Trane Engineers Newsletter Live

Applying Variable Refrigerant Flow

Presenters: Paul Solberg, John Murphy, Dave Guckelberger and Eric Sturm

Agenda

Trane *Engineers Newsletter Live* Series

Applying Variable Refrigerant Flow

Abstract
All HVAC systems have their own set of advantages, as well as application challenges. In this program, Trane applications engineers discuss some of the challenges when applying a variable refrigerant flow (VRF) system, such as complying with ASHRAE Standards 15 and 90.1, meeting the ventilation requirements of ASHRAE Standard 62.1, and zoning to maximize the benefit of heat recovery. In addition, the current state of modeling VRF in energy simulation software will be reviewed.

Presenters: Trane applications engineers John Murphy, Paul Solberg, Eric Sturm and Dave Guckelberger.

After viewing attendees will be able to:

1. Identify VRF system components and understand why design and installation is critical to the functionality of the system
2. Identify how controls for VRF systems differ from typical HVAC applications
3. Summarize how to comply with ASHRAE Standards 90.1 and 62.1 when using VRF
4. Summarize ASHRAE Standard 15, Safety Standard for Refrigeration Systems, requirements for VRF systems

Agenda

- Variable refrigerant flow (VRF) system overview
- Technology and operation considerations
- ASHRAE Standard 15
- ASHRAE Standard 90.1
- ASHRAE Standard 62.1
- Zoning
- Modeling considerations
- Summary

Presenter biographies

Applying Variable Refrigerant Flow

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. As a LEED Accredited Professional, he has helped our customers and local offices on a wide range of LEED projects. His main areas of expertise include energy efficiency, dehumidification, dedicated outdoor-air systems, air-to-air energy recovery, psychrometry, and ventilation.

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. As an ASHRAE member he 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, Eric worked in the Customer Direct Services (C.D.S.) department as a 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. As the newest member to the applications engineering team, Eric's areas of expertise include acoustics and airside systems. Eric is currently involved with ASHRAE at the local and national levels serving as a member of SSPC 140, SPC 205, TC 2.5, and TC 2.6.

Paul Solberg | systems engineer | Trane

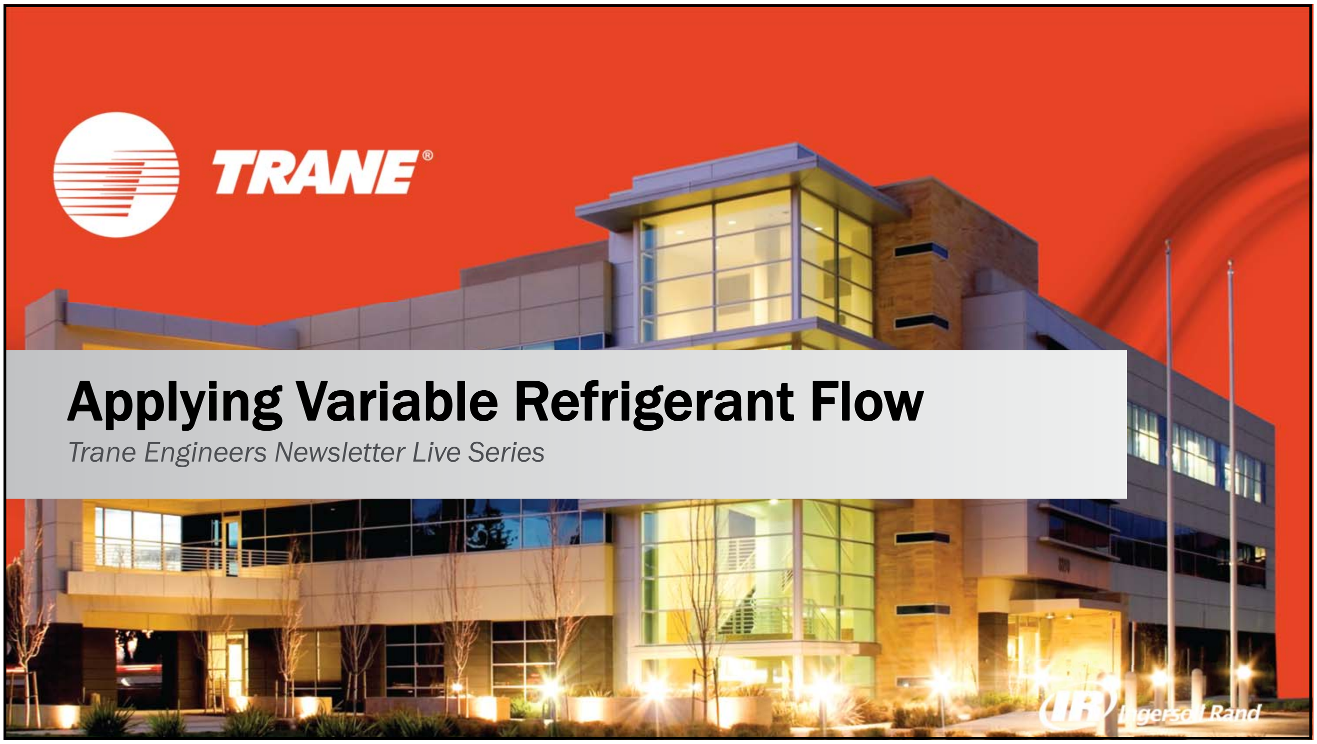
A mechanical engineer from the University of Wisconsin at Platteville, Paul is a 35-year veteran of Trane. He specializes in compressor and refrigeration systems, and has authored numerous Trane publications on these subjects, including application manuals, engineering bulletins, and *Engineers Newsletters*. Paul served in the technical service and applications engineering areas at various manufacturing locations, where he developed particular expertise supporting split systems, small packaged chillers, rooftop air conditioners, and other unitary products.

Paul is the Chair of ASHRAE Standard 147 "*Reducing the Release of Halogenated Refrigerants from Refrigerating and Air-Conditioning Equipment and Systems*", a corresponding member of TC 8.7 *VRF,* and is involved in other ASHRAE technical committees

Dave Guckelberger | applications engineer | Trane

Dave has a wide range of product and system responsibilities as a Trane applications engineer. His expertise includes acoustic analysis and modeling of HVAC systems, electrical distribution system design, and the refrigeration system requirements established by ASHRAE Standard 15. He also provides research and interpretation on how building, mechanical, and fire codes impact HVAC equipment and systems. In addition to traditional applications engineering support, Dave has authored a variety of technical articles on subjects ranging from acoustics to ECM motors to codes.

Dave is a past president of the Wisconsin Mechanical Refrigeration Code Council and has served on several ASHRAE committees at the national level. After graduating from Michigan Tech with a BSME in thermo-fluids, he joined Trane as a development engineer in 1982 and moved into his current position in Applications Engineering in 1987



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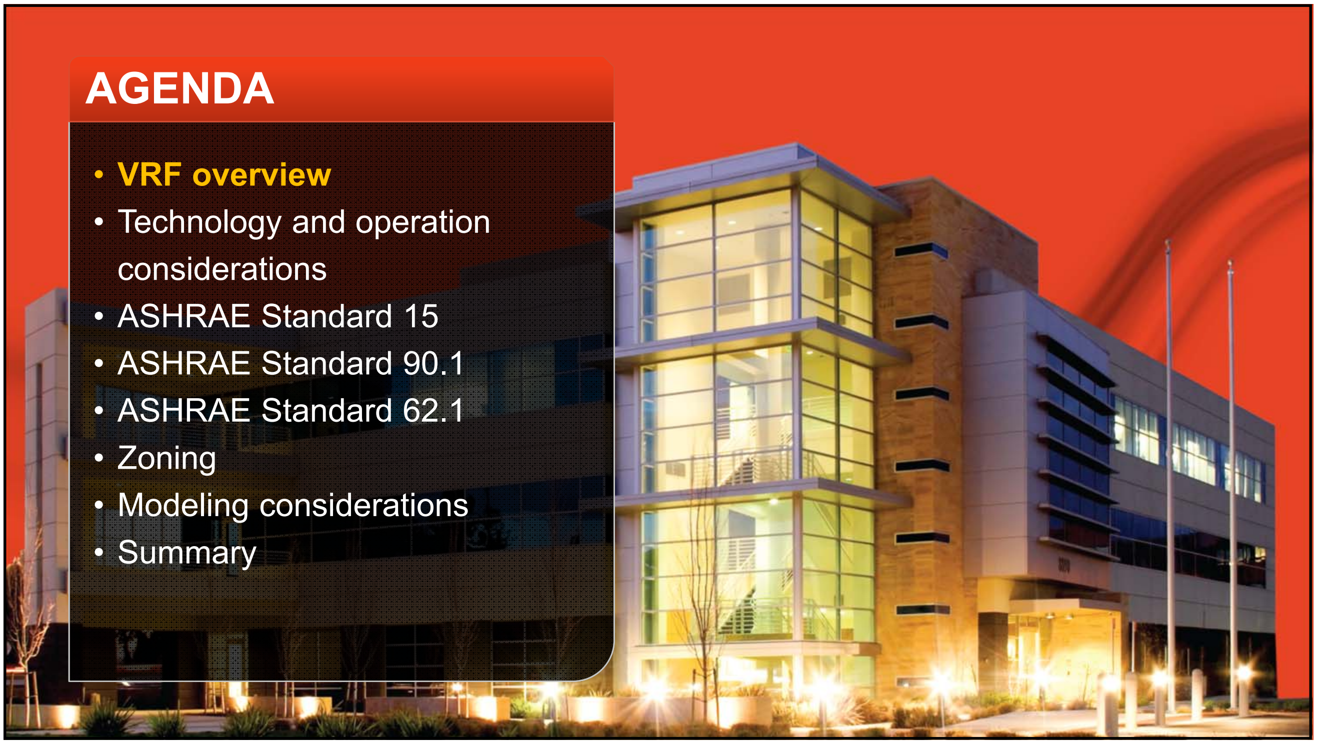
Today's Presenters

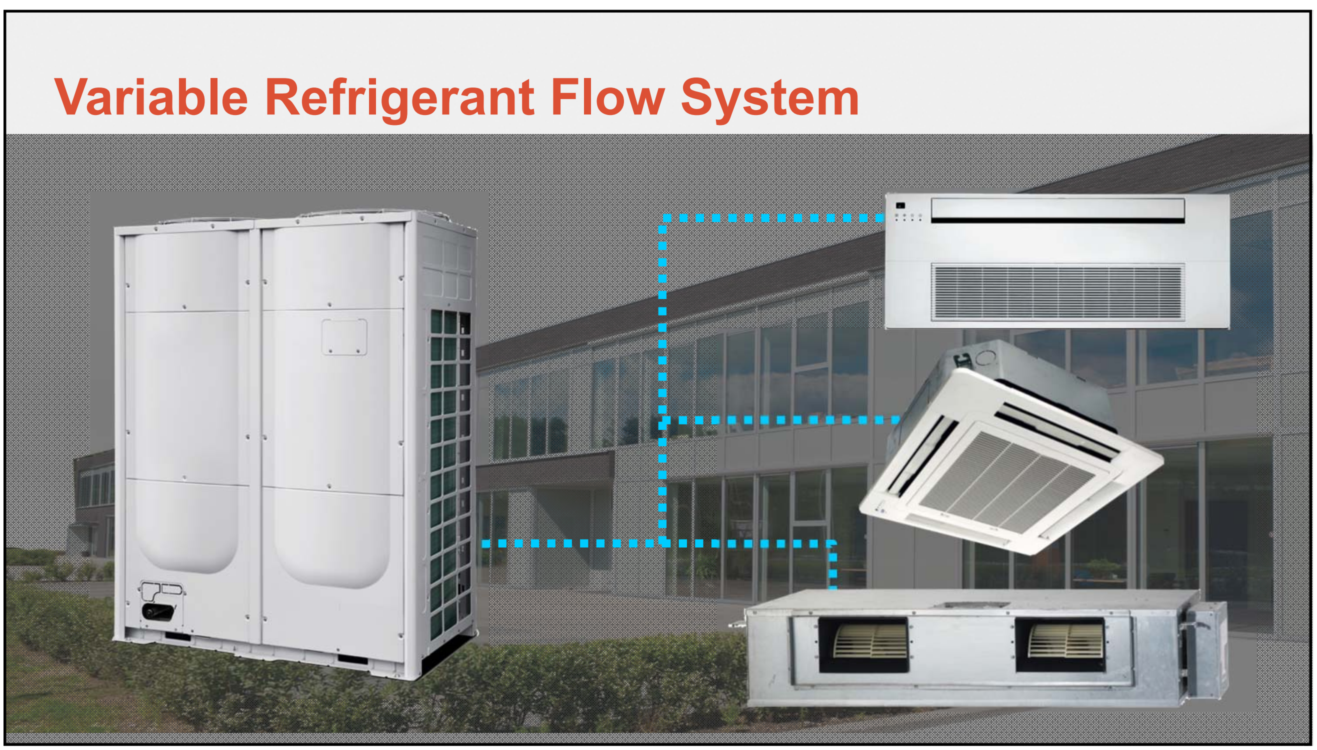
Eric Sturm
Applications Engineer

Paul Solberg
Applications Engineer

Dave Guckelberger
Applications Engineer

John Murphy
Applications Engineer


AGENDA
• VRF overview
• Technology and operation considerations
• ASHRAE Standard 15
• ASHRAE Standard 90.1
• ASHRAE Standard 62.1
• Zoning
• Modeling considerations
• Summary


Variable Refrigerant Flow System

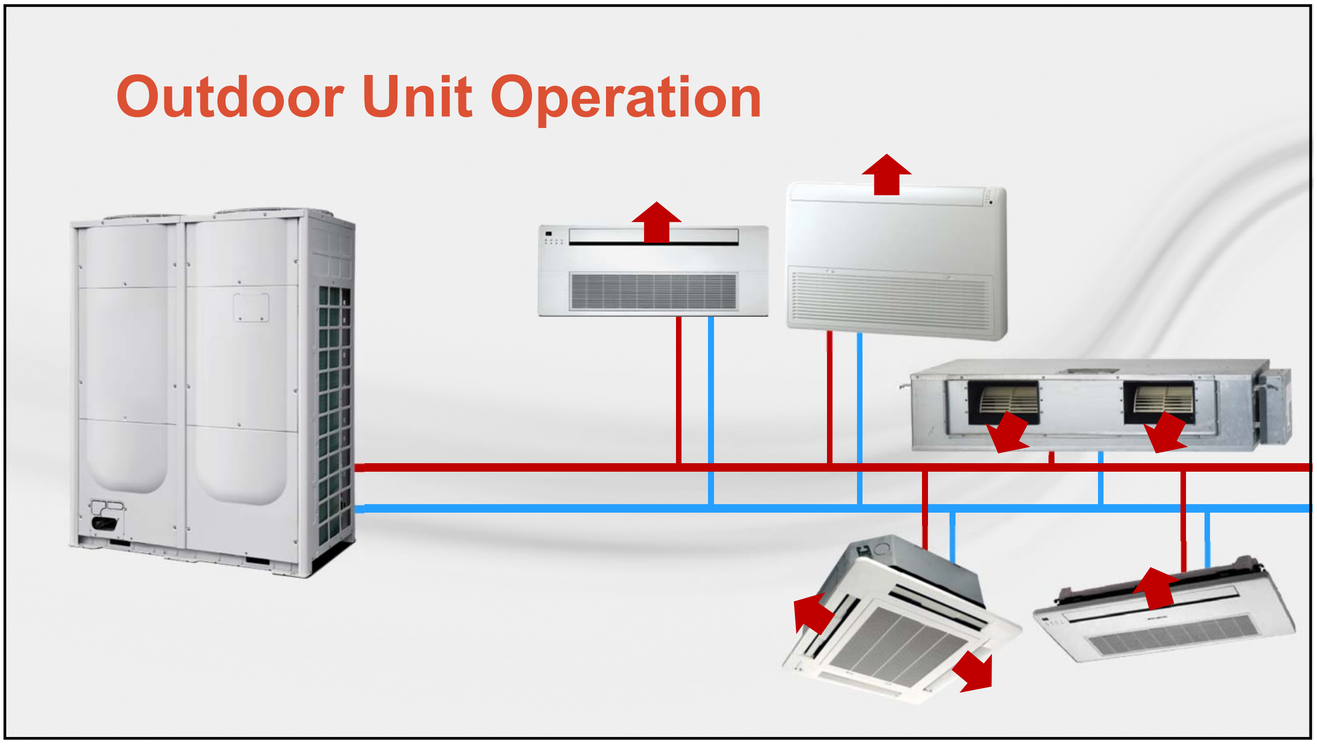
VRF System Components

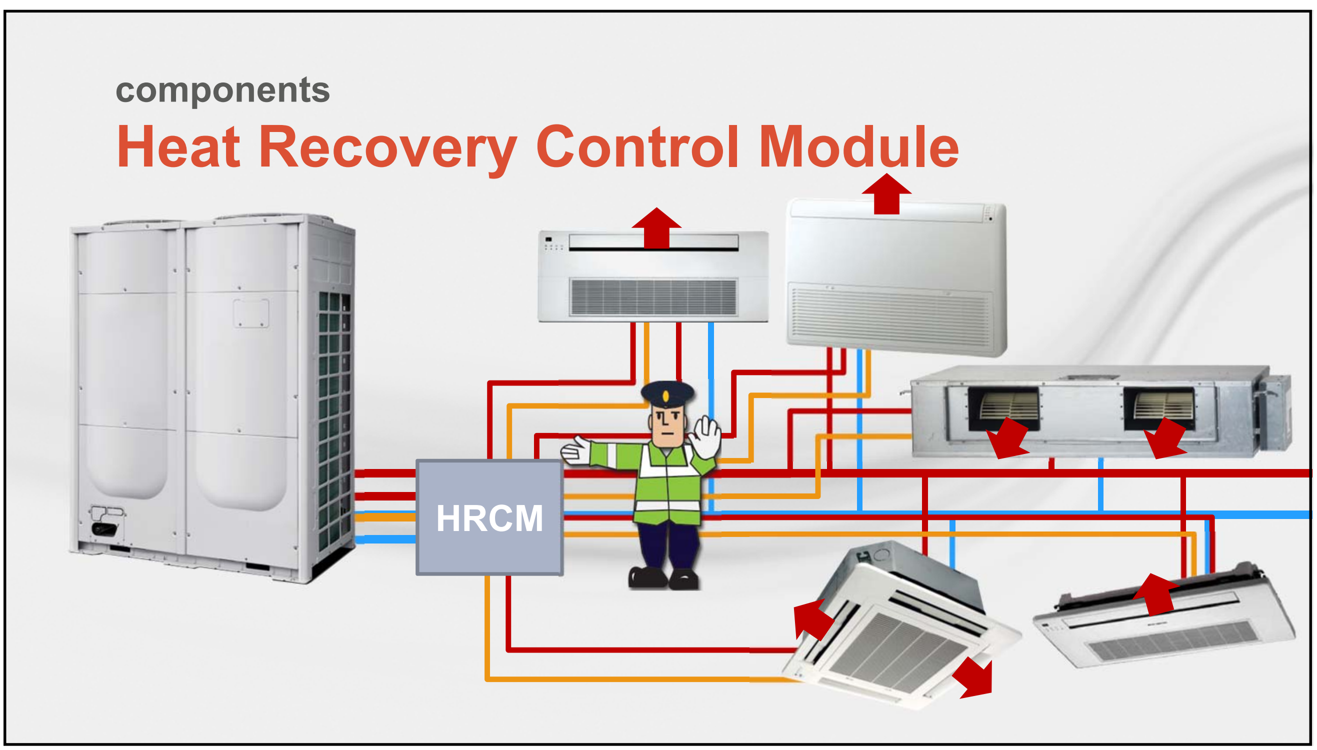
- Outdoor unit
- Heat recovery control unit
- Indoor units
- Controls
- Refrigerant piping

components

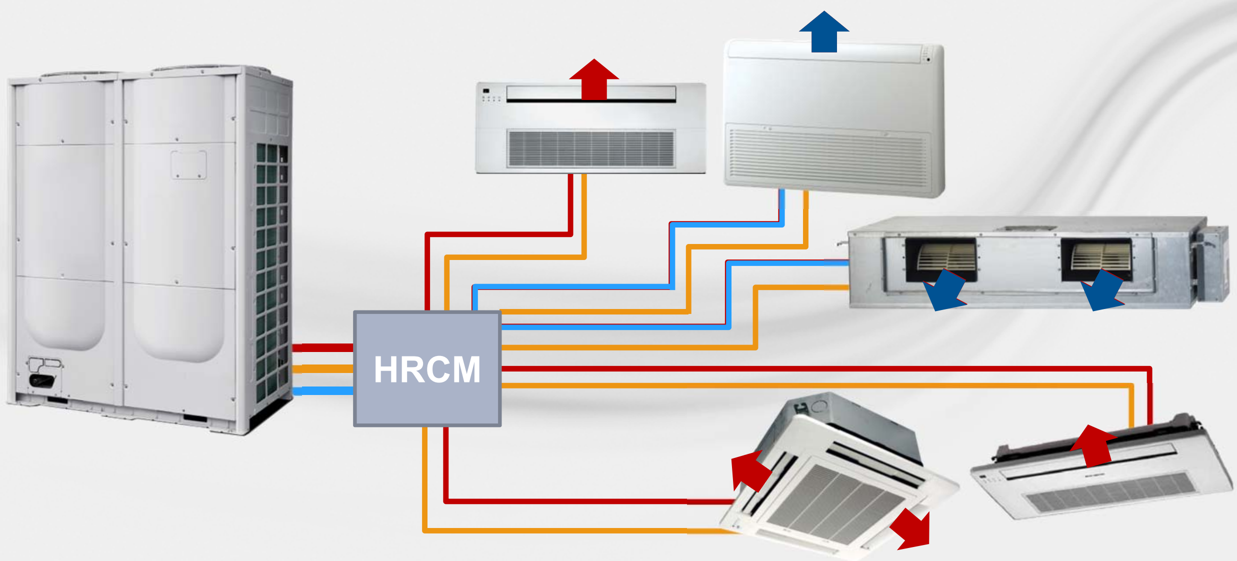
Outdoor Unit

- Variable speed compressor(s)
- Heat exchanger (condenser/evaporator)
- Intercooler
- Variable speed heat rejection fan(s)
- Expansion device
- Oil separator


Outdoor Unit Operation


components
Heat Recovery Control Module
HRCM

Simultaneous Heating and Cooling



components

Indoor Unit

- Indoor coil and fans
- Expansion valve
- Diffusers

components

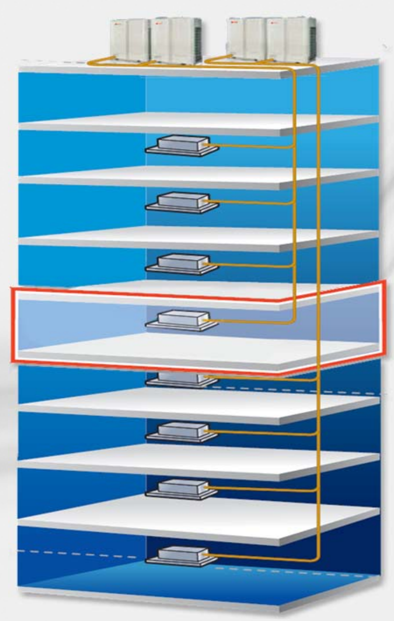
Controls

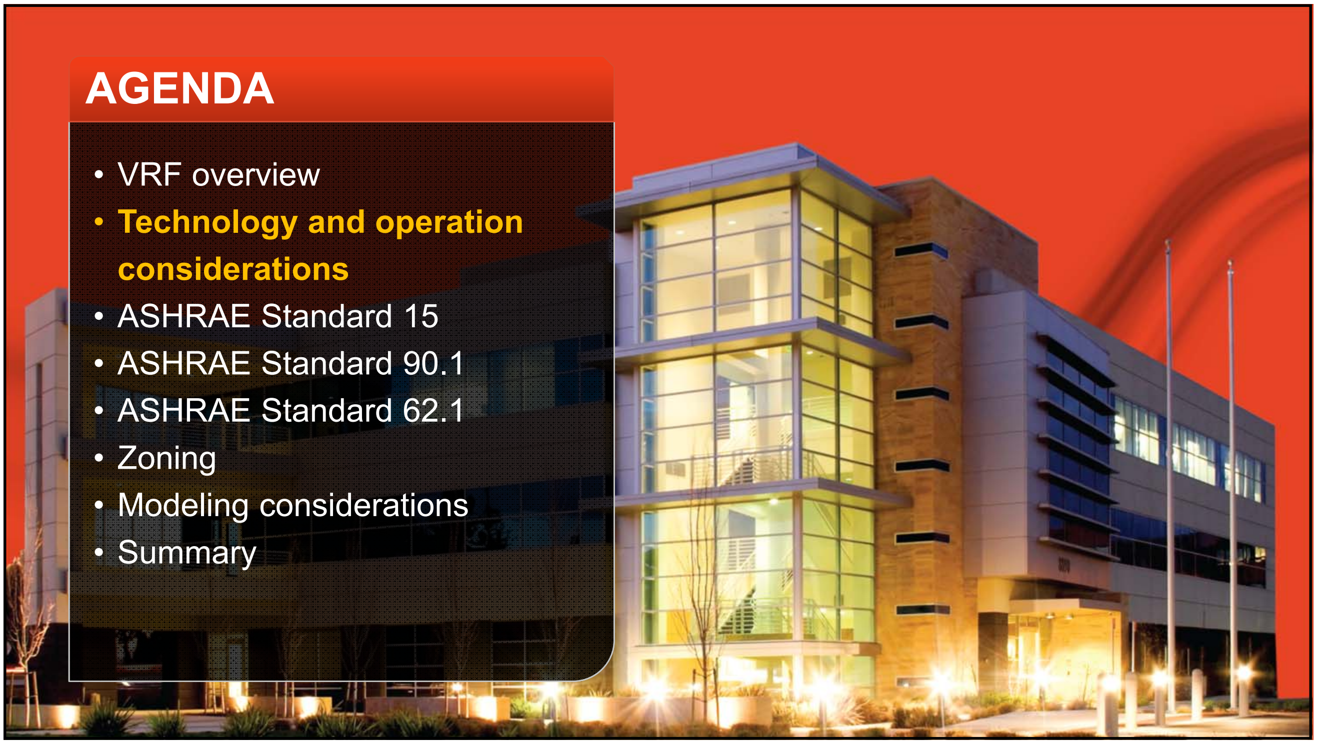
- Zone
- System
- Building
- Integral to system operation and coordination

components

Piping

- Refrigerant piping
- Long line lengths and lifts




AGENDA
• VRF overview
• Technology and operation considerations
• ASHRAE Standard 15
• ASHRAE Standard 90.1
• ASHRAE Standard 62.1
• Zoning
• Modeling considerations
• Summary


VRF Outdoor Unit Types
mini VRF
air-cooled
water-cooled

VRF Outdoor Unit Types

- 5 tons and under
- Single-phase power
- Limited indoor unit connections

VRF Outdoor Unit Types

- 6-14 tons
- Three-phase power
- Combined for capacity up to ~36 tons
- Heat pump or heat recovery configurations

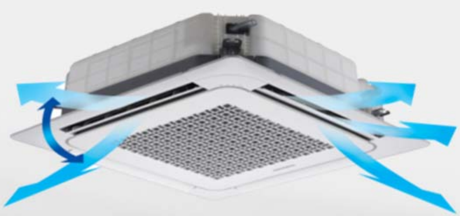
VRF Outdoor Unit Types

water-cooled

- Similar to air-cooled (voltage, tonnage, modularity)
- Installed with ground heat exchanger or cooling tower and boiler

VRF indoor unit types

Non-ducted



ceiling cassettes

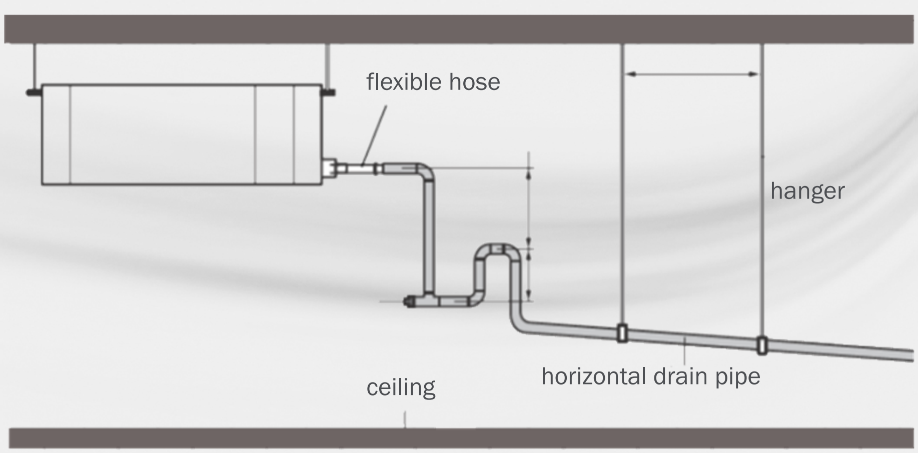
high wall

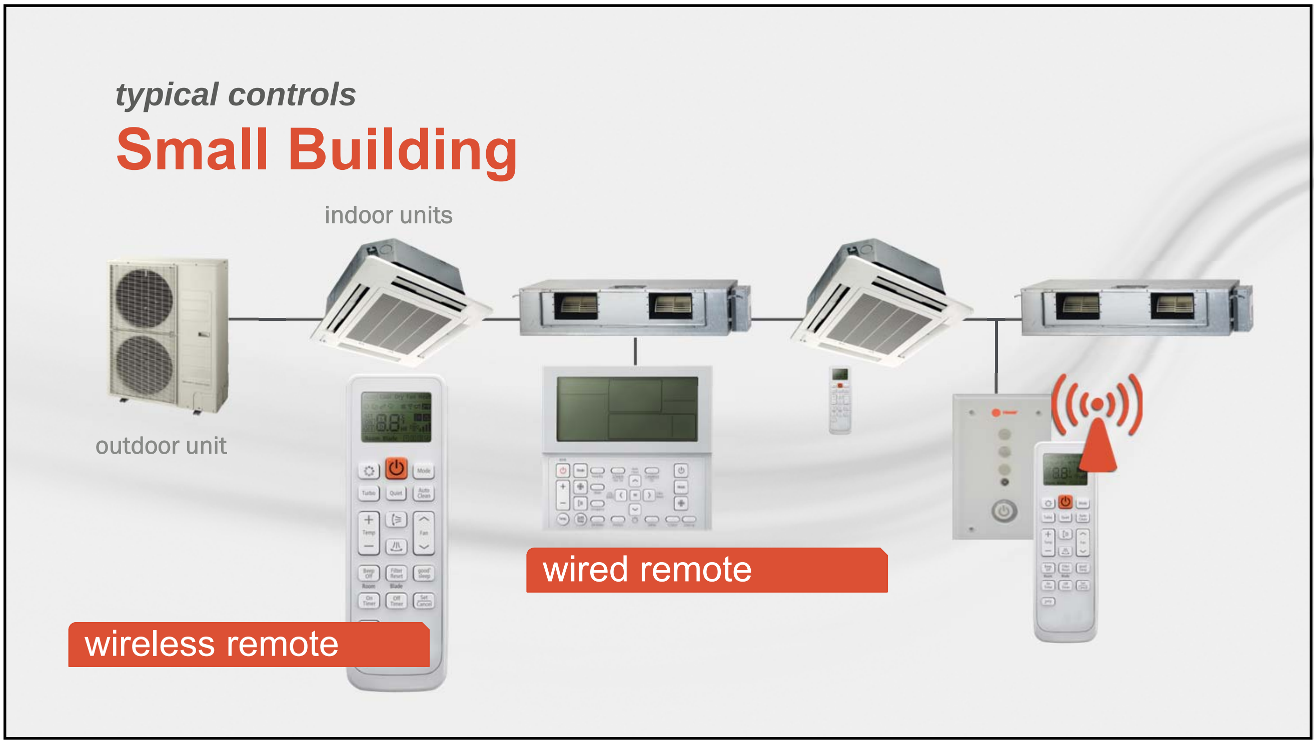
VRF indoor unit types

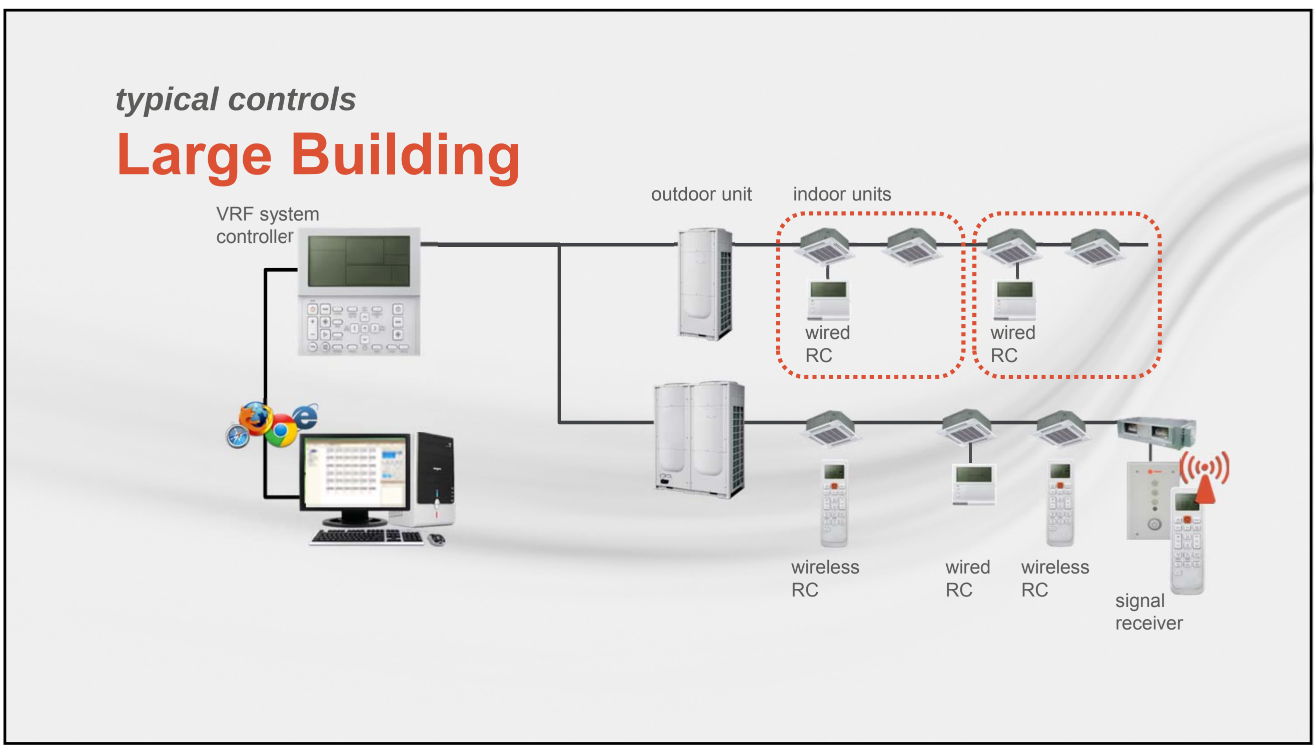
Ducted

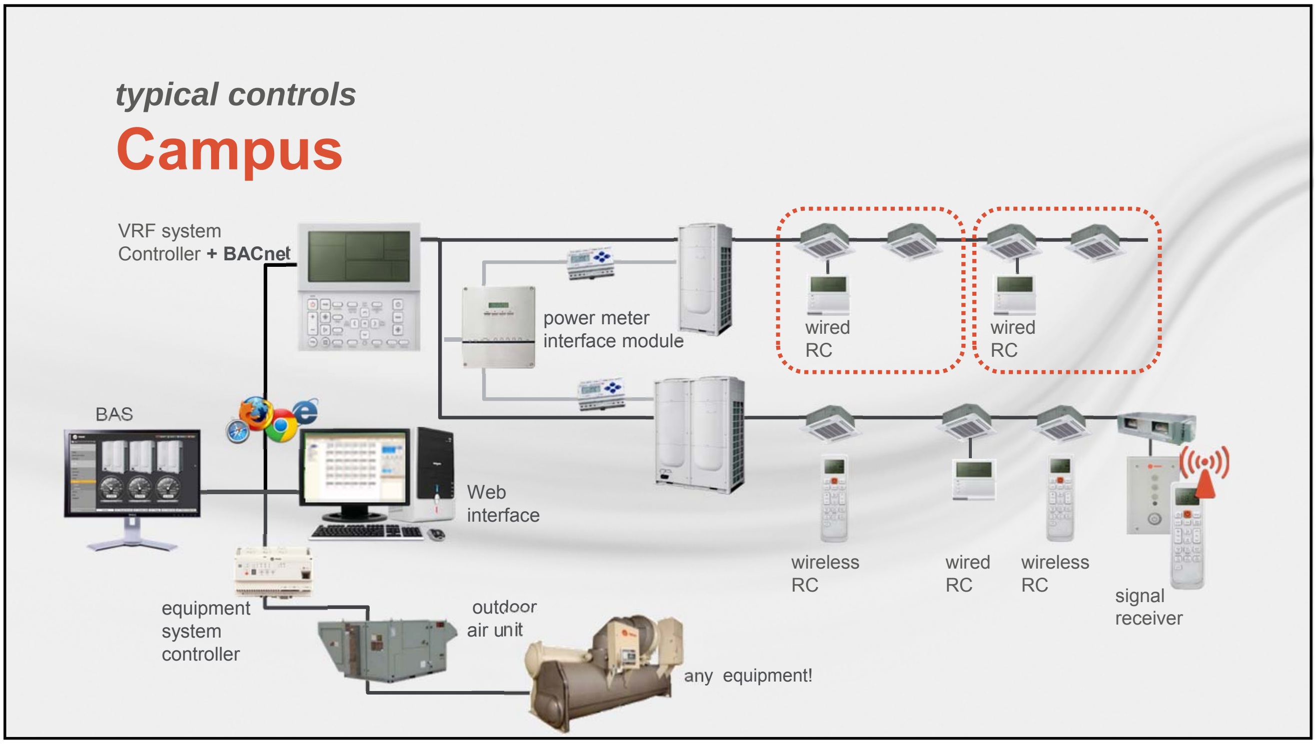
Condensate

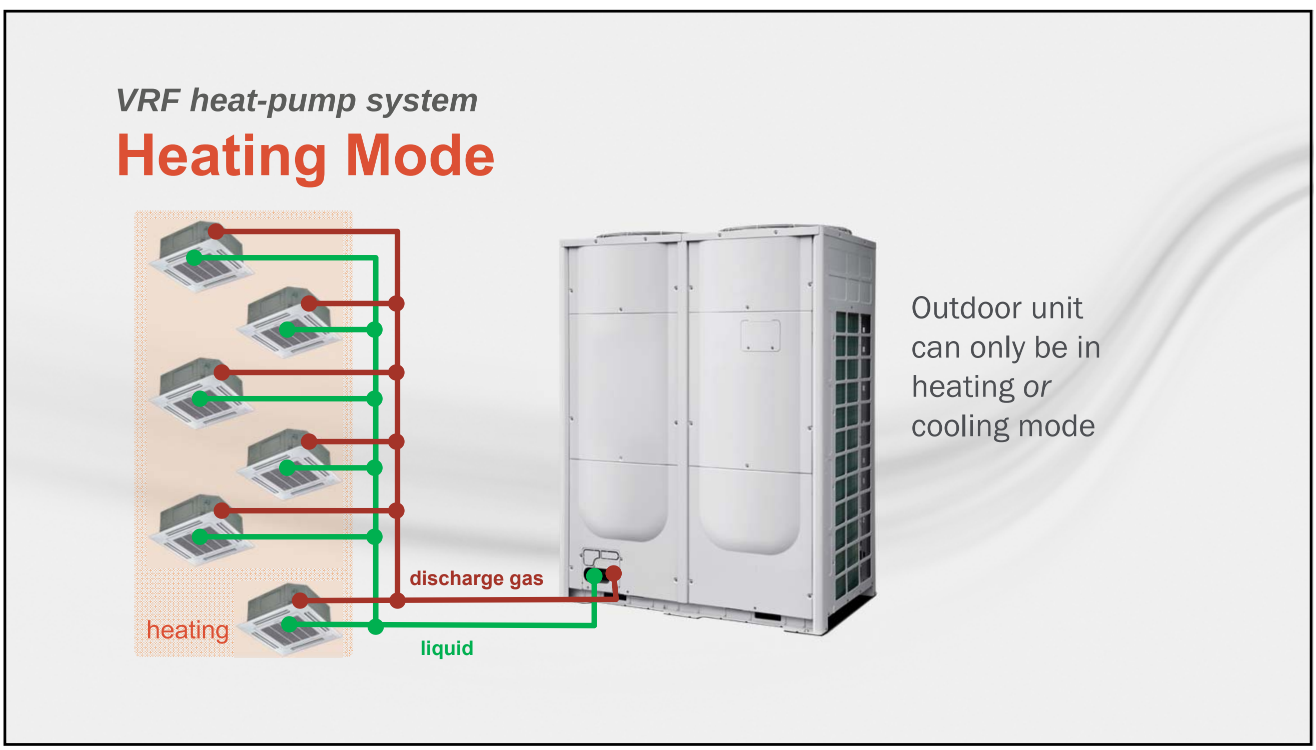
- Each indoor unit requires a condensate drain

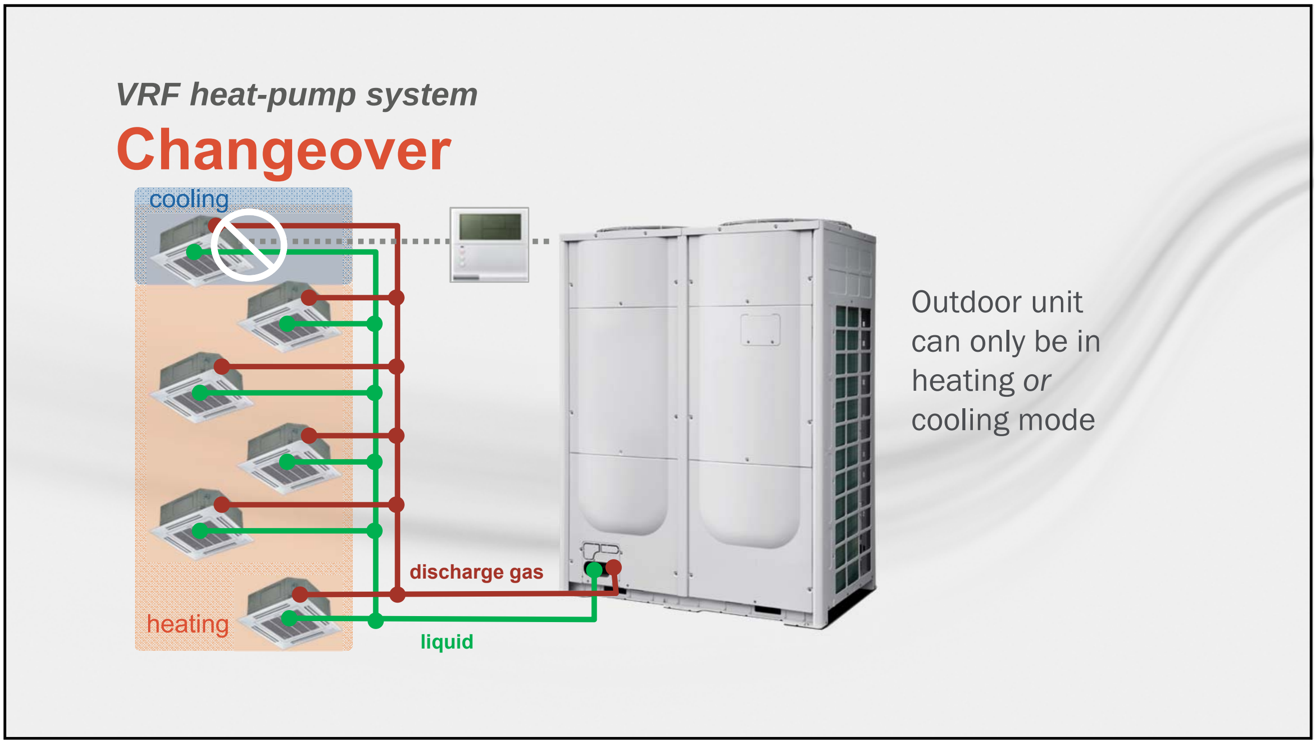



typical controls
Small Building
indoor units
outdoor unit
wired remote
wireless remote

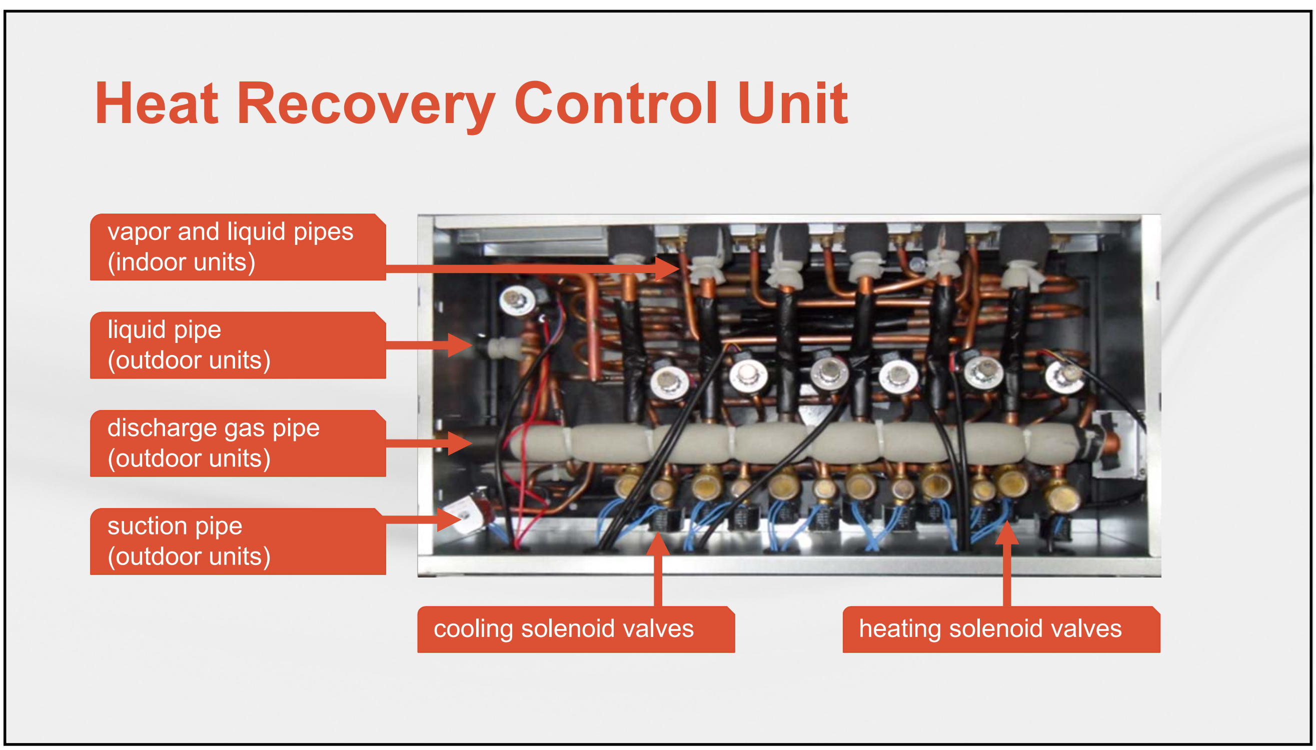

typical controls
Large Building
VRF system controller
outdoor unit
indoor units
wired RC
wired RC
wireless RC
wired RC
wireless RC
signal receiver


typical controls
Campus
VRF system
Controller + BACnet
power meter
interface module
wired
RC
wired
RC
BAS
Web
interface
wireless
RC
wired
RC
wireless
RC
signal
receiver
equipment
system
controller
outdoor
air unit
any equipment!

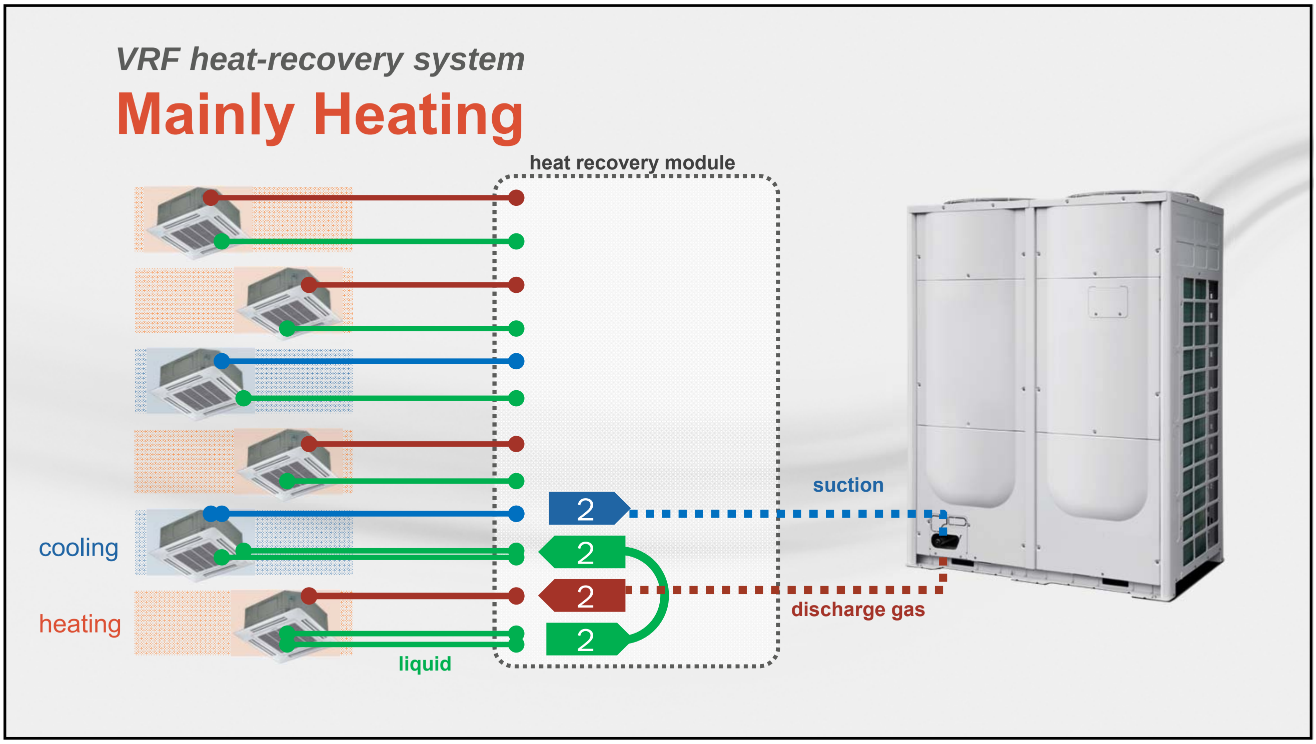

VRF heat-pump system
Heating Mode
Outdoor unit
can only be in
heating or
cooling mode
discharge gas
heating
liquid



VRF heat-pump system
Changeover
cooling
heating
discharge gas
liquid
Outdoor unit can only be in heating *or* cooling mode



Heat Recovery Control Unit
vapor and liquid pipes (indoor units)
liquid pipe (outdoor units)
discharge gas pipe (outdoor units)
suction pipe (outdoor units)
cooling solenoid valves
heating solenoid valves

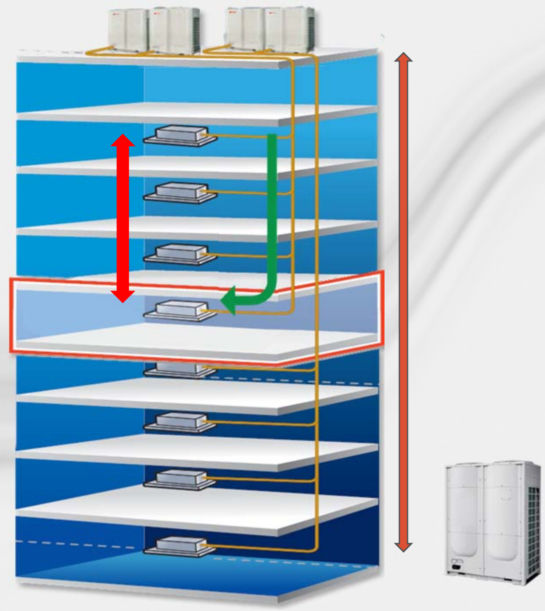

VRF heat-recovery system
Mainly Heating
heat recovery module
suction
2
2
2
2
cooling
heating
discharge gas
liquid


VRF system
Combination Ratio
3 tons
3 tons
2 tons
2 tons
8 tons
10/8 = 125%
Combination Ratio = Σ indoor tonnage / Σ outdoor tonnage

Piping Limits

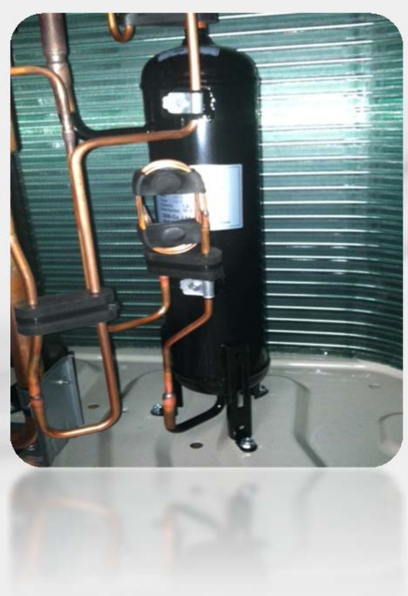
- Total elevation (may be less if outdoor unit is on the ground)
- Maximum separation between indoor units
- Maximum distance between first branch and farthest indoor unit
- Total piping length

NOTE: All of these limits vary by manufacturer and specific application



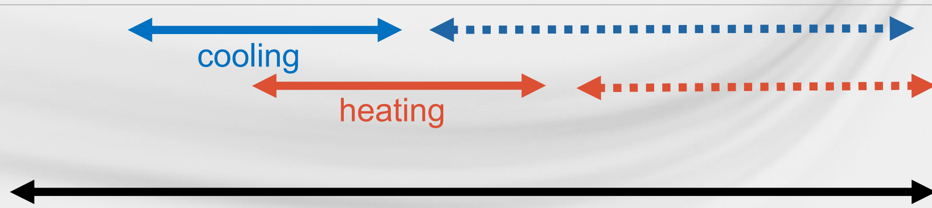
Oil Management

- Compressor oil retention and storage
- Cyclone oil separator
- Oil recovery cycles



Inverter/Compressor Operating Range

Hz	20	40	60	80	100	120	140
RPM	1200	2400	3600	4800	6000	7200	8400



VRF system

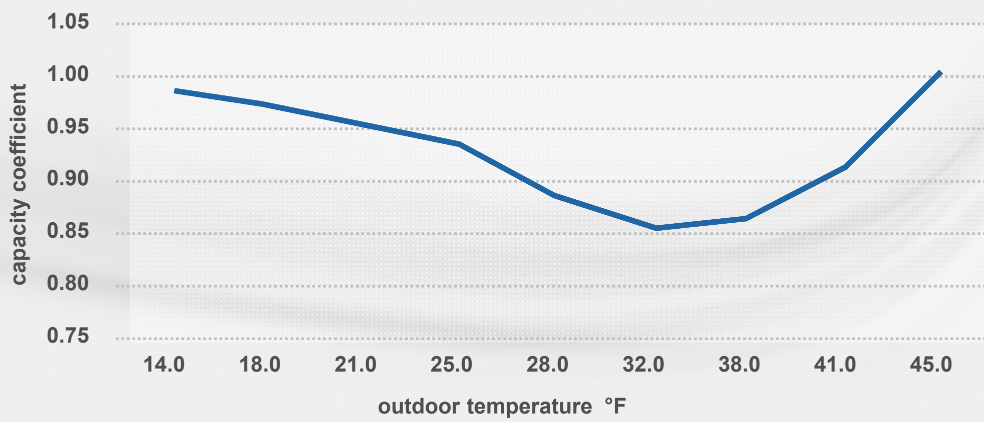
Defrost Cycles

Master	Sub 1	Sub 2
Heating	Heating	Heating
Defrost	Heating	Heating
Heating	**Defrost**	Heating
Heating	Heating	**Defrost**
Heating	Heating	Heating

Rotation

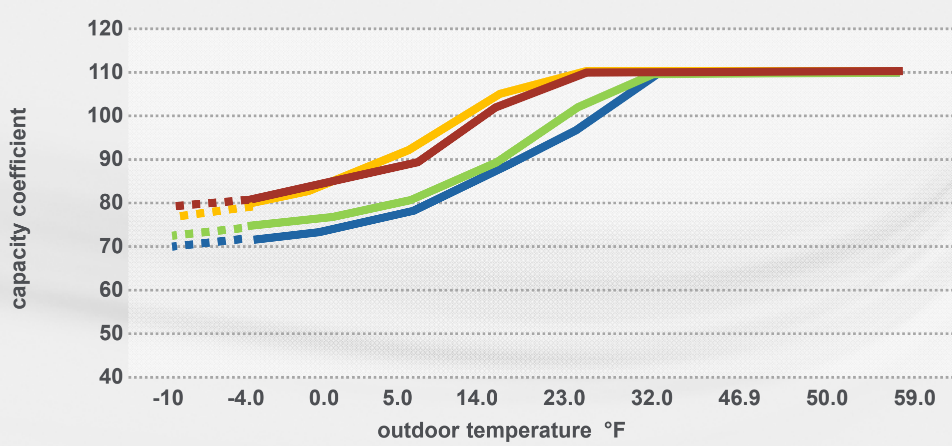
VRF system defrost cycles

Defrost Correction Factor



VRF system

Heating Capacity Loss Under Low Ambient Conditions



AGENDA

- VRF overview
- Technology and operation considerations
- **ASHRAE Standard 15**
- ASHRAE Standard 90.1
- ASHRAE Standard 62.1
- Zoning
- Modeling considerations
- Summary

Standard 15 and VRF

- Does Standard 15 apply to VRF?
- Overview of the standard
- Review example case

why Standard 15?

ANSI/ASHRAE Standards

Standard 15-2013:

Safety Standard for Refrigeration Systems

Standard 15 and VRF

standard

model code

state law

influential

enforceable

why Standard 15?

Enforceability

2012 IMC section 1101.6 General.
"Refrigeration systems shall comply with the requirements of this code and, except as modified by this code, ASHRAE 15. Ammonia-refrigerating systems shall comply with this code and, except as modified by this code, ASHRAE 15 and IIAR 2."

why Standard 15?

Summary

- Adopted by reference into model codes
- Enforced via state codes
- Details vary by jurisdiction

Standard 15 and VRF

- Why Standard 15 is appropriate
- **Structure and substance of Standard 15**
- Applying Standard 15 to VRF systems

Standard 15 substance and structure

Purpose and Scope

"… specifies safe design, construction, installation, and operation of refrigeration systems"

"… establishes safeguards for life, limb, health, and property and prescribes safety requirements"

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Applicability

New construction:

" … the design, construction, test, installation, operation and inspection of mechanical and absorption refrigeration systems, including heat pumps systems used in stationary applications"

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Applicability

Certain replacements:

"… modifications including replacement of parts or components if they are not identical in function and capacity …"

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Applicability

Certain conversions:

"… and to substitutions of refrigerant having a different designation"

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Classification Criteria

- **Building occupancy**
  - Speed of evacuation
- **Refrigerating system**
  - Probability of occupant exposure
- **Refrigerant safety**
  - Permissible human exposure level

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Building Occupancy

- Institutional
- Public assembly
- Residential
- Commercial
- Large mercantile
- Industrial

Share rules

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

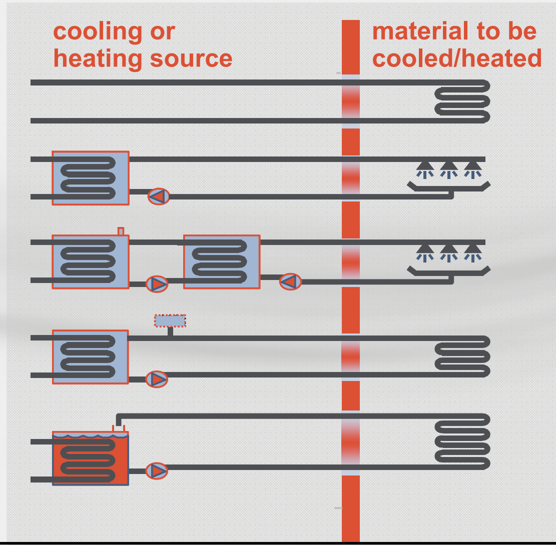
Building Occupancy

- **Institutional**
  - Occupant impairment prevents quick exit
- **Industrial**
  - Restricted access and worker training
- **Mixed**
  - Two or more occupancy types within the same building
  - Requires space and system isolation

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Refrigerating System



SYSTEM TYPE	SYSTEM CLASSIFICATION
direct	high probability
indirect open spray	high probability (conditional)
double indirect open spray	low probability
indirect closed	low probability
indirect vented closed	low probability

ANSI/ASHRAE Standard 34-2013

Safety Criteria

- Flammability:
  3 classes
  (plus one subclass)
- Toxicity:
  2 classes

Designation and Safety Classification of Refrigerants

ANSI/ASHRAE Standard 34-2013

Flammability Criteria

- Class 1
  No flame propagation
- Class 2
  Flammable, high LFL
  - Class 2L (low flame speed)
- Class 3
  Flammable, low LFL

Designation and Safety Classification of Refrigerants

LFL: Lower Flammability Limit

ANSI/ASHRAE Standard 34-2013

Toxicity Criteria

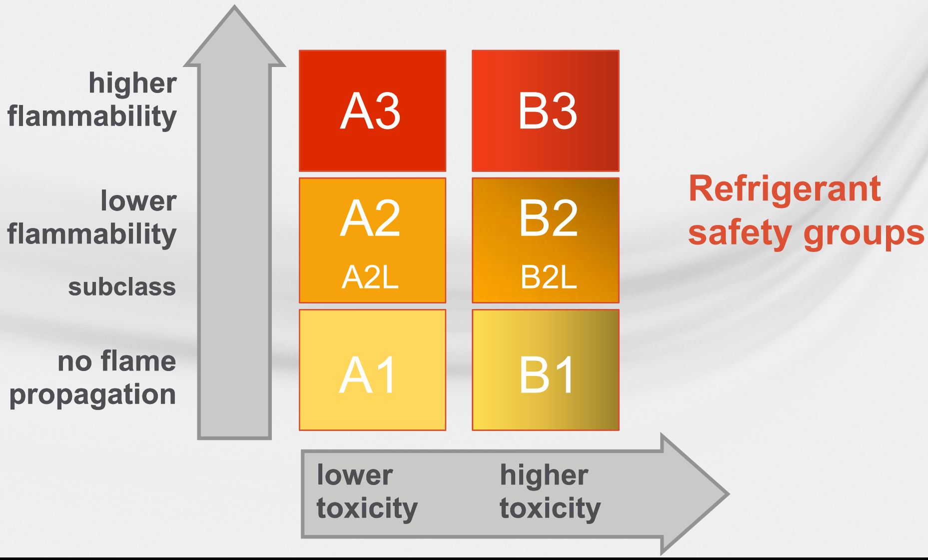
Occupational Exposure Limit (OEL)

- Class A
  Lower toxicity
  OEL ≥ 400 ppm
- Class B
  Higher toxicity
  OEL < 400 ppm

Designation and Safety Classification of Refrigerants

ANSI/ASHRAE Standard 34-2013

Safety Classifications



ANSI/ASHRAE Standard 34-2013

Refrigerant Concentration Limit

RCL based on:

- Toxicity
- Flammability
- Oxygen deprivation

Designation and Safety Classification of Refrigerants

ANSI/ASHRAE Standard 34-2013

Refrigerant/Blend Data

refrig number	chemical name or composition (% by weight)	composition-designating prefix	RCL (lb/Mcf)	safety group
methane series				
R-11	trichlorofluoromethane	CFC	0.39	A1
R-12	dichlorodifluoromethane	CFC	5.6	A1
R-22	chlorodifluoromethane	HCFC	13	A1
ethane series				
R-123	2,2–dichloro–1,1,1–trifluoroethane	HCFC	3.5	B1
R-134a	1,1,1,2–tetrafluoroethane	HFC	13	A1
R-152a	1,1–difluoroethane	HFC	2.0	A2
zeotropes				
R-407C	R-32/R-125/R-134a (23/25/52)	HFC	17	A1
R-410A	R-32/R-125 (50/50)	HFC	25	A1

ANSI/ASHRAE Standard 15-2013

Summary

- Occupancy, system type, and refrigerant safety classification determine rules for the application
- Rules provide guidance
- Standard 15 is not a design manual

Safety Standard for Refrigeration Systems

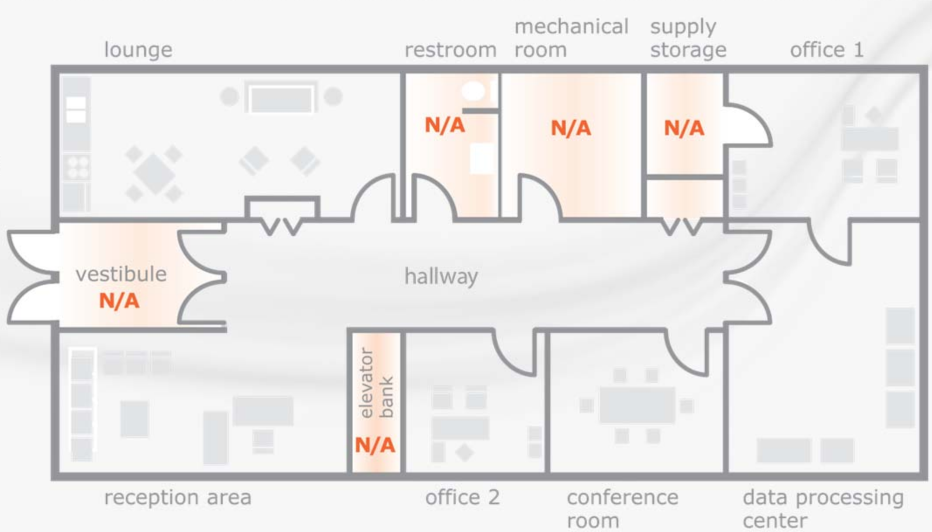
Standard 15 and VRF

- Why Standard 15 is appropriate
- Structure and substance of Standard 15
- **Applying Standard 15 to VRF systems**

Standard 15-2013

Applied to VRF

Example building



Standard 15-2013

Applied to VRF

Example building details:

- One outdoor unit, 6 indoor units
- Commercial occupancy
- Direct (high probability) system
- Refrigerant R410A
  - Safety group A1
  - RCL 26 per Standard 34-2013,
    RCL 25 per International Mechanical Code

ANSI/ASHRAE Standard 15-2013

Refrigerant Quantity Limit

High-probability systems:

- Must not exceed ASHRAE Standard 34 Refrigerant Concentration Limit (RCL)
- Special considerations for institutional and industrial occupancies (Sections 7.2.1, 7.2.2)
  - 50% of RCL for institutional

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Refrigerant Quantity Limit

Compliance with RCL:

Step 1: Determine proper RCL
(lb per 1000 cubic feet)

Step 2: Calculate total lb of refrigerant that could leak

Step 3: Determine space volume available for dilution
(Section 7.3)

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Quantity of Refrigerant

Refrigerant quantity for calculation:

- Use pounds refrigerant in largest circuit
  - Not sum of all circuits
- If two circuits in one room …
  - Use the one with most refrigerant unless different types of refrigerant are used
  - If different refrigerants, check both

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Quantity of Refrigerant

Refrigerant quantity for calculation:

- RCL check done prior to installation
- Requires accurate charge estimate
    - Charge in condensing unit plus
    - Charge in refrigerant pipe
- Estimated charge for example building is 31 lb

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Occupied Volume

Nonconnecting spaces (Section 7.3.1)
(Refrigeration system components in occupied space)

- No permanent openings, not ducted
- Use volume of smallest occupied space
- Limit height to 8.2 ft for spaces on different levels

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Occupied Volume

Nonconnecting spaces (Section 7.3.1)
(Refrigeration system components in occupied space)

- Volume = height x width x length
- Ignore furniture
- Exclude space that can be isolated
  - Closets
  - Hotel bathroom

Safety Standard for Refrigeration Systems

ANSI/ASHRAE Standard 15-2013

Occupied Volume

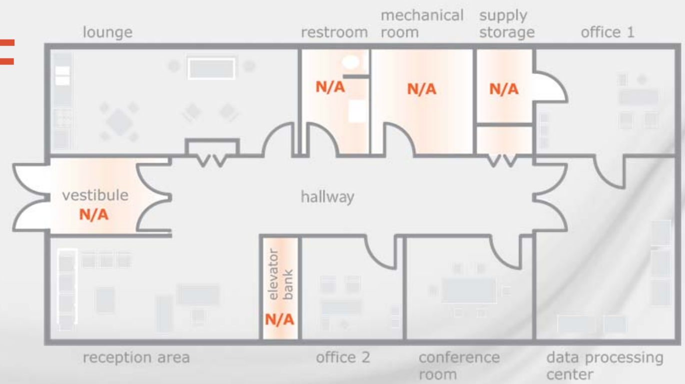
Ventilated spaces (Section 7.3.2)
(Refrigeration system components in air handler/ductwork)

- Sum occupied space volumes served
- Include rooms, plenums, and ductwork
- Omit spaces that can be isolated
  - Fire/smoke dampers excluded

Safety Standard for Refrigeration Systems

Standard 15-2013

Applied to VRF



For Office 2:

$$\frac{\text{lbs in system} \times 1000}{\text{Room volume}} = \frac{31 \times 1000}{10 \times 10 \times 9} = 34 \text{ lbs/1000ft}^3$$

For Conference room:

$$\frac{\text{lbs in system} \times 1000}{\text{Room volume}} = \frac{31 \times 1000}{10 \times 14 \times 9} = 24.6 \text{ lbs/1000ft}^3$$

ANSI/ASHRAE Standard 15-2013

Equipment Location

From Standard 15, Section 7.4:

Place all refrigeration components in a “machinery room” or outdoors if:

- Refrigerant exceeds allowable quantity
- Direct-fired absorption is used

Safety Standard for Refrigeration Systems

applying Standard 15-2013

Meeting the RCL

- Reduce refrigerant quantity
  - Serve office 2 with separate unit
  - Serve building with two units
- Increase dilution volume?

Safety Standard for Refrigeration Systems

applying Standard 15-2013

Meeting the RCL

Quote from July 2012 *ASHRAE Journal* article titled, “Applying VRF? Don’t Overlook Standard 15”

Does an undercut door or a transfer opening qualify as a permanent opening? If so, how large an undercut or transfer opening would be needed to qualify? These questions are not specifically addressed in Standard 15, neither to affirm nor disqualify. Clearly, undercut doors or transfer openings would *eventually* permit a large leak of refrigerant in one small room to disperse to adjacent rooms. However, without detailed study or modeling, we do not know that this will occur quickly enough to protect the safety of the room’s occupants. Keep in mind that the driving force expelling R-410A from a ruptured refrigerant pipe is on the order of 450 psi (3.1 MPa), but the driving force pushing transfer air under a door or through a transfer opening is five or six orders-of-magnitude less. Ceiling-mounted transfer ducts are even more suspect, since most commonly-used refrigerants are heavier than air.

Also see Interpretation IC 15-2010-1 of ANSI/ASHRAE Standard 15-2010

Safety Standard for Refrigeration Systems

applying Standard 15-2013

Meeting the RCL

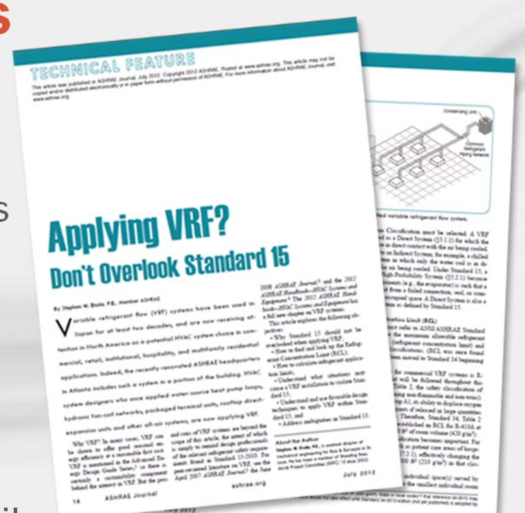
- Serve office 2 with ducted unit
- Dilution volume per ventilated spaces
    - Can include all spaces served

Safety Standard for Refrigeration Systems

applying Standard 15-2013

Additional Restrictions

- Section 7.5 Additional Restrictions
    - Refrigerant limited in corridors and lobbies
- Section 8 Installation Requirements
    - Refrigerant pipe installation restrictions
- ASHRAE article provides detail


TECHNICAL FEATURE

Applying VRF?

Don't Overlook Standard 15

Standard 15-2013 and VRF

Summary

Standard 15:

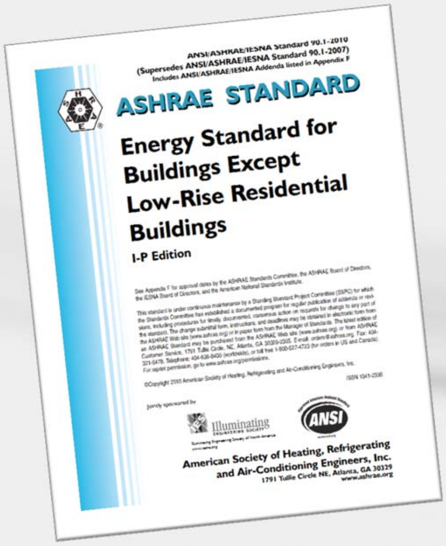
- Applies to all refrigeration equipment
- VRF requirements are not new
- Promotes safety for all systems

Safety Standard for Refrigeration Systems

AGENDA

- VRF overview
- Technology and operation considerations
- ASHRAE Standard 15
- **ASHRAE Standard 90.1**
- ASHRAE Standard 62.1
- Zoning
- Modeling considerations
- Summary

ASHRAE Standard 90.1-2010



- Minimum equipment efficiencies
- Fan power limitation
- Economizers
- Exhaust-air energy recovery

AHRI Standard 1230

Defines:

- Method of testing VRF equipment
- Standard rating conditions
- Published data required

Basis for ASHRAE 90.1 minimum efficiency requirements

ASHRAE 90.1-2010, Section 6.4.1 (mandatory)

Minimum Equipment Efficiencies

- VRF products added with 2010 edition
  (addenda to 2007 edition)
- Includes both cooling and heating efficiencies
- Includes both full-load and part-load efficiencies

"Where multiple rating conditions or performance requirements are provided, the equipment shall satisfy all stated requirements…"

ASHRAE 90.1-2010, Table 6.8.1J

VRF Air Cooled (Cooling Mode)

Size (Btu/hr)	Type	Minimum Efficiency
< 65,000	VRF Heat Pump	13.0 SEER
≥ 65,000 and < 135,000	VRF Heat Pump	11.0 EER and 12.9 IEER
	VRF Heat Recovery	10.8 EER and 12.7 IEER
≥ 135,000 and < 240,000	VRF Heat Pump	10.6 EER and 12.3 IEER
	VRF Heat Recovery	10.4 EER and 12.1 IEER
≥ 240,000	VRF Heat Pump	9.5 EER and 11.0 IEER
	VRF Heat Recovery	9.3 EER and 10.8 IEER

ASHRAE 90.1-2010, Table 6.8.1J

VRF Air Cooled (Heating Mode)

Size (Btu/hr)	Type/OA Condition	Minimum Efficiency
< 65,000	VRF Heat Pump	7.7 HSPF
≥ 65,000 and < 135,000	VRF Heat Pump 47°F DBT/43°F WBT	3.3 COP
	VRF Heat Pump 17°F DBT/15°F WBT	2.25 COP
≥ 135,000	VRF Heat Pump 47°F DBT/43°F WBT	3.2 COP
	VRF Heat Pump 17°F DBT/15°F WBT	2.05 COP

Efficiency Ratings

SEER (Seasonal Energy Efficiency Ratio)

- Season of cooling / Season of power

EER (Energy Efficiency Ratio)

- Cooling output / Input power @ AHRI rating condition

IEER (Integrated Energy Efficiency Ratio)

- Time-weighted efficiency calculation @ 100%, 75%, 50%, and 25% load conditions (defined in AHRI 1230)

Efficiency Ratings

HSPF (Heating Seasonal Performance Factor)

- Season of heating / Season of power

COP (Coefficient of Performance)

- Heating output / Input power @ AHRI rating condition

SCHE (Simultaneous Cooling and Heating Efficiency)

- Efficiency metric when zone cooling and heating loads are closely balanced

Performance Rating Standards

Useful for:

- Comparing products *within the same family* (e.g., VRF to VRF)
- Setting code-mandated minimum efficiency thresholds for a product

Not useful for:

- Comparing products *from different families* (e.g., VRF to WSHP)
- Depicting operation in an actual building

Standard 90.1-2010 User's Manual **(pp. 6-13 and 6-14):**

"The equipment efficiencies listed … are for standard rating conditions. Actual efficiency will vary depending on how the equipment is applied and how it is controlled."

"Also, the equipment efficiency data in the tables apply only to the equipment itself and not to any other equipment that may be required to complete the system. When determining which type of system to select, it is usually not possible to compare efficiency of different equipment types simply by looking at the values in the table."

"Even a direct comparison of seemingly like energy descriptors may be misleading because of differences in rating conditions or definitions."

"Often an energy analysis at the level of detail required by Section 11 is the only way to make an accurate comparison."

ASHRAE 90.1-2010, Section 6.5.3.1 (prescriptive)

Fan System Power Limitation

Applies to "fan systems" > 5 hp

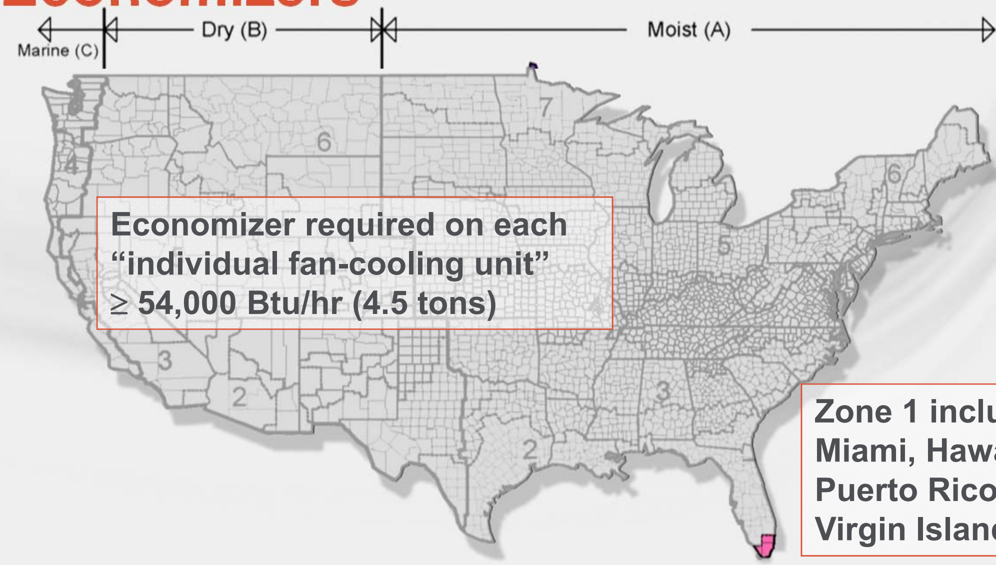
	Fan Power Limitation	
Option	**Constant Volume**	**Variable Volume**
1) Nameplate hp	hp ≤ CFMs x 0.0011	hp ≤ CFMs x 0.0015
2) Fan System bhp	bhp ≤ CFMs x 0.00094 + A	bhp ≤ CFMs x 0.0013 + A

Which fans' power apply to a VRF system?

(see example 6-DDD, *ASHRAE 90.1-2010 User's Manual*)

ASHRAE 90.1-2010, Section 6.5.1 (prescriptive)

Economizers



Economizer required on each "individual fan-cooling unit" ≥ 54,000 Btu/hr (4.5 tons)

Zone 1 includes Miami, Hawaii, Guam, Puerto Rico, and Virgin Islands

Standard 90.1-2010 User's Manual

Example 6-II

"…all but large (heat pumps) are exempted by Exception a and Table 6.5.1A. For this example… heat pumps below 4.5 tons (54,000 Btu/h or 16 kW) would not have to have economizers"

ASHRAE 90.1-2010, Section 6.5.1 (economizers)

VRF Indoor Units ≥ 4.5 Tons

- An airside economizer will likely be difficult to implement with a dedicated outdoor-air system
  - *"Air economizers shall …provide up to 100% of the design supply air quantity as outdoor air for cooling"*
  - OA duct is typically sized for minimum ventilation only
- Use Energy Cost Budget method (computer simulation)
- Exception i: Eliminate economizer by installing higher-efficiency VRF equipment

Climate Zone	Cooling Efficiency Improvement Required to Eliminate Economizer
2A	17%
2B	21%
3A	27%
3B	32%
3C	65%
4A	42%
4B	49%
4C	64%
5A	49%
5B	59%
5C	74%
6A	56%
6B	65%
7	72%
8	77%

ASHRAE 90.1-2010 Table 6.3.2

ASHRAE 90.1-2010, Table 6.3.2

Efficiency Improvement Applies to IEER

"If a unit is rated with an IPLV, IEER or SEER, then to eliminate the required air or water economizer, the minimum cooling efficiency of the HVAC unit must be increased by the percentage shown [in Table 6.3.2].*"*

ASHRAE 90.1-2010, Section 6.5.6.1 (prescriptive)

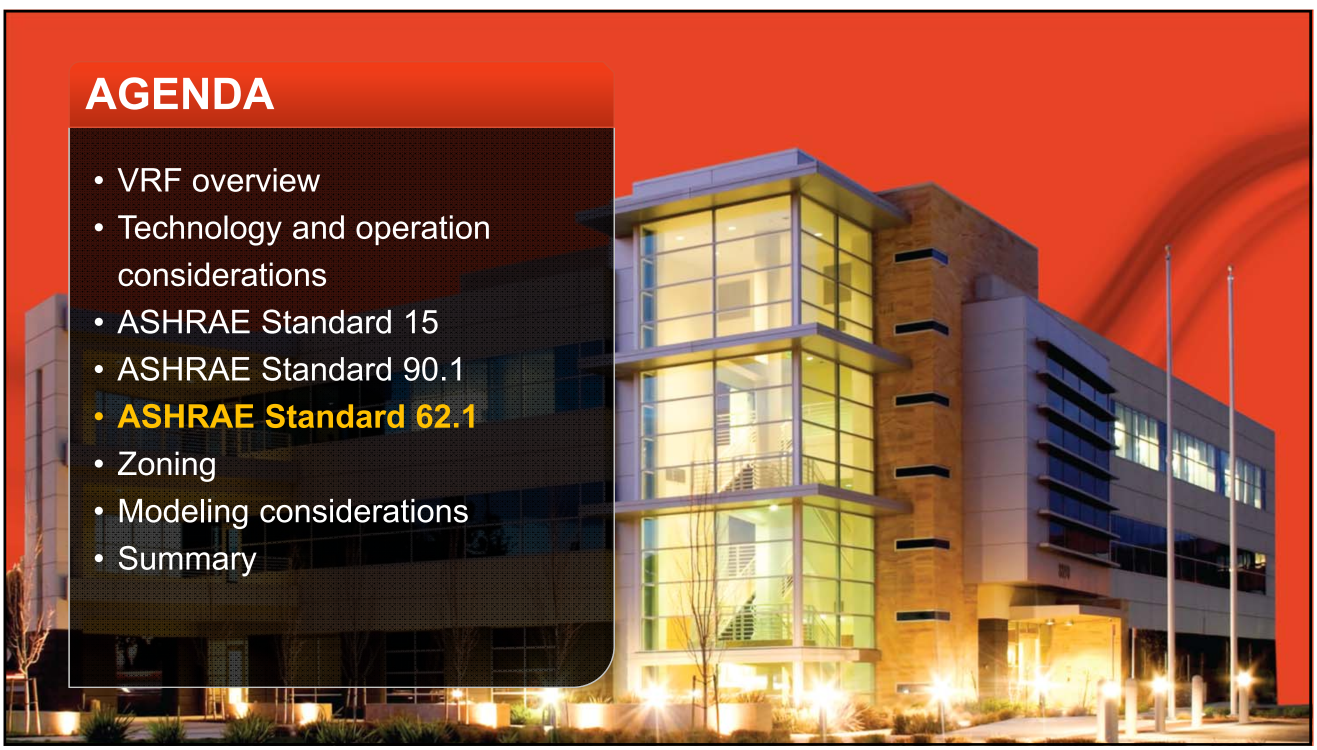
Exhaust-Air Energy Recovery

Climate Zone	% *Outdoor air* at full design airflow rate					
	≥ 30% and < 40%	≥ 40% and < 50%	≥ 50% and < 60%	≥ 60% and < 70%	≥ 70% and < 80%	≥ 80%
	Design supply fan airflow rate (cfm)					
3B, 3C, 4B, 4C, 5B	NR	NR	NR	NR	≥5000	≥5000
1B, 2B, 5C	NR	NR	≥26000	≥12000	≥5000	≥4000
6B	≥11000	≥5500	≥4500	≥3500	≥2500	≥1500
1A, 2A, 3A, 4A, 5A, 6A	≥5500	≥4500	≥3500	≥2000	≥1000	>0
7, 8	≥2500	≥1000	>0	>0	>0	>0

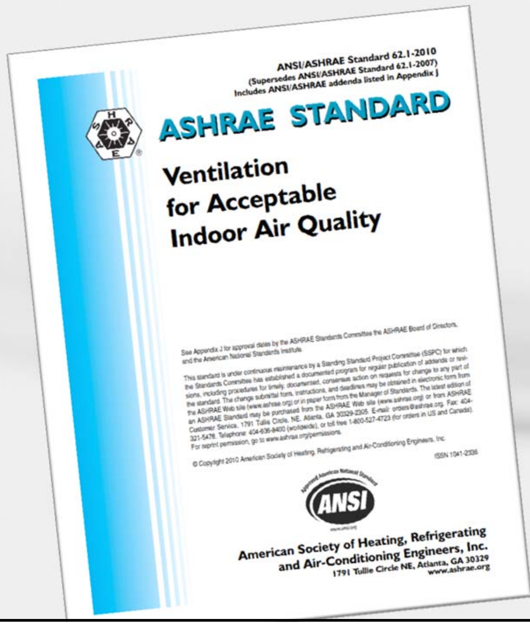
summary

VRF and ASHRAE 90.1

- Minimum cooling and heating efficiencies, at both full load and part load … all must be met
- Fan power limitation rarely applies, since the 5 hp threshold is seldom exceeded
- Economizers are typically not required, since indoor VRF units are rarely ≥ 4.5 tons
- Exhaust-air energy recovery likely required in DOAS

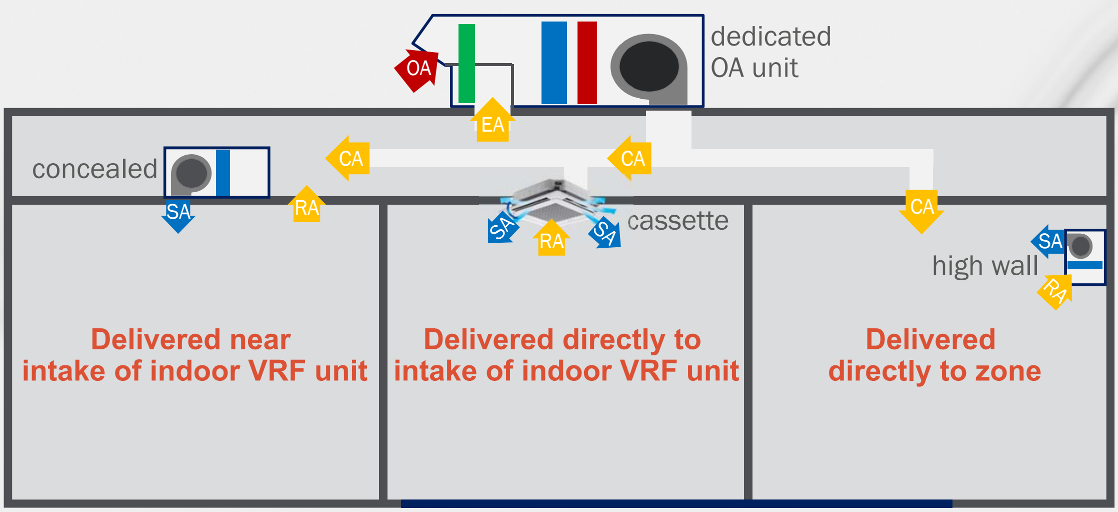


ASHRAE Standard 62.1-2010



- Distribution of OA to zones (delivery to ceiling plenum?)
- Demand-controlled ventilation

OA Delivery Configurations



conditioned OA delivered

Near Intake of Each Indoor Unit

Advantages

- Avoids cost and space to install additional ductwork and separate diffusers

conditioned OA delivered

Near Intake of Each Indoor Unit

Drawbacks

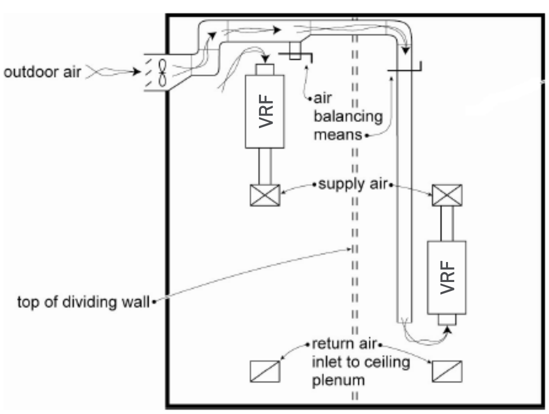
- More difficult to ensure required OA reaches each zone (not ducted directly)
- May need to account for zone air-distribution effectiveness (E_z) during heating mode
- Local fan must operate continuously to provide OA during scheduled occupancy
- Conditioned OA may not be able to be delivered at a cold temperature due to concerns over condensation

ASHRAE 62.1-2010, Section 5.1.2

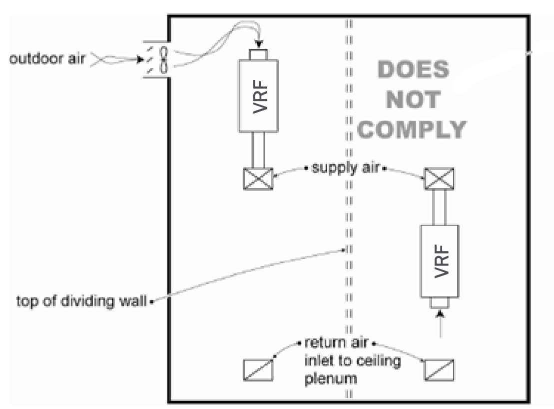
Plenum Systems

"When the ceiling or floor plenum is used both to recirculate return air and to distribute ventilation air to ceiling-mounted or floor-mounted terminal units, the system shall be engineered such that ***each space is provided with its required minimum ventilation airflow****.*

Note: *Systems with direct connection of ventilation air ducts to terminal units, for example, comply with this requirement."*



Plan of Correct Plenum System
Though the ducts are not connected to the terminal units, they discharge near them, with balancing means available to provide correct airflow to each.



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

ASHRAE 62.1-2010 User's Manual, Figures 5-D and 5-E

conditioned OA delivered

Directly to Intake of Each Indoor Unit

Advantages

- Helps ensure required OA reaches each zone (ducted directly to each unit)
- Easier to ensure that OA is adequately dispersed throughout zone because it is distributed by local fan through common diffusers

conditioned OA delivered

Directly to Intake of Each Indoor Unit

Drawbacks

- May require field-fabricated mixing box (or short duct section) to connect OA duct and mix with RA
- May need to account for zone air-distribution effectiveness (E_z) during heating mode
- Local fan must operate continuously to provide OA during scheduled occupancy

ASHRAE 62.1-2010, Section 5.1.1

Designing for Air Balancing

"The ventilation air distribution system shall be provided with means to adjust the system to achieve at least the minimum ventilation airflow as required by Section 6 ***under any load condition****."*

conditioned OA delivered

Directly to Each Zone

Advantages

- Easier to ensure required outdoor airflow reaches each zone (separate diffusers)
- Opportunity to cycle off the local fan (or vary speed) because OA is not distributed through it
- Opportunity to downsize indoor units (if OA delivered cold)

conditioned OA delivered

Directly to Each Zone

Drawbacks

- Requires installation of additional ductwork and separate diffusers
- May require multiple diffusers to ensure outdoor air is adequately dispersed throughout a larger zone

Dedicated OA Equipment

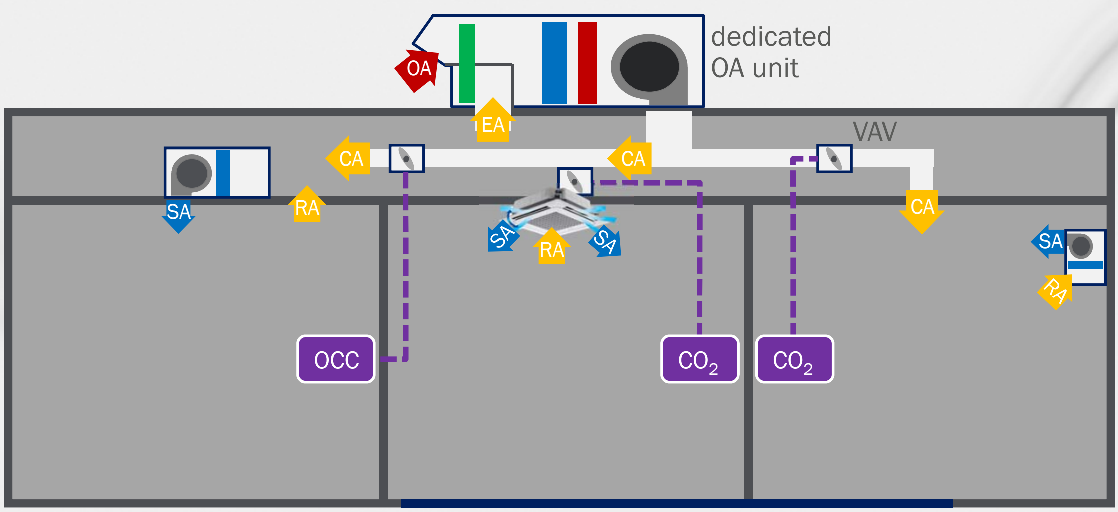
- Unconditioned OA
- Energy recovery ventilator
- Dedicated OA unit
- Standalone DX unit
- AHU connected to the VRF system

ASHRAE 62.1-2010, Section 6.2.7.1

Demand-Controlled Ventilation (DCV)

- Allows reset of V_{oz} based on variation in zone population
- Cannot reset lower than “area” ventilation rate (R_a)
- When dehumidifying, OA intake must exceed exhaust
- Document assumptions, sequences, and setpoints

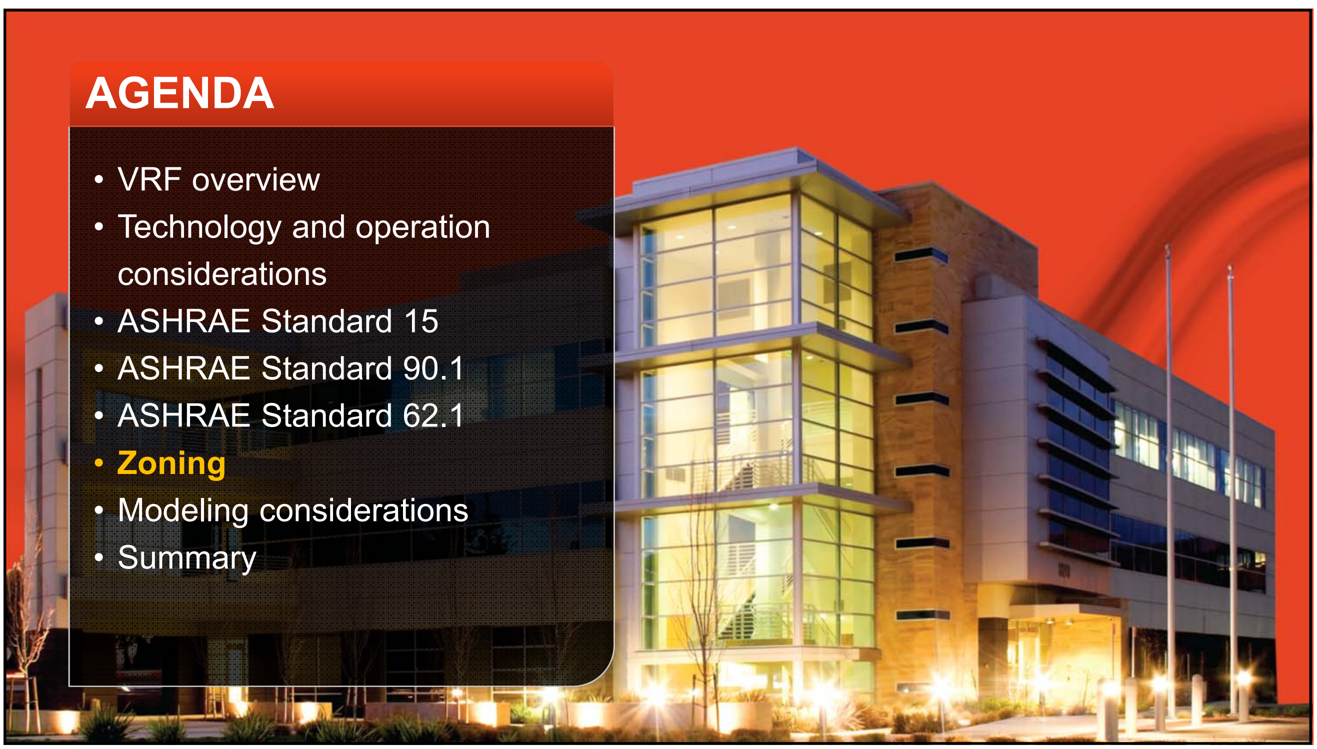
DCV with a Dedicated OA System



summary

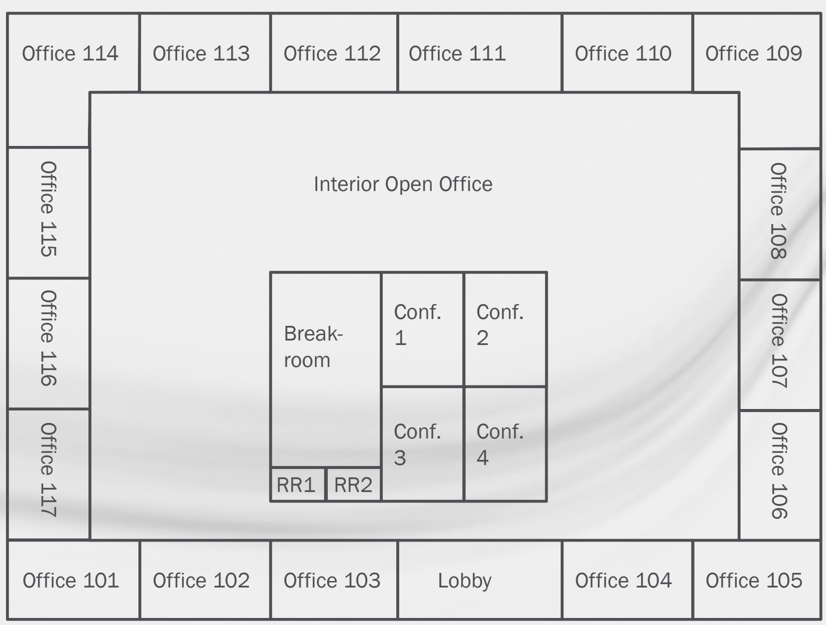
VRF and ASHRAE 62.1

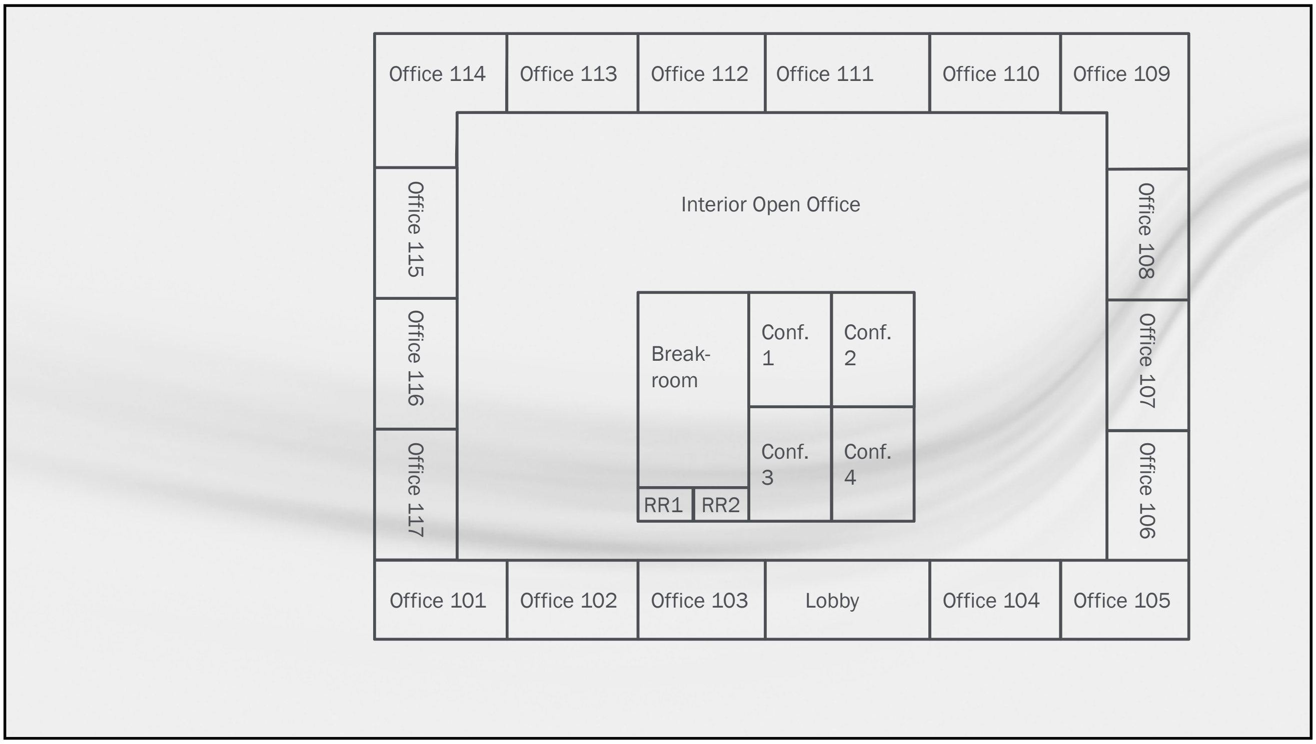
- Various configurations for delivering OA to the zones each have their advantages and challenges
- Whenever possible, deliver conditioned OA directly to each space, at a cold (rather than neutral) temperature
- DCV can be implemented in the dedicated OA system



Zoning

- Selecting multiple indoor units and outdoor units
- Minimize first cost, energy cost, while maintaining indoor comfort
- Heat pump – zone like spaces with similar load profiles

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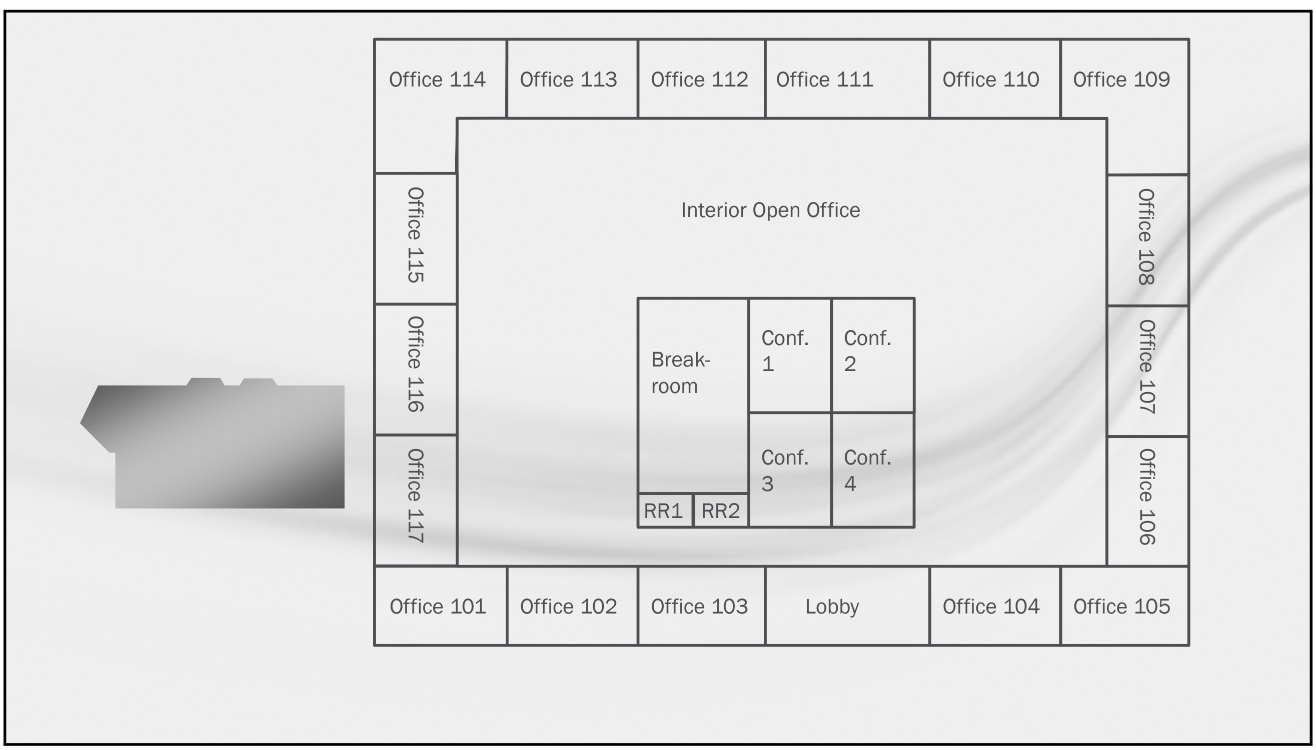
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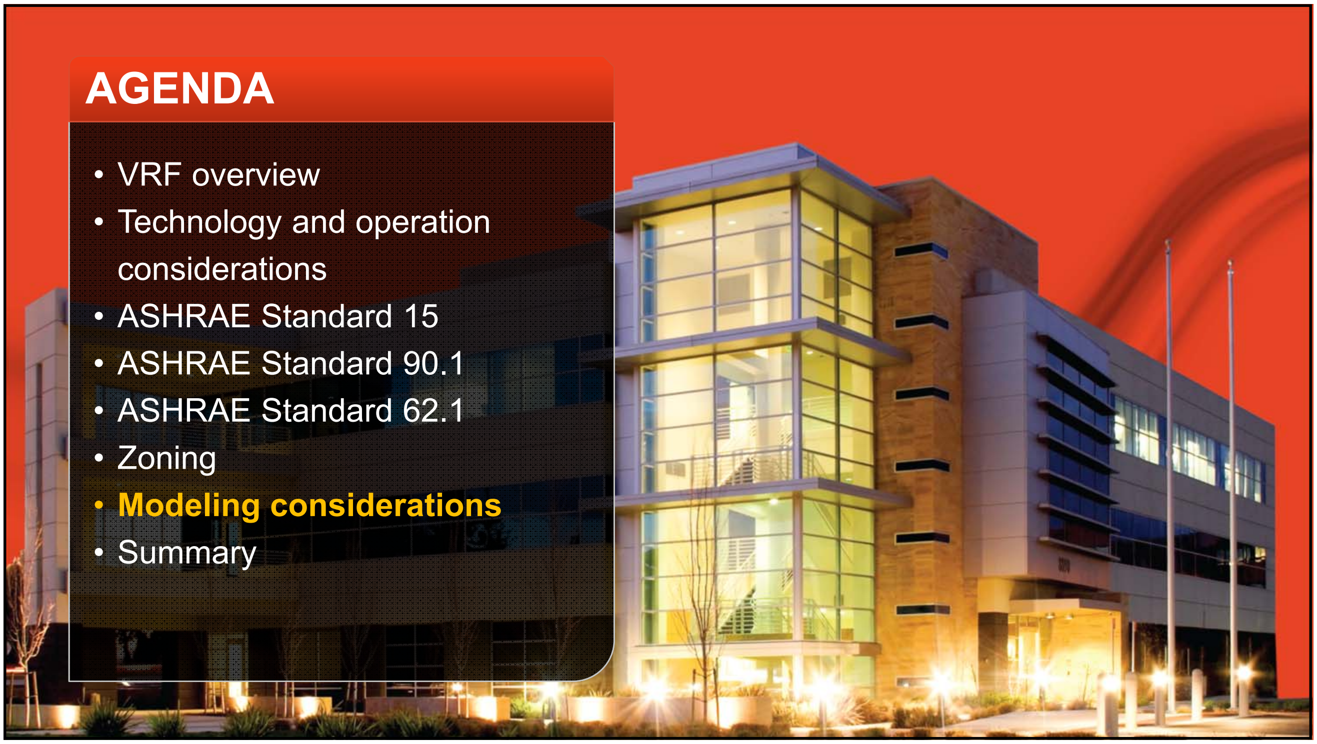


Modeling VRF Systems

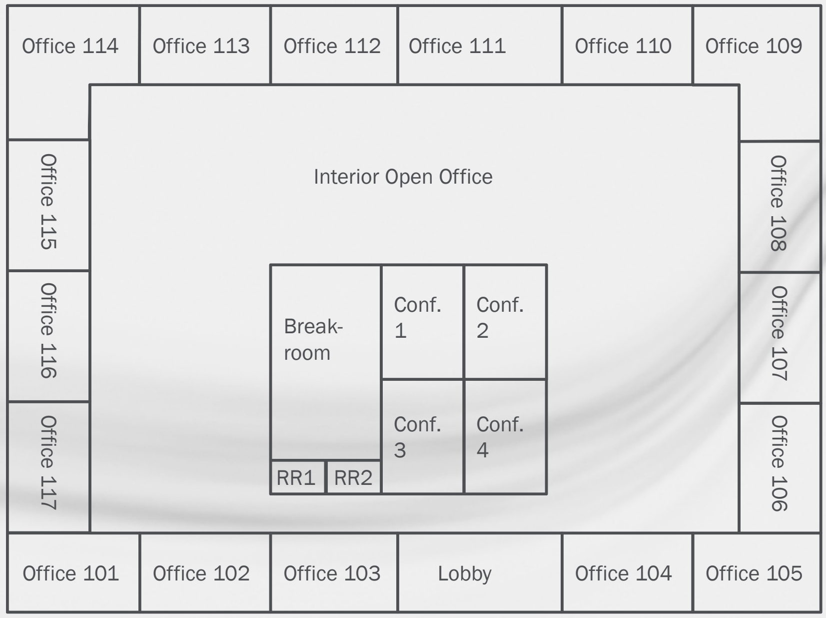
- Building simulation is important for many reasons
  - Code compliance
  - Life cycle cost analyses
  - Green ratings (e.g., LEED)
- AHRI 1230 gives standardized conditions – useful for equipment simulations

Simulation Parameters

- Location: Philadelphia, PA
- Single story office building
- 30,000 square feet
- Design cooling load: 70 tons
- Design heating load: 350 Mbh
- Dedicated DX outdoor air system

Building Outdoor Air System Inputs

- Cooling supply air temperature: 71°F
- Cooling supply air dew point: 55°F
- Heating supply air temperature: 68°F
- Conditioned ventilation air delivered directly to the spaces



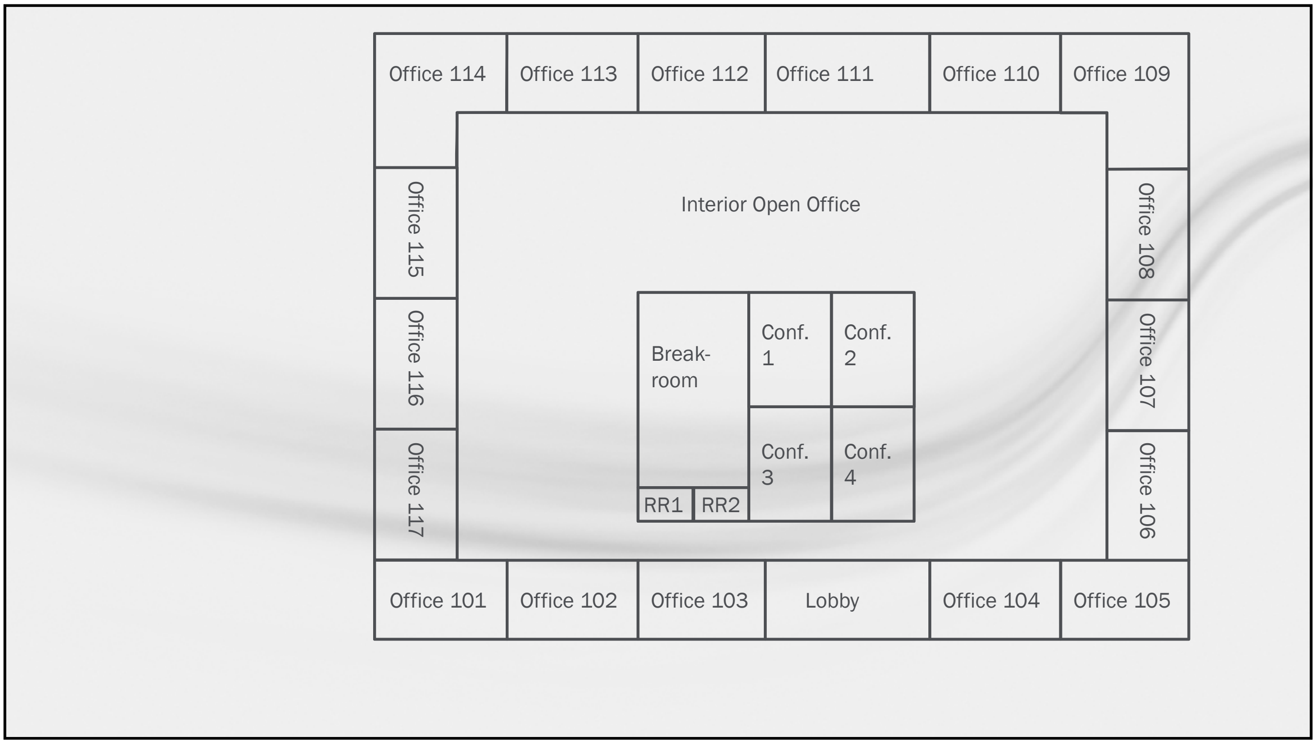
Use Temperature Profile Reports and Unmet Load Hours

BUILDING TEMPERATURE PROFI

By Trane

All hours - Alternative 2

System/Room Description	Unmet Clg Load Hours	---- Maximum ---- Temp	Mo	Hr	Day	--- Number of Hours at each Te >100°	100-95	95-90	90-85	85-80	80-75	75-70
VRF HP West												
3rd Flr 101 Office	0	85	2	18	Hol	0	0	0	0	450	991	5,656
3rd Flr 102 Office	0	85	2	17	Hol	0	0	0	0	459	1,050	5,994
3rd Flr 103 Office	0	85	2	17	Hol	0	0	0	0	459	1,050	5,994
3rd Flr 115 Office	0	85	4	18	Sun	0	0	0	0	391	1,161	6,003
3rd Flr 116 Office	0	85	4	18	Sun	0	0	0	0	391	1,161	6,003
3rd Flr 117 Office	168	85	4	24	Wed	0	0	0	0	1,117	3,624	3,338
3rd Flr Hallway	0	85	6	19	Sun	0	0	0	0	242	1,150	6,455
3rd Flr West Conference Room 1	0	85	4	18	Sun	0	0	0	0	463	2,081	6,139
3rd Flr West Conference Room 2	0	85	4	18	Sun	0	0	0	0	463	2,081	6,139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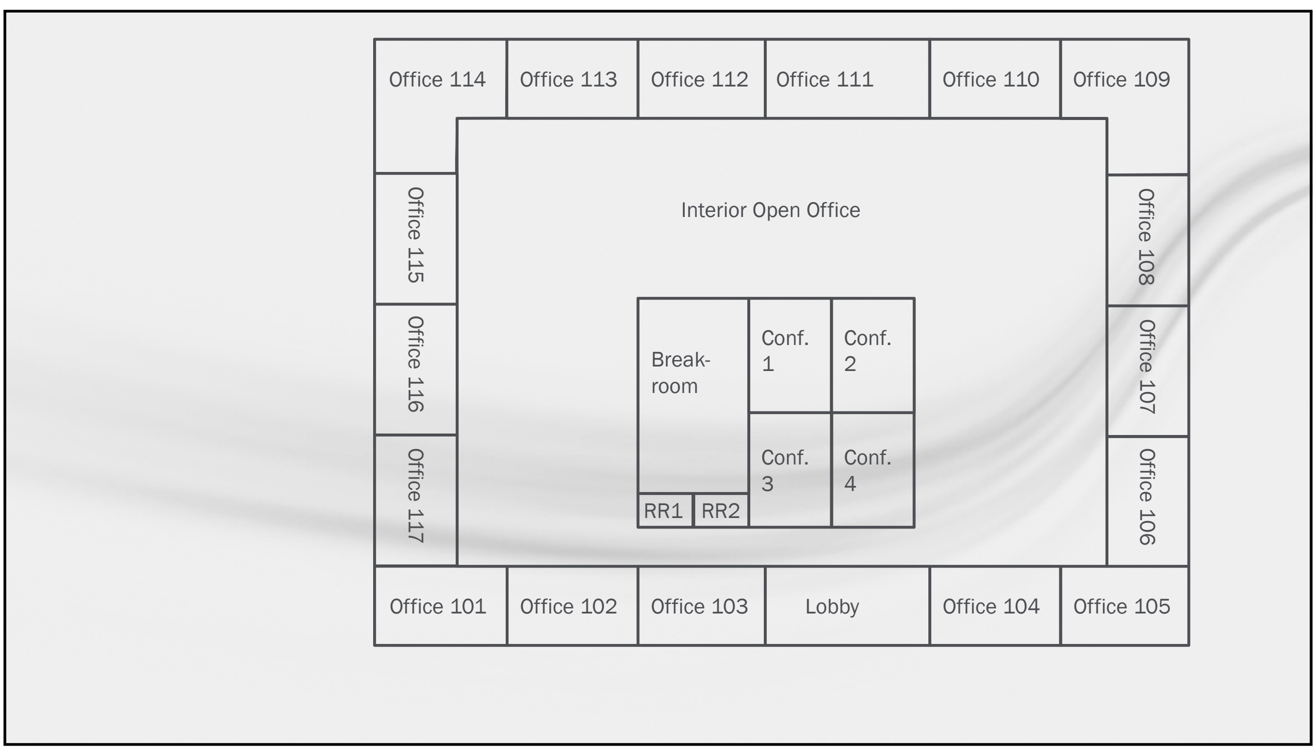
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Simulation Results

- Majority of heating load is handled by the dedicated outdoor air unit
- Limited heating load elsewhere

Modeling VRF System Challenges

- Water-cooled VRF
- Ground-coupled VRF
- Multiple outdoor units piped together
- Defrost operation
- Refrigerant piping
- Oil recovery
- System control

Outdoor Unit Configuration

- Air-cooled
- Water-cooled
- Ground-coupled
- Multiple ground units “ganged” together

modeling VRF system limitations

Defrost Operation

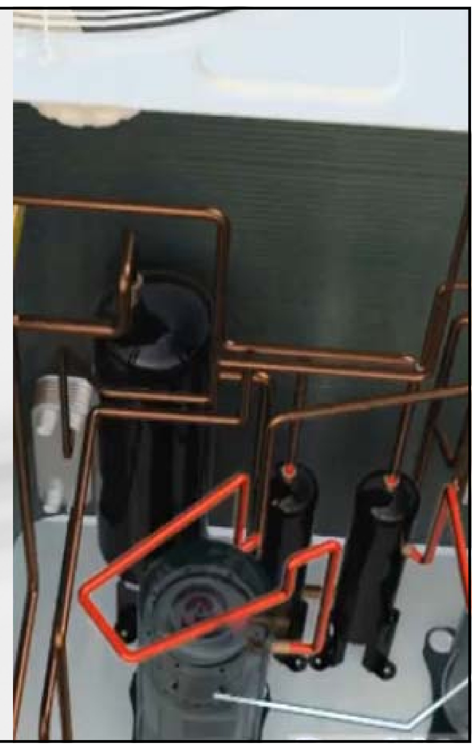
modeling VRF system limitations

Piping Losses and Capacity Degradation

Height Difference , ft (Outdoor – Indoor)	Equivalent Pipe Length (ft)									
	25	33	66	98	131	164	197	230	262	722
164						0.97	0.96	0.95	0.95	0.88
131					0.97	0.97	0.96	0.95	0.95	0.88
98				0.98	0.97	0.97	0.96	0.95	0.95	0.88
66			0.99	0.98	0.97	0.97	0.96	0.95	0.95	0.88
33		0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.95	0.88
0	1.00	0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.95	0.88
-33		0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.95	0.88
-66			0.99	0.98	0.97	0.97	0.96	0.95	0.95	0.88
-98				0.98	0.97	0.97	0.96	0.95	0.95	0.88
-131					0.97	0.97	0.96	0.95	0.95	0.88

modeling VRF system limitations

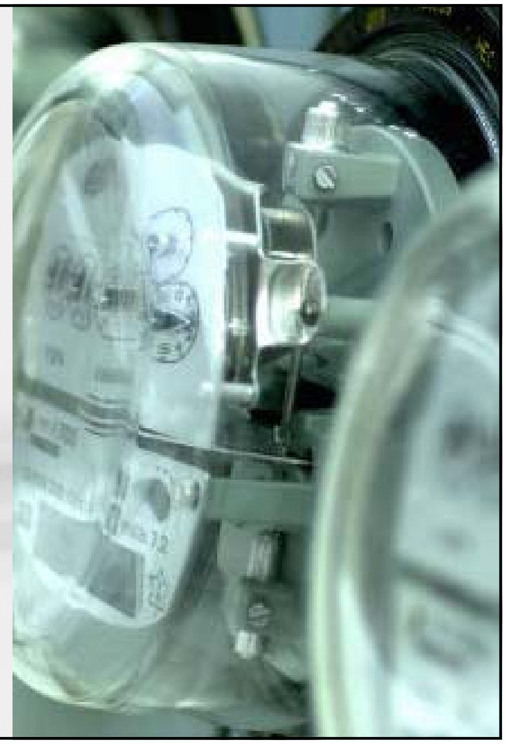
Oil Recovery Operation



modeling VRF system limitations

Packaged Energy Rates

- Packaged energy rates may include compressor, indoor fan, and outdoor fan
- Break energy rates down, if necessary



modeling VRF system limitations

System Control

- System controls are often proprietary
- Simulation programs may not be programed with manufacturer's system controls

Modeling Summary

- Possible modeling challenges
- Outdoor unit type (e.g., water-cooled, ground-coupled)
- Defrost
- Piping and capacity degradation for long runs
- Oil recovery
- Proprietary system controls

AGENDA

- VRF overview
- Technology and operation considerations
- ASHRAE Standard 15
- ASHRAE Standard 90.1
- ASHRAE Standard 62.1
- Zoning
- Modeling considerations
- **Summary**

Applying VRF

Summary

- Compliance with ASHRAE 15, 90.1, and 62.1 through careful system design and equipment selection
- Careful zoning can improve the performance of both heat pump and heat recovery VRF systems
- Energy simulation tools are available, but may have some shortcomings when it comes to modeling VRF

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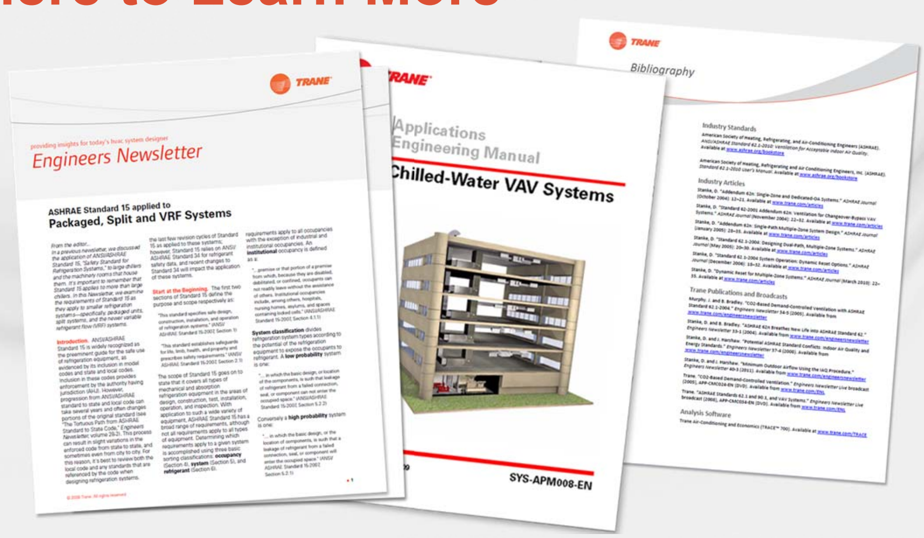
Where to Learn More



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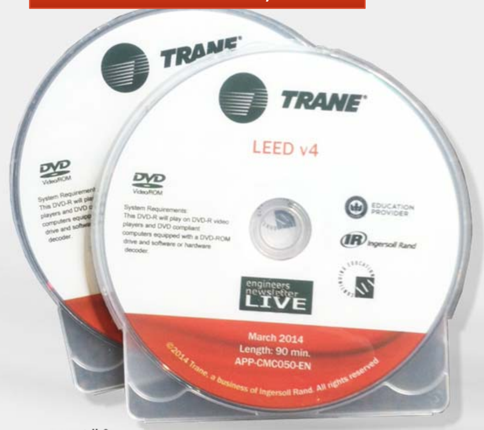

Past program topics:

- **NEW!** LEED® v4
- **NEW!** All Variable-Speed Chilled-Water Plants
- Air-to-air energy recovery
- ASHRAE Standards 189.1, 90.1, 62.1
- High-performance VAV systems
- WSHP/GSHP systems
- Control strategies
- Acoustics
- Demand-controlled ventilation
- Dehumidification
- Dedicated outdoor-air systems
- Ice storage
- Central geothermal systems

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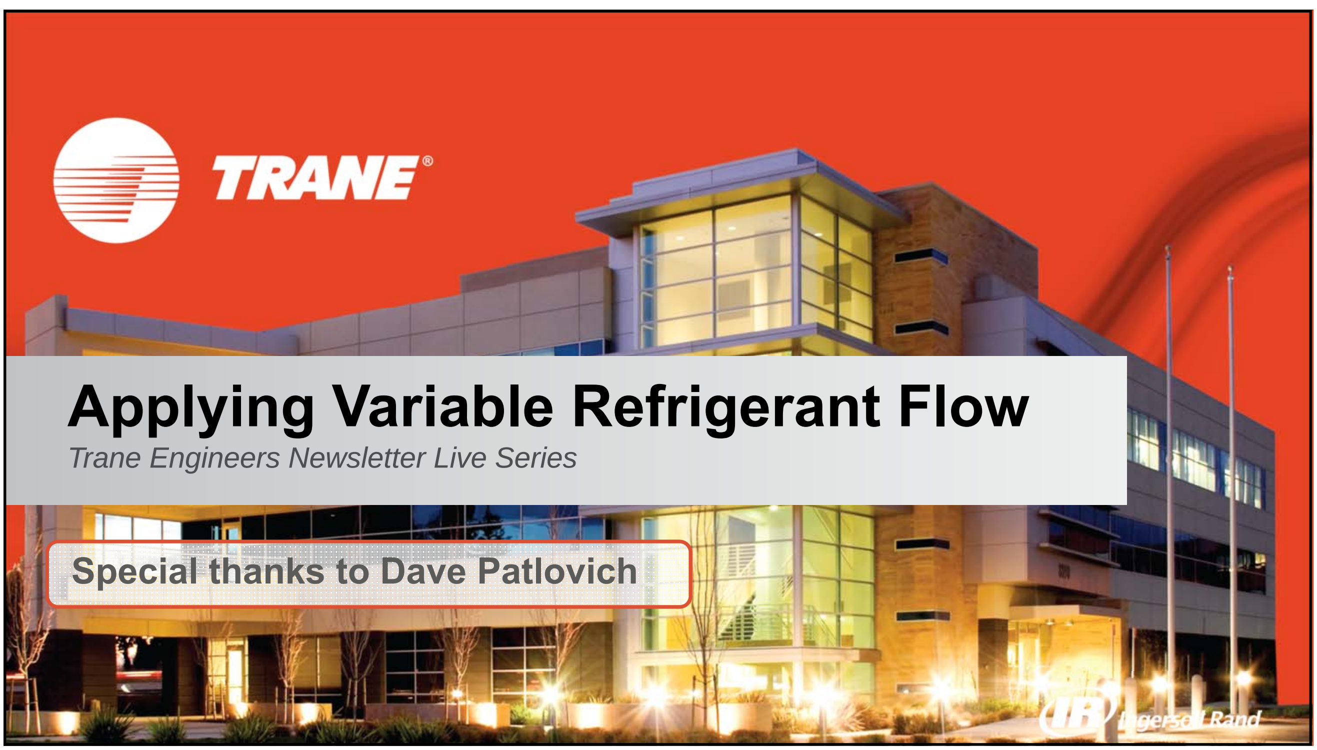
- ASHRAE Standard 62.1-2010
- ASHRAE Standard 90.1-2010
- ASHRAE Standard 189.1-2011
- High-Performance VAV Systems
- Single-Zone VAV Systems
- Ice Storage Design and Control
- All Variable-Speed Chiller Plant Operation

Mark Your Calendar!

- Energy-Saving Strategies for Chilled-Water Terminal Systems



Quiz

Trane Engineers Newsletter LIVE: Applying Variable Refrigerant Flow

1. Product rating standards are most useful for which of the following purposes? Circle all that apply
   a) Comparing products within the same family (e.g., VRF to VRF)
   b) Comparing products from different families (e.g., VRF to WSHP)
   c) Setting code-mandated minimum efficiency thresholds for a product family
   d) Predicting how that product will operate in an actual building

2. One benefit of delivering conditioned outdoor air directly to each zone is the opportunity to cycle off the fan inside the VRF terminal (or vary it's speed) because the OA is not distributed through that local fan.
   True
   False

3. ASHRAE Standard 90.1-2010 requires that most VRF systems be equipped with economizers.
   True
   False

4. A variable refrigerant flow system is an air conditioning system that connects multiple evaporators on a single refrigerant circuit.
   True
   False

5. A heat pump variable refrigerant flow system can simultaneously heat and cool separate spaces.
   True
   False

6. Proper variable refrigerant flow system zoning will result in the following:
   a) Minimizing first cost
   b) Minimizing energy cost
   c) Maintaining indoor comfort
   d) All of the above
   e) A and C

7. True/False ASHRAE Standard 15 does not apply to VRF systems because they are not traditional HVAC refrigeration systems.

8. Once a building is built and passes code inspection which of the following changes does NOT require compliance with the current code:
   a) Replacing a failed component with a like component.
   b) Adding an additional indoor cassette to an existing VRF system.
   c) Changing to a refrigerant with a different designation.

9. The refrigerant concentration limit is reduced in institutional occupancies because:
   a) Hospital HVAC equipment is more likely to fail because it runs 24/7/365.
   b) People in these facilities can't get out of the building quickly when there is a refrigerant leak.
   c) Institutional facilities are more likely to use traditional HVAC systems

10. What is the difference between a VRF system and a Mini-VRF system?
    a) Mini-VRF system is limited to single digit tonnage systems
    b) Mini- VRF outdoor units can't be modularly combined to form larger tonnages.
    c) Both a. and b.

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