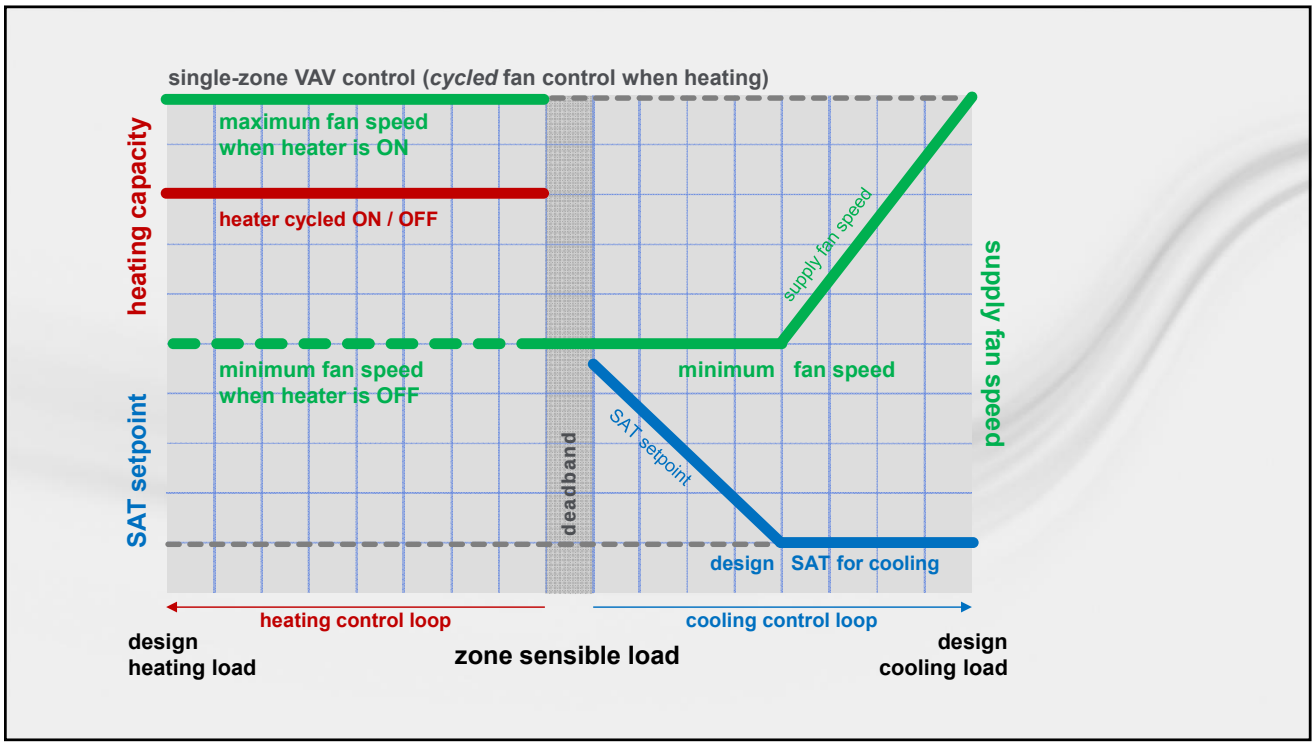
Modulated vs. Staged Heat for SZVAV

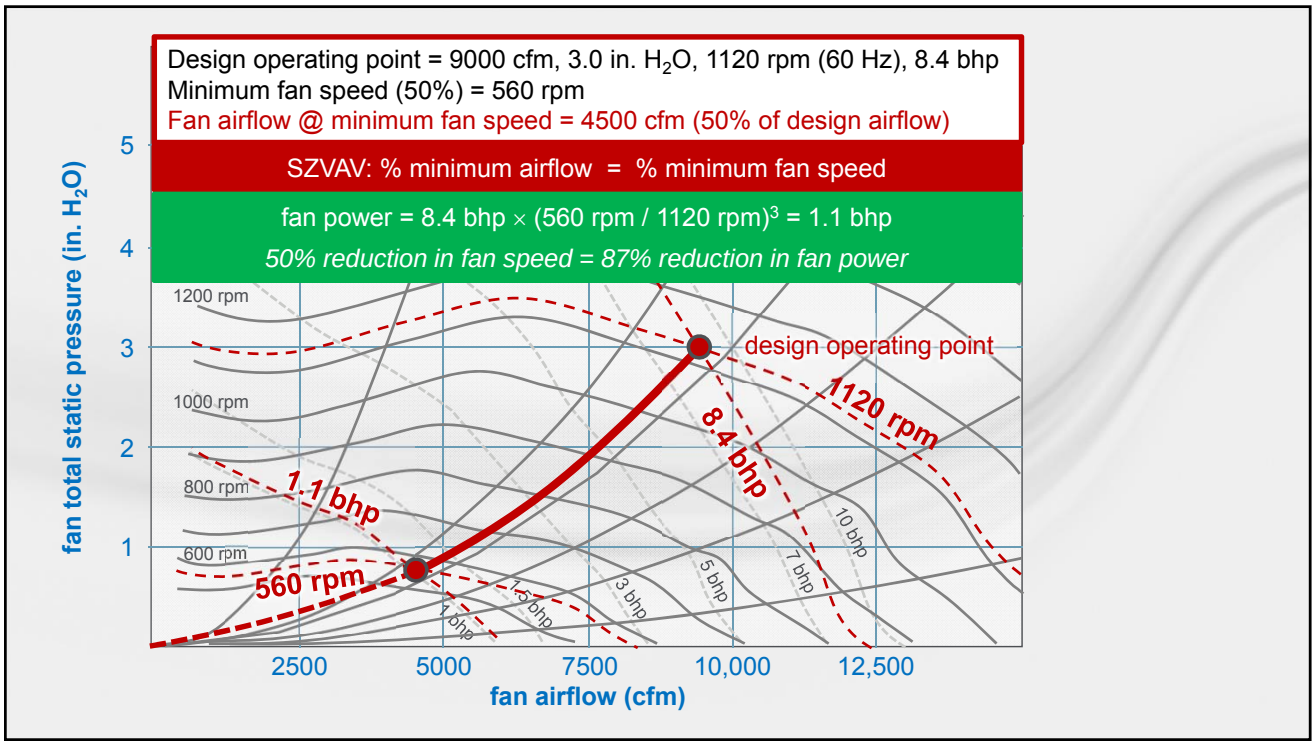
Variable-speed fan control when heating

- Modulated gas
- Modulated electric
- Hot water

Cycled fan control when heating

- Staged gas
- Staged electric
- Heat pump


single-zone VAV control (*cycled* fan control when heating)
heating capacity
maximum fan speed when heater is ON
heater cycled ON / OFF
SAT setpoint
minimum fan speed when heater is OFF
deadband
supply fan speed
minimum fan speed
SAT setpoint
design SAT for cooling
supply fan speed
heating control loop
cooling control loop
design heating load
zone sensible load
design cooling load


Design operating point = 9000 cfm, 3.0 in. H2O, 1120 rpm (60 Hz), 8.4 bhp
Minimum fan speed (50%) = 560 rpm
Fan airflow @ minimum fan speed = 4500 cfm (50% of design airflow)
SZVAV: % minimum airflow = % minimum fan speed
fan power = 8.4 bhp × (560 rpm / 1120 rpm)3 = 1.1 bhp
50% reduction in fan speed = 87% reduction in fan power
fan total static pressure (in. H2O)
1200 rpm
1000 rpm
800 rpm
600 rpm
design operating point
1120 rpm
8.4 bhp
1.1 bhp
560 rpm
10 bhp
7 bhp
5 bhp
3 bhp
1.5 bhp
1 bhp
2500
5000
7500
10,000
12,500
fan airflow (cfm)

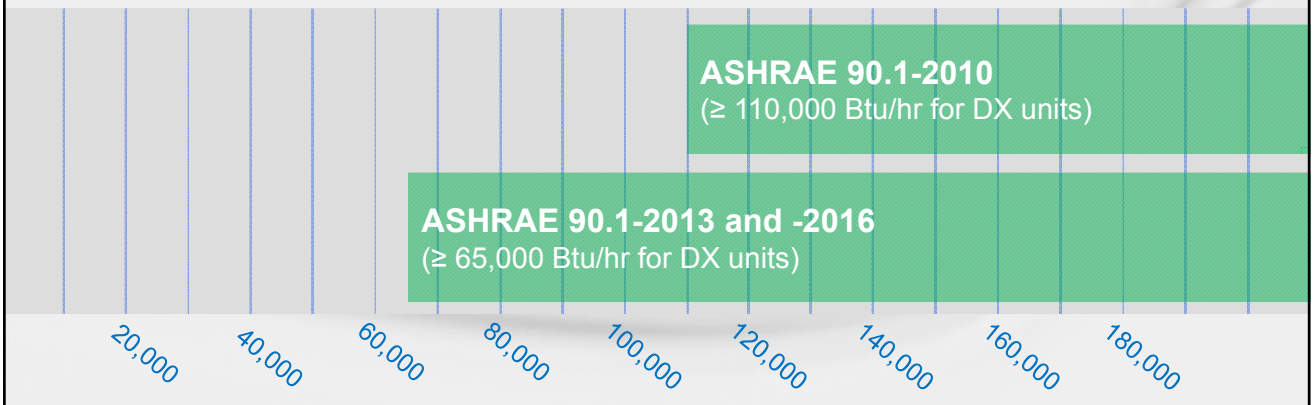
ASHRAE Standard 90.1-2010

Variable-Speed Fan Control

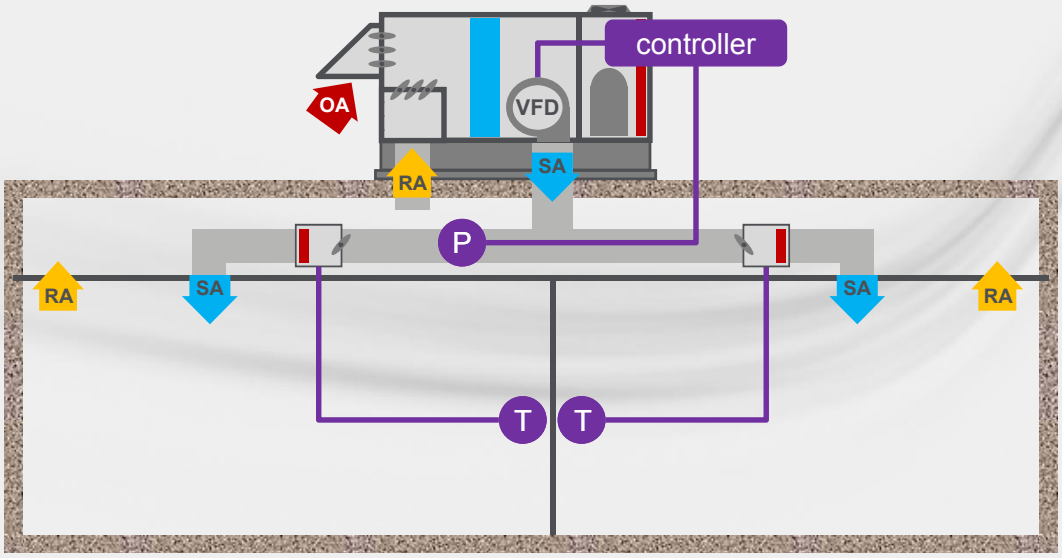
> ***6.4.3.10 Single Zone Variable-Air-Volume Controls.***
> *HVAC systems shall have variable airflow controls as follows:*
>
> *a. …*
>
> *b. Effective January 1, 2012, all air-conditioning equipment and air-handling units* ***with direct expansion cooling*** *and a cooling capacity at AHRI conditions* ***≥ 110,000 Btu/hr*** *that serve single zones shall have their supply fans controlled by two-speed motors or variable-speed drives. At cooling demands less than or equal to 50%, the supply fan controls shall be able to reduce the airflow to no greater than the larger of the following:*
>
> 1. ***Two-thirds of the full fan speed****, or*
> 2. *The volume of outdoor air required to meet the requirements of Standard 62.1*

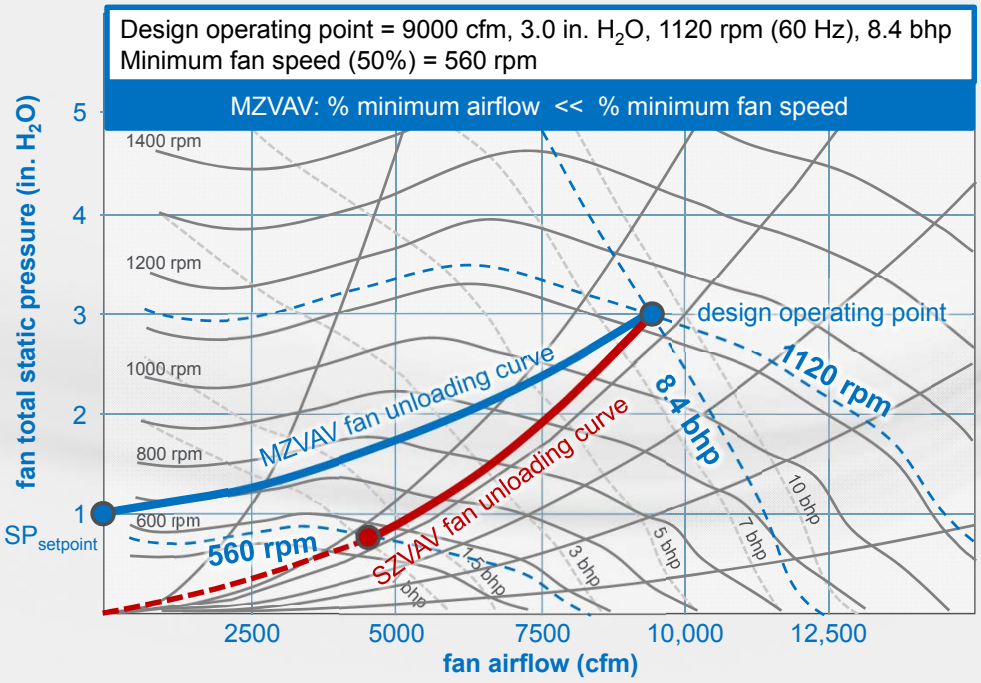
ASHRAE Standards 90.1-2013 and -2016

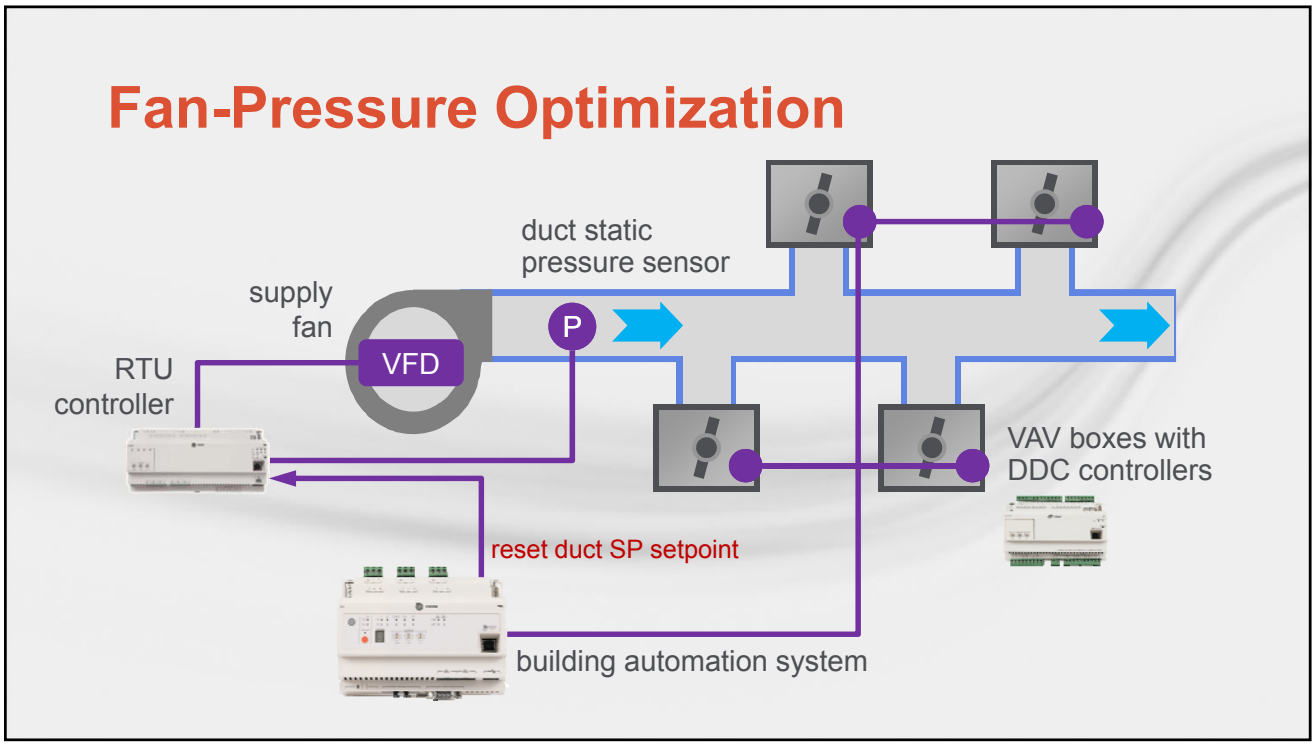
Variable-Speed Fan Control Required

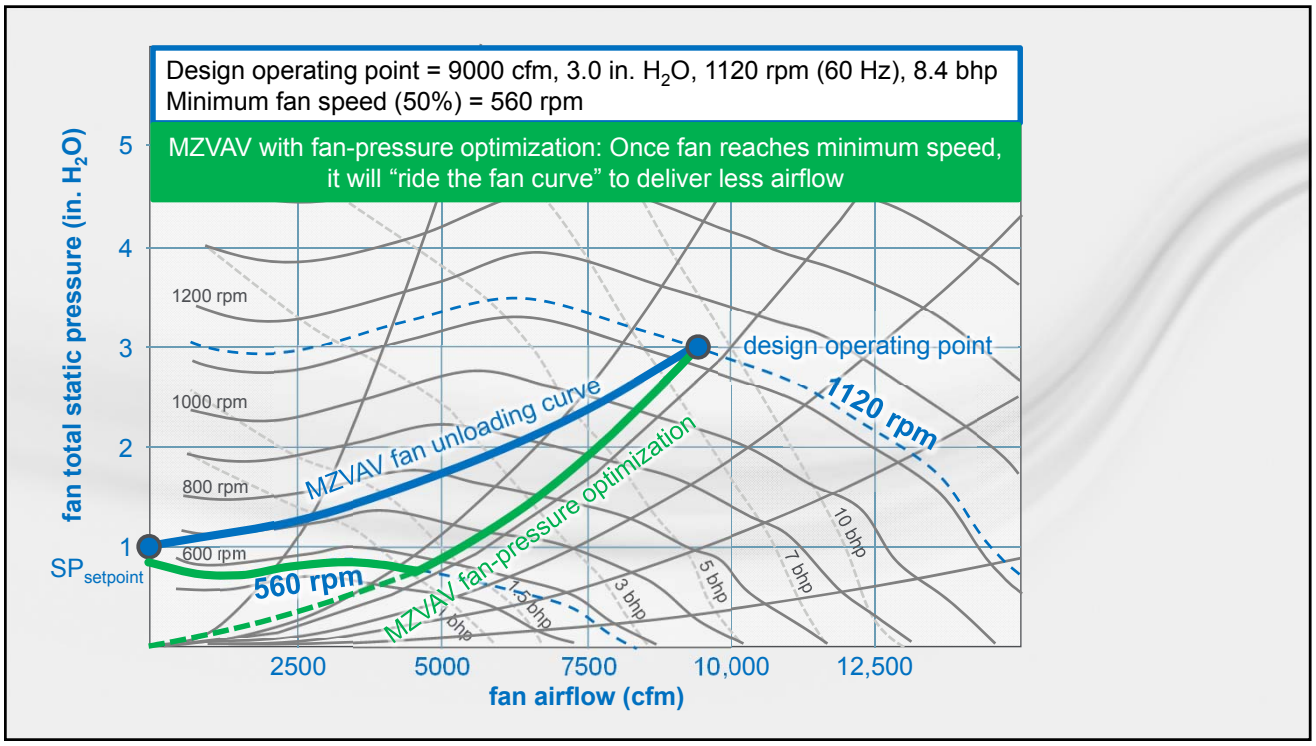


Multiple-Zone VAV System






Fan-Pressure Optimization
duct static
pressure sensor
supply
fan
VFD
P
RTU
controller
VAV boxes with
DDC controllers
reset duct SP setpoint
building automation system


Design operating point = 9000 cfm, 3.0 in. H2O, 1120 rpm (60 Hz), 8.4 bhp
Minimum fan speed (50%) = 560 rpm
MZVAV with fan-pressure optimization: Once fan reaches minimum speed, it will "ride the fan curve" to deliver less airflow
fan total static pressure (in. H2O)
fan airflow (cfm)
1200 rpm
1000 rpm
800 rpm
600 rpm
560 rpm
design operating point
1120 rpm
MZVAV fan unloading curve
MZVAV fan-pressure optimization
SP setpoint
10 bhp
7 bhp
5 bhp
3 bhp
1.5 bhp
bhp
2500
5000
7500
10,000
12,500

ASHRAE Standards 90.1-2013 and -2016

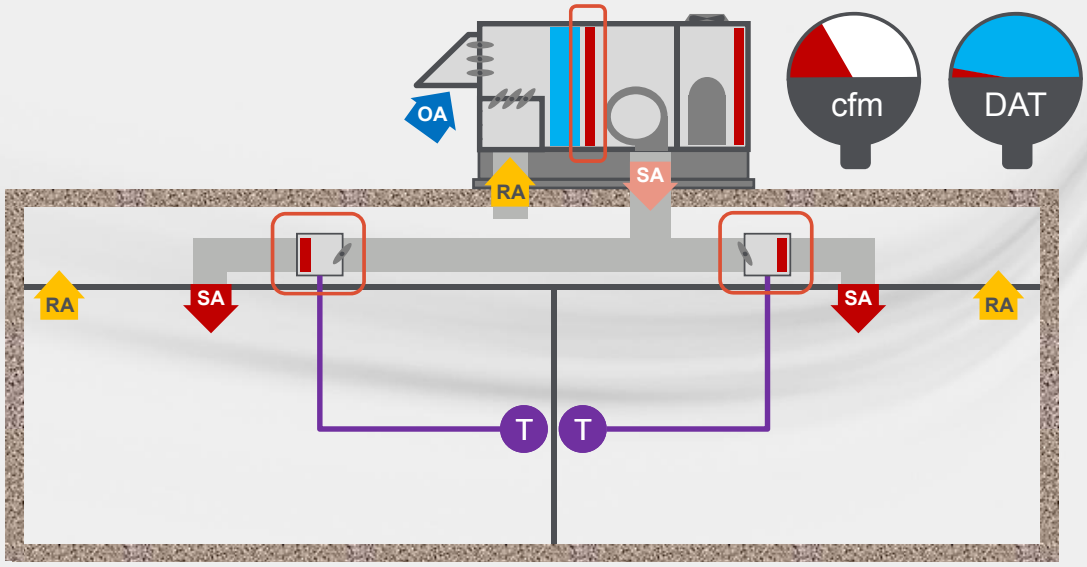
Fan-Pressure Optimization

6.5.3 Air System Design and Control. *Each HVAC system having a total fan system motor nameplate hp* ***exceeding 5 hp*** *shall meet the provisions of Sections 6.5.3.1 through 6.5.3.5.*

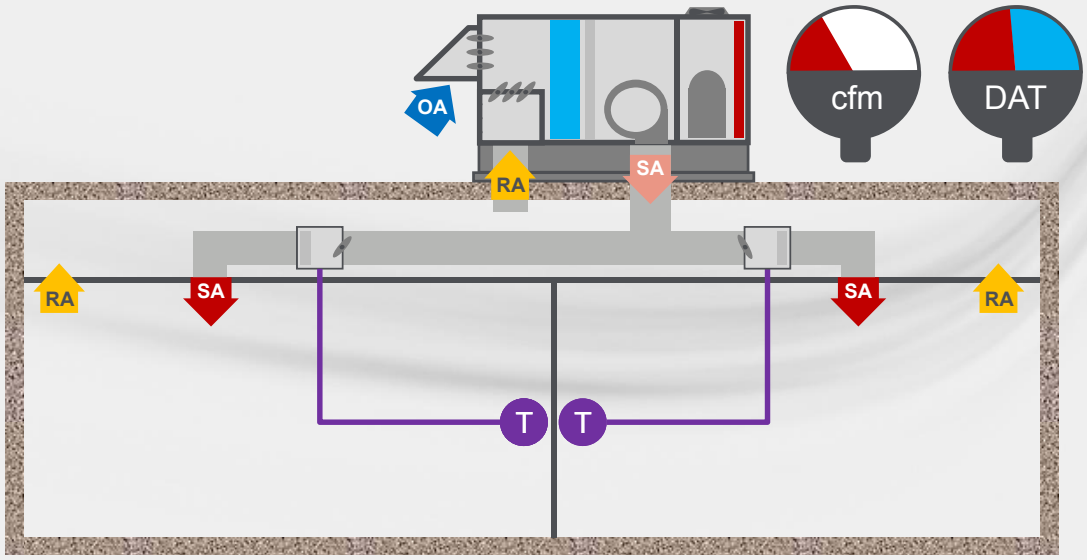
6.5.3.2.3 VAV Setpoint Reset. *For systems with DDC of individual zones reporting to the central control panel, static pressure setpoint shall be reset based on the zone requiring the most pressure; i.e., the setpoint is reset lower until one zone damper is nearly wide open.* ***Controls shall provide the following:***

a. ***Monitor zone damper positions or other indicator of need for static pressure***
b. ***Automatically detect those zones that may be excessively driving the reset logic and generate an alarm to the system operator***
c. ***Readily allow operator removal of zone(s) from the reset algorithm***

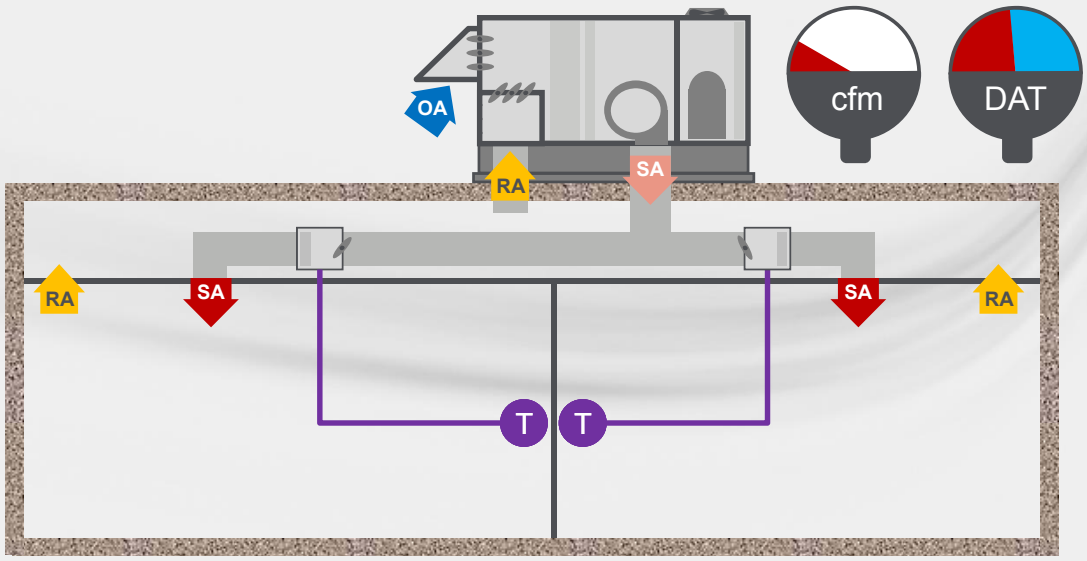
Heating in a Multiple-Zone VAV System



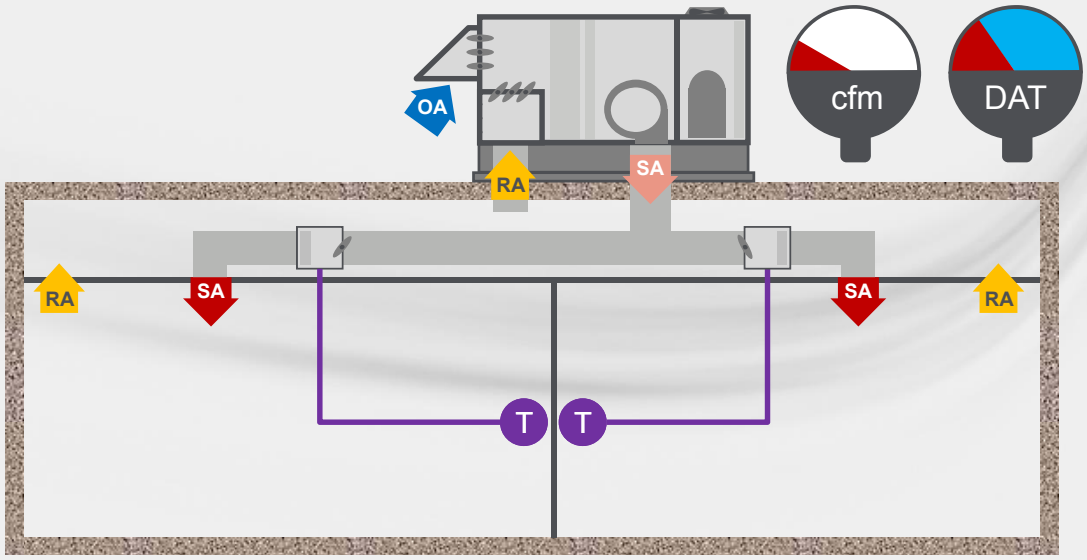
Modulating Heat



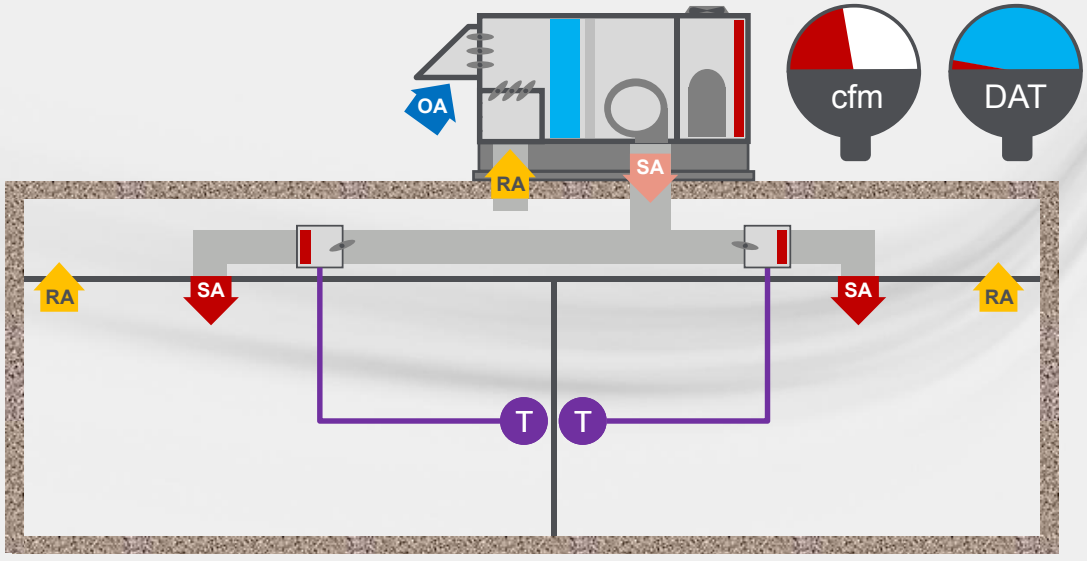
Staged Heat



Staged Heat – Daytime Warm-up



Changeover VAV



Modulated vs. Staged Heat for MZVAV

Variable-speed fan control when heating (modulated heat)

- Supply fan controlled to maintain duct SP at setpoint
- Heater modulated to maintain DAT at setpoint

Cycled fan control when heating (staged heat)

- VAV dampers driven open
- Supply fan operates at maximum speed
- Heater cycles on

AGENDA

- Efficiency regulations, standards, and codes
- Variable-speed compressors
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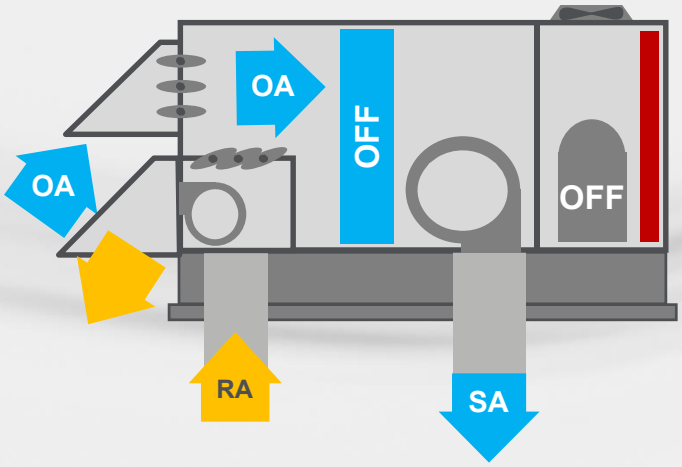
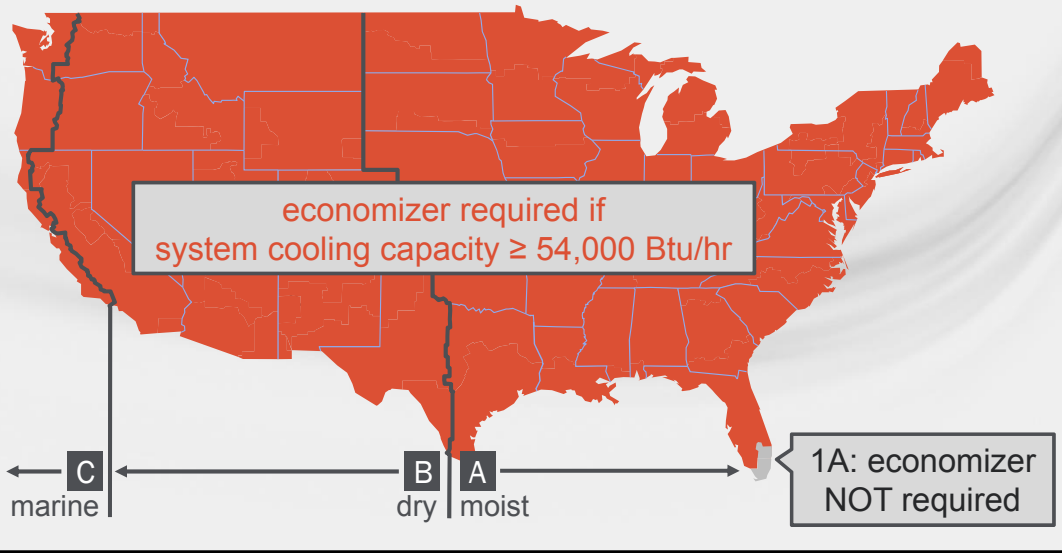
- **Controls**
- Summary (energy analysis)

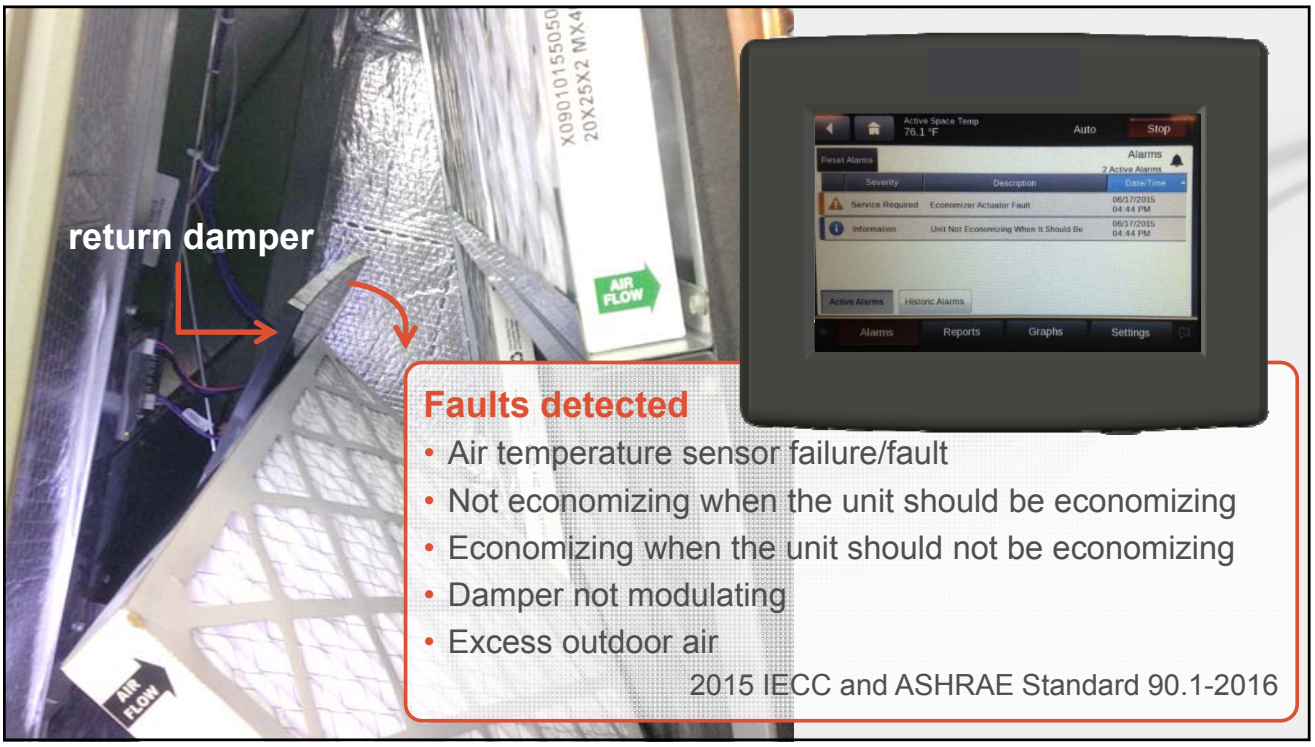
Airside Economizing



ASHRAE Standards 90.1-2010, -2013, and -2016

Economizer



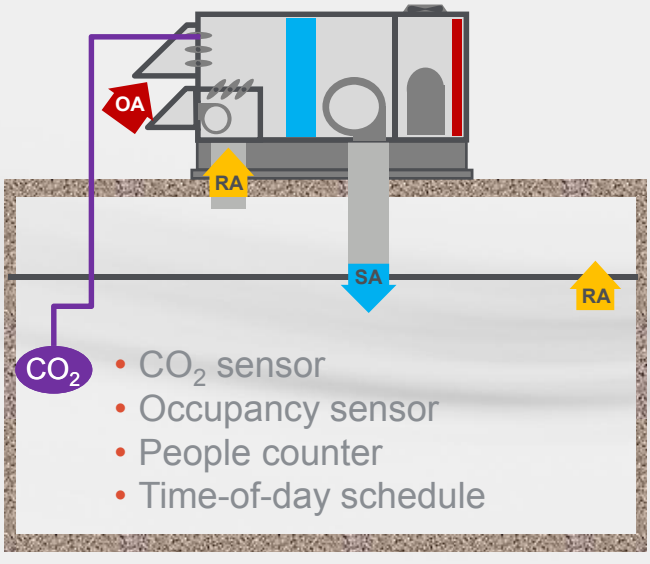


Faults detected

- Air temperature sensor failure/fault
- Not economizing when the unit should be economizing
- Economizing when the unit should not be economizing
- Damper not modulating
- Excess outdoor air

2015 IECC and ASHRAE Standard 90.1-2016

Demand-Controlled Ventilation (DCV)



- CO_2 sensor
- Occupancy sensor
- People counter
- Time-of-day schedule

ASHRAE Standards 90.1-2007 and -2010

Demand-Controlled Ventilation (DCV)

6.4.3.9 Ventilation Controls for High-Occupancy Areas.

Demand control ventilation (DCV) is required for spaces larger than 500 ft² and with a design occupancy for ventilation of ***> 40 people*** *per 1000 ft² of floor area and served by systems with one or more of the following:*

a. an air-side economizer,

b. automatic modulating control of the outdoor air damper,

or

c. a design outdoor airflow > 3000 cfm.

Exceptions:

a. Systems with exhaust air energy recovery complying with Section 6.5.6.1.

b. Multiple-zone systems without DDC of individual zones communicating with a central control panel.

c. Systems with a design outdoor airflow < 1200 cfm.

d. Spaces where the supply airflow rate minus any makeup or outgoing transfer air requirement < 1200 cfm.

Based on default occupant densities listed in ASHRAE Standard 62.1

ASHRAE Standards 90.1-2013 and -2016

Demand-Controlled Ventilation (DCV)

6.4.3.8 Ventilation Controls for High-Occupancy Areas.

Demand control ventilation (DCV) is required for spaces larger than 500 ft² and with a design occupancy for ventilation of ***≥ 25 people*** *per 1000 ft² of floor area and served by systems with one or more of the following:*

a. an air-side economizer,

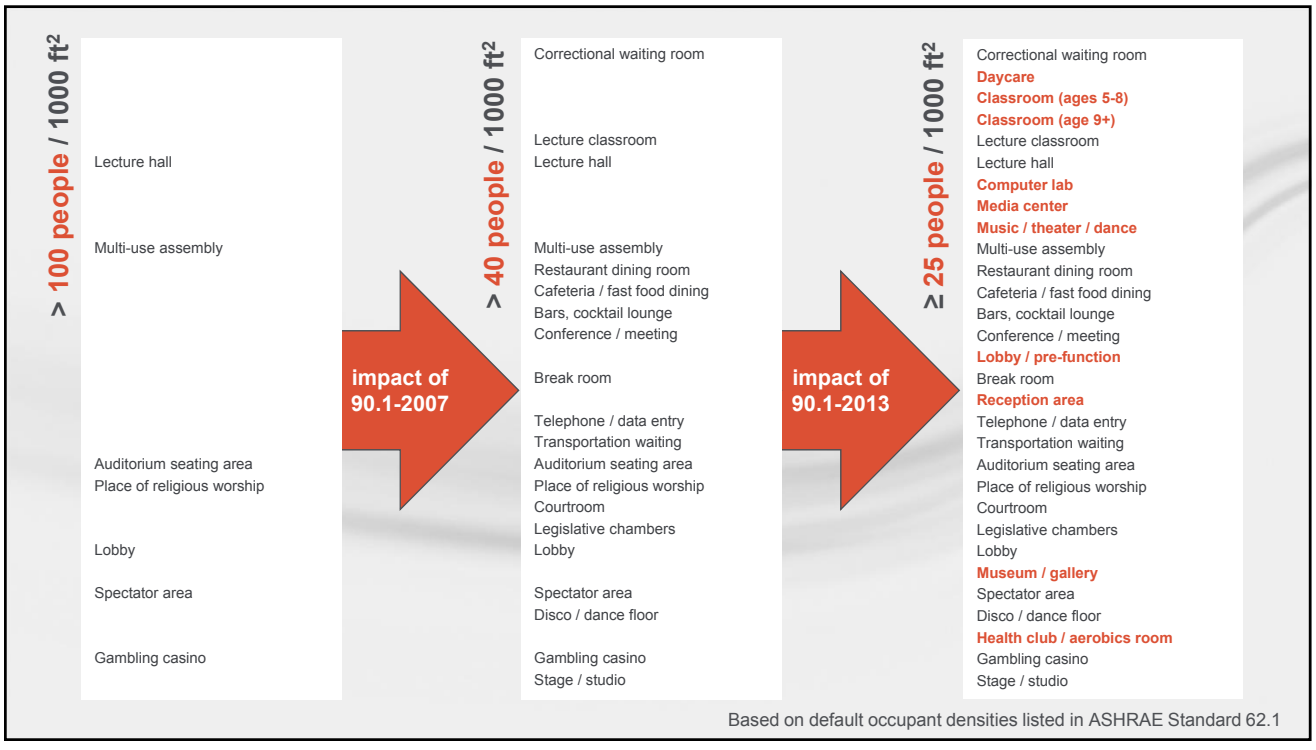
b. automatic modulating control of the outdoor air damper,

or

c. a design outdoor airflow > 3000 cfm.

Exceptions:

1. *Systems with exhaust air energy recovery complying with Section 6.5.6.1.*
2. *Multiple-zone systems without DDC of individual zones communicating with a central control panel.*
3. *Systems with a design outdoor airflow < 750 cfm.*
4. *Spaces where > 75% of the space design outdoor airflow is required for makeup air that is exhausted from the space or transfer air that is required for makeup air that is exhausted from other space(s).*
5. *Correctional cells, daycare sickrooms, science labs, beauty and nail salons, and bowling alley seating.*



Based on default occupant densities listed in ASHRAE Standard 62.1

ASHRAE Standards 90.1-2013 and -2016

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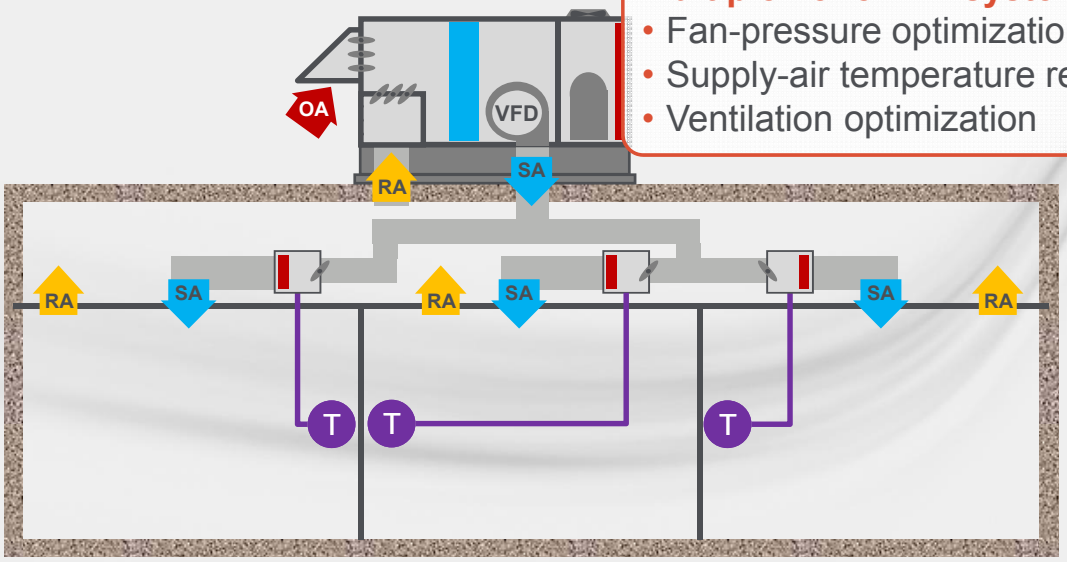
Multiple-zone VAV systems

- Fan-pressure optimization
- Supply-air temperature reset
- Ventilation optimization



ASHRAE Standards 90.1-2010, -2013, and -2016

Supply-Air Temperature Reset

6.5.3.4 Supply-Air Temperature Reset Controls. *Multiple-zone HVAC systems must include controls that automatically reset the supply-air temperature* ***in response to representative building loads, or to outdoor air temperature****. The controls shall reset the supply air temperature at least 25 percent of the difference between the design supply-air temperature and the design room air temperature. Controls that adjust the reset based on zone humidity are allowed. Zones which are expected to experience relatively constant loads, such as electronic equipment rooms, shall be designed for the fully reset supply temperature.*

Exceptions:

a. Climate zones 1a, 2a, and 3a

b. Systems that prevent re-heating, re-cooling, or mixing of heated and cooled supply air.

c. Systems in which at least 75 percent of the energy for reheating (on an annual basis) is from site recovered or site solar energy sources.

ASHRAE Standards 90.1-2010 and -2013

Ventilation Optimization

6.5.3.3 Multiple-zone VAV System Ventilation Optimization Control. *Multiple-zone VAV systems with DDC of individual zone boxes reporting to a central control panel shall include means to automatically reduce outdoor air intake flow below design rates in response to changes in system ventilation efficiency as defined by Appendix A of ASHRAE Standard 62.1.*

Exceptions:

a. VAV systems with zonal transfer fans that recirculate air from other zones without directly mixing it with outdoor air, dual-duct dual-fan VAV systems, and VAV systems with fan-powered terminal units.

b. Systems required to have the exhaust air energy recovery complying with Section 6.5.6.1.

c. Systems where total design exhaust airflow is more than 70% of total design outdoor air intake flow requirements.

Building Automation

ASHRAE Standards 90.1-2013 and -2016

New DDC Requirements

6.4.3.10 Direct Digital Control (DDC) Requirements.
Direct digital control shall be required as follows.

6.4.3.10.1 DDC Applications. *DDC shall be provided in the applications and qualifications listed in Table 6.4.3.10.1.*

Exception: *DDC is not required for systems using the simplified approach to compliance in accordance with Section 6.3.*

ASHRAE Standards 90.1-2013 and -2016

Excerpt from Table 6.4.3.10.1

Building Status	Application	DDC Required If:
New	Air-handling system and all zones served by the system	> three zones and fan system ≥ 10 bhp
Alteration or addition	New air-handling system and all new zones served by the system	> three zones and fan system ≥ 10 bhp and > 75% of zones are new
Alteration or addition	Zone terminal unit (e.g., VAV box)	existing zones served by the same air-handling system have DDC

DDC requirements of Standard 90.1-2013 (Section 6.4.3.10.2)

Impact on Small Rooftop Systems

Control Sequence	90.1-2013 Section	Applies to:
optimal start	6.4.3.3.3	• single-zone systems • multiple-zone systems
“dual maximums” VAV reheat control	6.5.3.2.1	• multiple-zone VAV systems
fan-pressure optimization	6.5.3.2.3	• multiple-zone VAV systems
ventilation optimization	6.5.3.3	• multiple-zone VAV systems

ASHRAE Standard 90.1-2013 and -2016

DDC Requirements (continued)

6.4.3.10.2 DDC Controls. *Where DDC is required by Section 6.4.3.10.1, the DDC system shall be capable of all of the following, as required, to provide the control logic required in Section 6.5:*

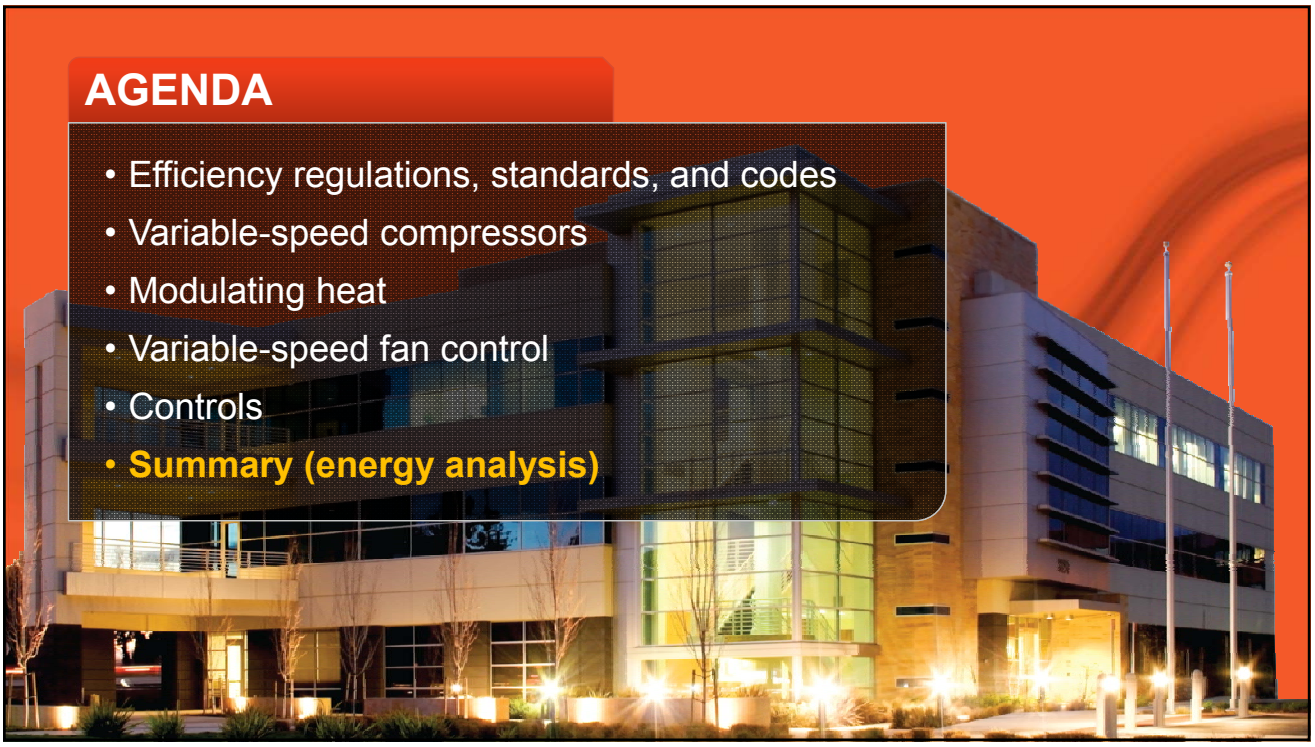
a. Monitoring zone and system demand for fan pressure, pump pressure, heating, and cooling

b. Transferring zone and system demand information from zones to air distribution system controllers and from air distribution systems to heating and cooling plant controllers

c. Automatically detecting those zones and systems that may be excessively driving the reset logic and generate an alarm or other indication to the system operator

d. Readily allowing operator removal of zone(s) from the reset algorithm

6.4.3.10.3 DDC Display. *Where DDC is required by Section 6.4.3.10.1 for new buildings,* ***the DDC system shall be capable of trending and graphically displaying input and output points****.*



Small Rooftop System Analysis

Locations:

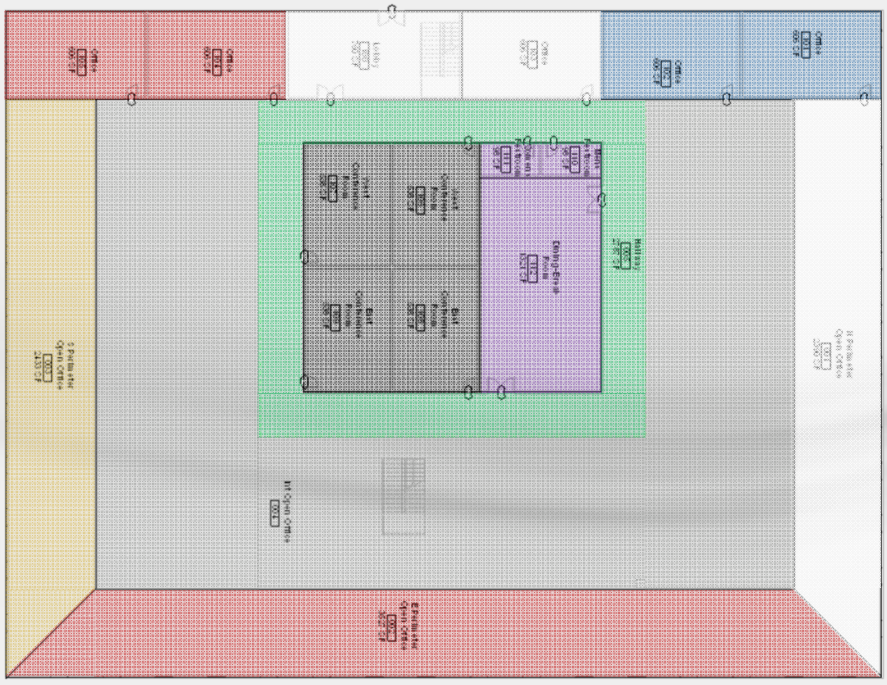
- Boston, Massachusetts (5A)
- St. Louis, Missouri (4A)
- Atlanta, Georgia (3A)

Three comparisons:

1. Traditional SZCV
2. Traditional SZVAV
3. High Performance SZVAV

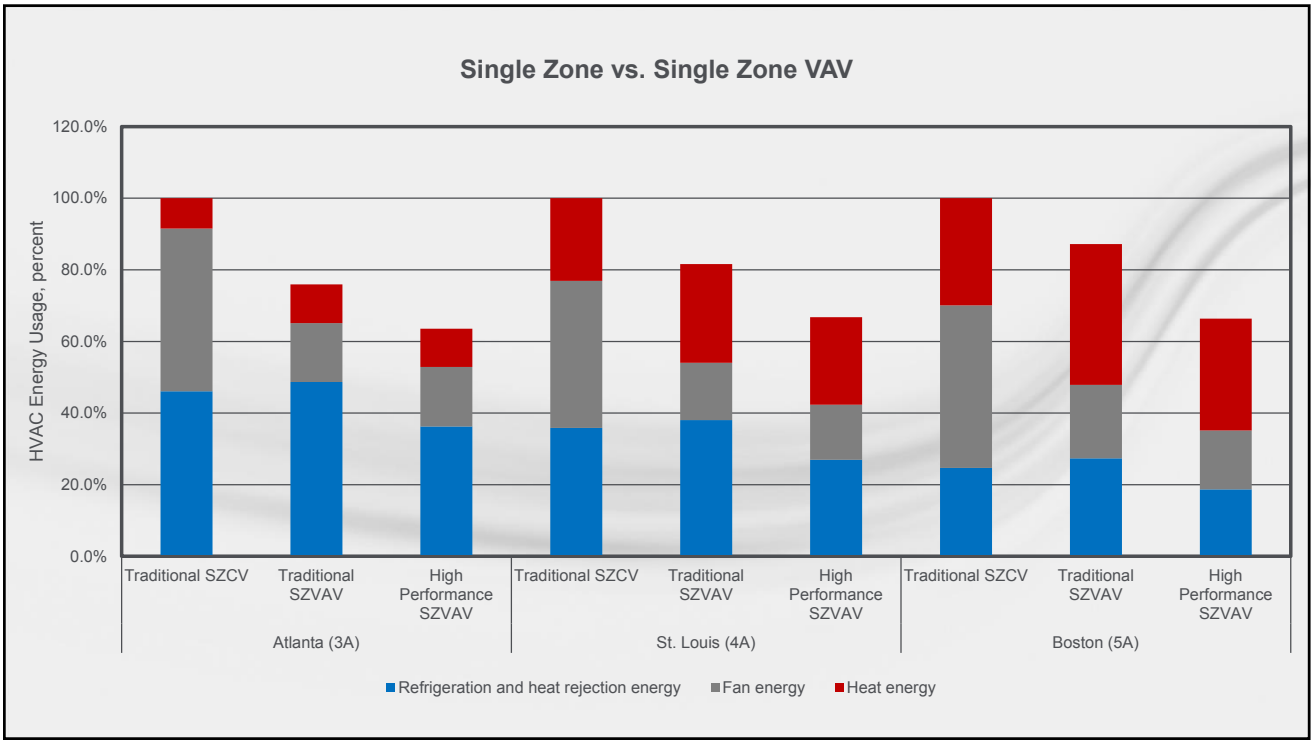
Complies with:

- ASHRAE 62.1-2010
- ASHRAE 90.1-2010



Rooftops

1. Office 104 & 105
2. Office 103 & Lobby
3. Office 101 & 102
4. Perimeter Open Office
5. Perimeter Open Office
6. Perimeter Open Office
7. Interior Open Office
8. Conference Rooms
9. Restrooms and Break room
10. Hallway



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Trends in Small Rooftop Systems

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Trends in Small Rooftop Systems

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Additional questions or comments:

Trane *Engineers Newsletter LIVE: Trends in Small Rooftop Systems*
APP-CMC061-EN QUIZ

1. Which industry standard lists minimum equipment efficiency requirements for small rooftop units?
   a. ASHRAE Standard 55
   b. ASHRAE Standard 62.1
   c. ASHRAE Standard 90.1
   d. AHRI Standard 885

2. Minimum efficiency requirements regulated by the U.S. Department of Energy (DOE) supersede the efficiency requirements listed in ASHRAE Standard 90.1.
   a. True
   b. False

3. In a single-zone VAV system, when the supply fan speed has been reduced to minimum, and the space cooling load continues to decrease, the supply-air temperature setpoint begins to be reset _____ to avoid overcooling the space.
   a. upward
   b. downward

4. In a single-zone VAV system, when the supply fan speed is reduced to 50% of full speed, the fan input power is reduced to ____% of full power.
   a. 12.5%
   b. 33%
   c. 50%
   d. It depends on the duct static pressure setpoint

5. Modulating gas heat enables the supply fan to use variable-speed control during the heating mode.
   a. True
   b. False

6. In a multiple-zone VAV system, when the supply fan speed is reduced to 50% of full speed, it is not able to deliver any lower than 50% of full airflow.
   a. True
   b. False

7. Recent versions of ASHRAE Standard 90.1 have required demand-controlled ventilation to be used in more types of spaces (with lower occupant densities).
   a. True
   b. False