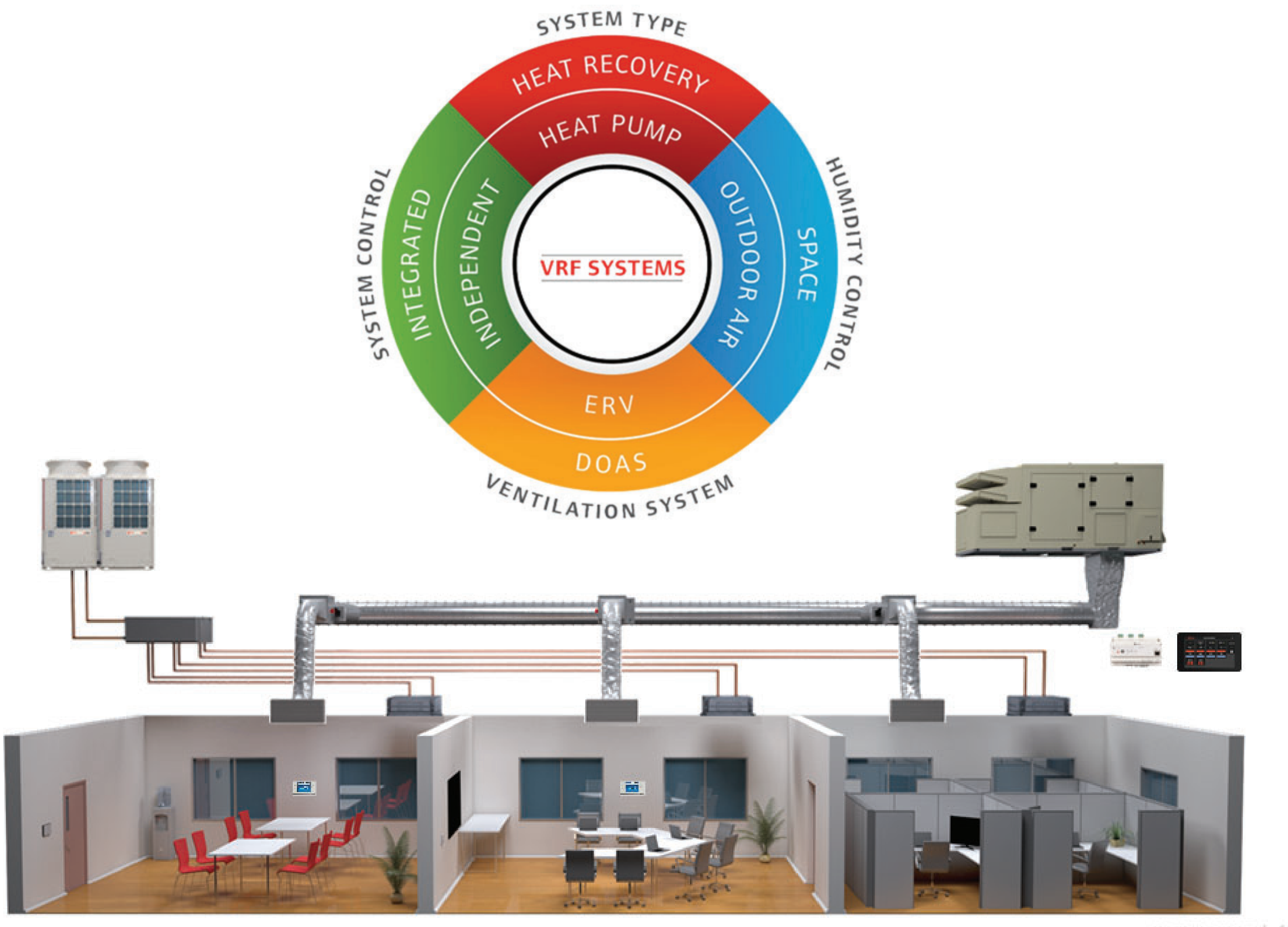
Trane Engineers Newsletter Live

Applying VRF for Complete Building Solution

with Trane Engineers Lee Cline, Brian Fiegen, Dustin Meredith and Eric Sturm



Trane program number: APP-CMC075-EN
November 2020

Agenda

Trane *Engineers Newsletter Live* Series

Applying VRF for a Complete Building Solution

Abstract
In this Engineers Newsletter Live program, we'll build upon the 2014 broadcast "Applying Variable Refrigerant Flow" with detailed discussions on several considerations. Topics will include: when to use heat recovery instead of heat pump configurations, how to scale VRF systems to include other building systems, ventilation delivery, humidity management and more.

Presenters: Trane engineers Lee Cline, Brian Fiegen, Dustin Meredith and Eric Sturm

After viewing attendees will be able to:

1. Understand the fundamentals of VRF operation
2. Explain the differences between heat pump and heat recovery systems including the differing operating modes
3. Determine what it takes to achieve consistent space humidity results and which ventilation equipment to use
4. Differentiate independent vs. integrated system control and understand when to use each system control strategy

Agenda

- Introduction
- VRF system elements
- VRF equipment and systems
- Ventilation system and humidity control
- System control

Presenter biographies

Applying VRF for a Complete Building Solution

BRIAN FIEGEN | SYSTEMS DEVELOPMENT LEADER | TRANE

Brian is the Systems Development Leader for Trane in North America. His responsibility is to lead the development and packaging of system offerings for both presently known systems as well as new system concepts. He is also responsible for evaluation of new and emerging system technology.

Brian is a 37 year industry veteran, all with Trane. He has previously held a number of product management positions. He led the development and promotion of air handling and variable air volume products, systems, and controls throughout the first 15 years of his career and focused on systems and applications for the last 22 years. Brian's expertise lies on the airside of systems including psychrometry, ventilation, air cleaning, and energy efficiency. In his broader systems role he has grown his background into chilled water and more recently VRF systems.Brian is a member of ASHRAE and earned his BSME from South Dakota School of Mines and Technology in Rapid City, SD.

DUSTIN MEREDITH | SYSTEMS ENGINEER | TRANE

Dustin began his career with Trane in 2000 as a marketing engineer. Since joining the systems and applications engineering team in 2005, his role has been to develop integrated customer solutions for HVAC products & systems providing a link between the sales, design, and manufacturing organizations. He has specific expertise in fans, acoustics, air system design and overall system optimization including unitary and variable refrigerant flow systems. Dustin holds multiple patents and has been instrumental in advancing cutting-edge fan and motor applications to industry. He has authored a wide variety of technical bulletins, white papers, articles and Trane Engineers Newsletter LIVE programs that have been widely published.

Dustin is a licensed professional engineer and earned his mechanical engineering and computer science degrees from the University of Kentucky. He continued his education by receiving an MBA from the Gatton College of Business and Economics. Dustin is an active member of ASHRAE having received awards at the local, regional, and society level including the Society's Distinguished Service Award. Dustin has been an ASHRAE Section Head and is presently the Chair of the committee that oversees ASHRAE technical activities. He also serves on the "Fans" and "Sound and Vibration" technical committees, including as past Chair of the latter. He is Trane's voting member for Air Movement and Control Association International, Inc. (AMCA) and serves on a number of AMCA committees including instrumental, first edition standards on the Fan Efficiency Grade (FEG) and Fan Energy Index (FEI) metrics.

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 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 as a representative on Members Council and member of the "indoor agriculture" and "Sound and Vibration" technical committees. Eric is the recipient of a Young Engineers in ASHRAE Award of Individual Excellence for service to the La Crosse Area Chapter and nationally recognized with an ASHRAE Distinguished Service Award.

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Learning Objectives

1. Understand the fundamentals of VRF operation
2. Explain the differences between heat pump and heat recovery systems including the differing operating modes
3. Determine what it takes to achieve consistent space humidity results and which ventilation equipment to use
4. Differentiate independent vs. integrated system control and understand when to use each system control strategy

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Agenda

- VRF system elements
- VRF equipment and systems
- Ventilation system and humidity control
- System control

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Today's Presenters

Eric Sturm
Applications Engineer

Lee Cline
Staff Systems Engineer

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Agenda

- **VRF system elements**
- VRF equipment and systems
- Ventilation system and humidity control
- System control

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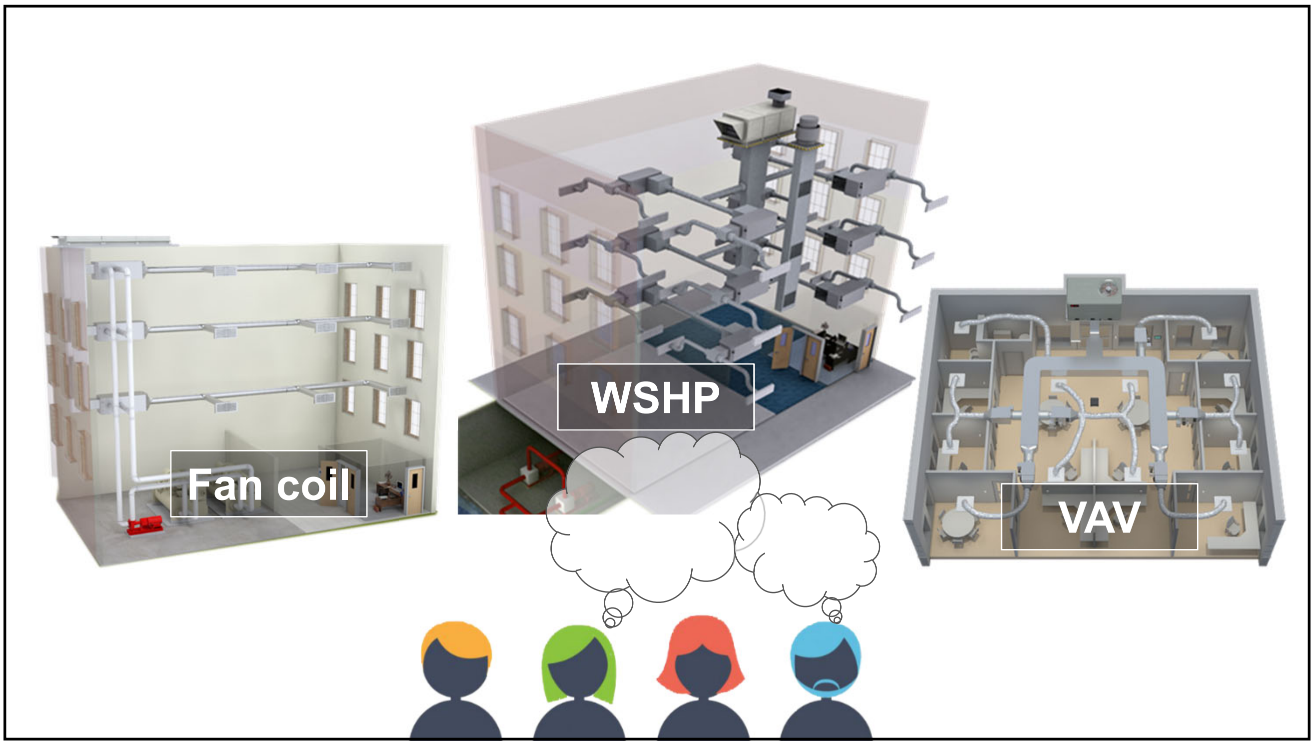

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VRF HVAC System

Equipment and piping

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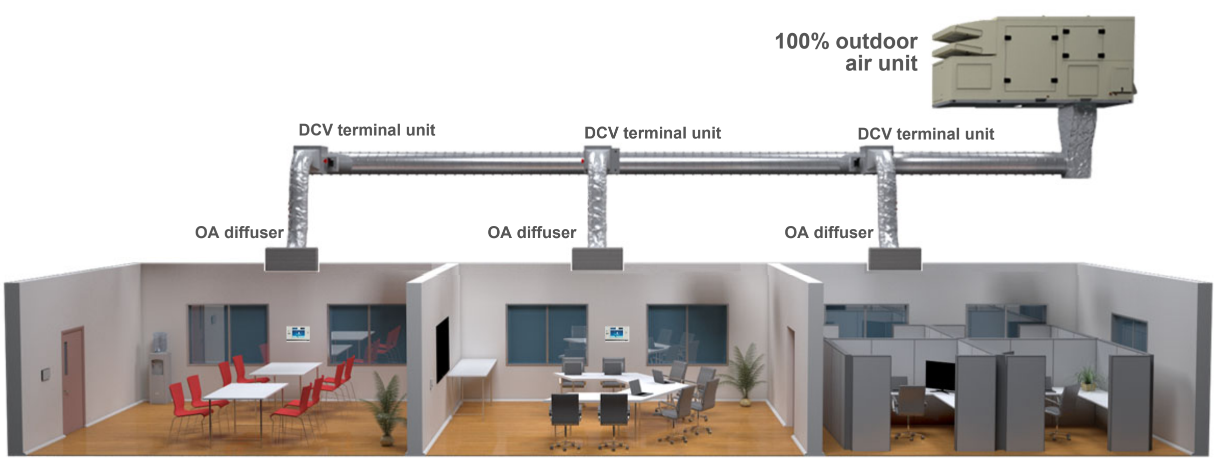
VRF HVAC System

Ventilation



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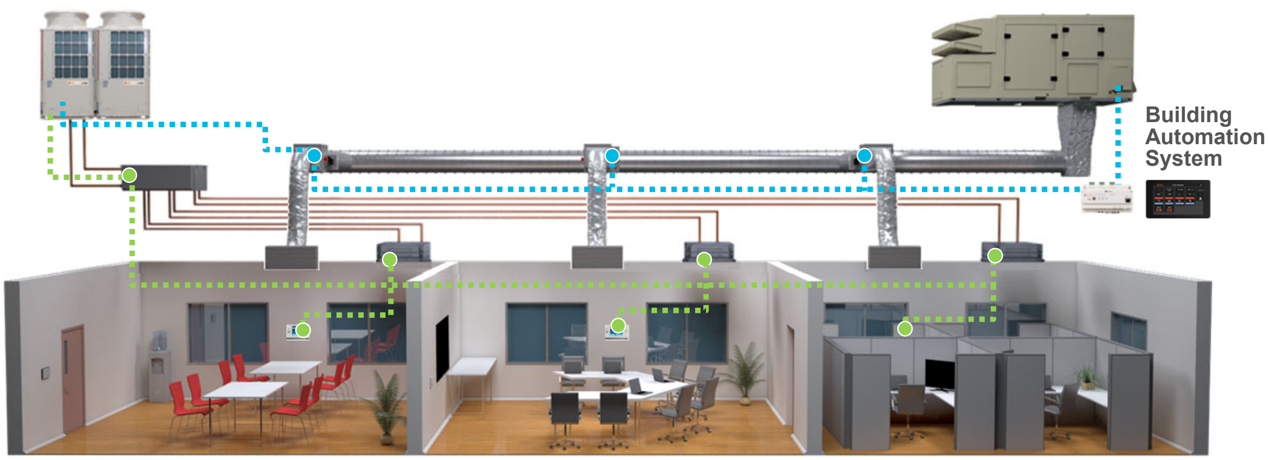
VRF HVAC System

Controls



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Agenda

- VRF system elements
- **VRF equipment** and systems
- Ventilation system and humidity control
- System control

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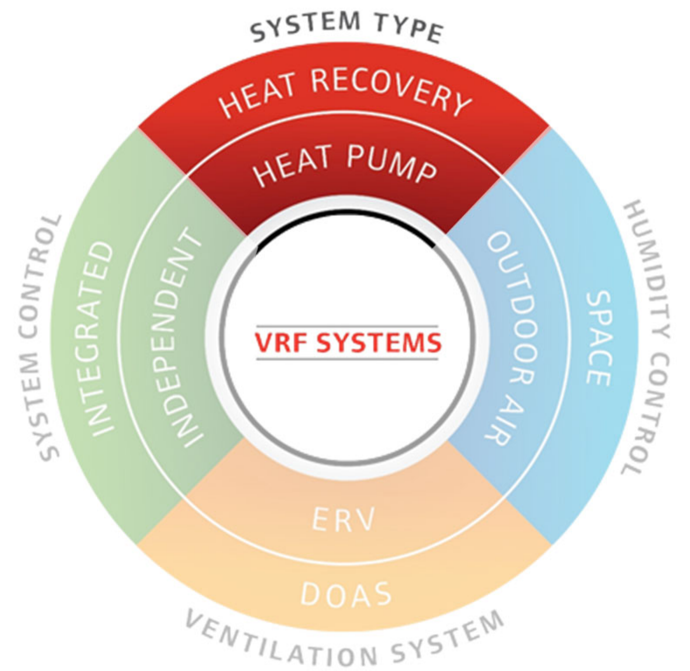

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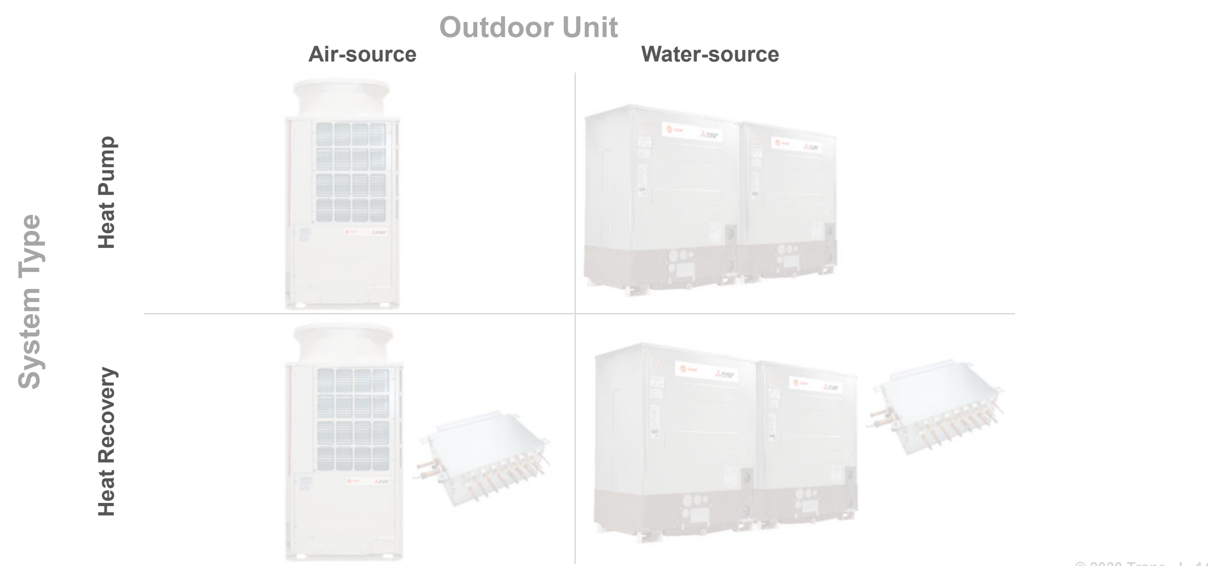
VRF System Options



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Air-source equipment

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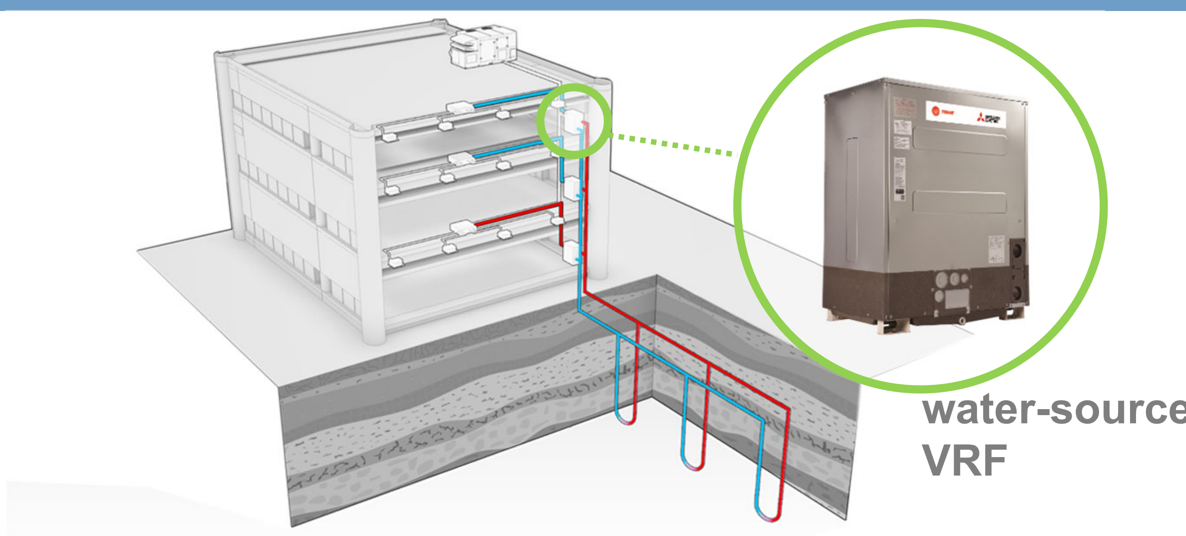
Water-source equipment



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Applied VRF solutions

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VRF System Options

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Agenda

- VRF **system elements**
- VRF equipment **and systems**
- Ventilation system and humidity control
- System control

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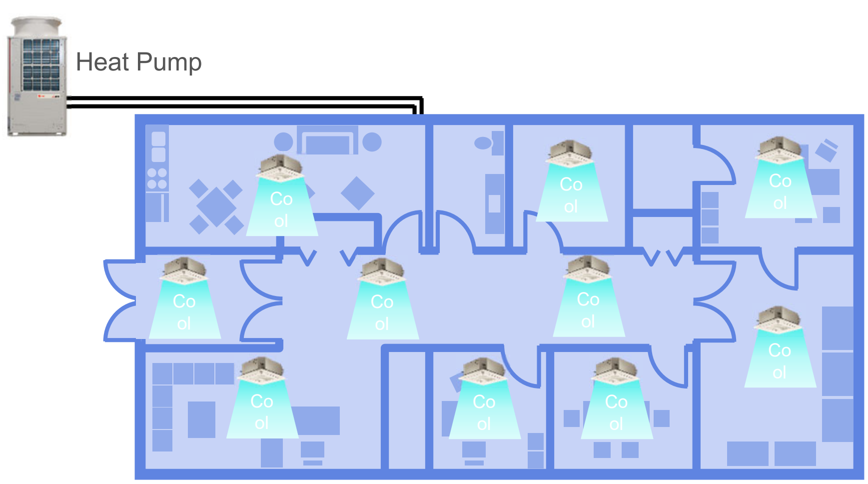
Heat Pump System Type



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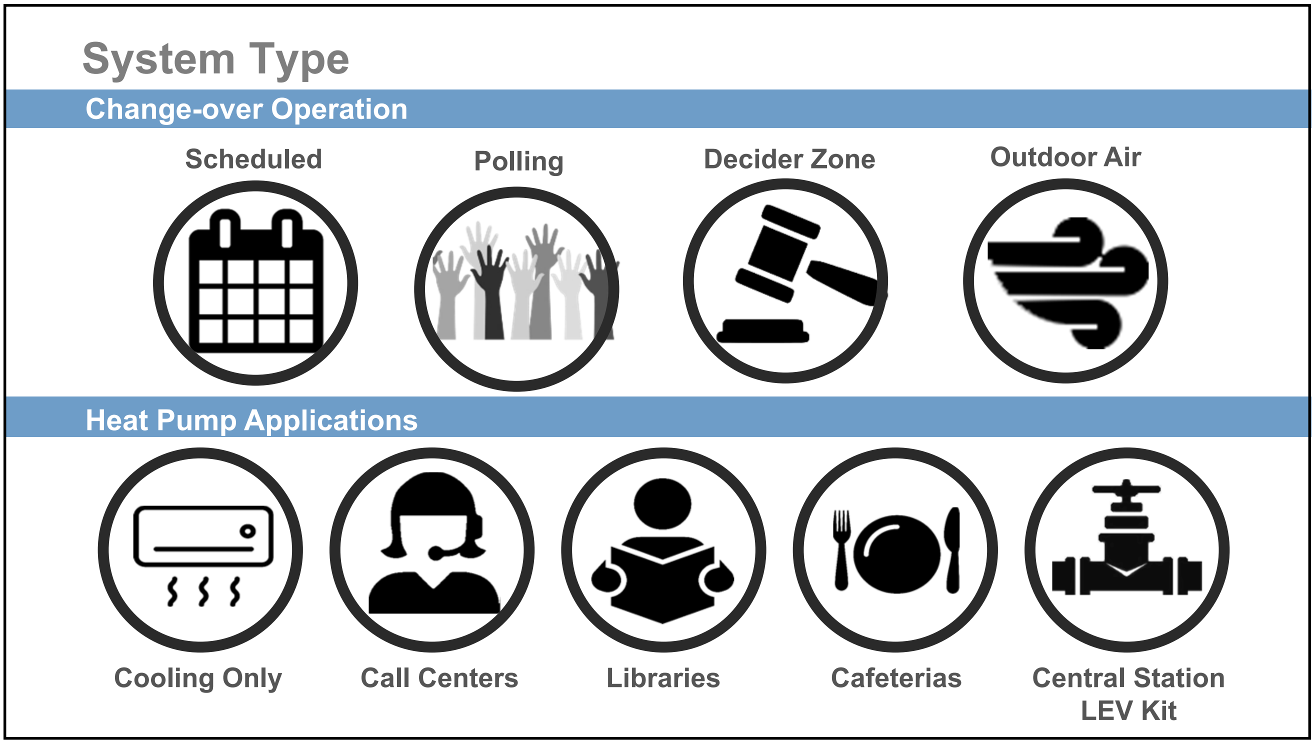
System Type
Change-over Operation
Scheduled
Polling
Decider Zone
Outdoor Air
Heat Pump Applications
Cooling Only
Call Centers
Libraries
Cafeterias
Central Station LEV Kit

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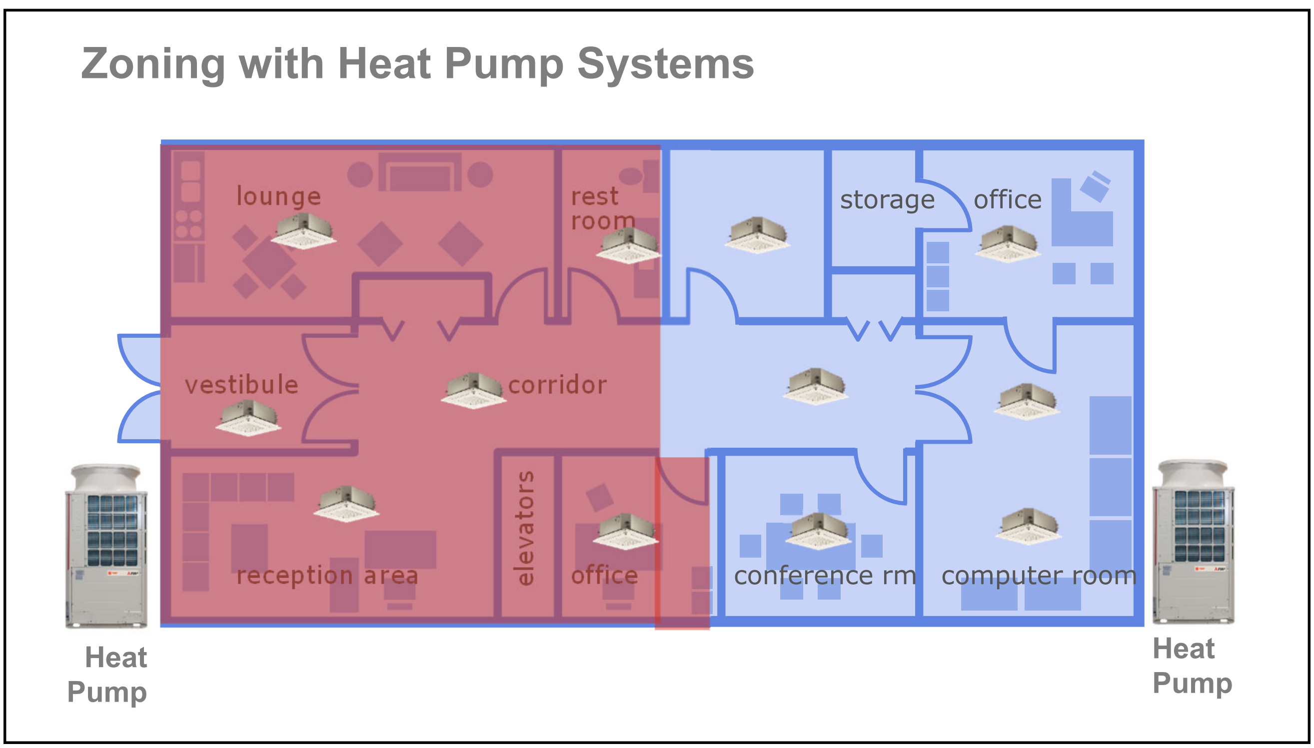
Zoning with Heat Pump Systems
lounge
rest room
storage
office
vestibule
corridor
elevators
office
reception area
conference rm
computer room
Heat Pump
Heat Pump

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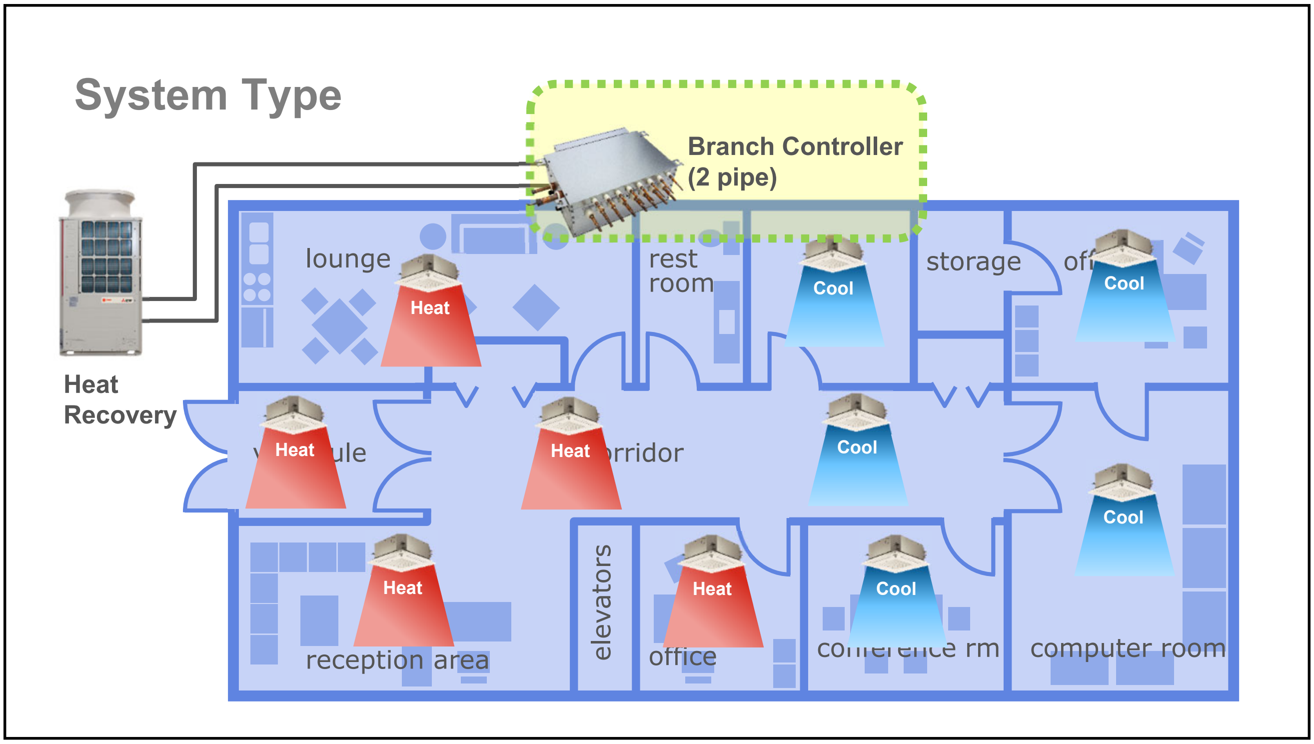
System Type
Branch Controller (2 pipe)
Heat Recovery
lounge
rest room
storage
Heat
Cool
rridor
elevators
reception area
office
computer room

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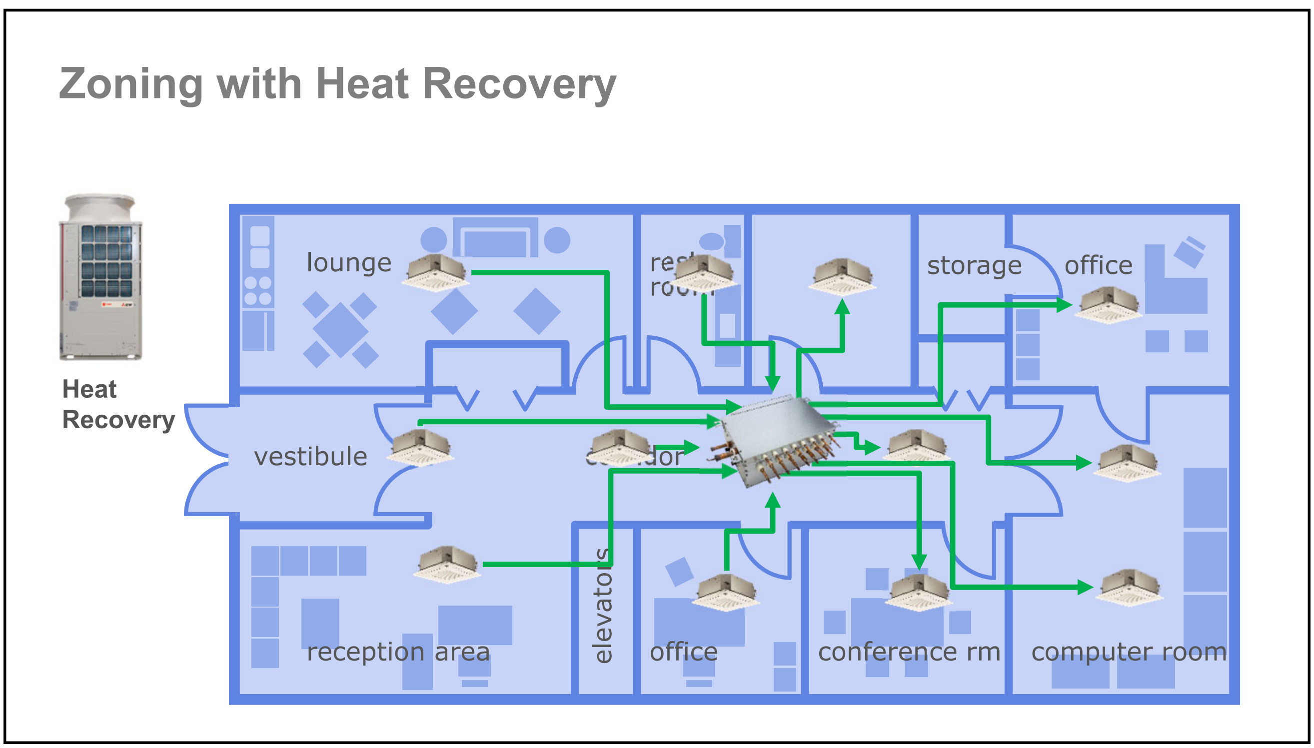
Zoning with Heat Recovery
Heat Recovery
lounge
storage
office
vestibule
elevators
reception area
office
conference rm
computer room

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Zone Terminal Unit Types

Terminals - Ductless

High Wall | Ceiling Recessed | Recessed One-Way | Ceiling Suspended | Floor Mounted

Terminals - Ducted

Low/Medium/High Ducted

Multi Position Air Handler

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VRF System Options

Outdoor Unit

System Type	Air-source	Water-source
Heat Pump		
Heat Recovery		

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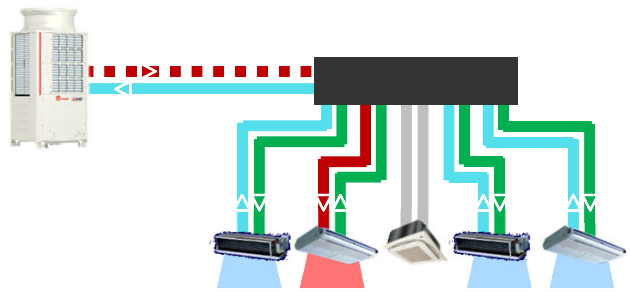
VRF Heat Recovery System Operating Modes

- Cooling Only
- Heating Only
- Cooling Main
- Heating Main



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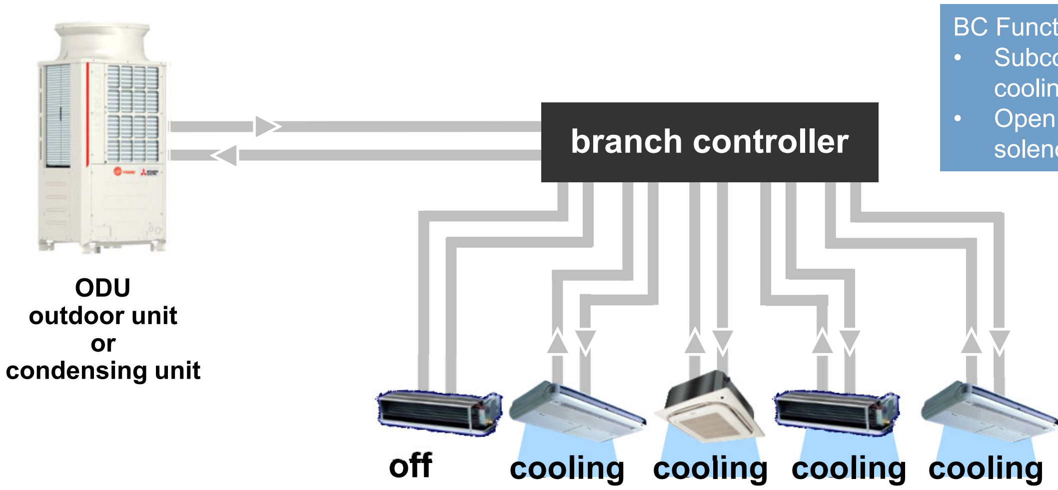
Cooling Only

- discharge pipe (high pressure saturated liquid)
- liquid pipe (medium pressure subcooled liquid)
- suction pipe (low pressure superheated gas)

BC Function
- Subcool liquid to cooling units
- Open cooling return solenoids



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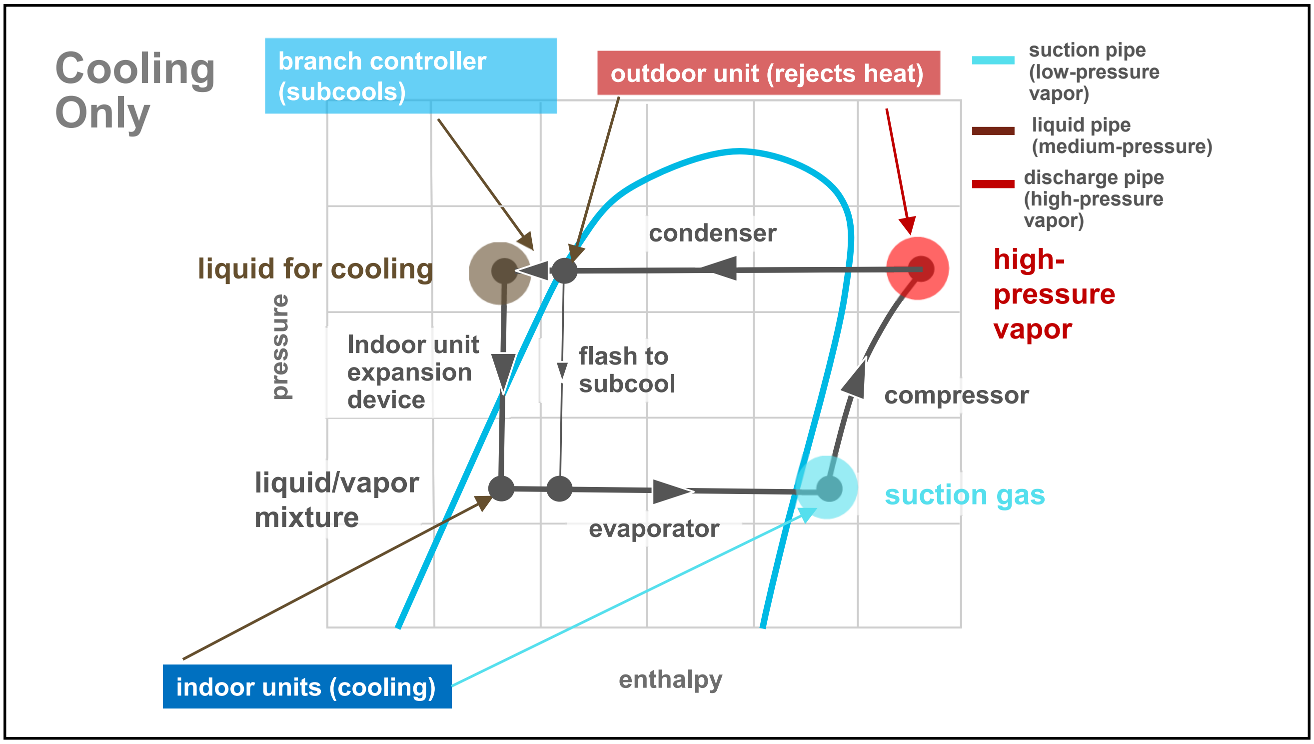
Cooling Only
branch controller (subcools)
outdoor unit (rejects heat)
suction pipe (low-pressure vapor)
liquid pipe (medium-pressure)
discharge pipe (high-pressure vapor)
condenser
liquid for cooling
high-pressure vapor
pressure
Indoor unit expansion device
flash to subcool
compressor
liquid/vapor mixture
suction gas
evaporator
indoor units (cooling)
enthalpy

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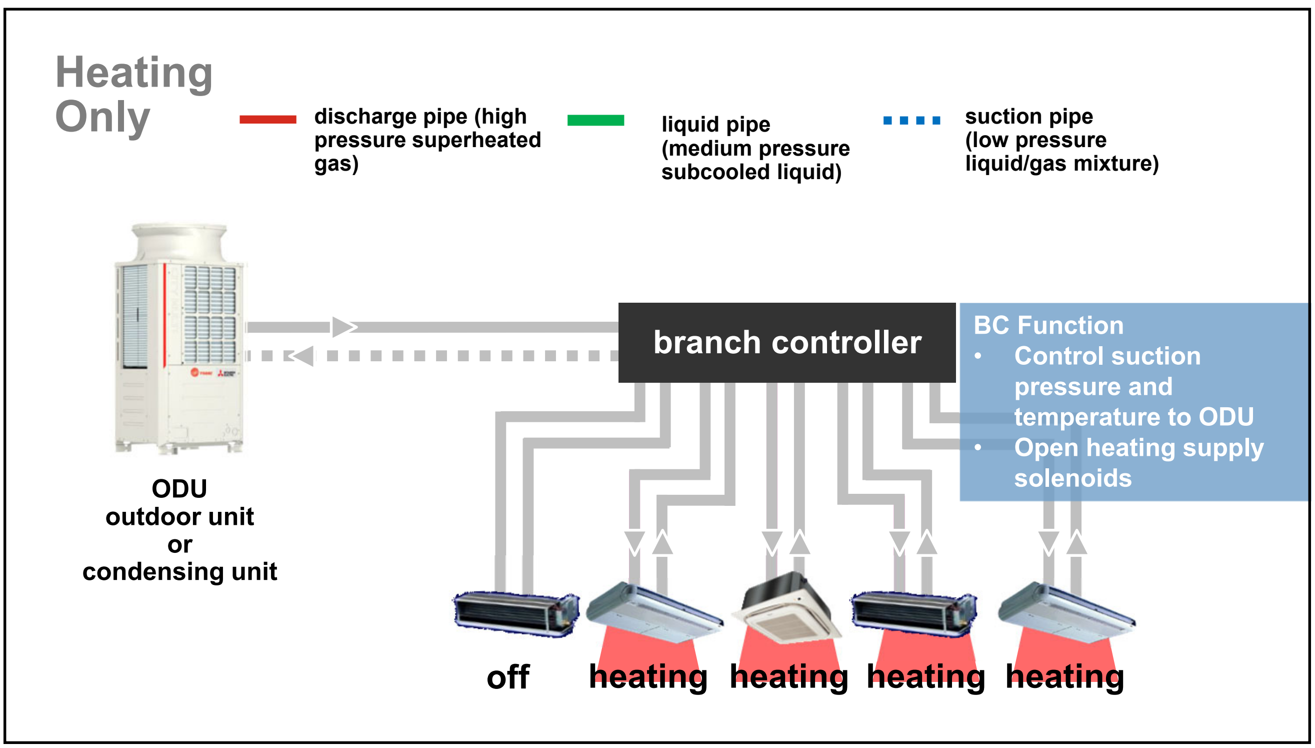
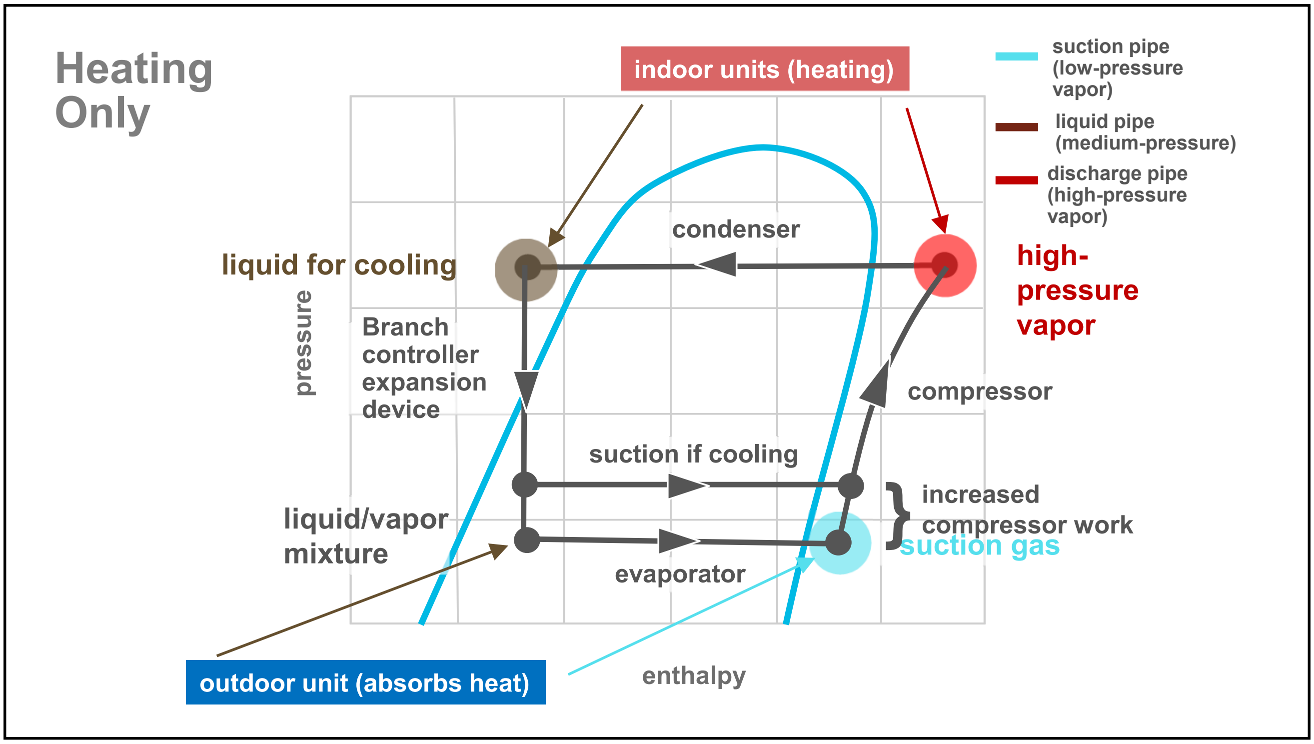

Heating Only
discharge pipe (high pressure superheated gas)
liquid pipe (medium pressure subcooled liquid)
suction pipe (low pressure liquid/gas mixture)
branch controller
BC Function
• Control suction pressure and temperature to ODU
• Open heating supply solenoids
ODU outdoor unit or condensing unit
off
heating
heating
heating
heating

30


Heating Only
indoor units (heating)
suction pipe (low-pressure vapor)
liquid pipe (medium-pressure)
discharge pipe (high-pressure vapor)
condenser
liquid for cooling
high-pressure vapor
pressure
Branch controller expansion device
compressor
suction if cooling
increased compressor work
liquid/vapor mixture
suction gas
evaporator
outdoor unit (absorbs heat)
enthalpy

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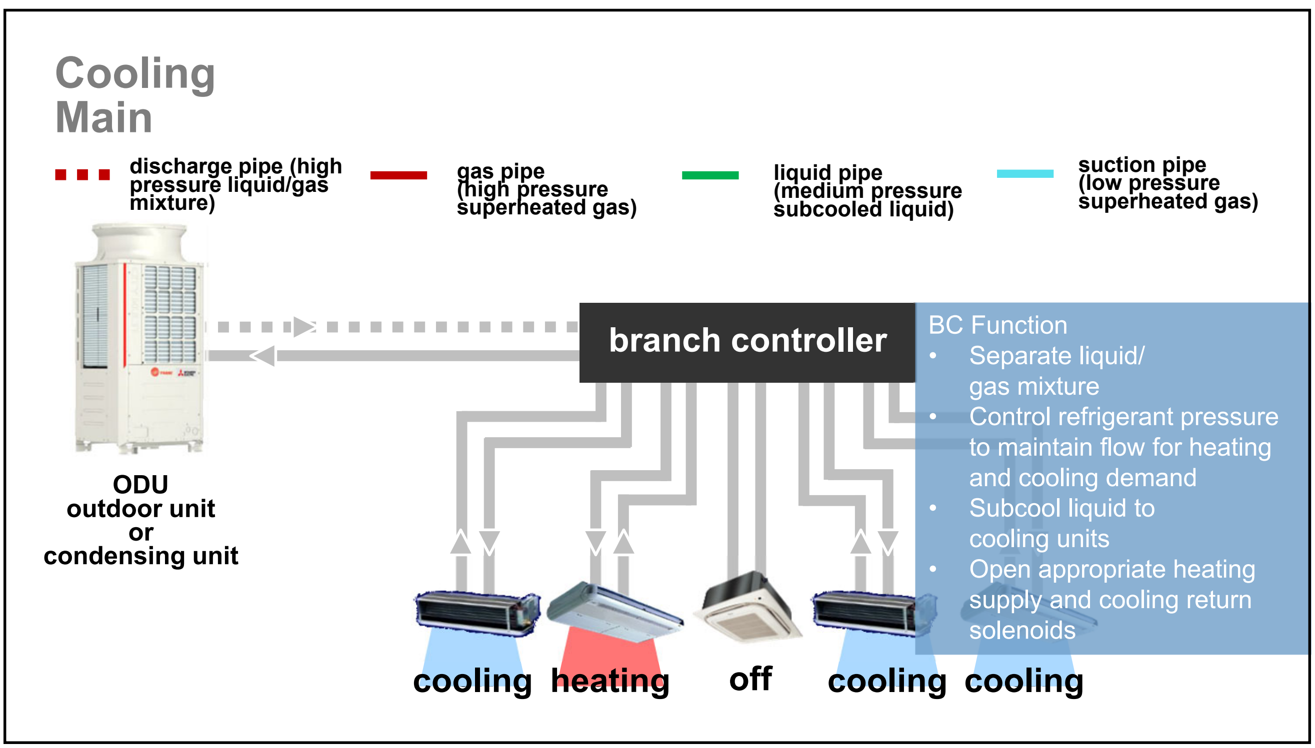
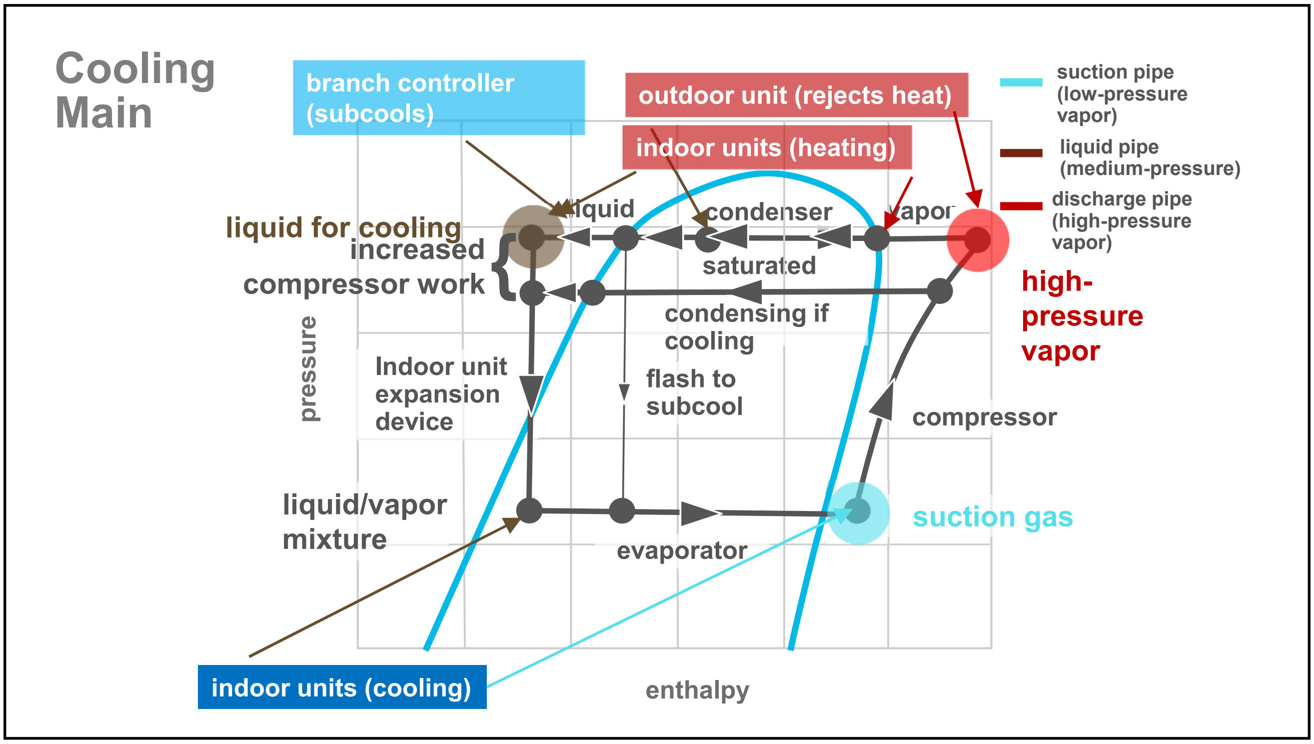

Cooling Main
discharge pipe (high pressure liquid/gas mixture)
gas pipe (high pressure superheated gas)
liquid pipe (medium pressure subcooled liquid)
suction pipe (low pressure superheated gas)
branch controller
BC Function
• Separate liquid/ gas mixture
• Control refrigerant pressure to maintain flow for heating and cooling demand
• Subcool liquid to cooling units
• Open appropriate heating supply and cooling return solenoids
ODU outdoor unit or condensing unit
cooling
heating
off
cooling
cooling

32


Cooling
Main
branch controller
(subcools)
outdoor unit (rejects heat)
indoor units (heating)
suction pipe
(low-pressure
vapor)
liquid pipe
(medium-pressure)
discharge pipe
(high-pressure
vapor)
liquid for cooling
increased
compressor work
liquid
condenser
vapor
saturated
condensing if
cooling
high-
pressure
vapor
pressure
Indoor unit
expansion
device
flash to
subcool
compressor
liquid/vapor
mixture
evaporator
suction gas
indoor units (cooling)
enthalpy

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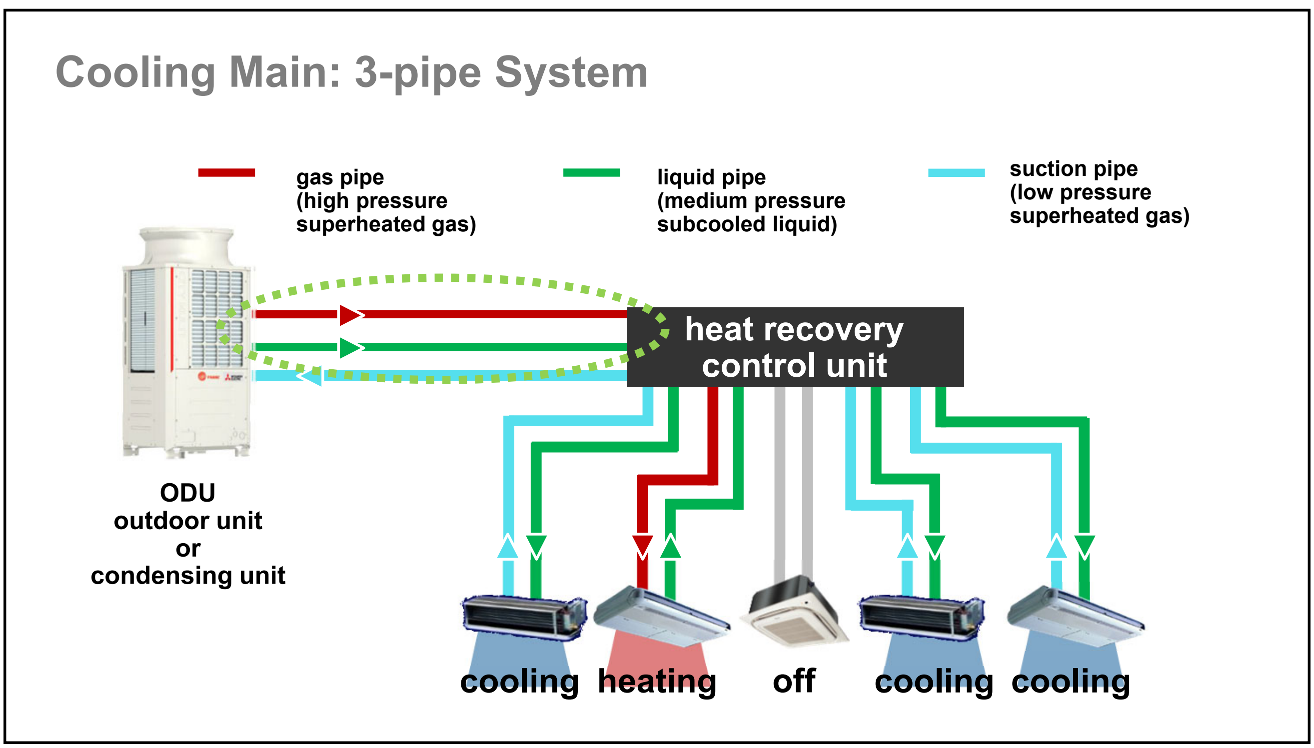
Cooling Main: 3-pipe System
gas pipe
(high pressure
superheated gas)
liquid pipe
(medium pressure
subcooled liquid)
suction pipe
(low pressure
superheated gas)
heat recovery
control unit
ODU
outdoor unit
or
condensing unit
cooling
heating
off
cooling
cooling

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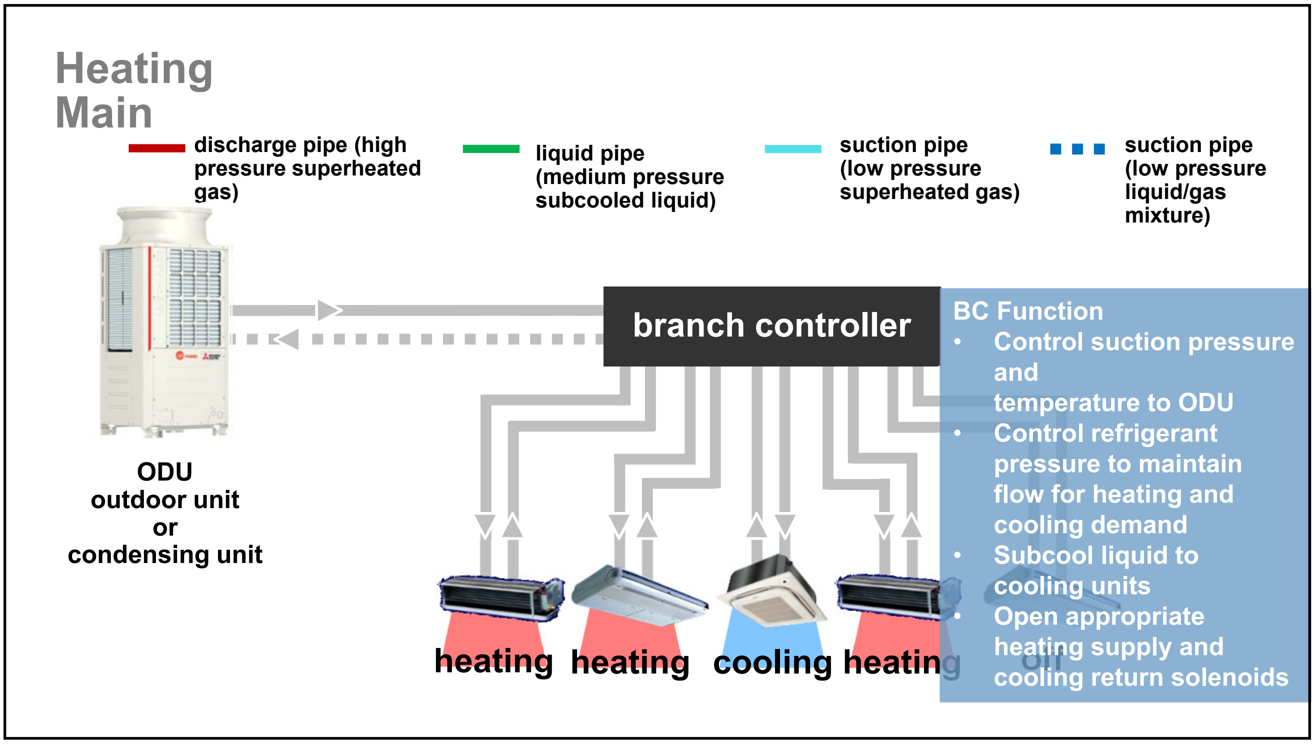
Heating Main
discharge pipe (high pressure superheated gas)
liquid pipe (medium pressure subcooled liquid)
suction pipe (low pressure superheated gas)
suction pipe (low pressure liquid/gas mixture)
branch controller
BC Function
• Control suction pressure and temperature to ODU
• Control refrigerant pressure to maintain flow for heating and cooling demand
• Subcool liquid to cooling units
• Open appropriate heating supply and cooling return solenoids
ODU
outdoor unit
or
condensing unit
heating
heating
cooling
heating
off

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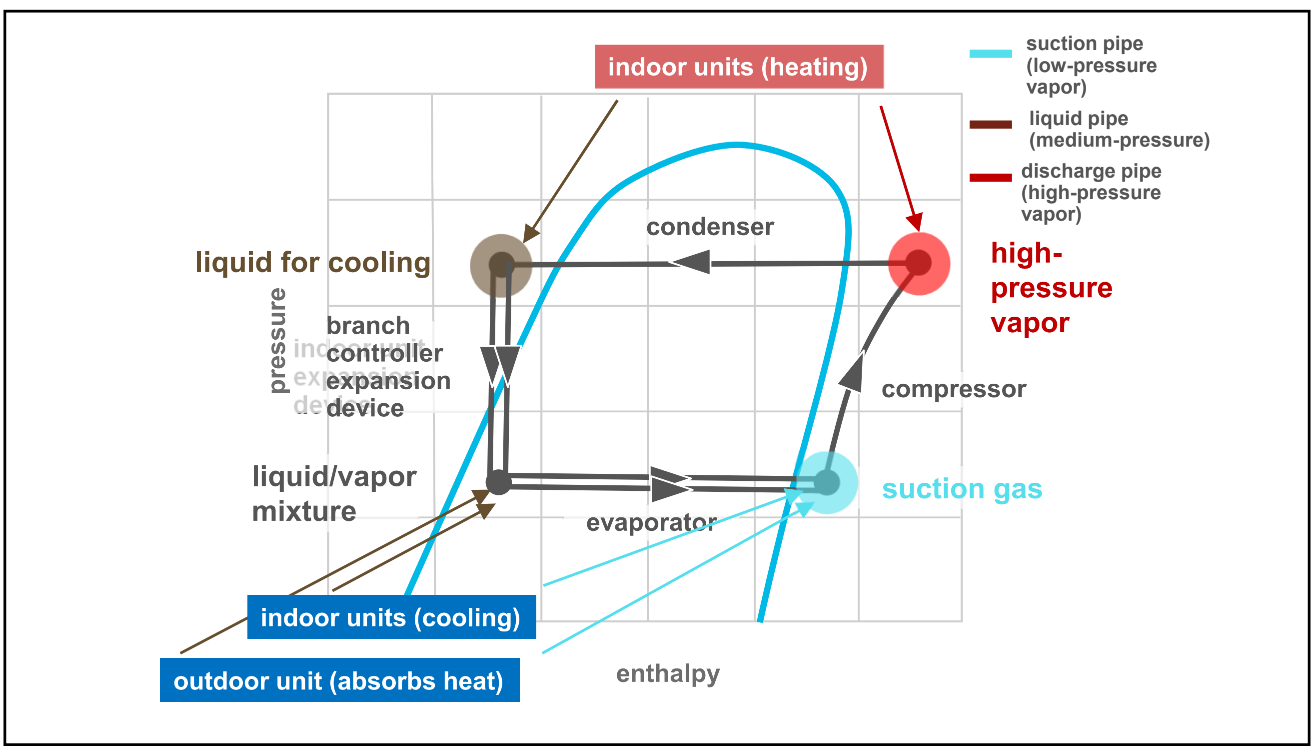
indoor units (heating)
suction pipe (low-pressure vapor)
liquid pipe (medium-pressure)
discharge pipe (high-pressure vapor)
condenser
liquid for cooling
high-pressure vapor
pressure
branch controller expansion device
compressor
liquid/vapor mixture
suction gas
evaporator
indoor units (cooling)
outdoor unit (absorbs heat)
enthalpy

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Agenda

- **VRF system elements**
- **VRF equipment** and systems
- **Ventilation system and humidity control**
- System control

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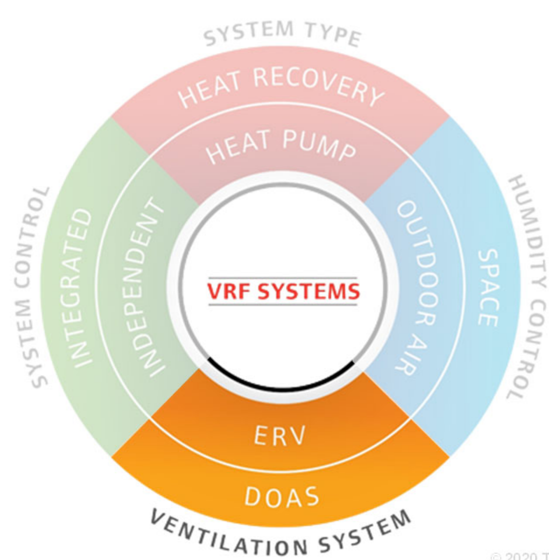
The Ventilation Opportunity

Type

- Dedicated outdoor air system (DOAS)
- Energy Recovery Ventilator (ERV)
- Unconditioned

Delivery

- Direct to space
- Direct to the terminal



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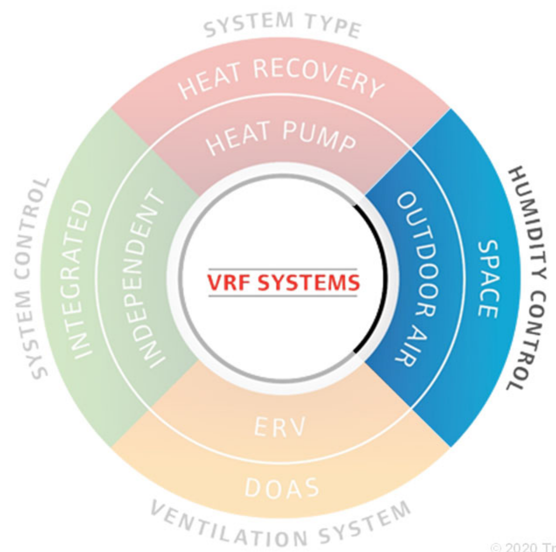
The Ventilation Opportunity

Humidity control

- Space
- Outdoor air



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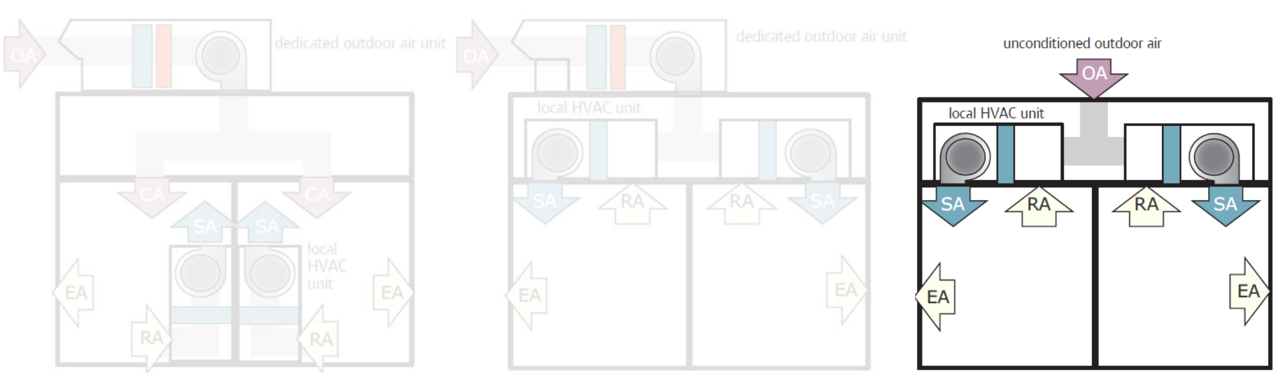
OA Delivery Configurations

Direct to the Zone
"Decoupled Ventilation"

Direct to the Terminal
"Integrated Ventilation"

Unconditioned to the Terminal
"Direct Ventilation"



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Demand-Controlled Ventilation

Allows reset of V_{oz} based on variation in zone population:

- Cannot reset lower than “area” ventilation rate (R_a) or occupied standby rate
- When dehumidifying, OA intake must exceed exhaust
- Document assumptions, sequences, and setpoints

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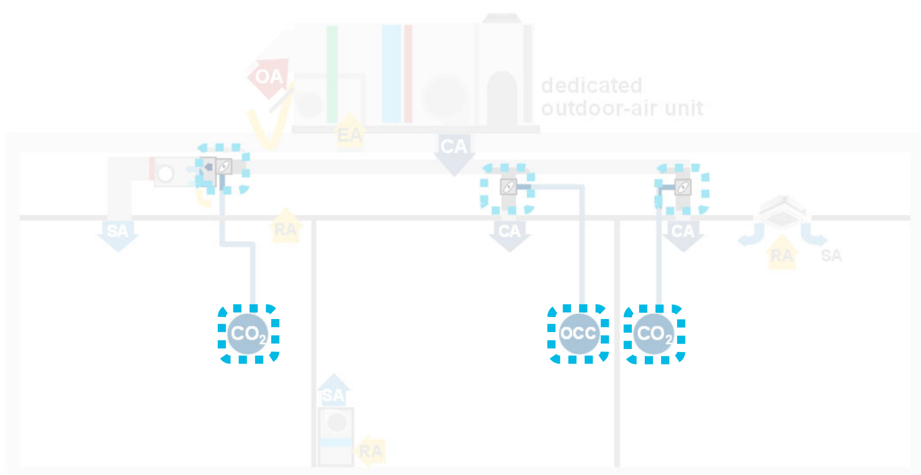
DCV with a Dedicated OA System



- **Pressure-independent VAV boxes**
- **Sensors**
  - **CO_2**
  - **Occupancy**
  - **Time-of-day**
- **VAV fan control**

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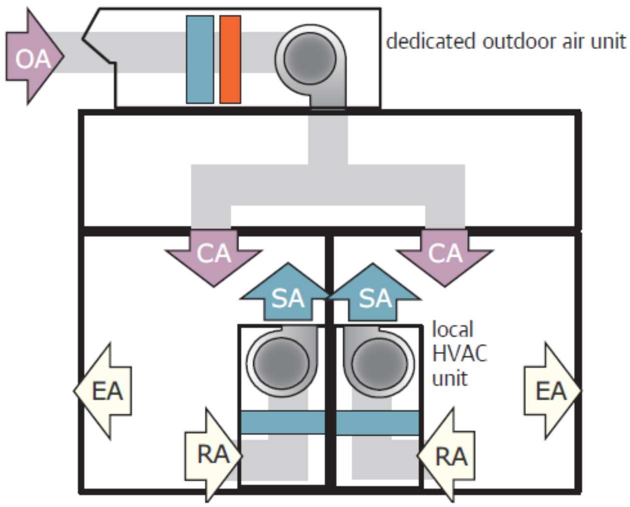
Conditioned Outdoor Air Direct to the Zone
"Decoupled Ventilation" Method



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Conditioned Outdoor Air Direct to the Zone
Advantages and Drawbacks

Advantages

- Easier to ensure required ventilation airflow reaches zone
- Ability to cycle VRF terminal fans
- DOAS or ERV can operate during unoccupied periods without terminal fan operation
- Opportunity to downsize terminal equipment (if OA delivered at a temperature below space setpoint)

Drawbacks

- Requires additional ductwork and separate diffusers
- May require multiple outdoor air diffusers to ensure adequate dispersion within zone

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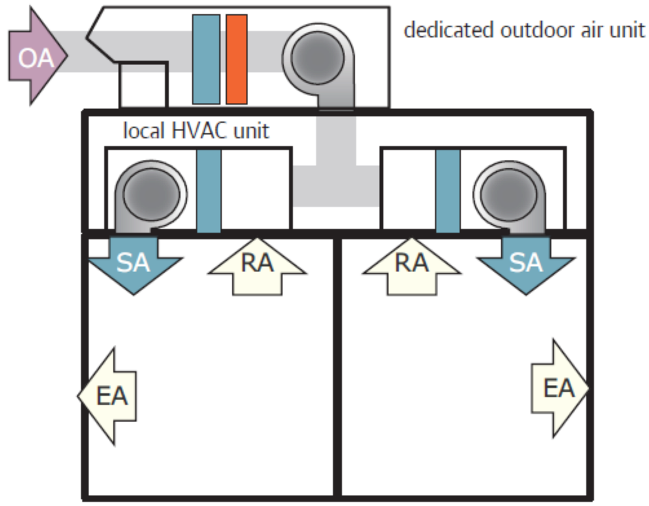
Conditioned Outdoor Air Direct to the Terminal Unit
The "Integrated Ventilation" Method



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Conditioned Outdoor Air Direct to the Terminal Unit
Advantages and Drawbacks

Advantages

- Helps ensure ventilation requirements are met
- Avoids cost of separate ductwork and diffusers
- Easier to ensure outdoor air distribution

Drawbacks

- Measurement and balancing more challenging (compared to direct-to-zone)
- Terminal unit fan must operate continuously
- VRF terminal fan must operate if dedicated outdoor air system operates during unoccupied period
- May require increased OA during heating mode (E_z > 1.0)
- Requires field fabrication

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Zone Air Distribution Effectiveness, E_z (section 6.2.1.2)

Determine the effectiveness (E_z) of the airside system's air distribution according to Table 6-4 or Appendix C:

E_z = (typically sourced from Table 6-4)

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply or warm air 15°F above space and ceiling return	0.8
Ceiling supply of warm air less than 15°F above space and ceiling return…	1.0
Floor supply of (low-velocity) cool air and ceiling return provided thermal stratification	1.2

Excerpt from Table 6-4

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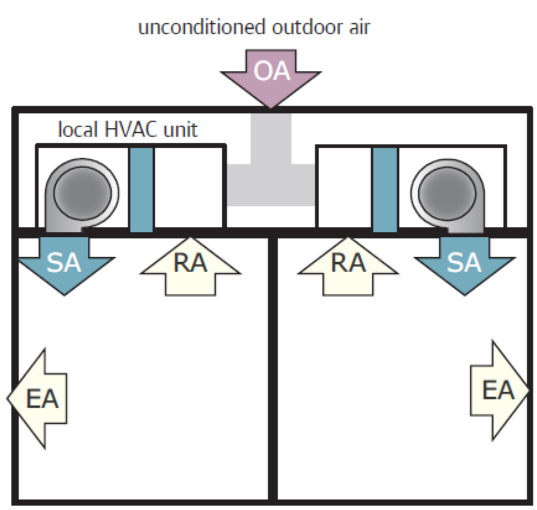
Unconditioned Outdoor Air Direct to the Terminal Unit "Direct Ventilation" Method



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Unconditioned Outdoor Air Direct to the Terminal Unit
Advantages and Drawbacks

Advantages

- Simple, inexpensive ventilation solution

Drawbacks

- May require specific terminals
- Terminal unit fan must operate continuously
- May require booster fan(s)
- May require airflow modulation for DCV
- May require increased OA during heating mode (E_z > 1.0)
- Requires field fabrication

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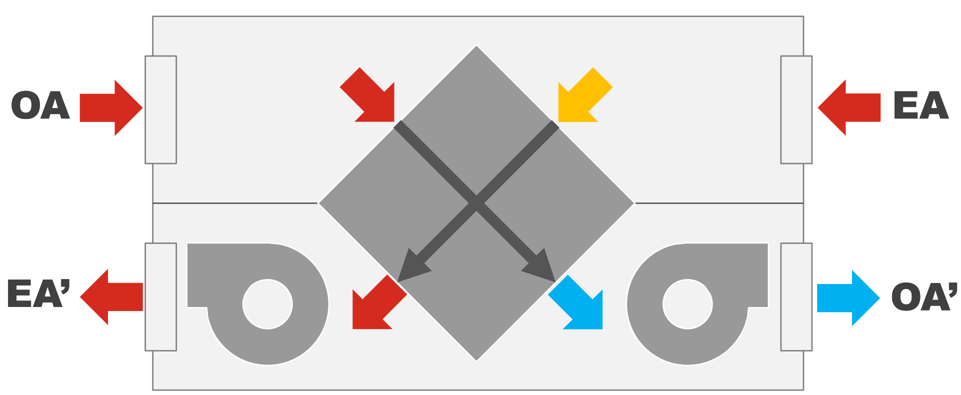
ERV and DOAS
Energy Recovery Ventilator (ERV)



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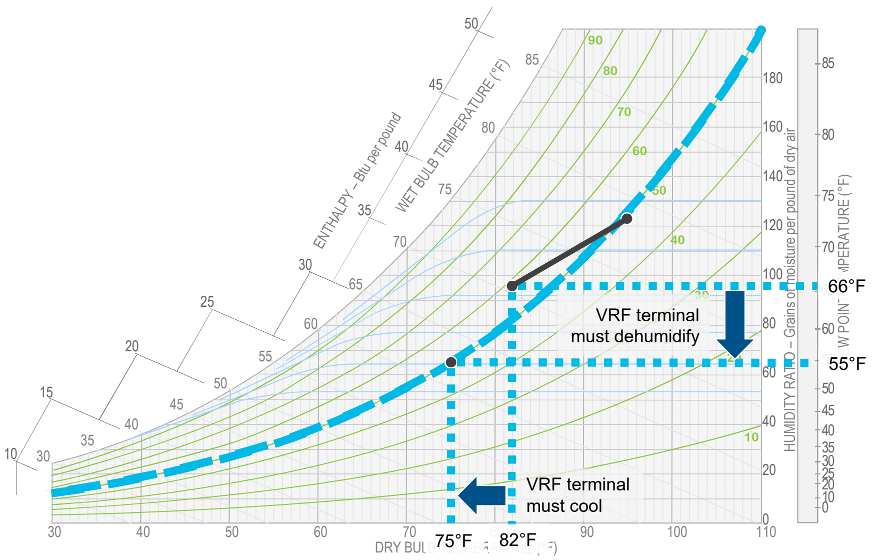
ERV and DOAS
Energy Recovery Ventilator Performance



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ERV and DOAS
Dedicated Outdoor Air System (DOAS)

Ability to:
- Cool, dehumidify, heat

Varieties:
- Air-cooled DX
- AHU + VRF + LEV

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AHRI Standard 920
What is a Dedicated Outdoor-Air Unit?

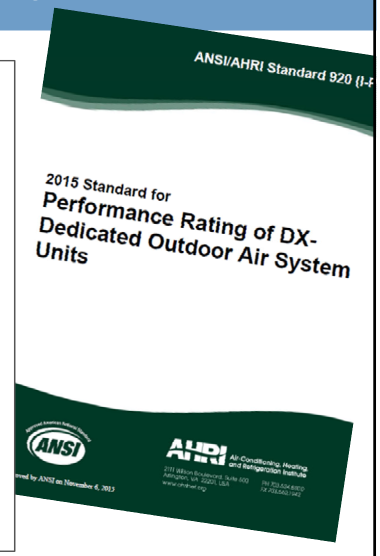
A dedicated outdoor-air unit …

"operate[s] in combination with a separate sensible cooling system to satisfy the entire building humidity load.

The system is sized to maintain a prescribed ventilation rate under any load condition. The ventilation rate can be constant or varied based on the building operation or occupancy schedule or in response to the actual occupancy.

It may pre-condition outdoor air by incorporating an enthalpy wheel, sensible wheel, desiccant wheel, plate heat exchanger, heat pipes or other heat or mass transfer apparatus.

It shall reheat the ventilation air by containing a reheat refrigerant circuit, sensible wheel, heat pipe, or other heat or mass transfer apparatus."



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example: conference room
What DOAS Supply-Air DPT is Required?

$$Q_{space,latent} = 0.69 \times V_{oz} \times (W_{space} - W_{ca})$$

example conference room:

$Q_{space,latent}$ = **3900 Btu/hr**

V_{oz} = **185 cfm**

W_{space} = **64.9 gr/lb** (75°F DBT and 50% RH)

$$3900 \text{ Btu/hr} = 0.69 \times 185 \text{ cfm} \times (64.9 \text{ gr/lb} - W_{ca})$$

W_{ca} = **34.3 gr/lb** (~38°F DPT)

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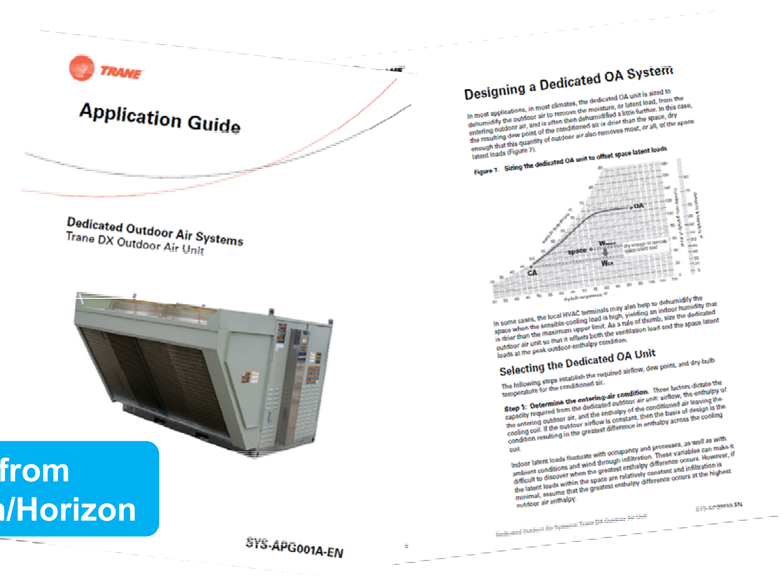
What DOAS Supply-Air DPT is Required?



Download from
www.trane.com/Horizon

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Humidity Control with Outdoor Air

Determine supply air temperature

- Simple setpoint vs. calculated, load-based setpoint

Dehumidification equipment

- ERV vs. DOAS (passive vs. active)

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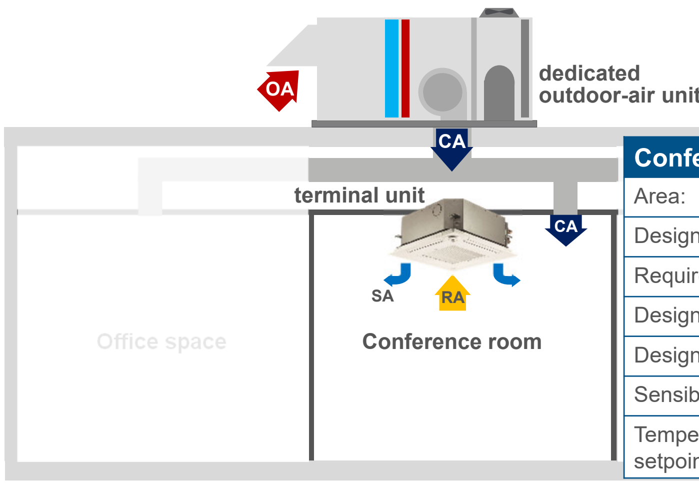
Psychrometric Analysis



Conference room	
Area:	1000 ft²
Design occupancy:	25 people
Required ventilation:	185 cfm
Design sensible load:	11,800 Btu/hr
Design latent load:	3,900 Btu/hr
Sensible heat ratio (SHR):	0.75
Temperature and humidity setpoints:	75°F, 50% rh (~55.1°F DPT)

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Psychrometric Analysis Results

	55-degree DOAS		45-degree DOAS	ERV	
Supply (DBT/DPT)	55.0°F / 54.4°F		45.0°F / 44.5°F	81.7°F / 62.3°F	77.2°F / 68.1°F
Space Sensible Heat Ratio (SHR)	0.75	0.61			
Load offset by DOAS (Sensible)	4,015 Btu/hr	4,015 Btu/hr			
Terminal unit airflow	400 cfm	300 cfm			
Load offset by terminal (Sensible)	7,785 Btu/hr	2,110 Btu/hr			
Space relative humidity	54%	66%			

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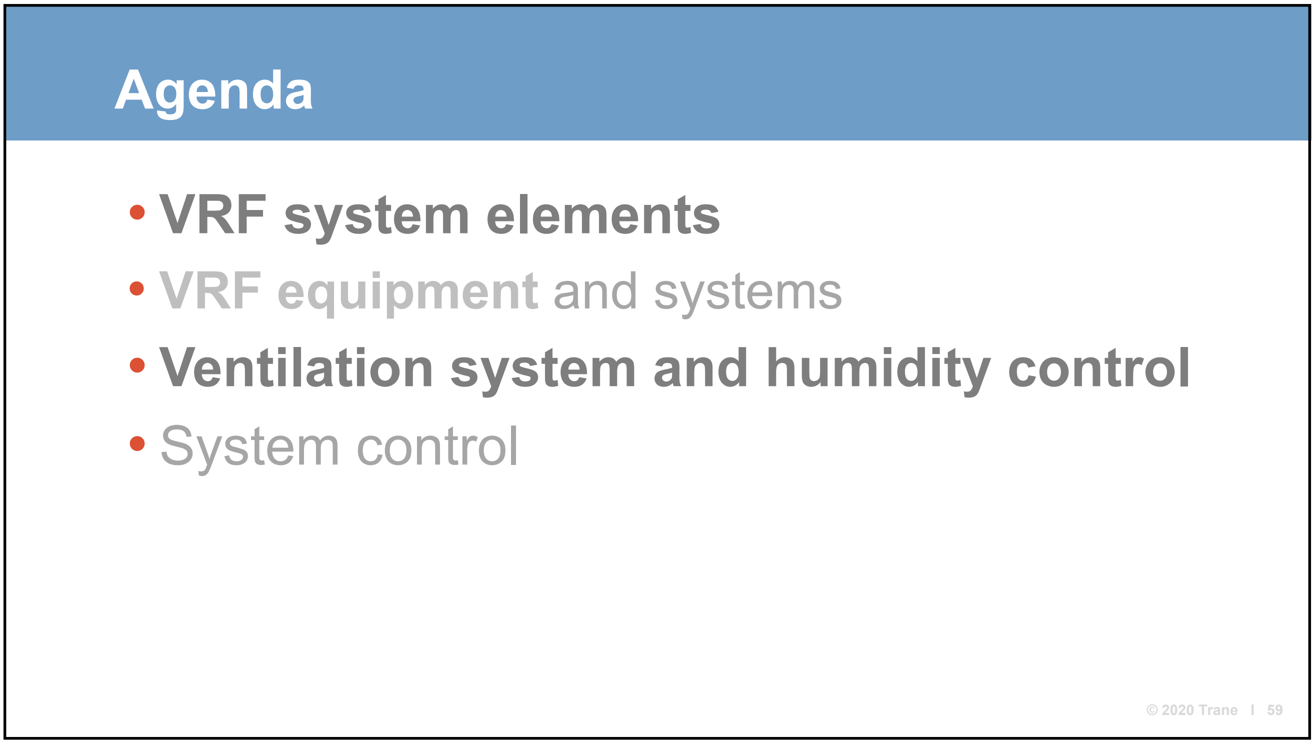
Agenda
• VRF system elements
• VRF equipment and systems
• Ventilation system and humidity control
• System control
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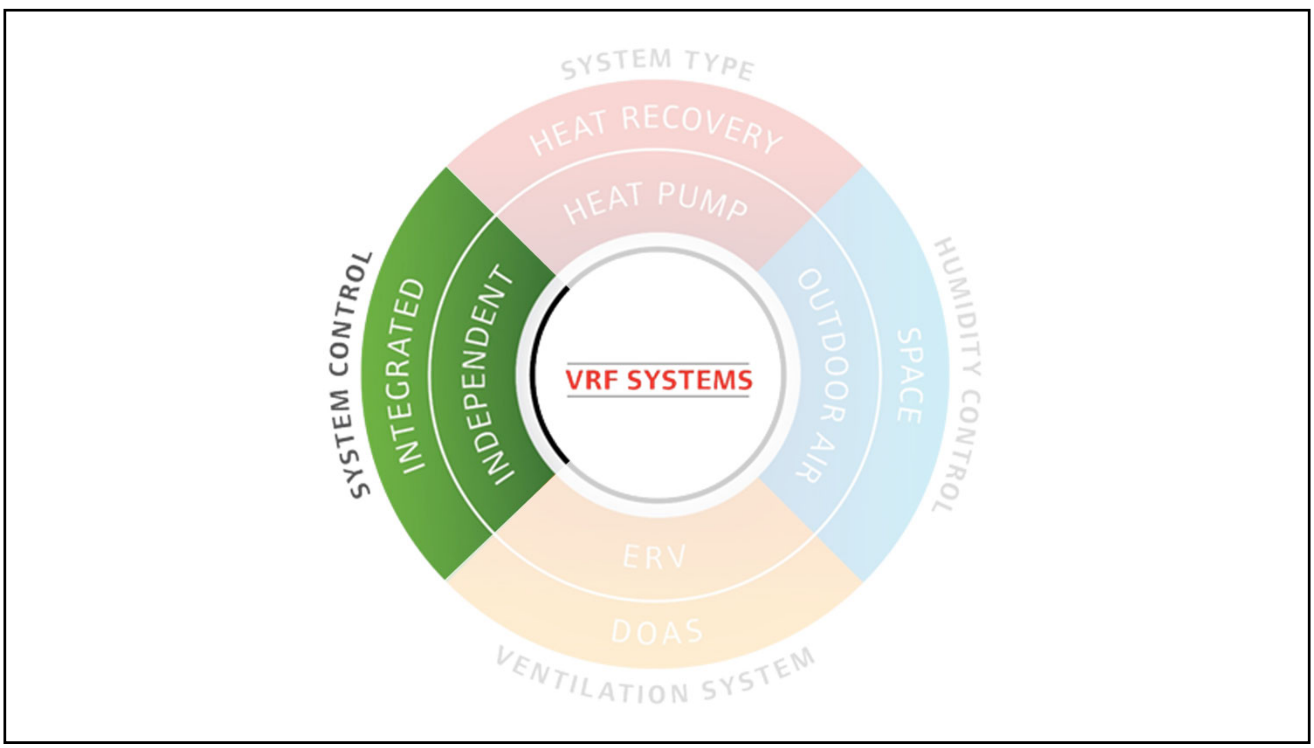
SYSTEM TYPE
HEAT RECOVERY
HEAT PUMP
HUMIDITY CONTROL
SPACE
OUTDOOR AIR
VENTILATION SYSTEM
DOAS
ERV
SYSTEM CONTROL
INTEGRATED
INDEPENDENT
VRF SYSTEMS

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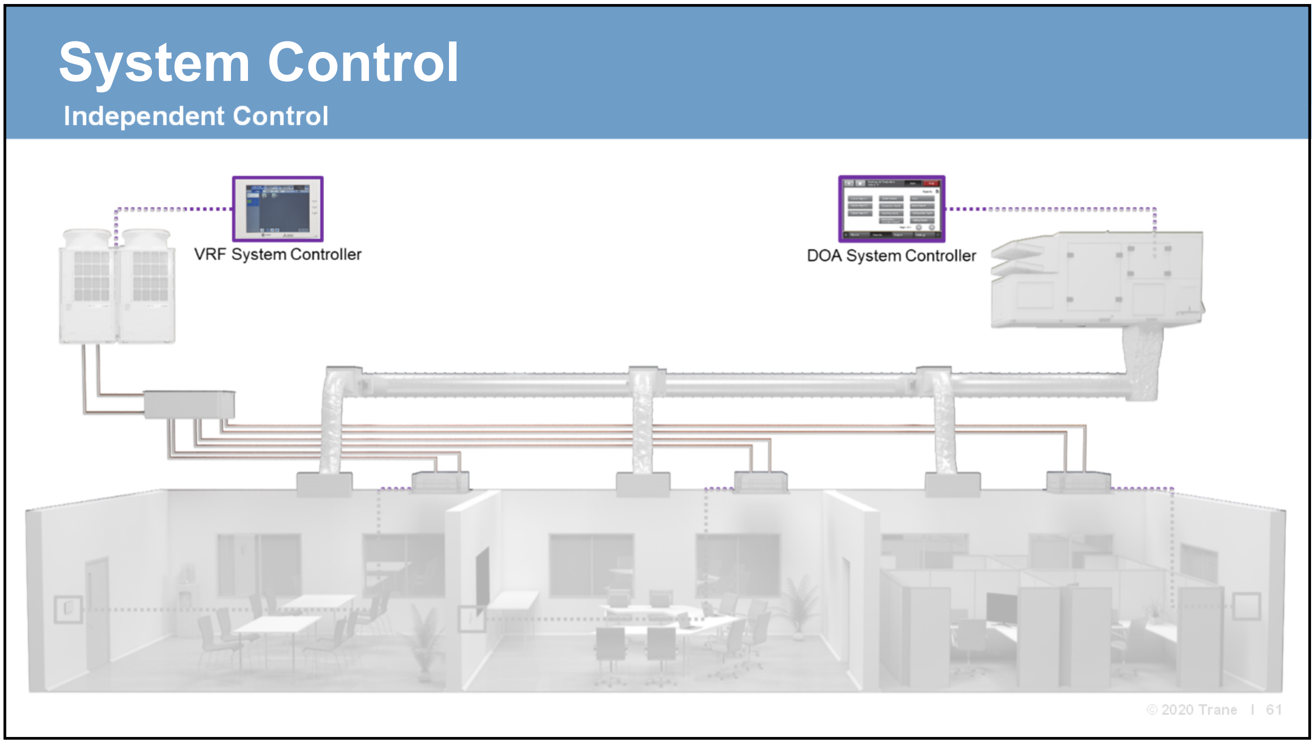
System Control
Independent Control
VRF System Controller
DOA System Controller
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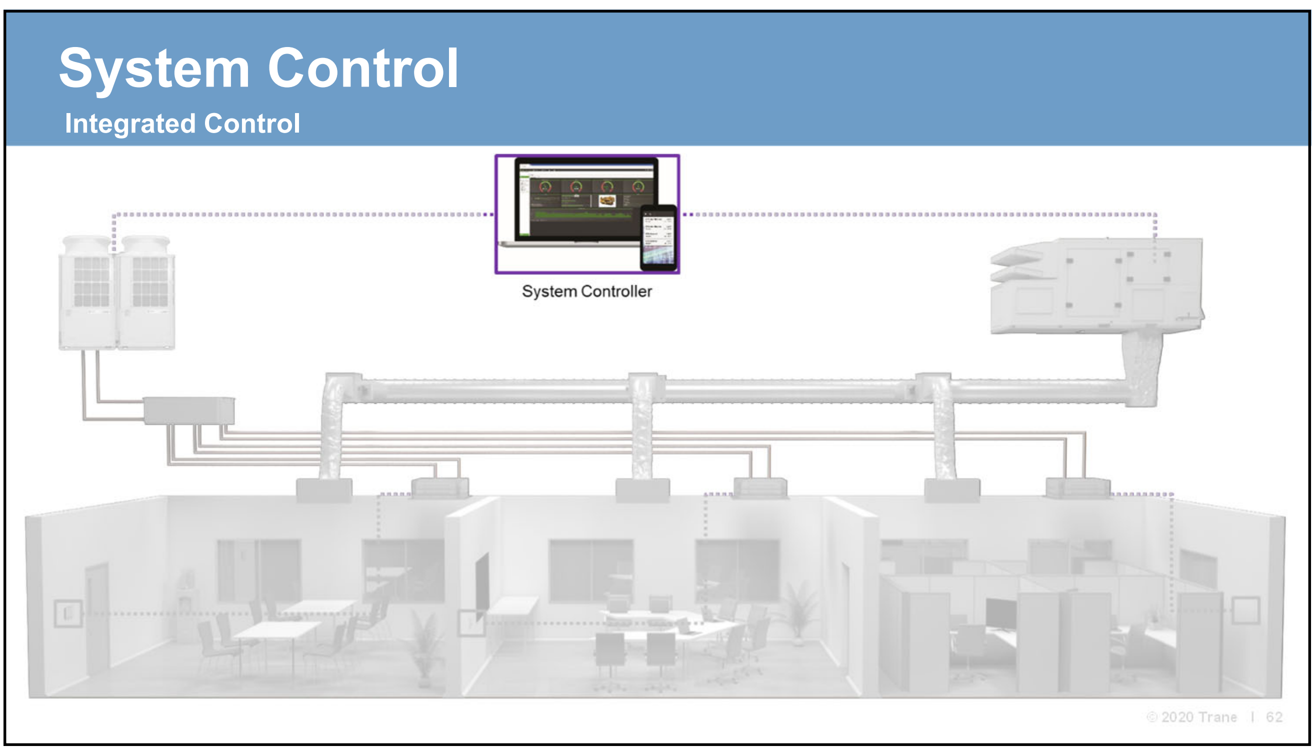
System Control
Integrated Control
System Controller
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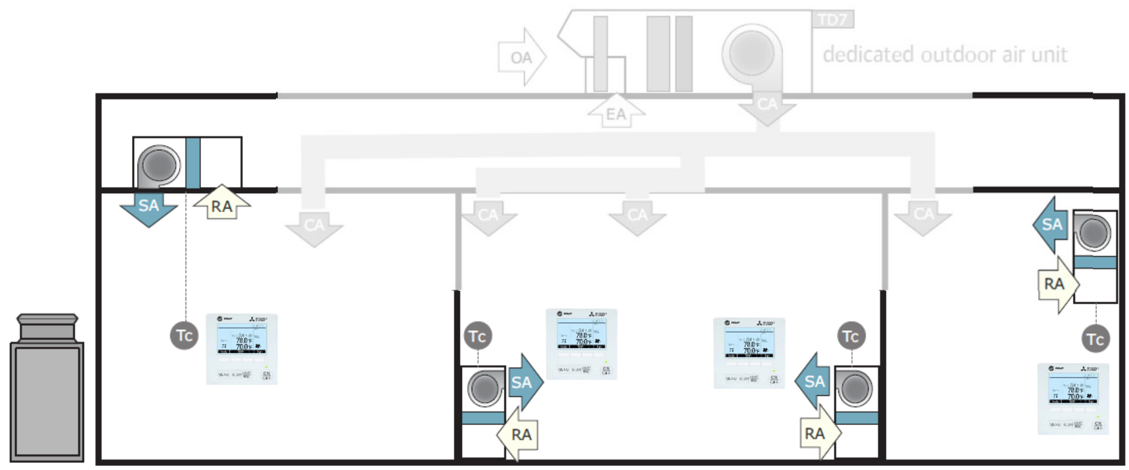
System Control

Independent Control (no BAS installed)



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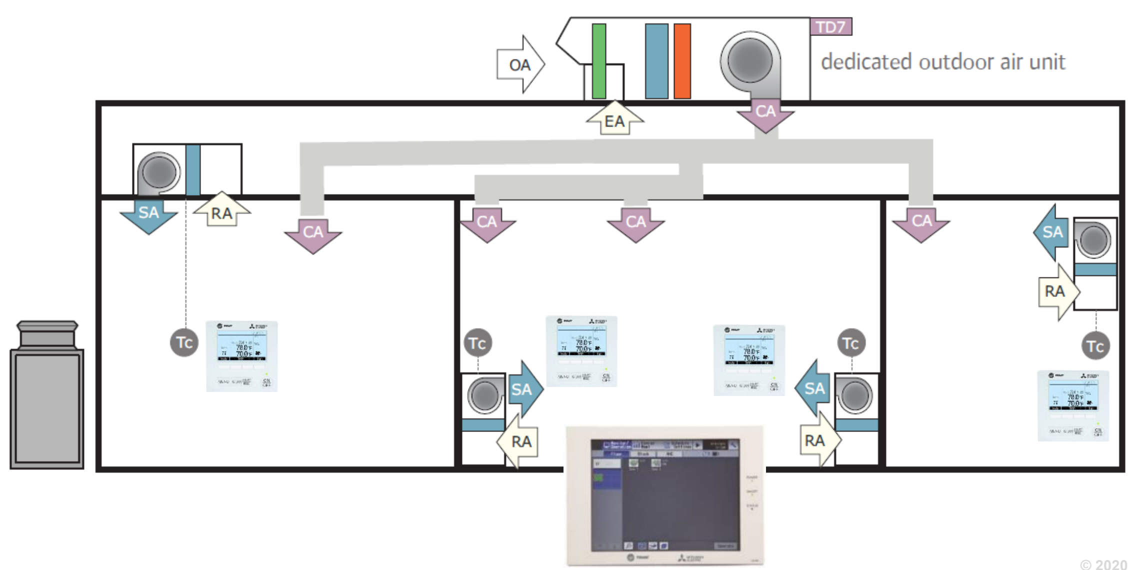
System Control

Independent Control (no BAS installed)



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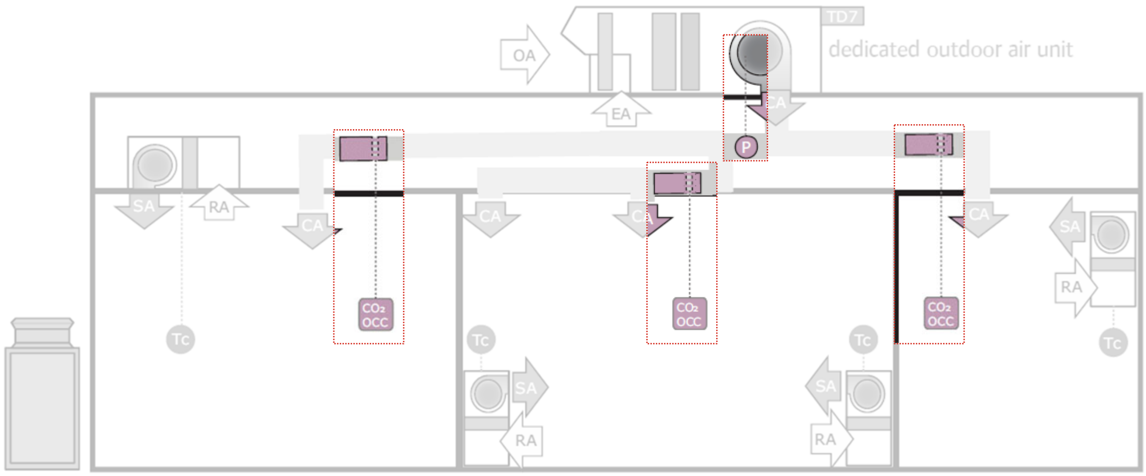
System Control

Independent Control (with DCV)



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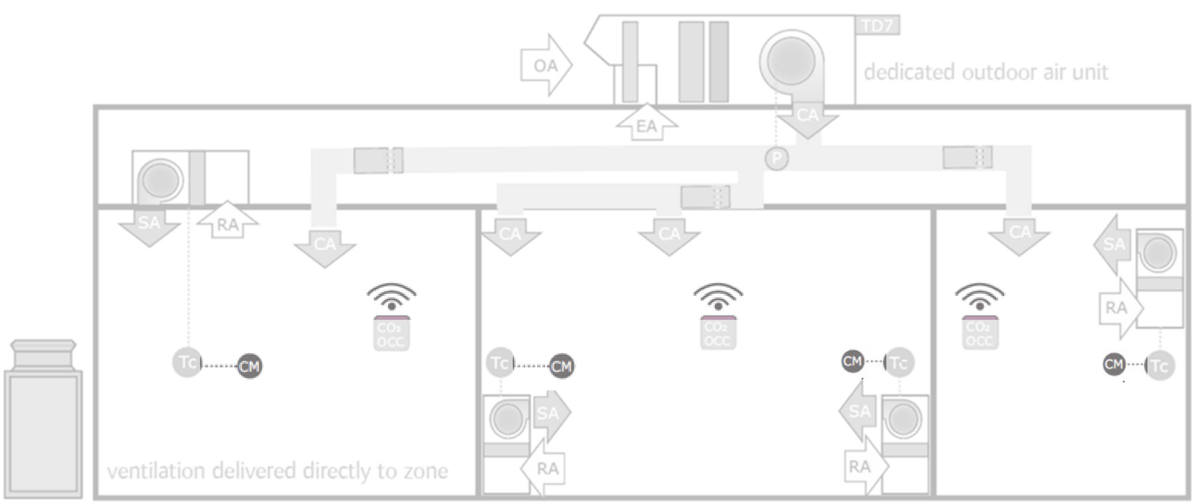
System Control

Integrated Control for Small Applications (10 zones or fewer)



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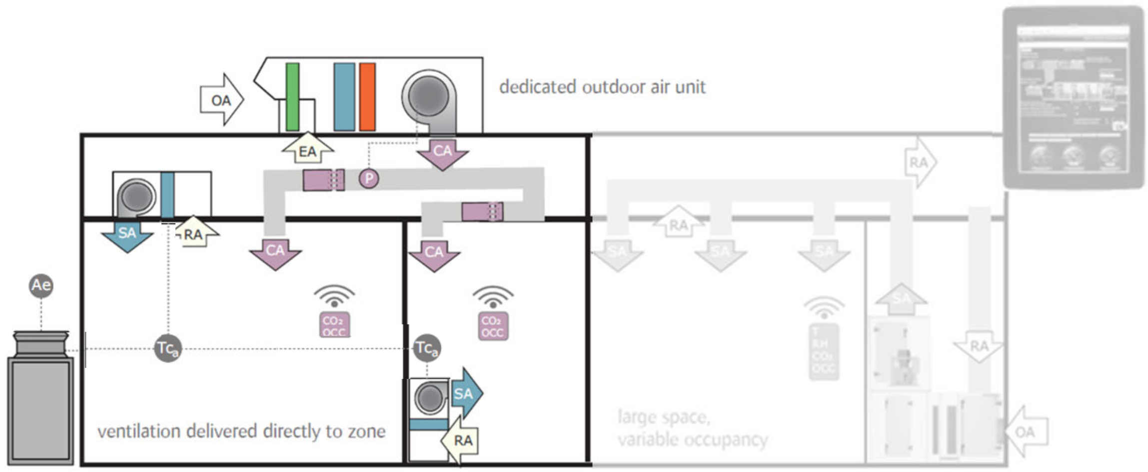
System Control

Integrated Control for Large Applications (more than 10 zones)



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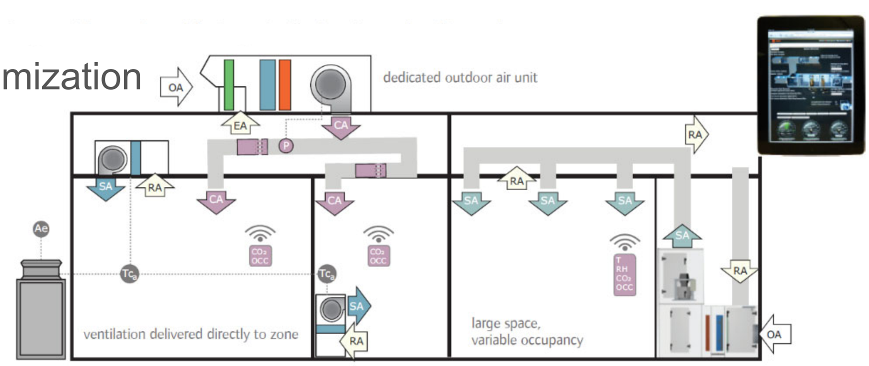
System Control

Integrated Control for Large Applications (more than 10 zones)

- Dehumidification overrides
  - Zone DOAS airflow reset
  - DOAS dew point reset
- Morning warm-up
- Fan pressure optimization
- Lighting, etc.



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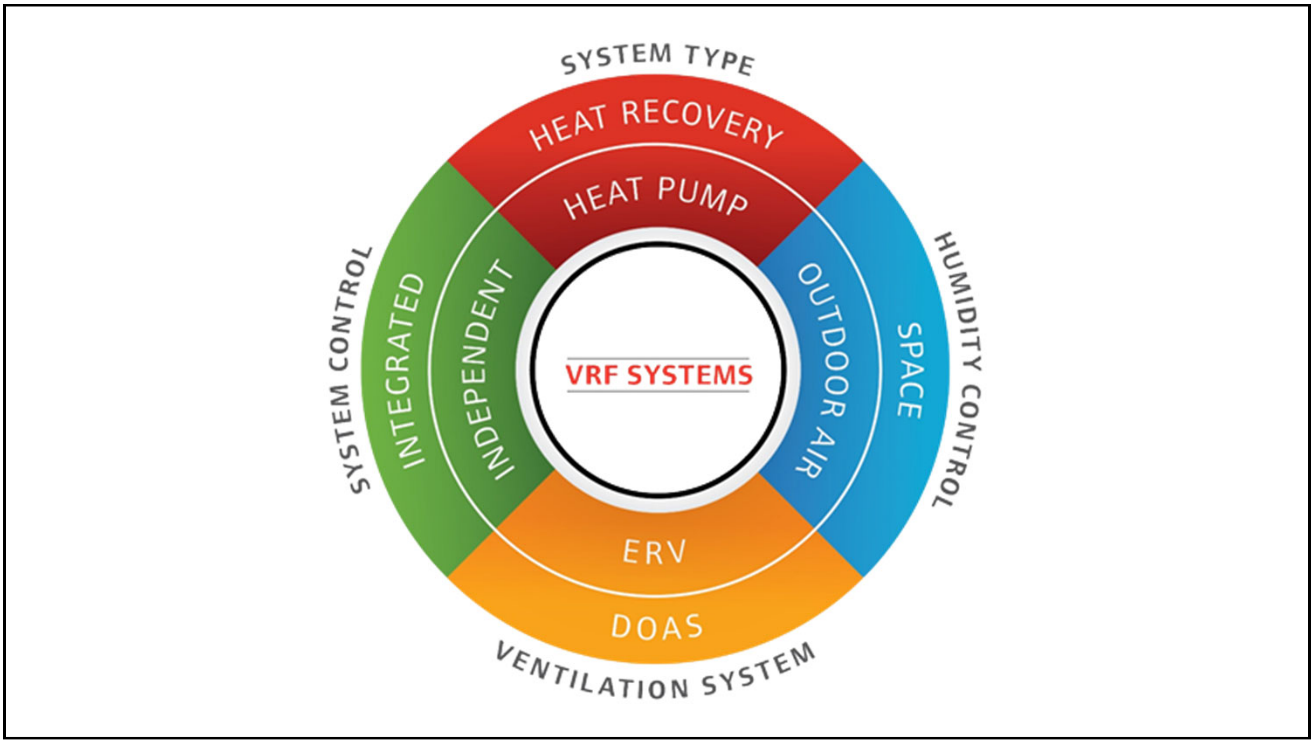
SYSTEM TYPE
HEAT RECOVERY
HEAT PUMP
HUMIDITY CONTROL
SPACE
OUTDOOR AIR
VENTILATION SYSTEM
DOAS
ERV
SYSTEM CONTROL
INTEGRATED
INDEPENDENT
VRF SYSTEMS

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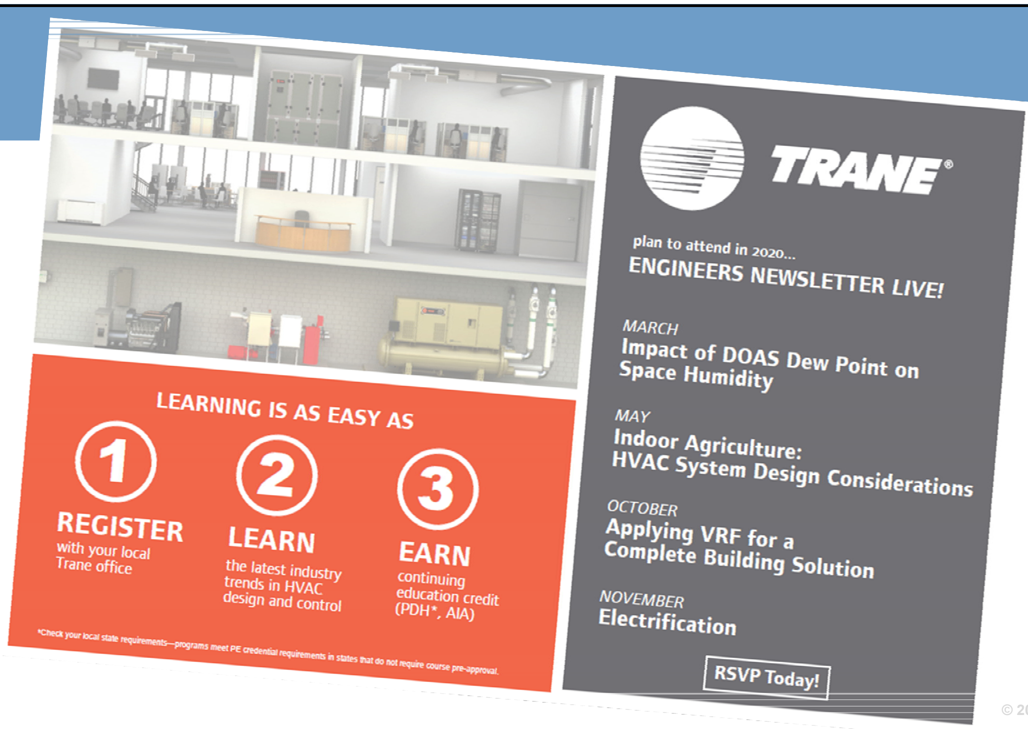

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Special Thanks To …

Dustin Meredith and Brian Fiegen

VRF content and systems development

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Resources

Applying VRF for a Complete Building HVAC Solution

References

- APP-CMC051-EN (2014) "Applying Variable Refrigerant Flow (VRF)"
- APP-CMC072-EN (2020) "Impact of DOAS Dew Point on Space Humidity"
- APP-CMC043-EN (2011) "Dedicated Outdoor Air Equipment"
- ADM-APN073-EN (March 2020) *Trane Engineers Newsletter*, "Impact of DOAS Supply-Air Dew Point Temperature on Space Humidity"
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- Application Manual – APP-APM001-EN – Refrigerating System and Machinery Rooms
- Application Manual – APP-APM004-EN – "Dehumidification in HVAC Systems"
- Application Guide – APP-APG001A-EN – "Designing Dedicated Outdoor Air Systems"
- Industry Resource – ASHRAE Standard 15
- Industry Resource – ASHRAE Standard 62.1-2019
- Industry Resource – 2020 ASHRAE Handbook – HVAC Systems and Equipment – Chapter 18 "Variable Refrigerant Flow"
- Analysis Software – TRACE 3D Plus