Trane Engineers Newsletter LIVE Series

Demand-Controlled Ventilation

with Trane Engineers John Murphy and Eric Sturm

Trane program number: APP-CMC067-EN

www.trane.com/ENL

Agenda

Trane *Engineers Newsletter Live* Series

Demand-Controlled Ventilation

Abstract

Demand-controlled ventilation (DCV) is an energy-saving control strategy that reduces the rate at which outdoor air is delivered to a zone during periods of partial occupancy. This ENL will discuss various technologies used to implement DCV, how to apply DCV control strategies to the different types of ventilation systems, and review the related requirements for compliance with ASHRAE Standards 62.1 and 90.1.

Presenters: Eric Sturm and John Murphy

After attending, you will be able to:

- Recognize applications for which ASHRAE Standard 90.1 and energy codes might require demand-controlled ventilation
- Identify various technologies available for implementing demand-controlled ventilation
- Apply various demand-controlled ventilation strategies to single-zone systems, dedicated outdoor-air systems, and multiple-zone VAV systems
- Understand what ASHRAE Standard 62.1 requires when implementing demand-controlled ventilation
- Identify several challenges of integrating DCV with other control sequences

Agenda

- Changes to Energy Standards and Codes
- Common DCV Technologies
- DCV in Single-Zone Systems
- DCV in DOAS
- DCV in Multiple-Zone Systems

Presenter biographies

Demand-Controlled Ventilation

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.

Demand-Controlled Ventilation

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Learning objectives

1. Recognize applications for which ASHRAE Standard 90.1 and energy codes require demand-controlled ventilation (DCV)
2. Identify various technologies available for implementing DCV
3. Apply various DCV strategies to single-zone systems, dedicated outdoor-air systems, and multiple-zone VAV systems
4. Understand what ASHRAE Standard 62.1 requires when implementing DCV
5. Identify several challenges of integrating DCV with other control sequences

Demand-Controlled Ventilation (DCV)

- DCV is a control strategy that varies the rate at which outdoor air is delivered to a zone, based on the number of people currently in that zone.
- The goal is to save energy, not to improve IAQ.
  - If your goal is to improve IAQ, you would keep outdoor airflow high at all times, rather than reducing it during periods of partial occupancy.

Agenda

- Recent changes to energy standards and codes
- Common DCV technologies
- Implementing DCV into HVAC systems
  - Single-zone systems
  - Dedicated outdoor-air systems
  - Multiple-zone VAV systems

Today's Presenters

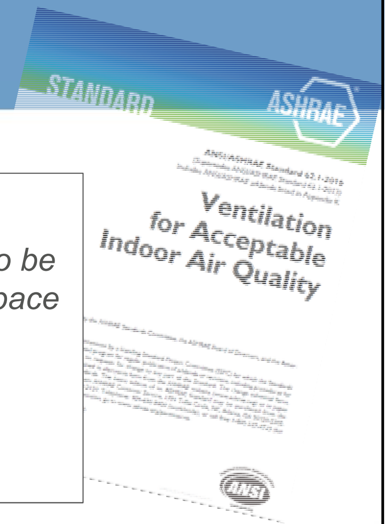
Eric Sturm
Applications Engineer

John Murphy
Applications Engineer

Agenda

- **Recent changes to energy standards are codes**
- Common DCV technologies
- Implementing DCV into HVAC systems
  - Single-zone systems
  - Dedicated outdoor-air systems
  - Multiple-zone VAV systems

ASHRAE Standard 62.1-2016

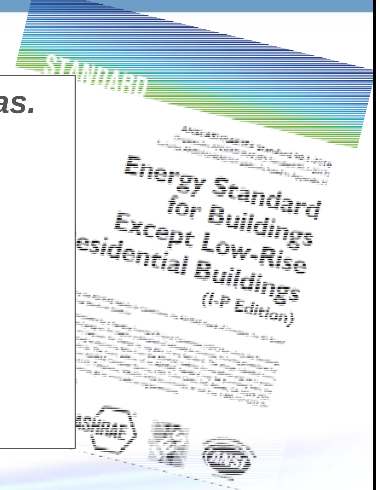


6.2 Ventilation Rate Procedure

6.2.7 Dynamic Reset. *The system shall be permitted to be designed to reset the outdoor air intake flow (V_{ot}), the space or ventilation zone airflow (V_{oz}) as operating conditions change, or both.*

6.2.7.1 Demand Control Ventilation. *DCV shall be permitted as an optional means of dynamic reset.*

ASHRAE Standard 90.1-2013 and -2016



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. Air economizer

b. Automatic modulating control of outdoor air damper

c. Design outdoor airflow greater than 3000 cfm

ASHRAE Standard 90.1-2013 and -2016

Exceptions to Section 6.4.3.8:

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 spaces.

5. Spaces with one of the following occupancy categories as defined in ASHRAE Standard 62.1: correctional cells, daycare sickrooms, science labs, barbers, beauty and nail salons, and bowling alley seating.

DCV Required by Standard 90.1 More Often

90.1-2004	90.1-2007 and -2010	90.1-2013 and -2016
	A_z > 500 ft^2	A_z > 500 ft^2
P_z > 100 people/1000 ft^2	P_z > 40 people/1000 ft^2	P_z ≥ 25 people/1000 ft^2
V_{ot} < 3000 cfm (exempt)	V_{ot} < 1200 cfm (exempt)	V_{ot} < 750 cfm (exempt)

Occupancy Categories ≥ 25 people/1000 ft^2

Based on the Default Occupant Density from ASHRAE 62.1-2016, Table 6.2.2.1

- Correctional waiting room
- **Daycare**
- **Classroom (ages 5-8)**
- **Classroom (age 9+)**
- Lecture classroom
- Lecture hall
- **Computer lab**
- **Media center**
- **Music / theater / dance**
- Multi-use assembly
- Restaurant dining room
- Cafeteria / fast food dining
- Bars, cocktail lounge
- Conference / meeting
- **Lobby / pre-function**
- Break room
- **Reception area**
- Telephone / data entry
- Transportation waiting
- Auditorium seating area
- Place of religious worship
- Courtroom
- Legislative chambers
- Lobby
- **Museum / gallery**
- Spectator area
- Disco / dance floor
- **Health club / aerobics**
- Gambling casino
- Stage / studio

IECC 2012 and 2015

C403.2.6.1 Demand controlled ventilation. *Demand control ventilation (DCV) shall be provided for spaces larger than 500 ft^2 and with an average occupant load of 25 people per 1000 ft^2 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

c. A design outdoor airflow greater than 3000 cfm

Exceptions to Section C403.2.6.1:

1. Systems with energy recovery complying with Section C403.2.7.

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

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

4. Spaces where the supply airflow rate minus any makeup or outgoing transfer air requirements is less than 1200 cfm.

5. Ventilation provided for process loads only.

differs from ASHRAE 90.1

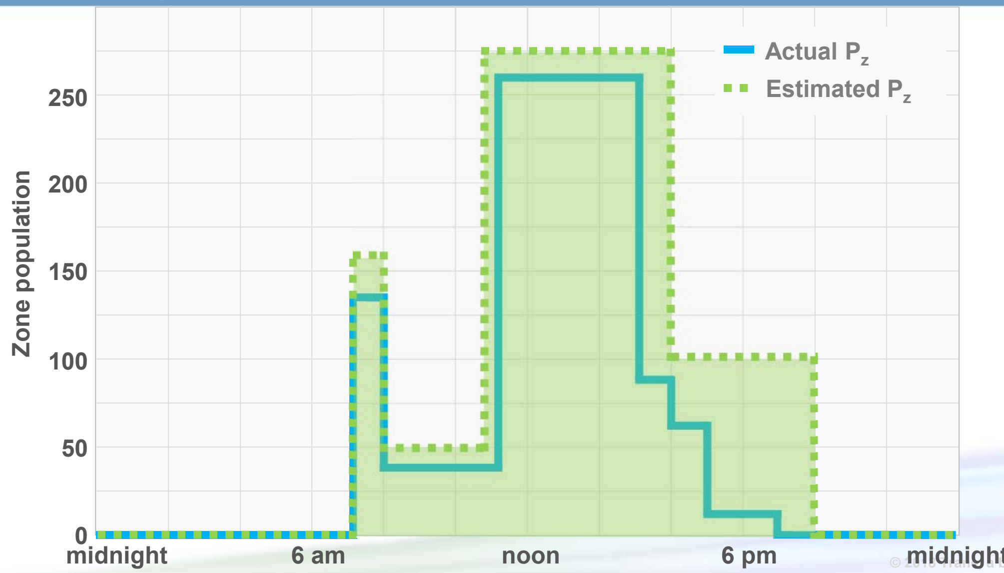
Agenda

- Recent changes to energy standards are codes
- **Common DCV technologies**
- Implementing DCV into HVAC systems
  - Single-zone systems
  - Dedicated outdoor-air systems
  - Multiple-zone VAV systems

DCV Technologies

- Occupancy schedules
- People counters
- Occupancy sensors
- Carbon dioxide sensors

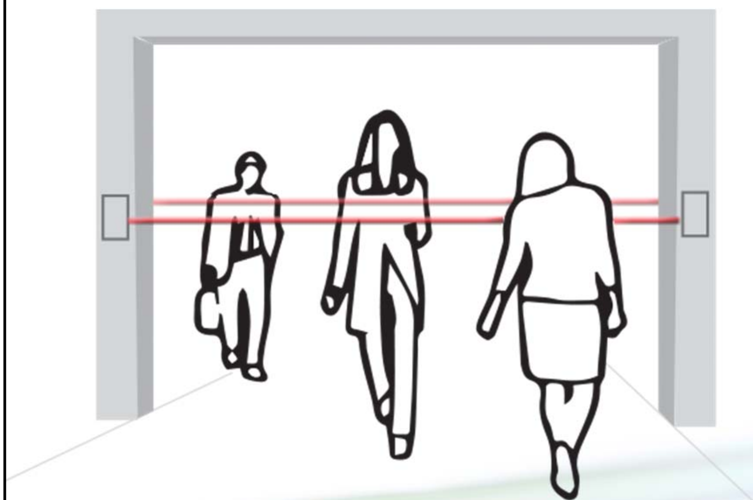
Occupancy and Ventilation TOD Example: High school cafeteria



People Counters

- Infrared systems
- Camera systems
- Thermal imaging
- Point-of-sale
- Wi-Fi and Bluetooth®

Infrared Systems – Infrared Beams



Camera Systems

Thermal Imaging

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Point-of-Sale Systems

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Theater Example

$V_{bz} = R_p \times P_z + R_a \times A_z$

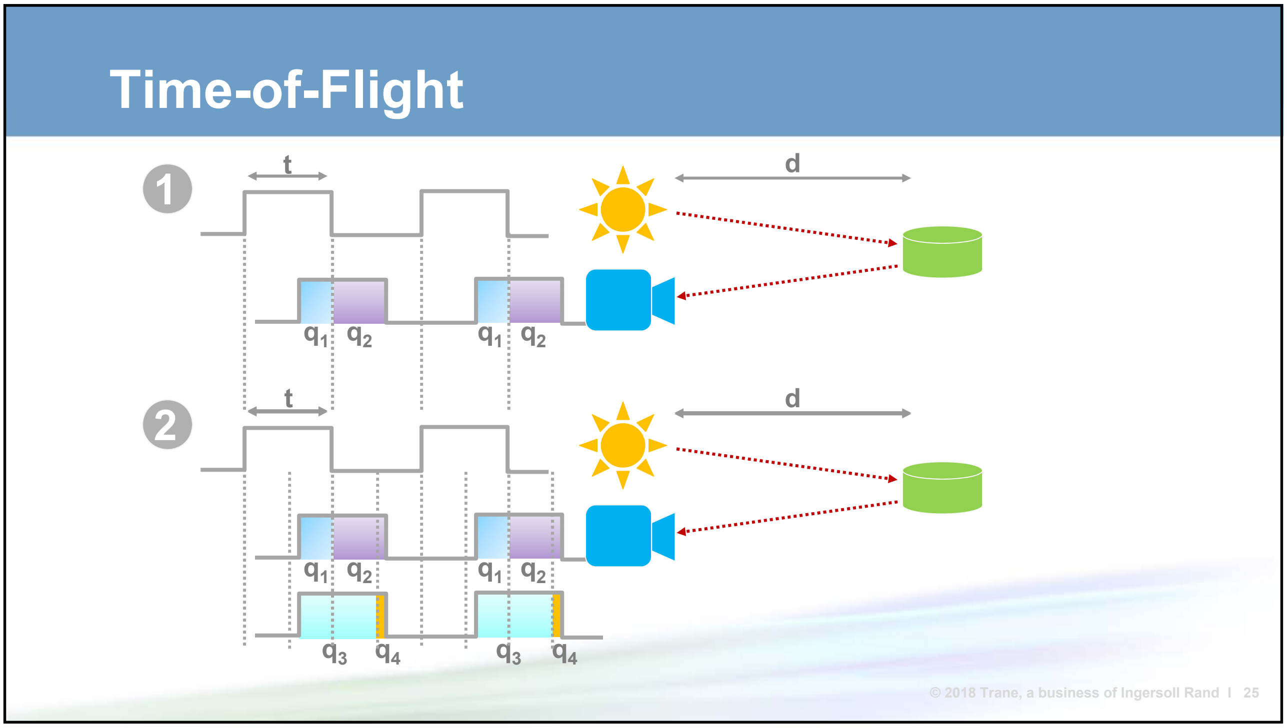
$V_{bz\text{-}design}$ = 5 cfm/person × **200 people** + 0.06 cfm/ft^2 × 2400 ft^2 = **1144 cfm**

Theater Example

$V_{bz} = R_p \times P_z + R_a \times A_z$

$V_{bz\text{-}design}$ = 5 cfm/person × **200 people** + 0.06 cfm/ft^2 × 2400 ft^2 = **1144 cfm**

$V_{bz\text{-}DCV}$ = 5 cfm/person × **63 people** + 0.06 cfm/ft^2 × 2400 ft^2 = **459 cfm**


Time-of-Flight
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q1
q2
q3
q4
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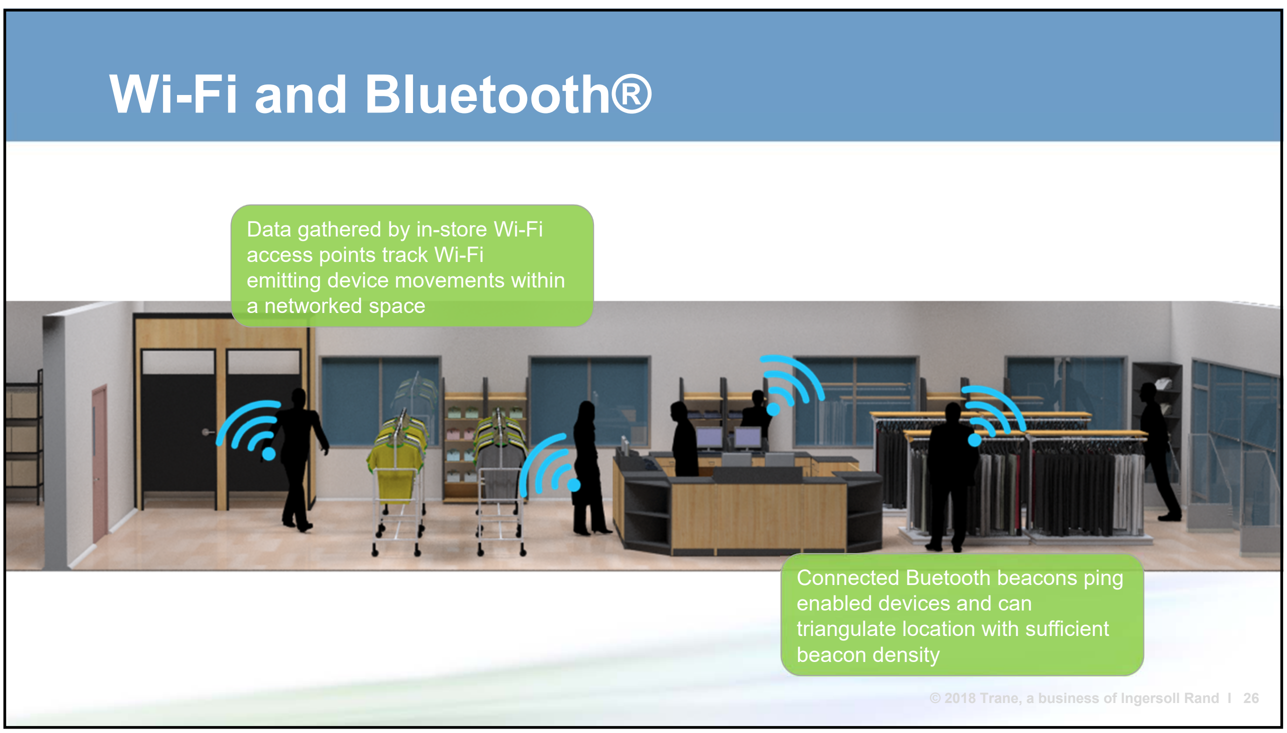
Wi-Fi and Bluetooth®
Data gathered by in-store Wi-Fi access points track Wi-Fi emitting device movements within a networked space
Connected Buetooth beacons ping enabled devices and can triangulate location with sufficient beacon density
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Occupancy Sensors

V_{bz} = 4 people x 5 cfm/p + 680 ft^2 x 0.06 cfm/ft^2
V_{bz} = 20 + 41 cfm
V_{bz} = 61 cfm

Occupancy Sensors at Occupied Standby

V_{bz} = 4 people x 5 cfm/p + 680 ft^2 x 0.06 cfm/ft^2
V_{bz} = 20 + 41 cfm
V_{bz} = 61 cfm

$V_{bz\text{-}unoccupied}$ = 0 people x 5 cfm/p + 680 ft^2 x 0.06 cfm/ft^2
$V_{bz\text{-}unoccupied}$ = 0 + 41 cfm
$V_{bz\text{-}unoccupied}$ = 41 cfm

Changes to 62.1-2016

***6.2.7.1.2** For DCV zones in the occupied mode, breathing zone outdoor airflow (V_{bz}) shall not be less than the building component ($R_a \times A_z$) for the zone.*

***Exception:** Breathing zone outdoor airflow shall be permitted to be reduced to zero for zones in occupied-standby mode for the occupancy categories indicated in Table 6.2.2.1 provided that airflow is restored to V_{bz} whenever occupancy is detected.*

Section 3. Definitions

***occupied mode:** when a zone is scheduled to be occupied*

***occupied-standby mode:** when a zone is scheduled to be occupied and an occupancy sensor indicates zero population within the zone*

Carbon Dioxide Sensors

Standard 62.1-2016 – Appendix D

Predicts difference between indoor and outdoor CO_2 concentrations at steady-state given constant ventilation and CO_2-generation rates

- Use equation D-1: $C_{space} - C_{OA} = N / V_{OA}$

Where:

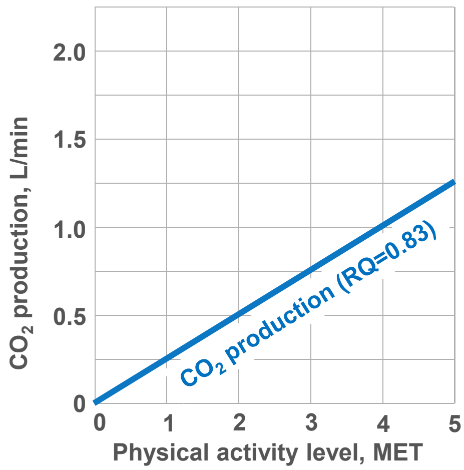
C_{space} = *Indoor CO_2 concentration*

C_{OA} = *Outdoor CO_2 concentration*

N = *CO_2 generation rate, cfm/person*

V_{OA} = *Ventilation rate, cfm/person*

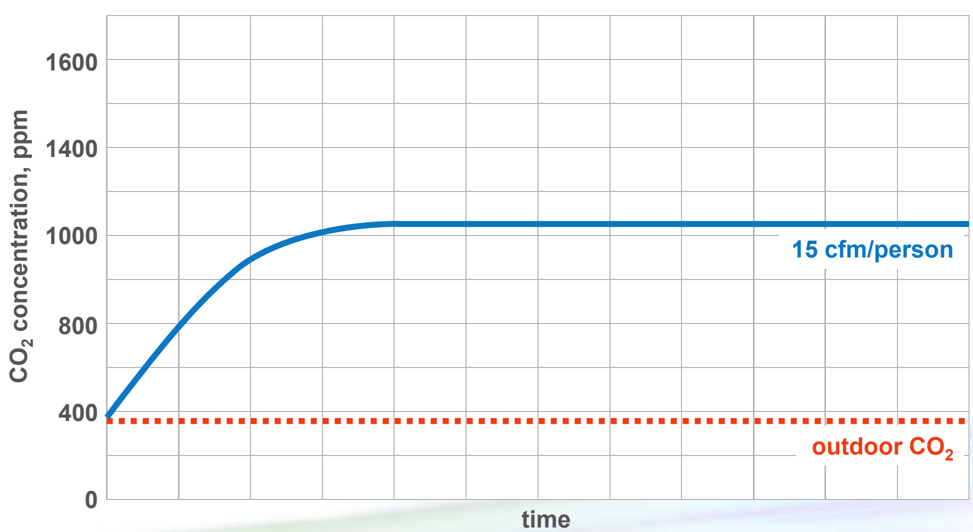
Carbon Dioxide Sensors



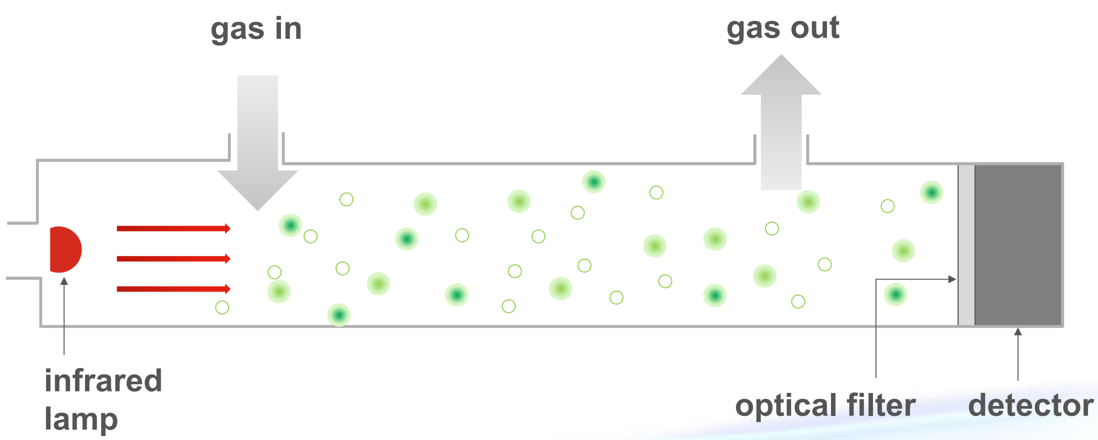
- Production of CO_2 is related to a person's activity level
- CO_2 can be used as a "tracer gas" for occupancy

Source: *ASHRAE Standard 62.1-2013, Figure C-2*

CO_2 Concentration Mass Balance



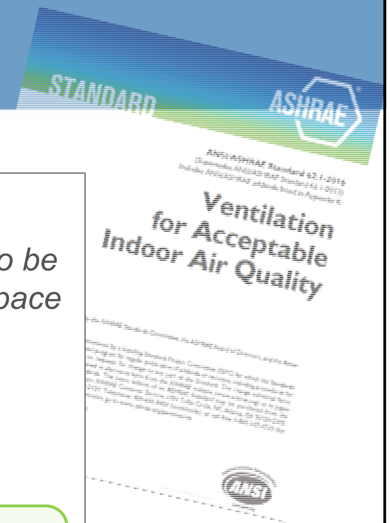
Nondispersive Infrared (NDIR) CO_2 Sensing



Sensor Selection

Sensor	Occupancy	Population Variation
Time-of-day	Predictable	Low or highly variable
Occupancy	Low-density	Minimal
Population counters	Any	Highly variable
CO_2	High-density	Highly variable

ASHRAE Standard 62.1-2016



6.2 Ventilation Rate Procedure

6.2.7 Dynamic Reset. *The system shall be permitted to be designed to reset the outdoor air intake flow (V_{ot}), the space or ventilation zone airflow (V_{oz}) as operating conditions change, or both.*

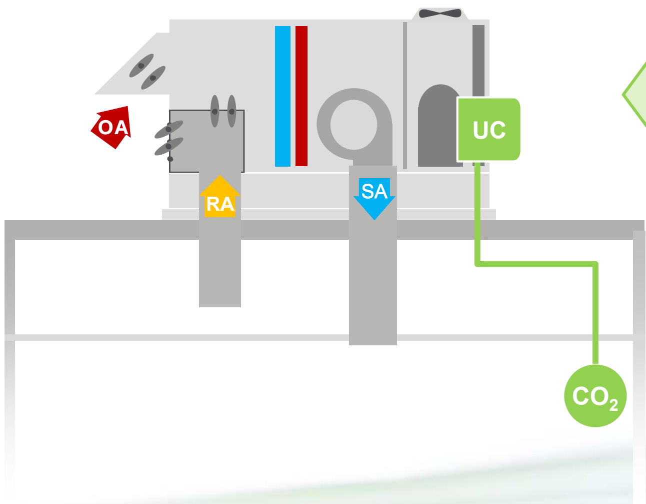
6.2.7.1 Demand Control Ventilation. *DCV shall be permitted as an optional means of dynamic reset.*

> ***Exception:*** *CO_2-based DCV shall not be applied in zones with indoor sources of CO_2 other than occupants or with CO_2 removal mechanisms, such as gaseous air cleaners.*

Agenda

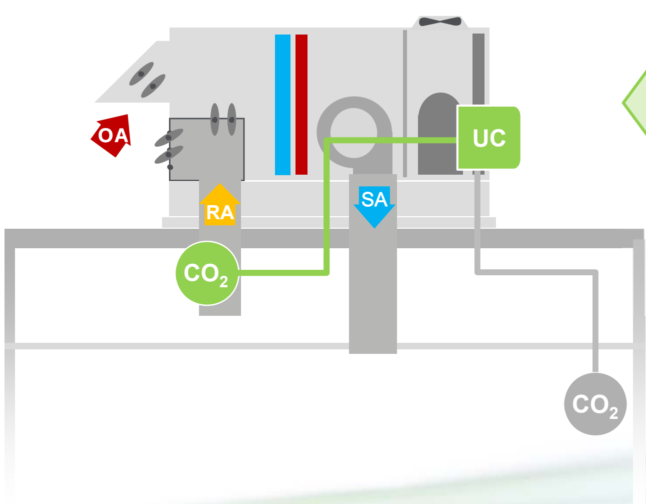
- Recent changes to energy standards are codes
- Common DCV technologies
- **Implementing DCV into HVAC systems**
  - **Single-zone systems**
  - Dedicated outdoor-air systems
  - Multiple-zone VAV systems

DCV in single zone systems



CO_2 sensor location
- Typical: installed directly in the occupied space on a wall (Often looks like a zone sensor)

DCV in single zone systems



CO_2 sensor location
- Typical: installed directly in the occupied space on a wall (Often looks like a zone sensor)
- Alternate: installed in the return air duct

62.1 Appendix A: Proportional Control

Example: University lecture classroom

- Floor area (A_z) = 1000 ft^2
- Peak population (P_z) = 65 people
- CO_2 generation rate (N*) = 0.0105 cfm/person (light desk work)
- Outdoor CO_2 concentration (C_{OA}) = 350 ppm

For this occupancy classification, Table 6-1 of ASHRAE Standard 62.1 requires:

- R_p = 7.5 cfm/person
- R_a = 0.06 cfm/ft^2

* N, cfm/person = MET × 0.0084 for average adult population (Standard 62.1-2010 User's Manual, p. 158)

62.1 Appendix A: Proportional Control

1. Calculate breathing-zone outdoor airflow (V_{bz}) for both design population, and with zero people

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

$$V_{bz\text{-}design} = 7.5 \times \mathbf{65} + 0.06 \times 1000 = 550 \text{ cfm}$$

$$V_{bz\text{-}DCVmin} = 7.5 \times \mathbf{0} + 0.06 \times 1000 = 60 \text{ cfm}$$

62.1 Appendix A: Proportional Control

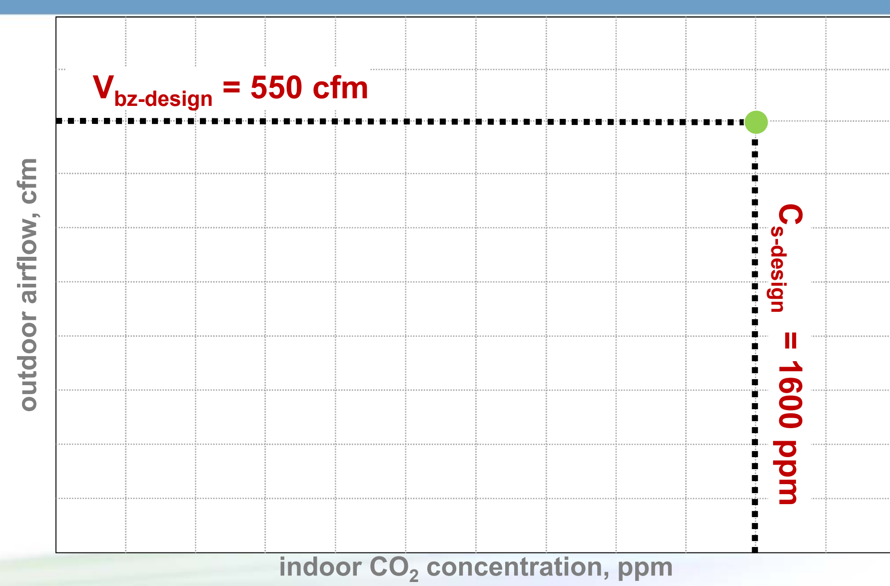
2. Calculate steady-state indoor CO_2 concentration (C_s) for both design population, and with zero people

$C_s = C_{OA} + N / (V_{bz} / P_z)$

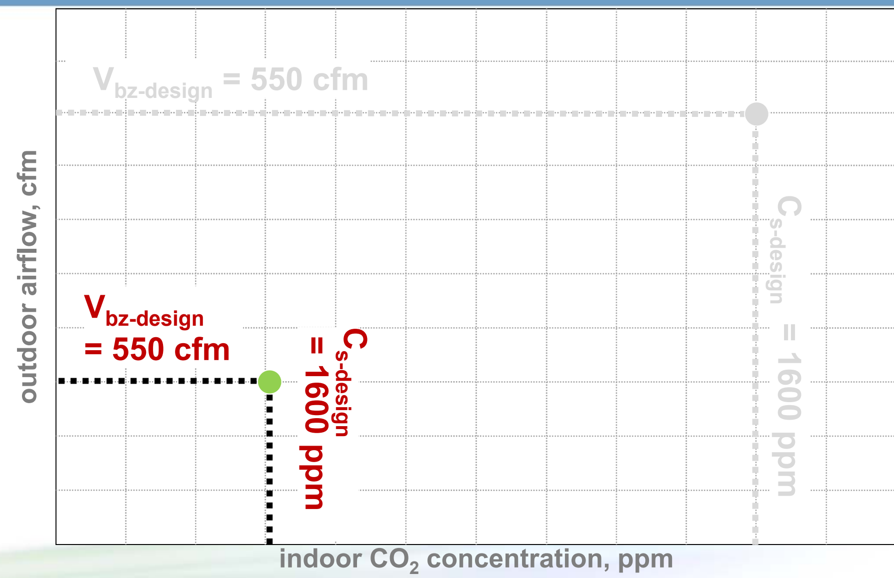
$C_{s\text{-design}} = 350 + 0.0105 / (550 \text{ cfm} / \mathbf{65} \text{ people}) \times 1{,}000{,}000 = 1600 \text{ ppm}$

$C_{s\text{-DCVmin}} = 350 + 0.0105 / (60 \text{ cfm} / \mathbf{0} \text{ people}) \times 1{,}000{,}000 = 350 \text{ ppm}$

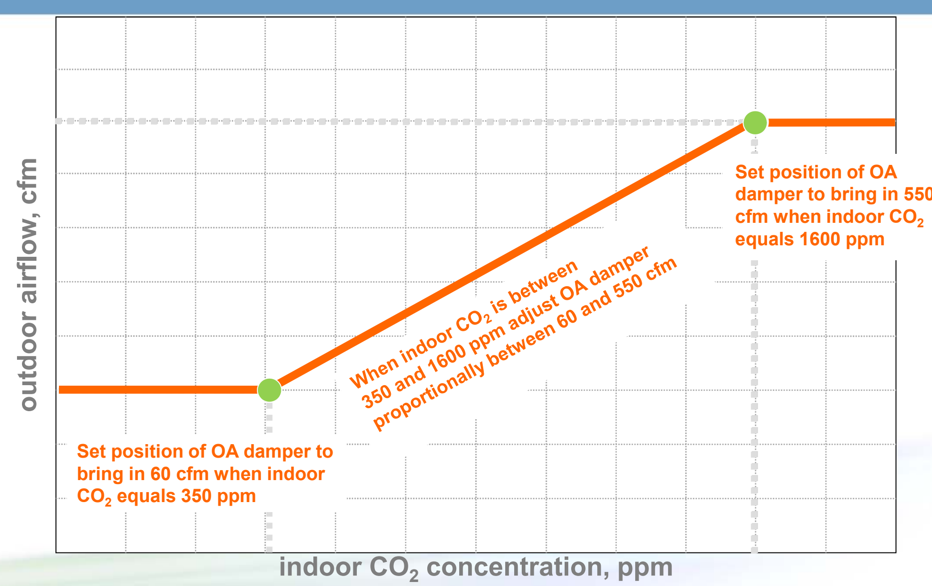
62.1 Appendix A: Proportional Control



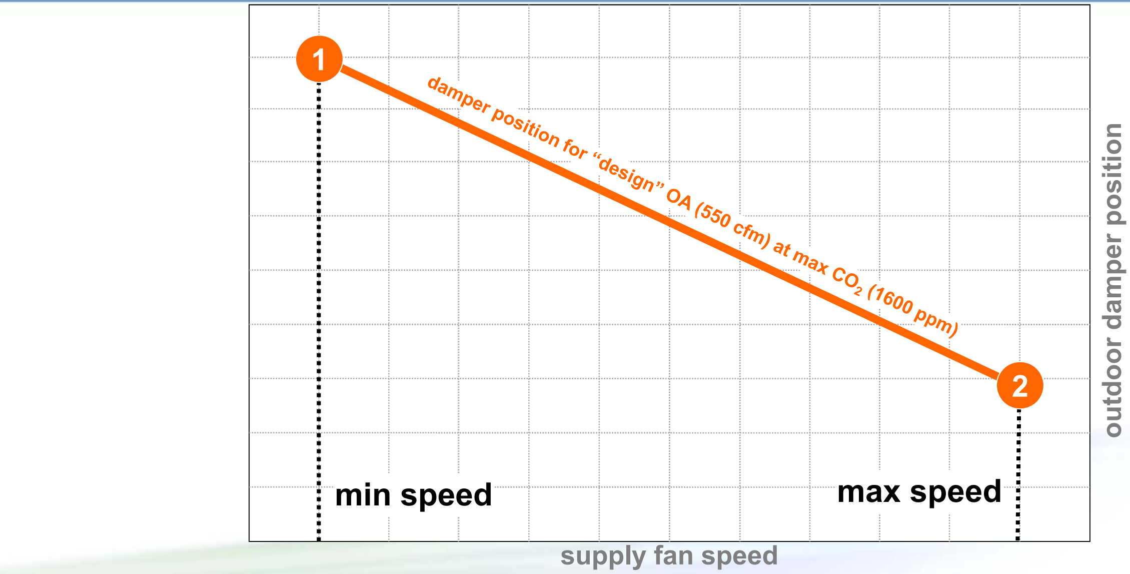
62.1 Appendix A: Proportional Control



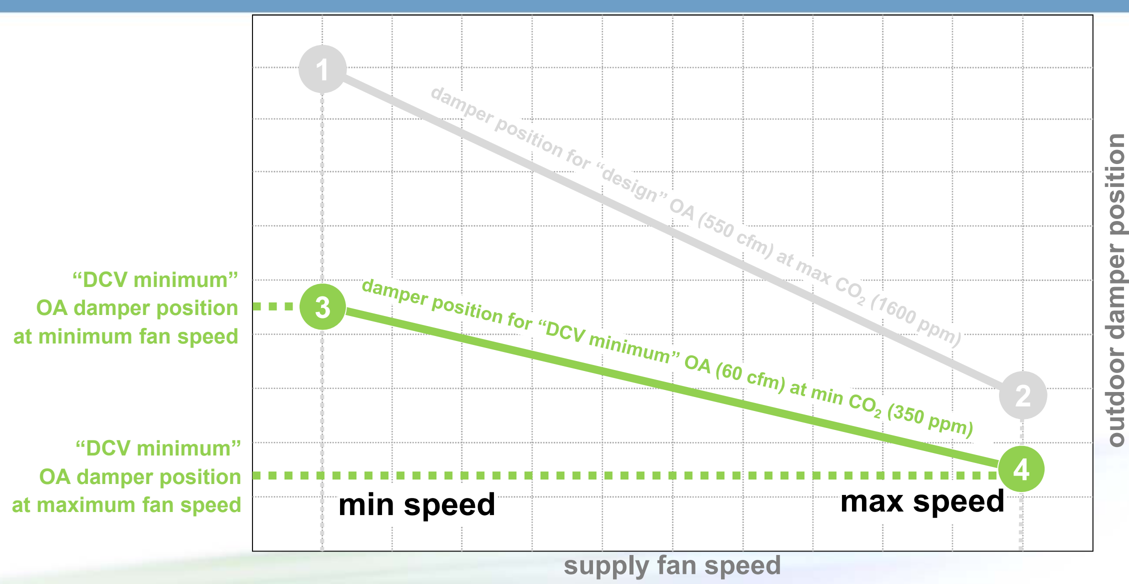
62.1 Appendix A: Proportional Control

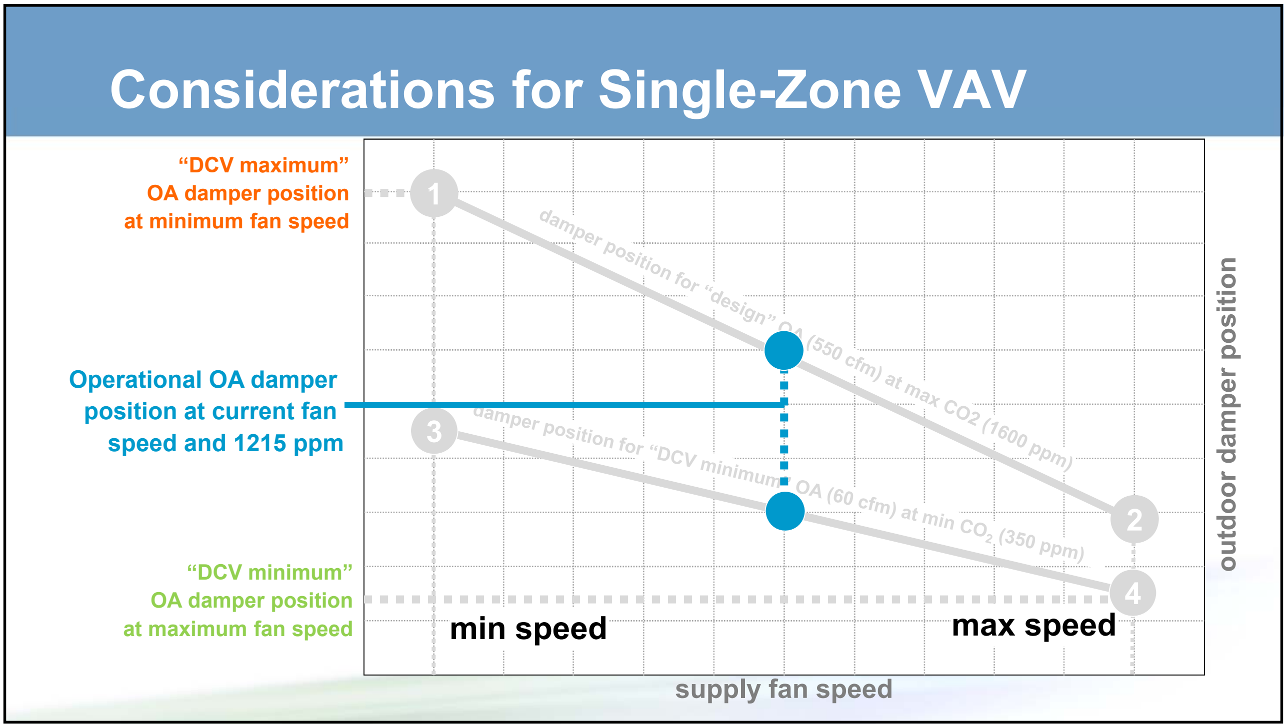


Considerations for Single-Zone VAV



Considerations for Single-Zone VAV




Considerations for Single-Zone VAV
"DCV maximum"
OA damper position
at minimum fan speed
Operational OA damper
position at current fan
speed and 1215 ppm
"DCV minimum"
OA damper position
at maximum fan speed
damper position for "design" OA (550 cfm) at max CO2 (1600 ppm)
damper position for "DCV minimum" OA (60 cfm) at min CO_2 (350 ppm)
min speed
max speed
supply fan speed
outdoor damper position
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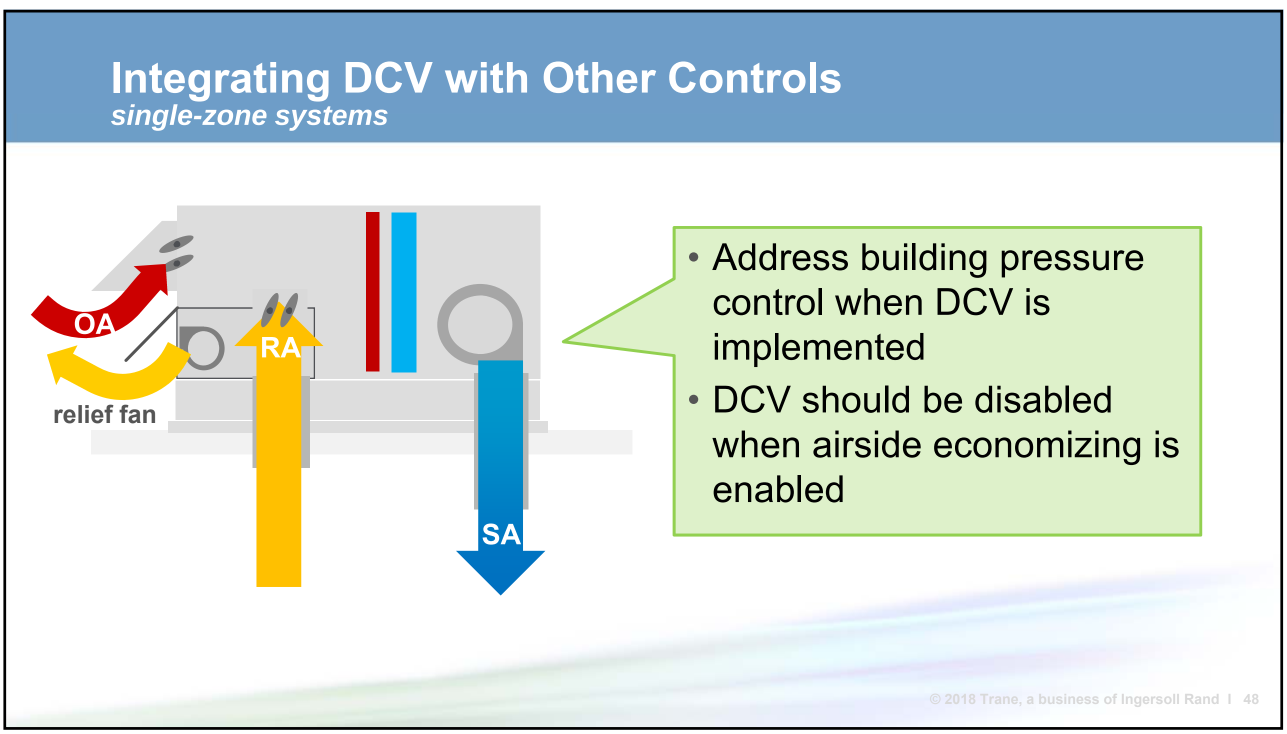
3
4


Integrating DCV with Other Controls
single-zone systems
OA
RA
SA
relief fan
• Address building pressure control when DCV is implemented
• DCV should be disabled when airside economizing is enabled
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Agenda

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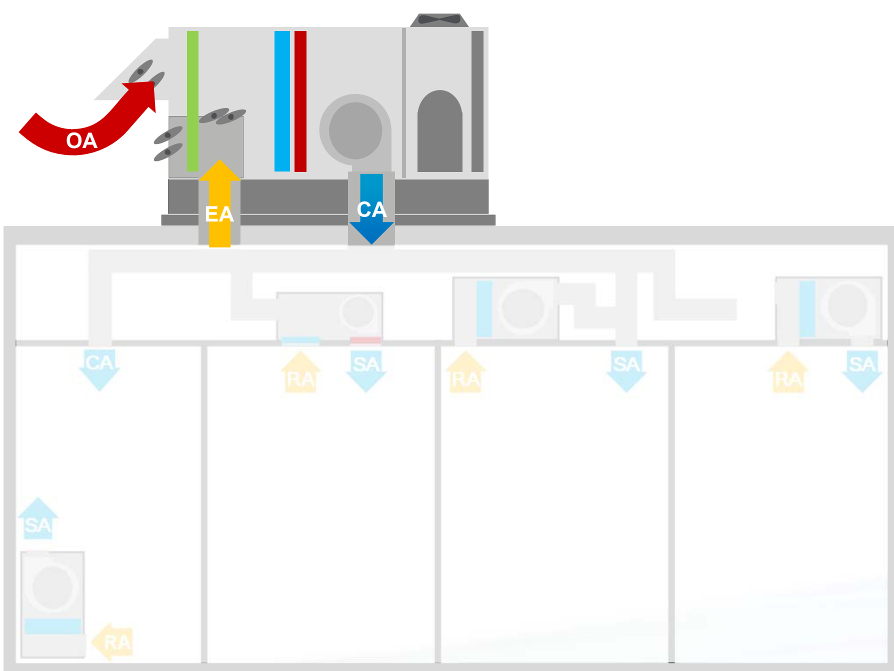
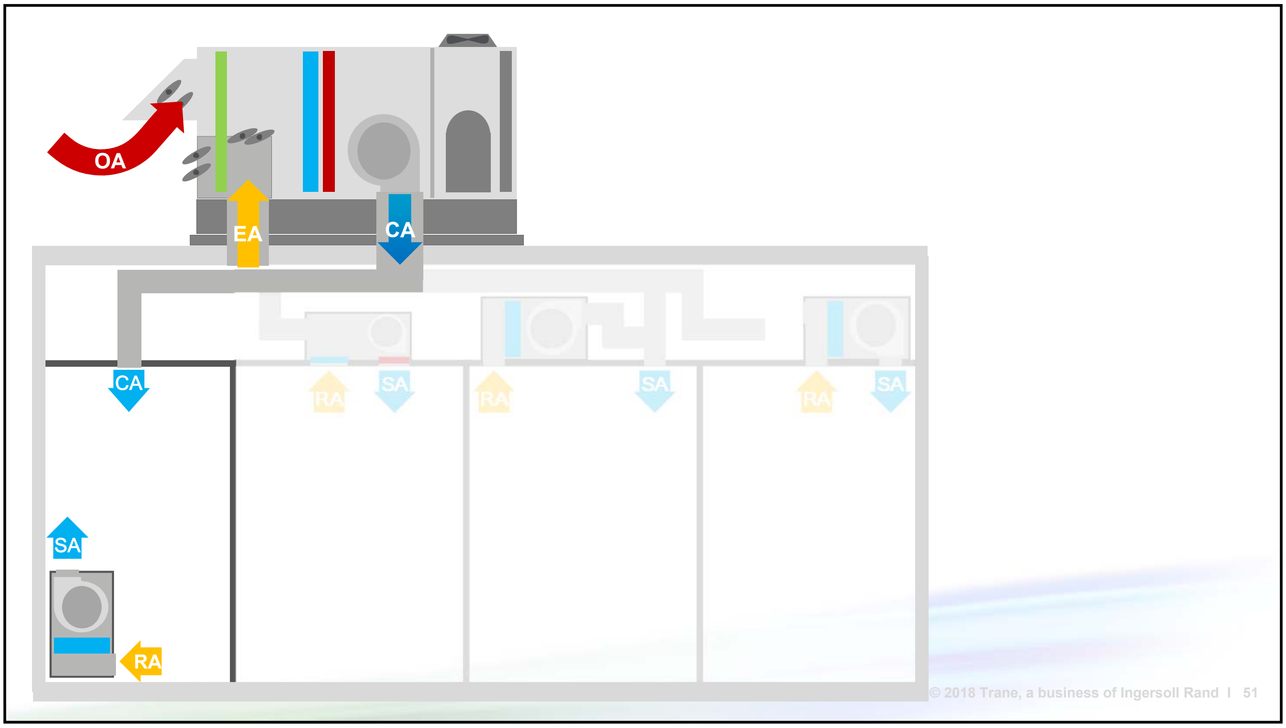
  - **Dedicated outdoor-air systems**
  - Multiple-zone VAV systems

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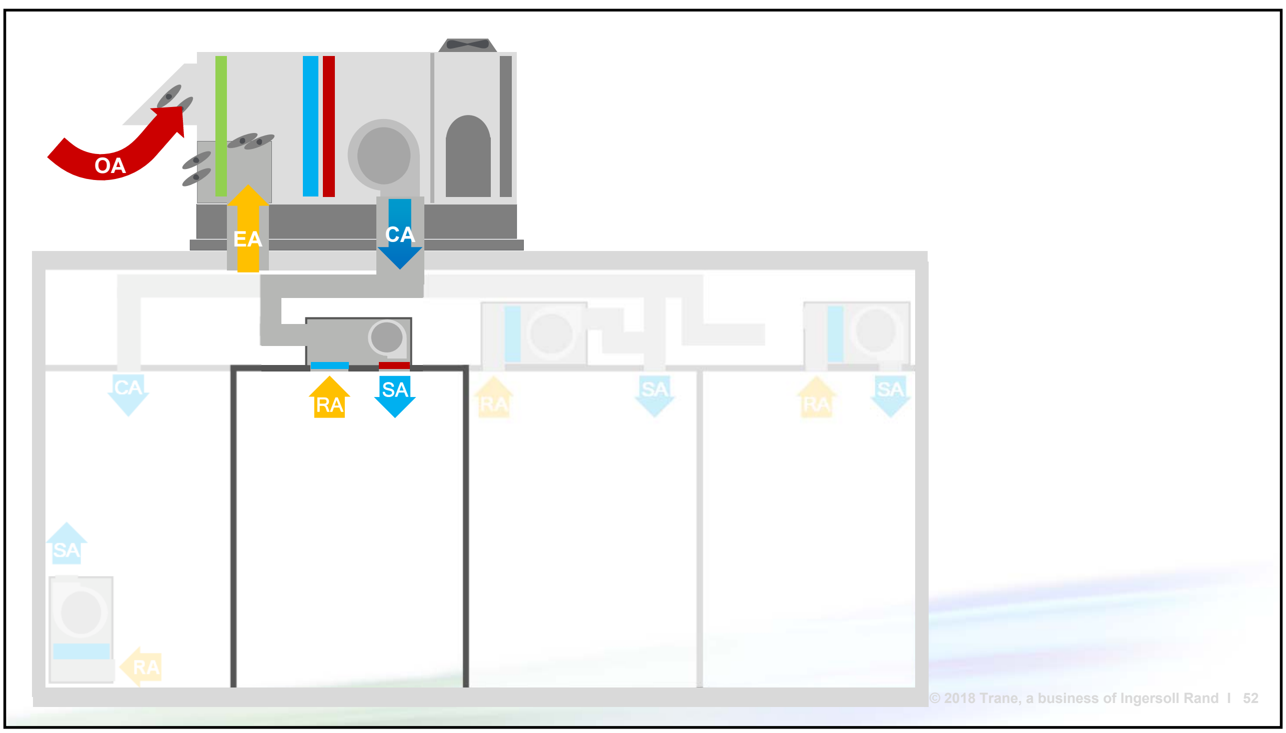
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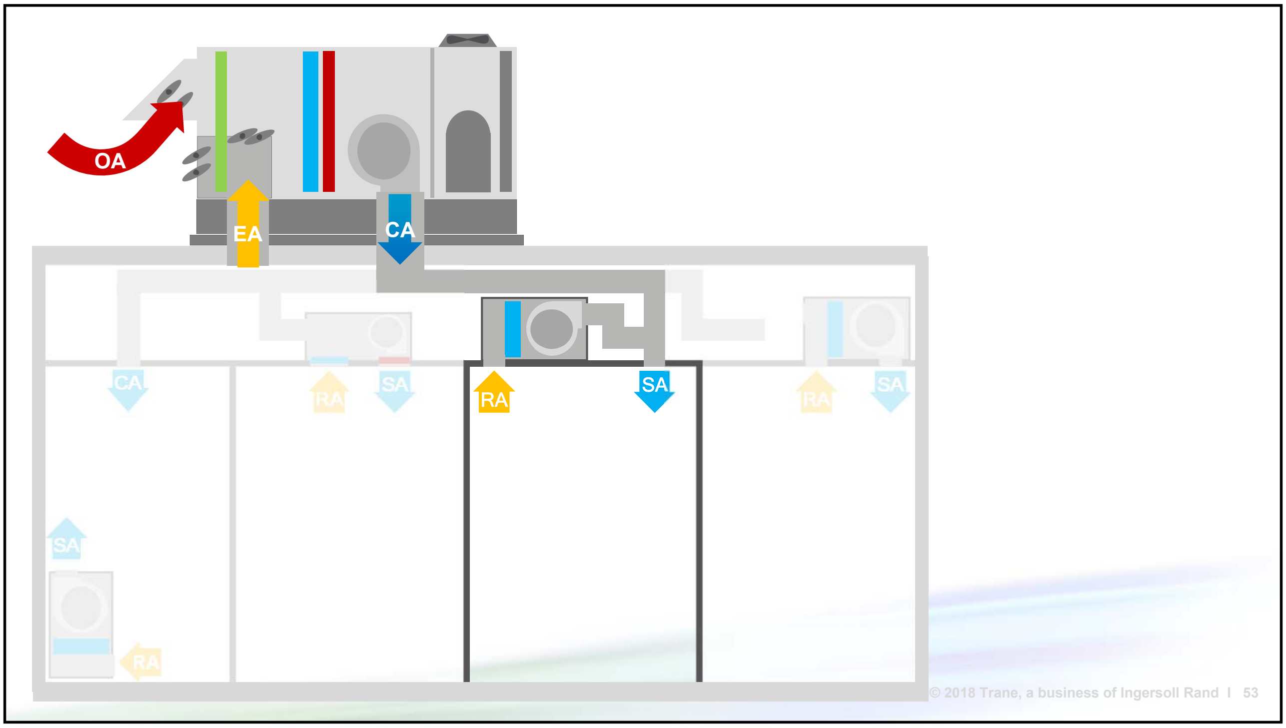
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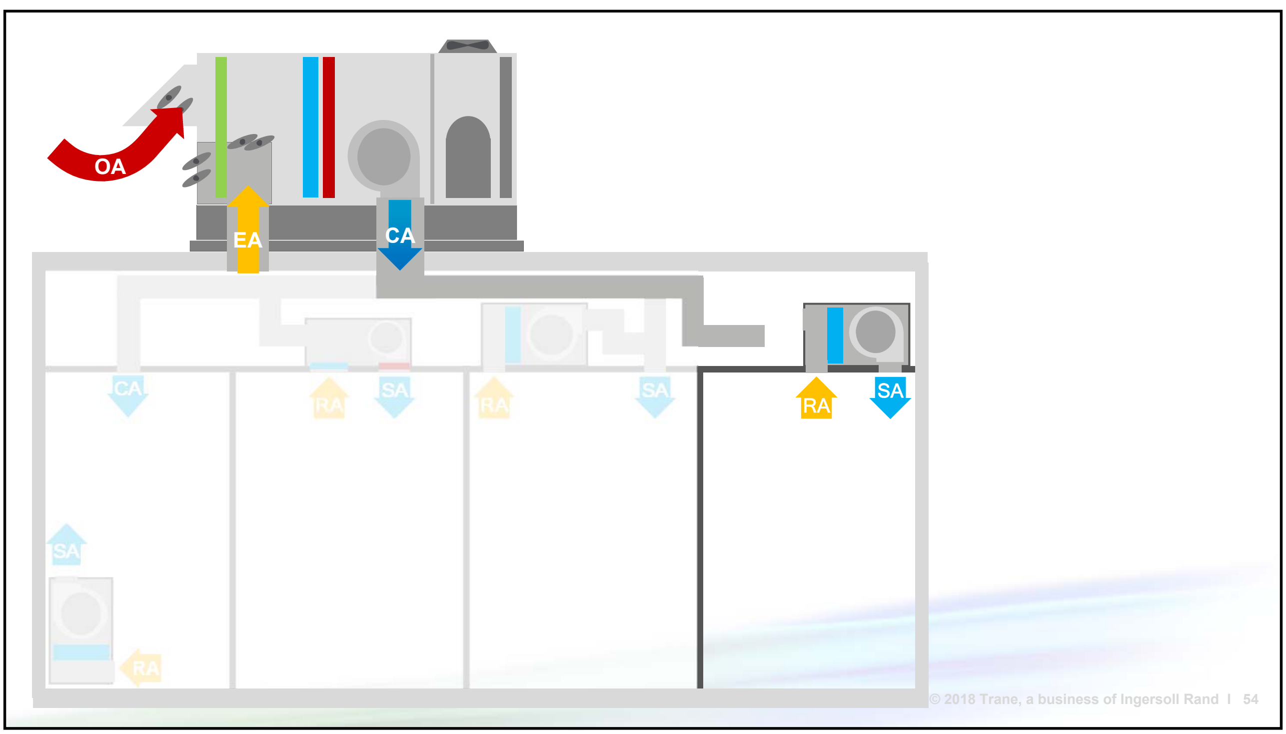
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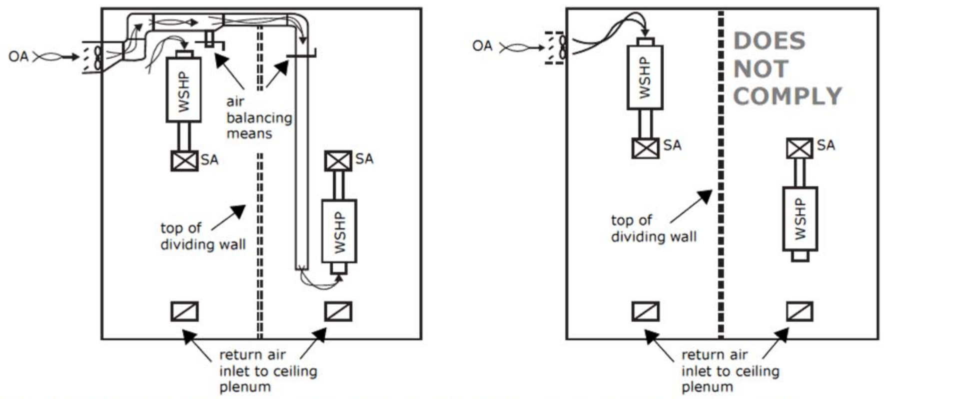
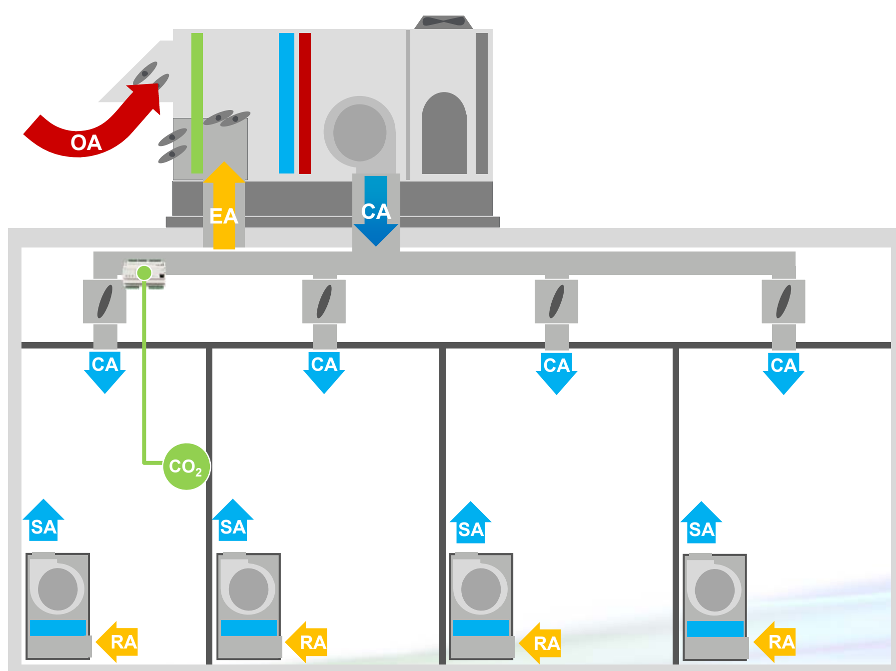
To Plenum, Near Local Units

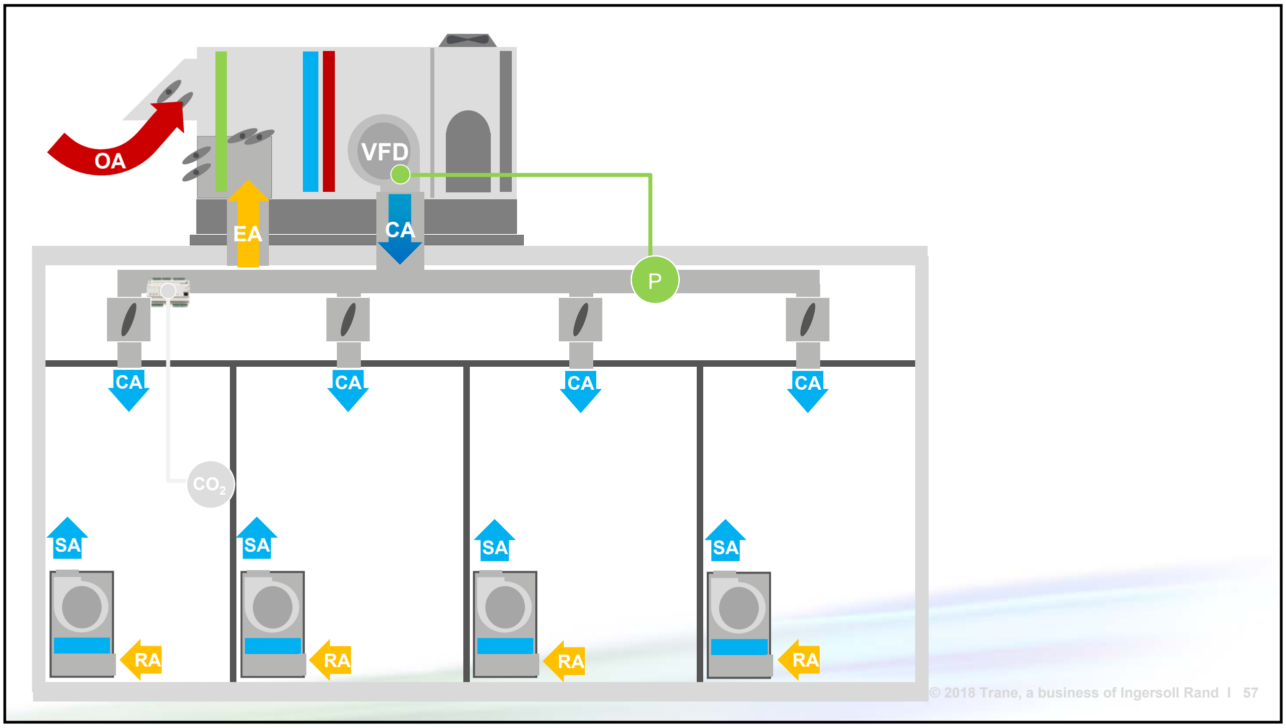


Correct plan of plenum system with discharge near terminal ends
Though the ducts are not connected to the terminal units, they discharge near them, with balancing means available to provide correct airflow to each.

Incorrect plan of plenum system
In this case, outdoor air ventilation is provided to one ventilation zone, but not the other. This could only meet the requirement if it could be shown that sufficient air gets to the remote system, perhaps by mixing between the zones.

Source: ASHRAE *62.1-2010 User's Manual*, Figures 5-D and 5-E ©American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, www.ashrae.org.

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CA
CO_2
SA
SA
SA
SA
RA
RA
RA
RA
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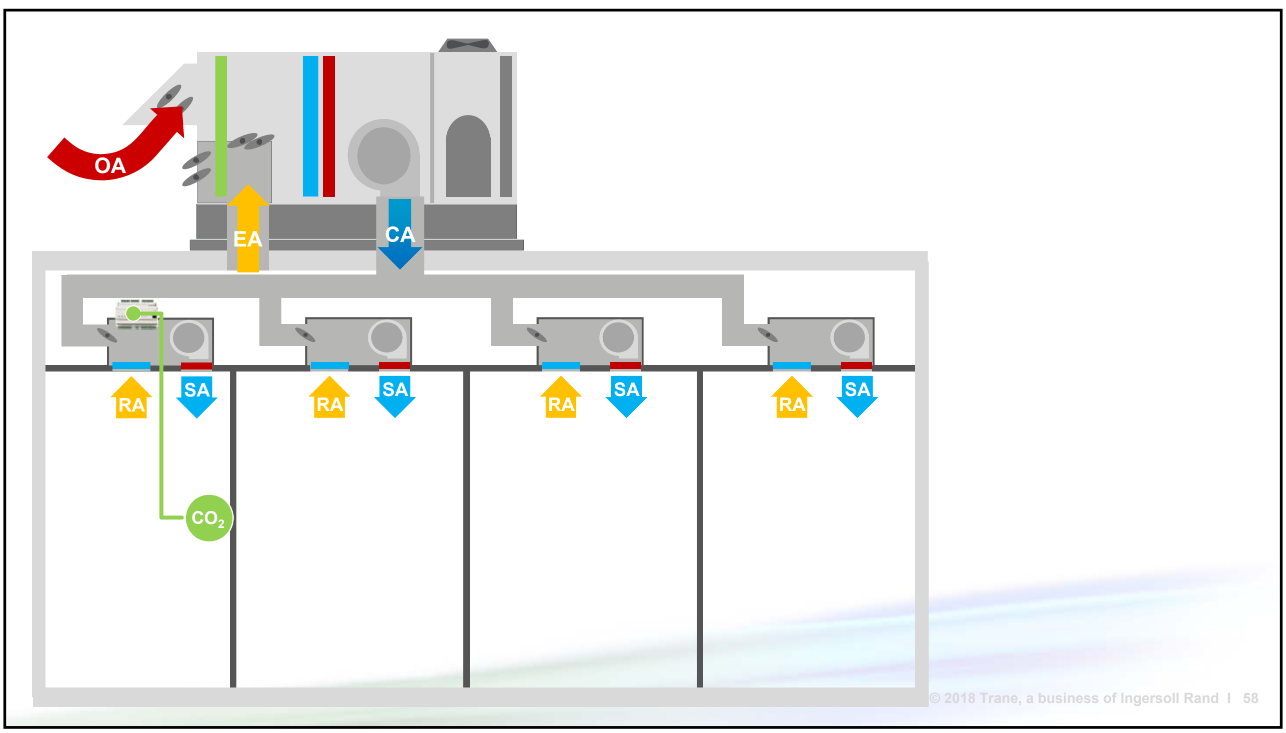
OA
EA
CA
RA
SA
RA
SA
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CO_2
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Integrating DCV with Other Controls

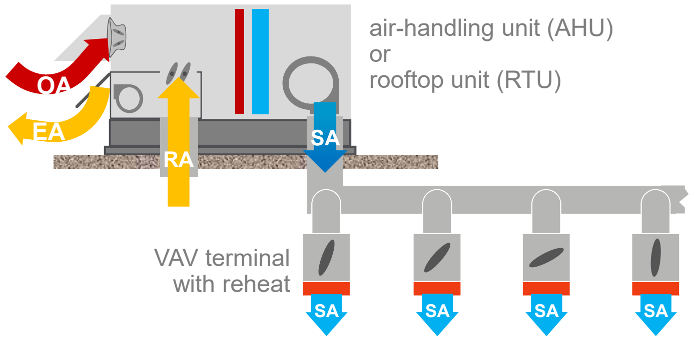
dedicated outdoor-air systems

- Requires pressure-independent OA dampers for non-DCV zones
- Requires variable airflow at the dedicated OA unit
- Don’t forget about building pressure control

Agenda

- Recent changes to energy standards are codes
- Common DCV technologies
- **Implementing DCV into HVAC systems**
  - Single-zone systems
  - Dedicated outdoor-air systems
  - **Multiple-zone VAV systems**

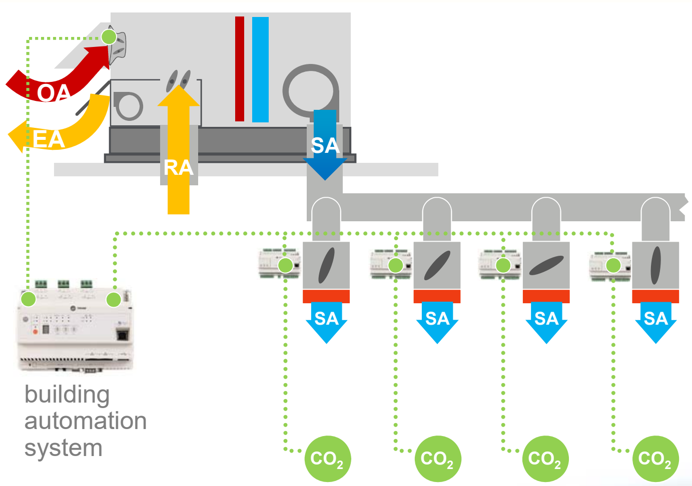
Multiple-Zone VAV System



- Air from several zones returns to central AHU
- Some of this return air is recirculated and mixed with fresh outdoor air
- Mixture is cooled or heated and then supplied to zones

CO_2 Sensor in Every Zone

implementing DCV in a multiple-zone VAV system



- BAS monitors all sensors, determines OA damper position needed to satisfy ventilation requirements of every zone

Target Indoor CO_2 Varies by Space Type

	lecture classroom
Outdoor CO_2 concentration, ppm	350
CO_2 generation rate, cfm/person	0.0105 (1.25 MET)
Ventilation rate, cfm/person*	8.5
Target indoor CO_2 concentration, ppm	**1600**

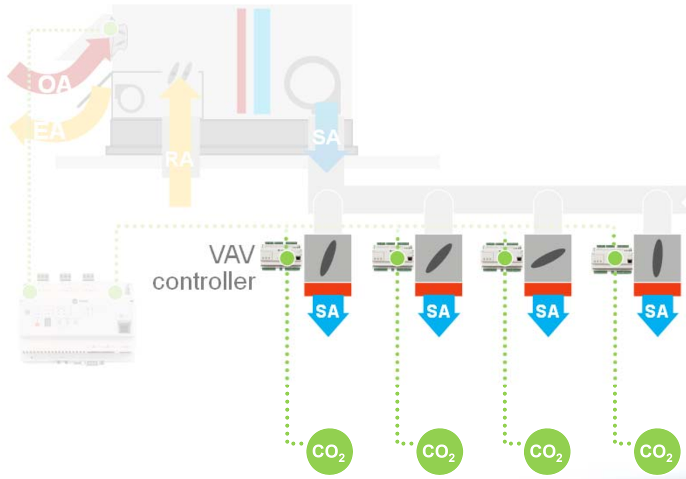
* assuming default occupant density from ASHRAE Standard 62.1-2016,Table 6.2.2.1

Target Indoor CO_2 Varies by Space Type

	lecture classroom	office space	conference room
Outdoor CO_2 concentration, ppm	350	350	350
CO_2 generation rate, cfm/person	0.0105 (1.25 MET)	0.0105 (1.25 MET)	0.0105 (1.25 MET)
Ventilation rate, cfm/person*	8.5	17	6
Target indoor CO_2 concentration, ppm	**1600**	**970**	**2100**

* assuming default occupant density from ASHRAE Standard 62.1-2016,Table 6.2.2.1

CO_2 Sensor in Every Zone (Alternate)
implementing DCV in a multiple-zone VAV system



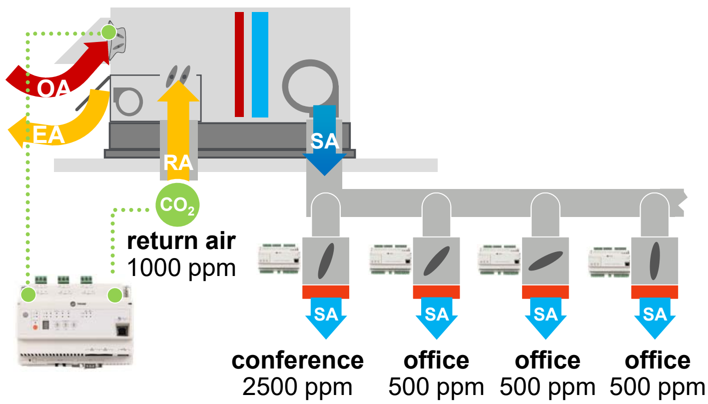
- VAV controller first drives its damper further open
  - Increases primary airflow, which increases outdoor airflow delivered to zone
  - But also over-cools zone, activating reheat
- If a VAV damper reaches 100% open, the OA damper is opened further

CO_2 Sensor in Every Zone
implementing DCV in a multiple-zone VAV system

- CO_2 sensors increase installed cost
- BAS needs to poll all sensors and determine required OA damper position
- Requires means to ensure minimum ventilation

CO_2 Sensor in Common Return-Air Duct

implementing DCV in a multiple-zone VAV system



- Measures average CO_2 concentration of the zones
  - Some zones will be under-ventilated
  - Some zones will be over-ventilated

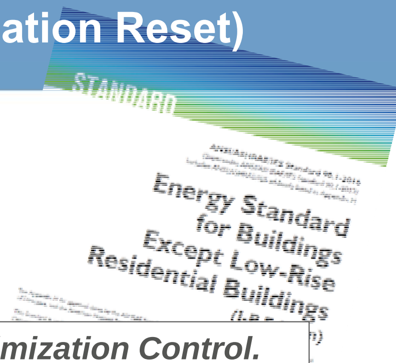
CO_2 Sensor in Common Return-Air Duct

implementing DCV in a multiple-zone VAV system

- Only one CO_2 sensor reduces installed cost
- Measures average CO_2 concentration (some zones will be under-ventilated, some over-ventilated)

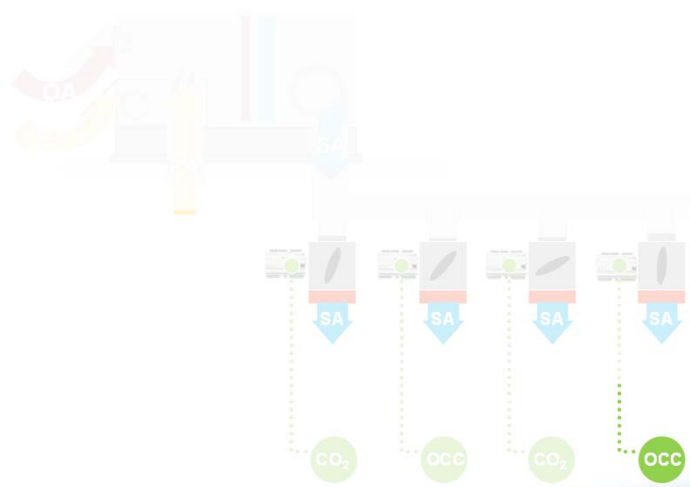
Ventilation Optimization (a.k.a. Ventilation Reset)

ASHRAE Standard 90.1-2016, Section 6.5.3.3



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.*

DCV at Zone Level



CO_2 sensors

- Use is densely-occupied zones with widely-varying population

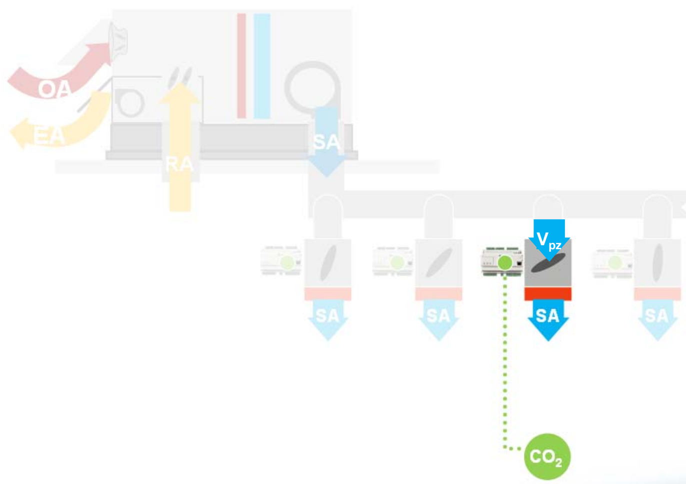
Occupancy sensors (OCC)

- Use in zones that are not densely-occupied or where population varies minimally

Time-of-day schedules

- Use in zones with predictable occupancy patterns

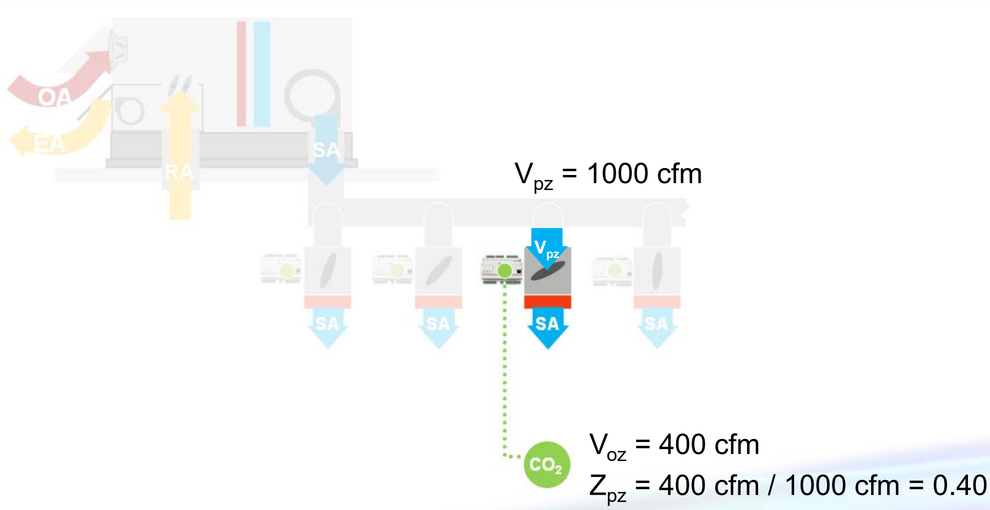
DCV at Zone Level



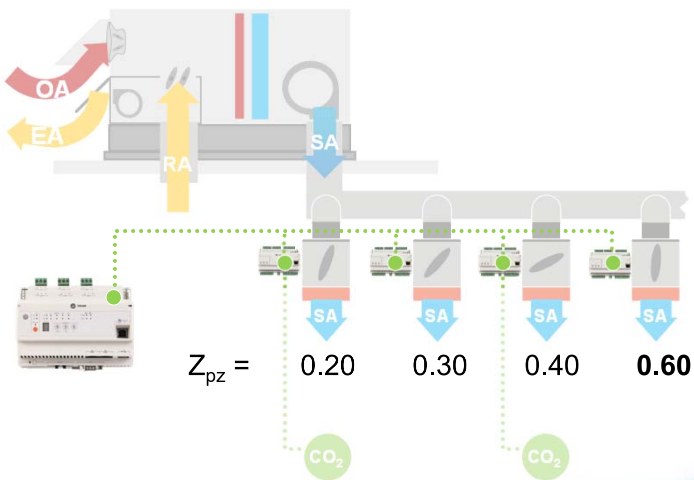
VAV controller

- Measures CO_2 concentration in zone and calculates current outdoor airflow (V_{oz}) required
- Measures current primary airflow (V_{pz})
- Calculates current zone OA fraction ($Z_{pz} = V_{oz} / V_{pz}$)

DCV at Zone Level



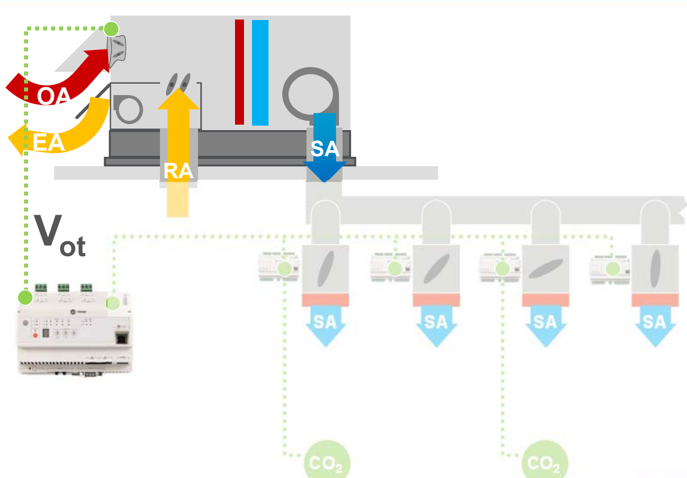
Ventilation Optimization at System Level



System controller

- Reads Z_{pz} from each VAV controller, finds largest value
- Calculates current system ventilation efficiency (E_v) and system intake airflow (V_{ot}) (ASHRAE 62.1, Appendix A)

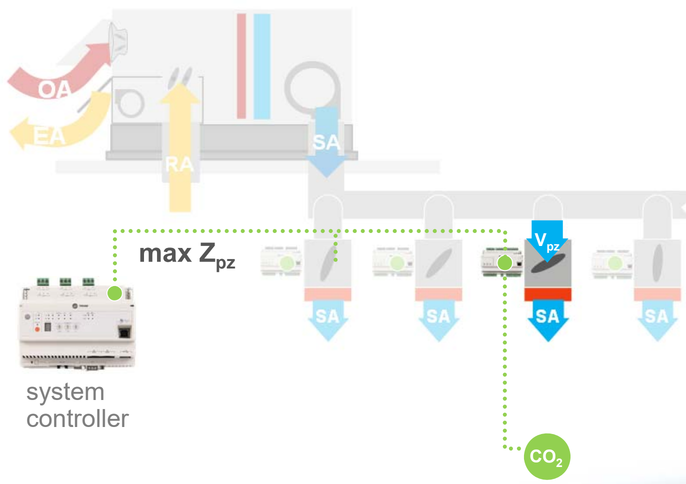
Ventilation Optimization at System Level



System controller

- Communicates current system intake airflow (V_{ot}) setpoint to AHU/RTU controller
- Flow-measuring OA damper controls to this setpoint

DCV at Zone Level (Enhanced)



VAV controller

- Calculates current zone OA fraction ($Z_{pz} = V_{oz} / V_{pz}$)
- If Z_{pz} > max Z_{pz}, controller increases primary airflow (V_{pz})
  - Increases outdoor airflow delivered to zone
  - But also over-cools zone, activating reheat

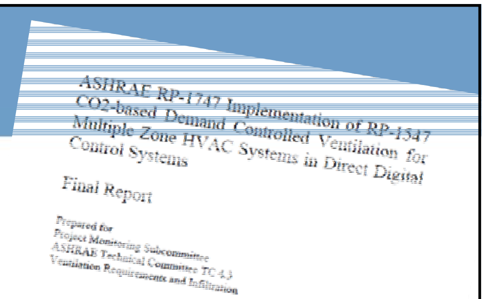
DCV at Zone Level + Ventilation Opt. at System Level

implementing DCV in a multiple-zone VAV system

- Lower installed cost than installing a CO_2 sensor in every zone
- Requires means to measure and control outdoor airflow at the central air handler
- Earn LEED "Enhanced IAQ Strategies" credit

> - *Monitor CO_2 concentrations within all densely occupied spaces.*
> - *Provide a direct outdoor airflow measurement device capable of measuring the minimum outdoor air intake flow.*
>
> LEED BD+C: New Construction (v4)

ASHRAE Research Project 1747
implementing DCV in a multiple-zone VAV system

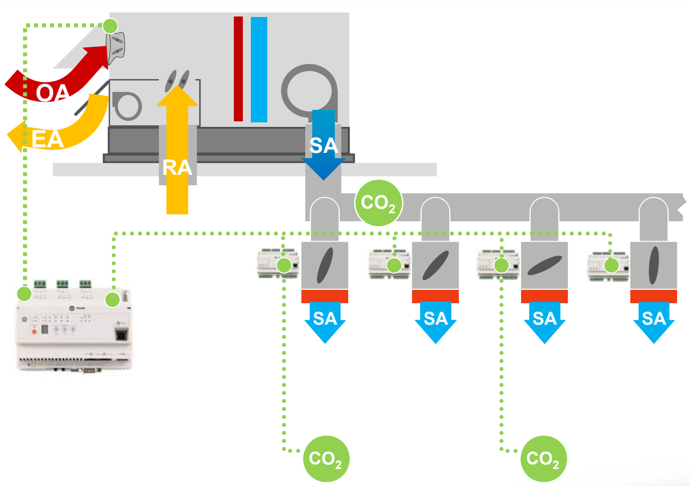

ASHRAE RP-1747 Implementation of RP-1547 CO2-based Demand Controlled Ventilation for Multiple Zone HVAC Systems in Direct Digital Control Systems

Final Report

Prepared for
Project Monitoring Subcommittee
ASHRAE Technical Committee TC 4.3
Ventilation Requirements and Infiltration

> *"Valid logic was developed in Research Project 1547, but it is not readily implemented in real control systems.*
>
> *This project will develop practical control sequences, then test them in a real-world building environment with a commercial-grade DDC system."*
>
> RFP for ASHRAE Research Project 1747

ASHRAE Research Project 1747
implementing DCV in a multiple-zone VAV system



VAV controller

- Dynamically calculates current outdoor airflow (V_{oz}) required
- Resets zone minimum primary airflow settings
  - If primary air is rich with OA, reduce minimum setting
  - Otherwise, increase minimum setting (prevent $V_{ot} > V_{ot\text{-}design}$)

System controller

- Dynamically calculates current system intake airflow (V_{ot})

ASHRAE Research Project 1747

implementing DCV in a multiple-zone VAV system

- Requires additional CO_2 sensor in primary airstream
- Requires means to measure and control *total* outdoor airflow at the central air handler (including additional OA when economizing)

Summary

demand-controlled ventilation

- ASHRAE 62.1 allows DCV as zone population changes
- ASHRAE 90.1 is requiring DCV in more space types
- Consider CO_2-based DCV in densely-occupied zones with widely-varying population
- Use other DCV technologies (occupancy sensors, schedules, people counting) where they make sense
- Correctly integrate DCV with airside economizing and building pressure control

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Engineers Newsletter Live - Audience Evaluation

Demand-Controlled Ventilation

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Trane *Engineers Newsletter LIVE: Demand-Controlled Ventilation*

APP-CMC067-EN QUIZ

1. Which of the following are possible technologies for implementing demand-controlled ventilation? Select all that apply.
   a. Carbon dioxide (CO_2) sensors
   b. Temperature sensors
   c. Time-of-day schedules in a building automation system
   d. Occupancy sensors

2. TRUE or FALSE: Demand-controlled ventilation in certain densely occupied spaces is a mandatory requirement of ASHRAE Standard 90.1.

3. Which of the following are concerns when implementing demand-controlled ventilation? Select all that apply.
   a. Allowing the OA damper to open further for economizing, when applicable
   b. Installing accurate sensors
   c. Maintaining proper building pressurization
   d. Cross-leakage between the exhaust and outdoor air streams

4. TRUE or FALSE: The primary motivation for implementing demand-controlled ventilation is to improve indoor air quality.

5. Which of the following statements are true about CO_2-based demand-controlled ventilation?
   a. The target indoor CO_2 concentration depends on the activity level of the occupants and the rate at which they generate carbon dioxide.
   b. The target indoor CO_2 concentration for every zone is 1000 ppm.
   c. ASHRAE Standard 62.1 allows the use of CO_2 for demand-controlled ventilation in most space types.
   d. All of the above