VARIABLE REFRIGERANT FLOW APPLICATION AND DESIGN

Prepared for: New Jersey ASHRAE

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Agenda

• Thank You!
• Introduction to VRF
• Typical Applications
• Heat Pump vs. Heat Recovery
• ASHRAE 15
Initial Thoughts

What is VRF?
What is VRF?

**Basic Components**

- Heat Pump Outdoor Unit or Water-Source Unit
- Indoor Unit(s)
- Refrigerant Piping
- Controls
- Heat Recovery Control Module (HR Only)
components

**Typical Outdoor/Water-Source Unit**

- Variable speed compressor(s)
- Condenser/Evaporator Coil
- Variable speed heat rejection fan(s)
- Heat exchanger (sub-cooler)
- Expansion device
- Oil separator
components

Indoor Unit

- Indoor coil and fans
- Expansion valve
- Diffusers
Refrigerant Piping

- Total elevation
- 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.
Components

Controls

- Zone
- System
- Building

Scalable control options support many different application needs
Why VRF?

Traditional DX System Challenges

Single thermostats on traditional split systems may present a challenge…
What is VRF?

System Configuration

Two types of VRF: Heat Pump or Heat Recovery
What is VRF?

Simultaneous Heating and Cooling

Two types of VRF: Heat Pump or Heat Recovery
Why VRF?

Simultaneous Heating and Cooling

Dedicated Indoor Units
+ Dedicated Controllers/Sensors
+ Heat Recovery Control Module
= Individualized Zone Control

VRF technology allows for simultaneous heating and cooling
Why VRF?

Benefits and Advantages

- Energy Efficiency
- Comfortable Control
- Quiet Operation
- Small Footprint
- Scalable Capacity
- Ductless*
- Flexible Design
Why VRF?

Applications Suitable for VRF

- Buildings without ductwork
  - Historic buildings
  - Older homes being renovated
  - Buildings with hydronic heat
- Tenant finish and renovation
- Schools, day care facilities
- Banks & offices
- Extended care facilities
- Supplemental systems for off-season conditioning (e.g. school administrative wings)
- Upscale residences and condominiums
Why VRF?

Applications Suitable for VRF

- Restaurants
- Small retail
- Boutique hotels
- Bed and Breakfast
- Multi-use commercial buildings
Why VRF?

Applications to Avoid VRF

- Buildings with large open spaces and high ceilings
  - Big box retail
  - Supermarkets
  - Arenas (other than box office and office areas)
- Applications incorporating data centers and server rooms
- Applications requiring superior air quality
  - Critical care facilities and surgical suites
- Applications with concerns about refrigerants within occupied spaces
- Applications requiring large amounts of outside air
System Configuration

**Heat Pump vs. Heat Recovery**

**Goal:**
Size and select indoor units and outdoor units to minimize the first cost and energy usage, while maintaining indoor comfort.
<table>
<thead>
<tr>
<th><strong>System Configuration</strong></th>
<th><strong>Heat Pump vs. Heat Recovery</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat Pump</strong></td>
<td><strong>Heat Recovery</strong></td>
</tr>
<tr>
<td>• Cooling OR heating at any given time</td>
<td>• Simultaneous heating and cooling</td>
</tr>
<tr>
<td>• Very little system diversity</td>
<td>• Maximize system diversity</td>
</tr>
<tr>
<td>• Similar exposures/load profiles</td>
<td>• Requires a heat recovery control module between outdoor unit and indoor units</td>
</tr>
<tr>
<td>• Indoor units connected to outdoor unit via refrigerant piping and branch joints</td>
<td></td>
</tr>
</tbody>
</table>

*Without custom control logic, Heat Pump changeover is a challenge*
System Configuration

Heat Recovery Module Operation

• System control determines the type of refrigerant each indoor unit requires (liquid or hot gas), and supplies it using solenoid valves.
• Recycles waste product of heating zone to cooling zone
System Configuration

Heat Recovery Module Operation

heat recovery module

suction

discharge gas

cooling

heating

liquid

2

2

2

2
System Configuration

Heat Recovery Piping Architectures

Key Differences
- Amount of refrigerant pipe required
- Number of zones on each heat recovery module
- Localized vs. centralized energy exchange
- Location of branch selectors
System Configuration

Heat Pump vs. Heat Recovery

Diagram showing a grid with directions N, S, E, W.
System Configuration

Heat Pump
System Configuration

Heat Recovery
Combination Ratio

Zone Peak Loads

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 tons</td>
<td>3 tons</td>
<td></td>
</tr>
<tr>
<td>½ ton</td>
<td>3 tons</td>
<td></td>
</tr>
<tr>
<td>½ ton</td>
<td>2 tons</td>
<td></td>
</tr>
</tbody>
</table>

Combination Ratio = \[\frac{\text{Indoor Capacity}}{\text{Outdoor Capacity}}\]

= \[\frac{10 \text{ tons}}{10 \text{ tons}}\]

= 100% CR
### System Configuration

#### Combination Ratio

**Morning Load:** 8 tons

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>W</th>
<th>E</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 tons</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 ton</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0 ton</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
System Configuration

Combination Ratio

Afternoon Load: 8 tons

Combination Ratio = \frac{\text{Indoor Capacity}}{\text{Outdoor Capacity}}

= \frac{10 \text{ tons}}{8 \text{ tons}}

= 125\% \text{ CR}

Size indoor unit for individual zone peak loads, and outdoor unit for block load

But use caution!
Heat Pump vs. Heat Recovery

**Summary**

- System Diversity
- Zoning
- Combination Ratio

Remember....

**Goal:**
Size and select indoor units and outdoor units to minimize the first cost and energy usage, while maintaining indoor comfort.
ASHRAE Standard 15

- Applicability
- Overview
- Example
International Mechanical Code

2015 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.”
Standard 15

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”

Keep refrigerants contained within their systems. In the event of a refrigerant leak, mitigate its impact on people.
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”

Certain replacements:
“… modifications including replacement of parts or components if they are not identical in function and capacity …”

Certain conversions:
“… and to substitutions of refrigerant having a different designation”
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 Classification Criteria

Building Occupancy

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

Safety Standard for Refrigeration Systems
ANSI/ASHRAE Standard 15-2013 Classification Criteria

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 system isolation
ANSI/ASHRAE Standard 15-2013 Classification Criteria

Refrigerating System

<table>
<thead>
<tr>
<th>SYSTEM TYPE</th>
<th>cooling or heating source</th>
<th>material to be cooled/heated</th>
<th>SYSTEM CLASSIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>direct</td>
<td></td>
<td></td>
<td>high probability</td>
</tr>
<tr>
<td>indirect open spray</td>
<td></td>
<td></td>
<td>high probability</td>
</tr>
<tr>
<td>double indirect open spray</td>
<td></td>
<td></td>
<td>low probability</td>
</tr>
<tr>
<td>indirect closed</td>
<td></td>
<td></td>
<td>low probability</td>
</tr>
<tr>
<td>indirect vented closed</td>
<td></td>
<td></td>
<td>low probability</td>
</tr>
</tbody>
</table>
ANSI/ASHRAE Standard 34-2013 Classification Criteria

Refrigerant Safety Criteria

- Flammability: 3 classes (plus one subclass)
- Toxicity: 2 classes
ANSI/ASHRAE Standard 34-2013 Classification Criteria

Refrigerant 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

Refrigerant Toxicity Criteria

Occupational Exposure Limit (OEL)

- Class A
  Lower toxicity
  OEL ≥ 400 ppm

- Class B
  Higher toxicity
  OEL < 400 ppm
ANSI/ASHRAE Standard 34-2013
Safety Classifications

- **A3**: lower toxicity, higher flammability
- **A2**: lower toxicity, lower flammability
- **A2L**: lower toxicity, no flame propagation
- **A1**: no flame propagation
- **B1**: lower toxicity, higher flammability
- **B2**: lower toxicity, lower flammability
- **B2L**: lower toxicity, no flame propagation
- **B3**: higher toxicity, higher flammability

Refrigerant safety groups
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

<table>
<thead>
<tr>
<th>Refrigerant Number</th>
<th>Composition (Mass %)</th>
<th>Composition Tolerances</th>
<th>OEL h (ppm v/v)</th>
<th>Safety Group</th>
<th>RCL a (ppm v/v)</th>
<th>RCL b (lb/Mcf)</th>
<th>RCL c (g/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeotropes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>407F</td>
<td>R-32/125/134a (30.0/30.0/40.0)</td>
<td>(±2.0/±2.0/±2.0)</td>
<td>1000</td>
<td>A1</td>
<td>95,000</td>
<td>20</td>
<td>320</td>
</tr>
<tr>
<td>408A²</td>
<td>R-125/143a/22 (7.0/46.0/47.0)</td>
<td>(±2.0/±1.0/±2.0)</td>
<td>1000</td>
<td>A1</td>
<td>95,000</td>
<td>21</td>
<td>340</td>
</tr>
<tr>
<td>409A</td>
<td>R-22/124/142b (60.0/25.0/15.0)</td>
<td>(±2.0/±2.0/±1.0)</td>
<td>1000</td>
<td>A1</td>
<td>29,000</td>
<td>7.1</td>
<td>110</td>
</tr>
<tr>
<td>409B</td>
<td>R-22/124/142b (65.0/25.0/10.0)</td>
<td>(±2.0/±2.0/±1.0)</td>
<td>1000</td>
<td>A1</td>
<td>30,000</td>
<td>7.3</td>
<td>120</td>
</tr>
<tr>
<td>410A¹</td>
<td>R-32/125 (50.0/50.0)</td>
<td>(+0.5,−1.5/+1.5,−0.5)</td>
<td>1000</td>
<td>A1</td>
<td>140,000</td>
<td>26</td>
<td>420</td>
</tr>
<tr>
<td>410B¹</td>
<td>R-32/125 (45.0/55.0)</td>
<td>(±1.0/±1.0)</td>
<td></td>
<td>A1</td>
<td>140,000</td>
<td>27</td>
<td>430</td>
</tr>
</tbody>
</table>

\[ RCL = \frac{26 \text{ lbs}}{1000 \text{ ft}^3} \]

**Institutional Occupancy is 50% of this!**
ANSI/ASHRAE Standard 15-2013

**Review**

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

Let’s walk through an example…

Safety Standard for Refrigeration Systems
Standard 15-2013

Applied to VRF

Example building

9ft ceilings

- 15 ft
- 10 ft
- 25 ft
- 15 ft
- 8 ft
- 12 ft
- 12 ft
- 8 ft
- 30 ft

Sales  Support  Conference Room

Corridor

Office  Private  Computer Room
Standard 15-2013

Applied to VRF

Example building parameters:
• 10 Ton System: One outdoor unit, 6 indoor units
• Commercial occupancy
• Direct (high probability) system
• Total Charge: 40 lbs (factory charge + field piping)
• Refrigerant R410A
  • Safety group A1
  • RCL = 26lbs /1000 ft³ per Standard 34-2013
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 40 lb
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
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
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 plenums and ductwork if applicable
- Omit spaces that can be isolated
For Private office:

\[
\text{lbs in system } \times 1000 = 40 \times 1000 = 46 \text{ lbs/1000ft}^3 > 26 \text{ lbs/1000 ft}^3
\]

Room volume: \(8 \times 12 \times 9\)
Standard 15-2013

Applied to VRF

Method 2

For Private office:

\[
\frac{26 \text{ lbs}}{1000 \text{ ft}^3} = \frac{X}{8 \times 12 \times 9}
\]

\[X = 22.46 \text{ lbs MAX} < 40 \text{ lbs}\]
applying Standard 15-2013

Meeting the RCL

- Reduce refrigerant quantity
  - Computer room
  - Serve building with two systems
- Increase dilution volume
  - Office 2 + Private Office

For Support:

lbs in system x 1000 = 40 x 1000 = 29.6 lbs/1000ft³
Room volume = 10 x 15 x 9
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
<table>
<thead>
<tr>
<th>Standard 15-2013 and VRF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASHRAE Summary</strong></td>
</tr>
</tbody>
</table>

**Standard 15:**
- Applies to all refrigeration equipment
- VRF requirements are not new
- Promotes safety for all systems
VRF Design

Key Takeaways

• VRF Benefits/Applications
• Load analysis and careful zoning
• Be cognizant of refrigeration safety
Thank You!

Questions