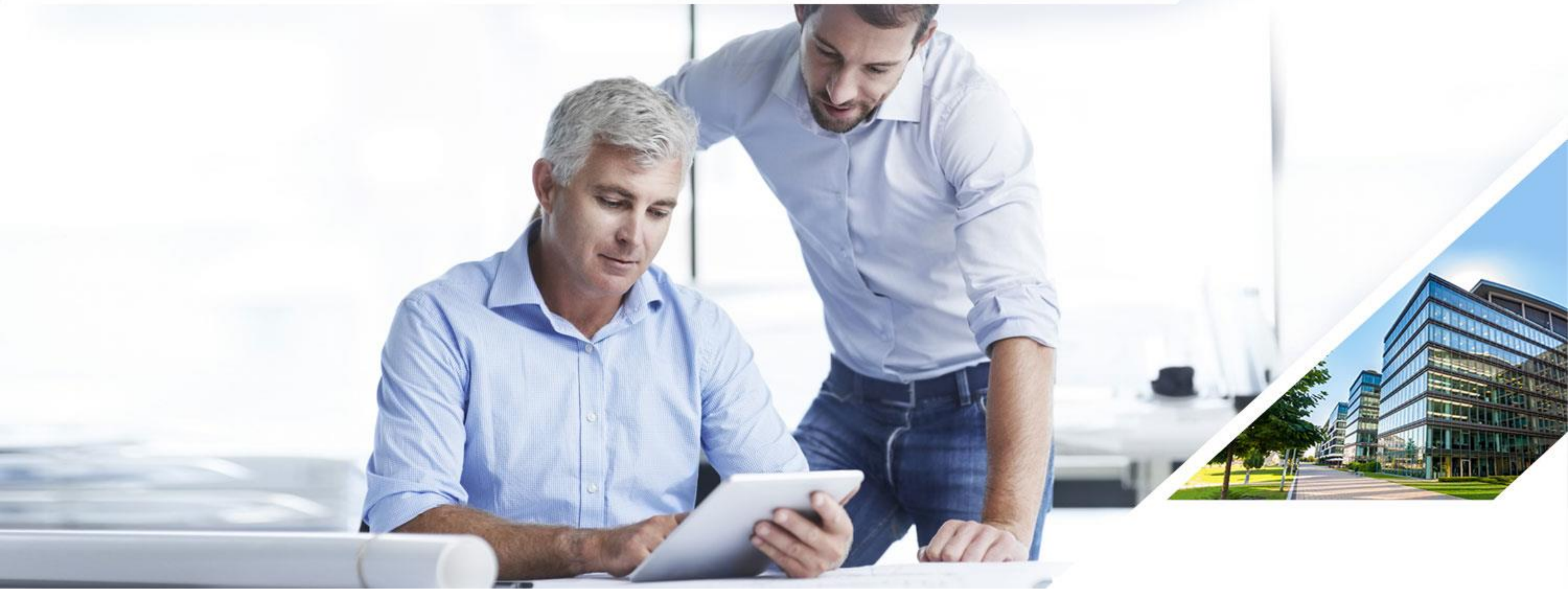

Variable Refrigerant Flow 101-

Bill Artis

People and ideas you can trust.™

Your Presenters

Bill Artis LEED AP BD+C
Business Development
Daikin NY
ASHRAE LI Member, BOG
ASHRAE TC 8.7 Member

- Guideline 41 Project Committee: "VRF Design, Installation, and Commissioning
- Handbook: Systems and Equipment 2016 "Variable Refrigerant Flow", ch18

~10yrs in HVAC industry

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VRF Resources:

ASHRAE Handbook: 2016 Systems and Equipment, ch18 "Variable Refrigerant Flow"
VRF Design and Application Webinar- ASHRAE Learning Institute (spring)

Agenda

- **Review System Types and Architecture**
- **Describe Basic Sequence of Operations**
- **Discuss design and application considerations for equipment, piping, and airside**.
- **Introduction to the Dark Side of ASHRAE**

VRF Architecture & System Types

VRF Overview + Architecture

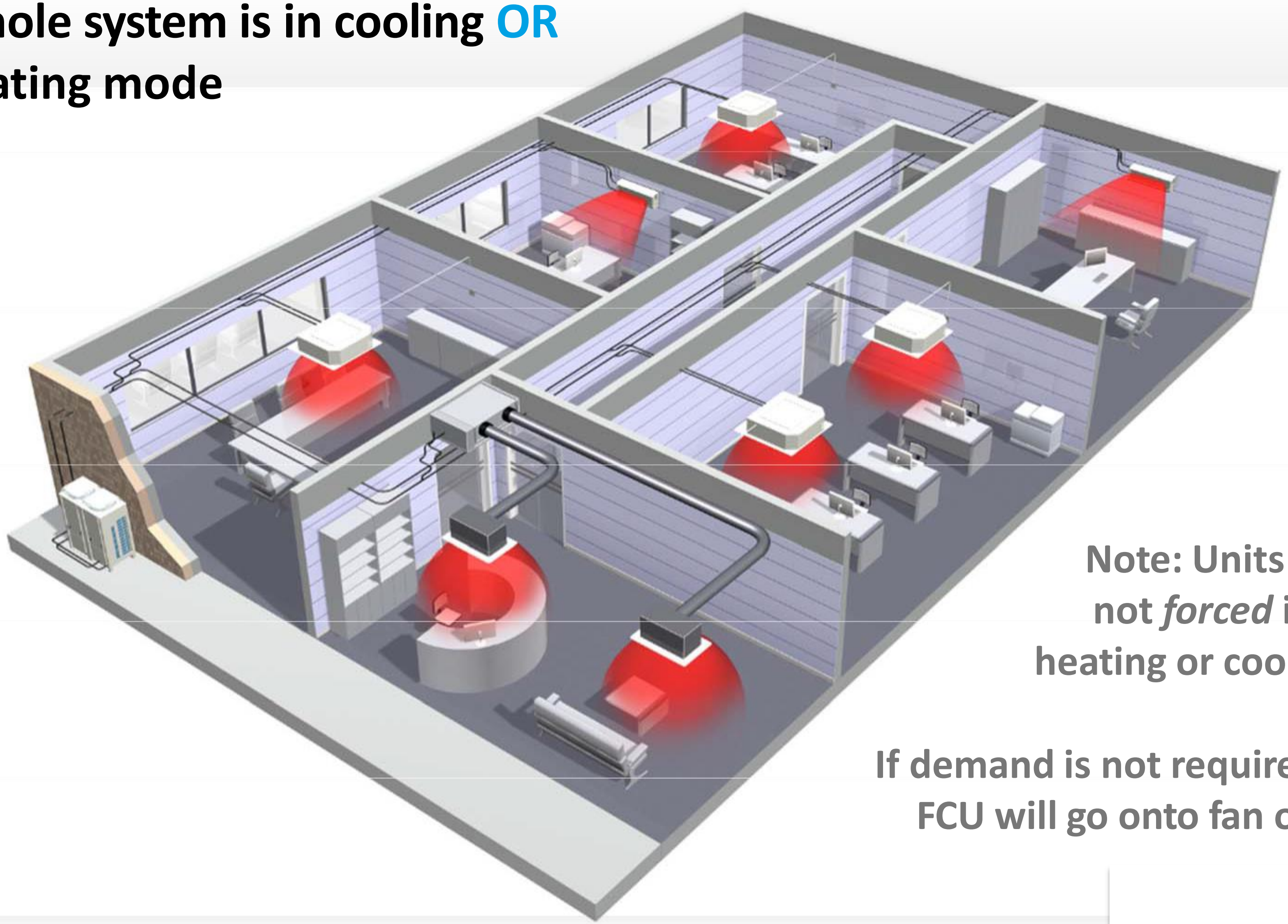
VRF Overview

- Developed in 1982
- ~5% Market Share in NA
- Expected to reach ~$10,251MM in 2019

VRF Concept

- Indoor (fan coil) unit(s) connected to an outdoor (condensing) unit
  - Up to 64 units on **a single** refrigerant piping network
  - One-One configurations
- Available in either **air cooled** or **water cooled**
- Heat Pump or Heat Recovery

Whole system is in cooling **OR** heating mode

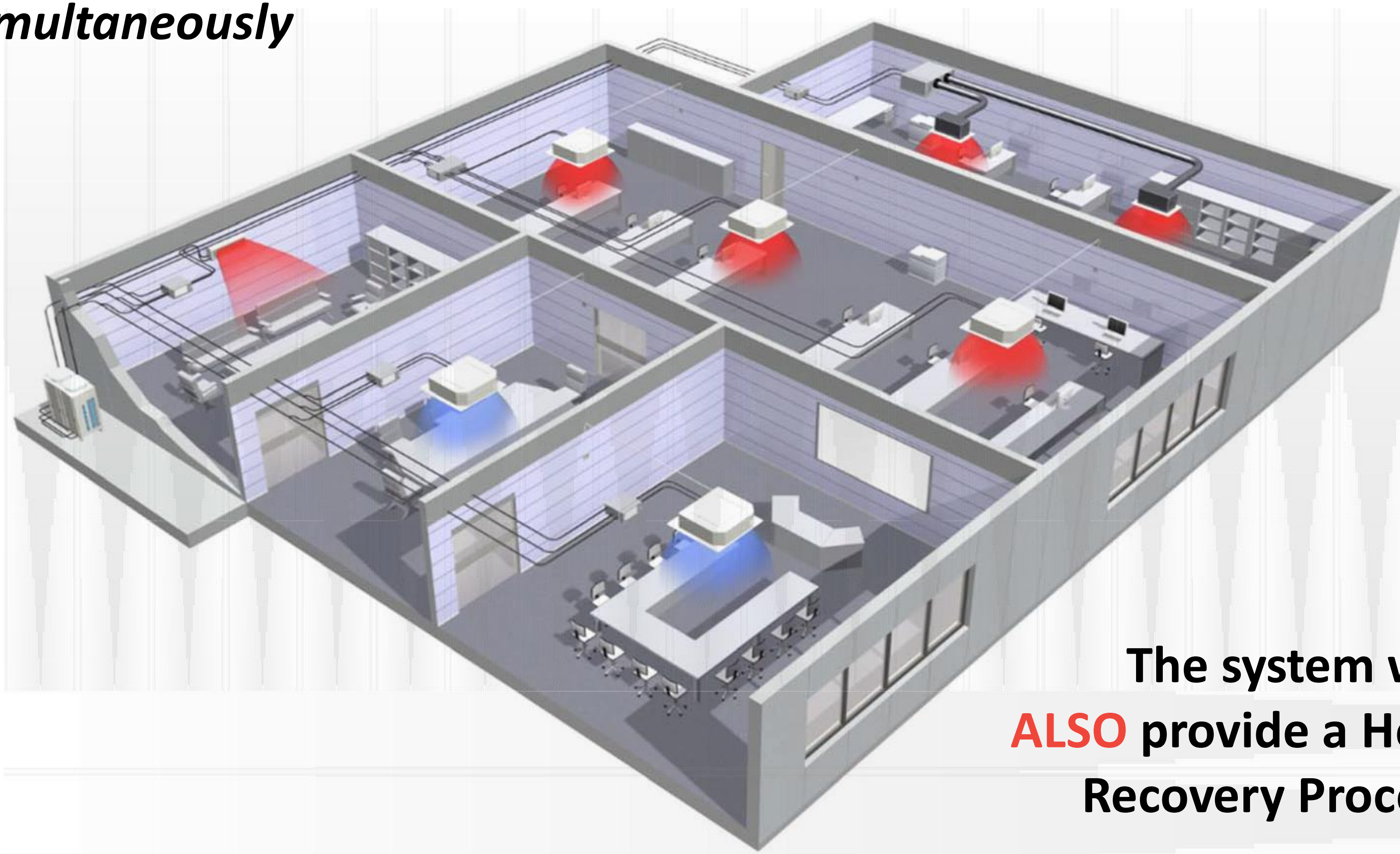


Note: Units are not *forced* into heating or cooling

If demand is not required a FCU will go onto fan only

Heat Recovery Series

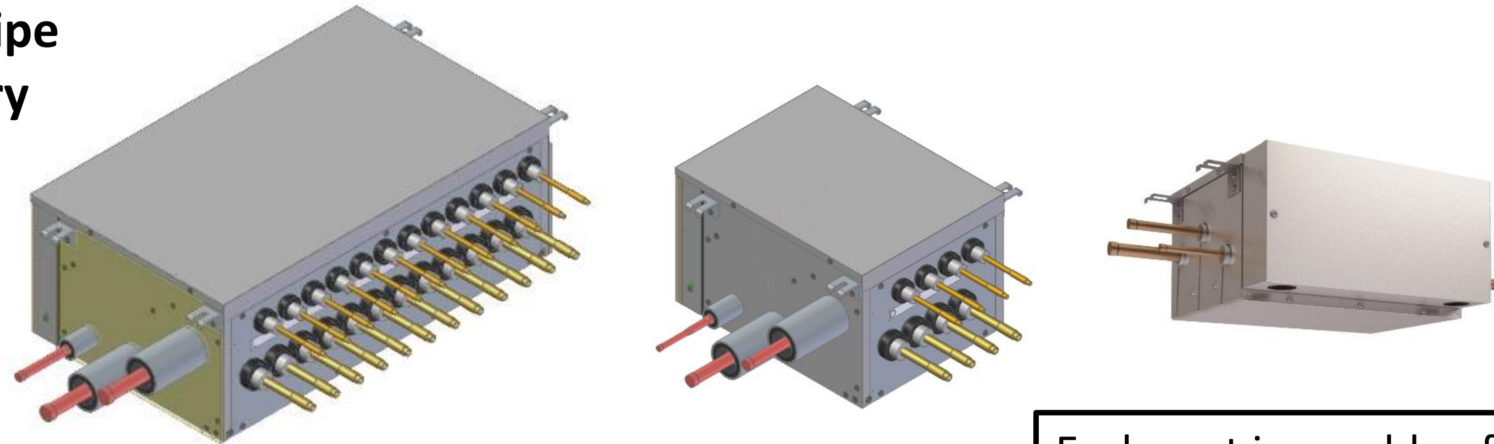
The system can cool AND heat *simultaneously*



The system will ALSO provide a Heat Recovery Process

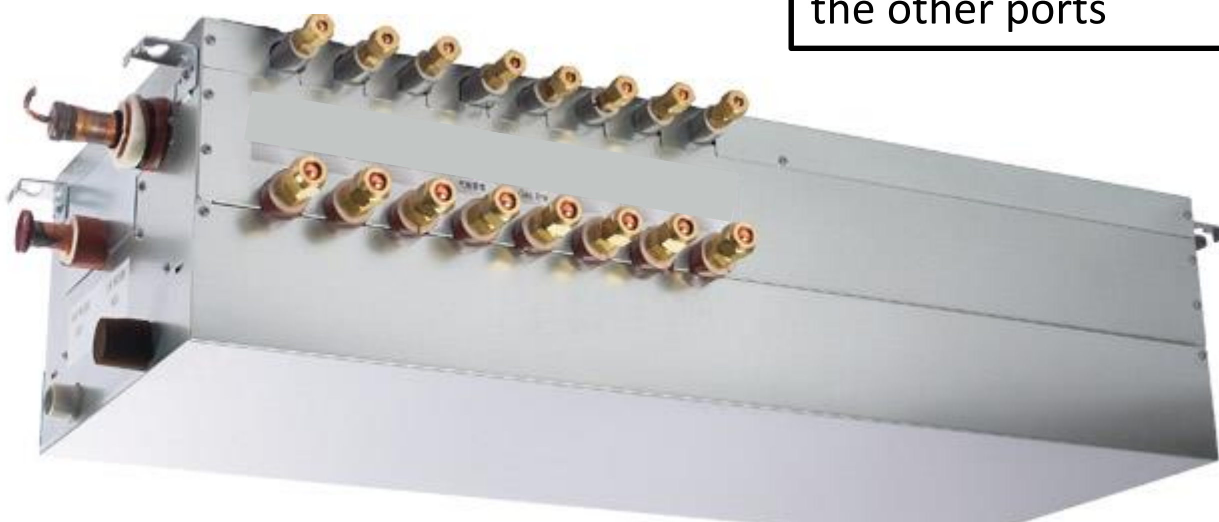
Heat Recovery Control Units

HRCU for 3 Pipe Heat Recovery



Each port is capable of operating in heating or cooling independent of the other ports

HRCU for 2 Pipe Heat Recovery



sample image for reference

Basic Operation of VRF Systems

Sequence of Operations- Indoor Unit

- Refrigerant Flow Control
  - Control refrigerant flow based on enter/leaving refrigerant temp at coil
  - Superheat control for cooling/subcooling control for heating
  - Adjusts target as error between thermostat set-point and room temperature changes
- Fan Control
  - Fan cycling or continuous operation
  - User-set
  - “Single Zone VAV” type fan control capable

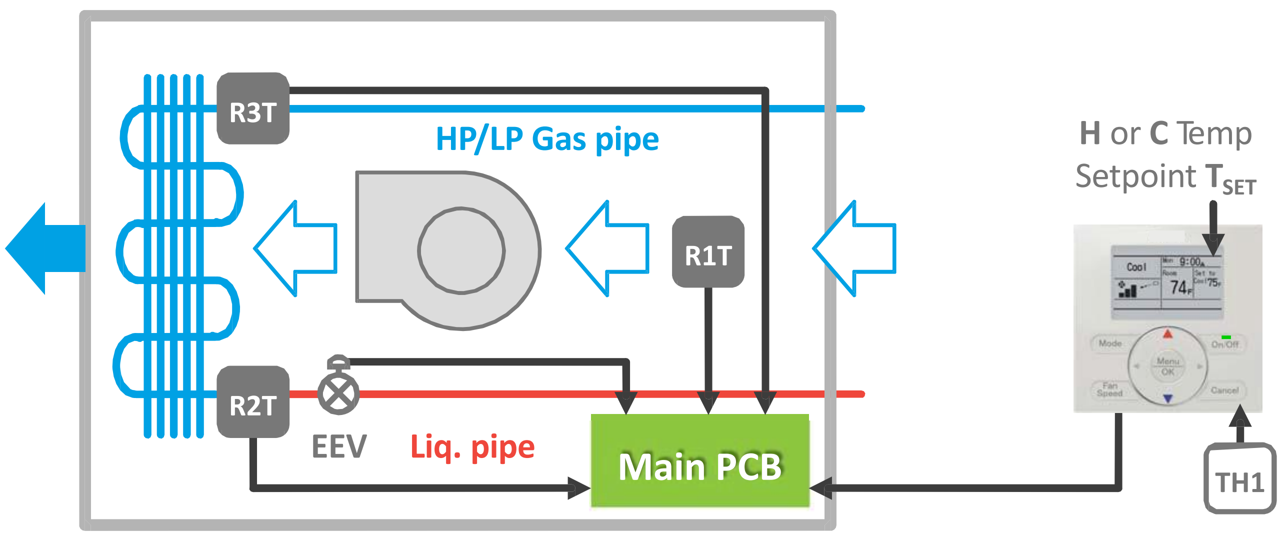
Room Capacity Control

Indoor Unit Brain

VRF fan coils have 3 thermistor sensors

- The sensor signals are used to regulate refrigerant volume through the fan coil using Proportional, Integral & Derivative (PID) control, to correct deviation from target temperature values by adjusting the Electronic Expansion Valve in pulses to modulate open and close

Indoor Fan Coil Unit



SENSOR LEGEND

R1T: Return Air

R2T: Saturated Liquid Pipe

R3T: Gas Pipe

TH1: Remote Controller Sensor

T_{SET}: Remote Controller Set Point

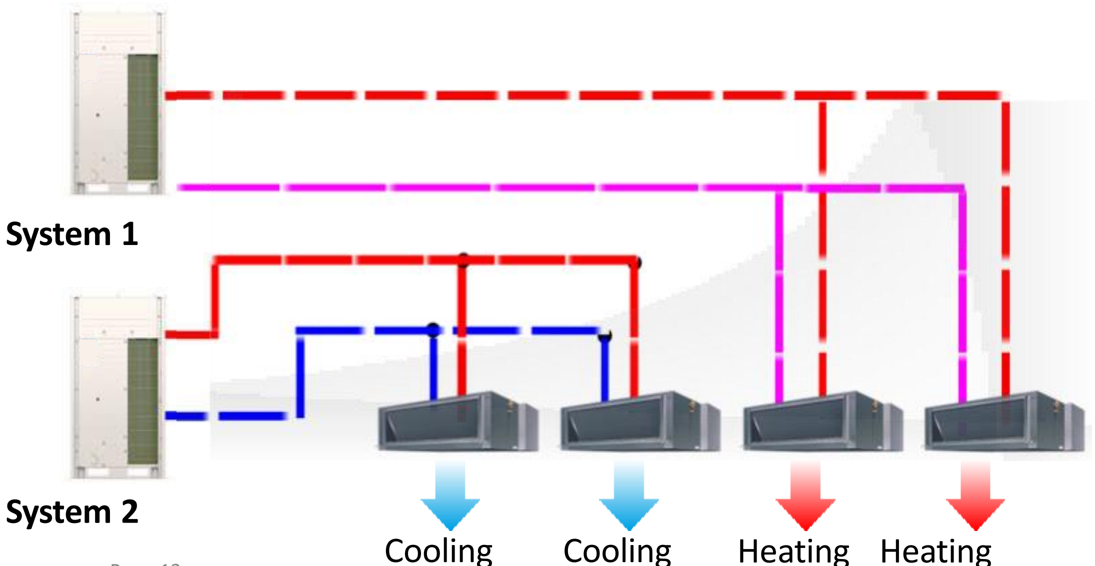
Sequence of Operations- Condenser

Two types of control:

- Refrigerant Volume w. Constant Saturation Temperature
  - Adjusts compressor speed/mass flow with system load
- Refrigerant Volume + Saturation Temperature Reset
  - In addition, adjusts saturated refrigerant temperature
    - OA Conditions
    - Thermostat set-point error for each unit
    - Refrigerant temperatures at coil
    - Can be configured for capacity or efficiency preference
    - Identifies "critical zone"

Heat Pump

- Entire system is either in cooling or heating mode
- Indoor unit will operate in “Fan Only” when there is no demand
- Mode changeover can be accomplished based on
  - Outside ambient
  - Averaging temperatures from all units on system
  - Weighted vote from all units based on demand and priority
  - Critical zone unit



System Capacity Control

Condensing Unit Brain

Control System

- Sets Target low & high pressure values at the Condenser
- Sets the Target evap. & cond. Temps in the indoor Fan Coils
- Local Remote Controllers initiate a system Thermo-ON with a 1° deviation from set point
- Local Remote Controllers initiate a system Thermo-OFF when all set points are reached

Condenser Control

COOL Operation

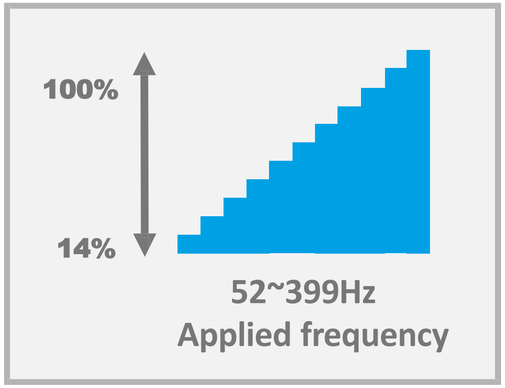
- Detects the system operating suction pressure at the condenser once every 20 seconds & Target Evap temp

HEAT Operation

- Detects the system operating high pressure at the condenser once every 20 seconds & Target Cond temp

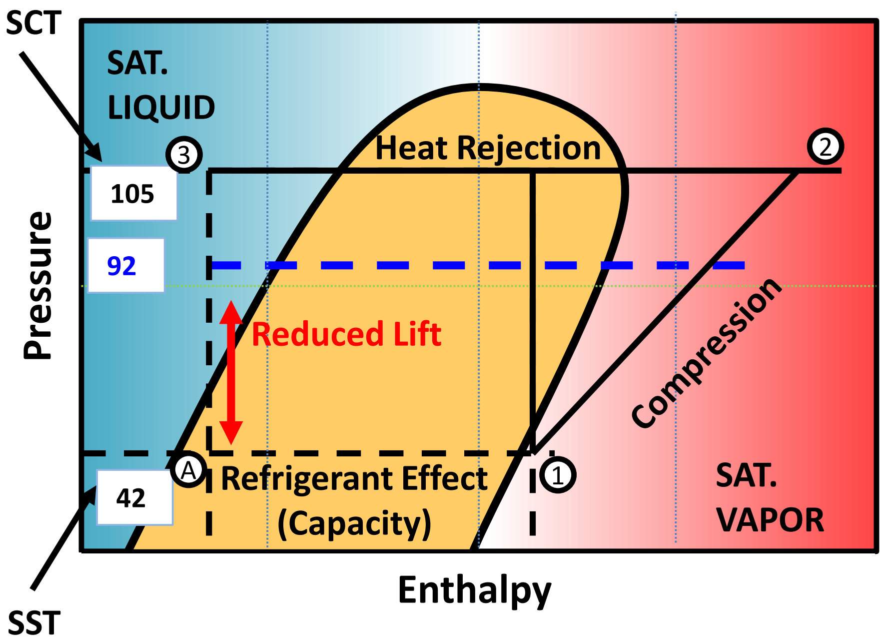
Inverter Control

- Adjusts compressor speed (capacity) up or down to correct deviation from the target pressure values (system load)

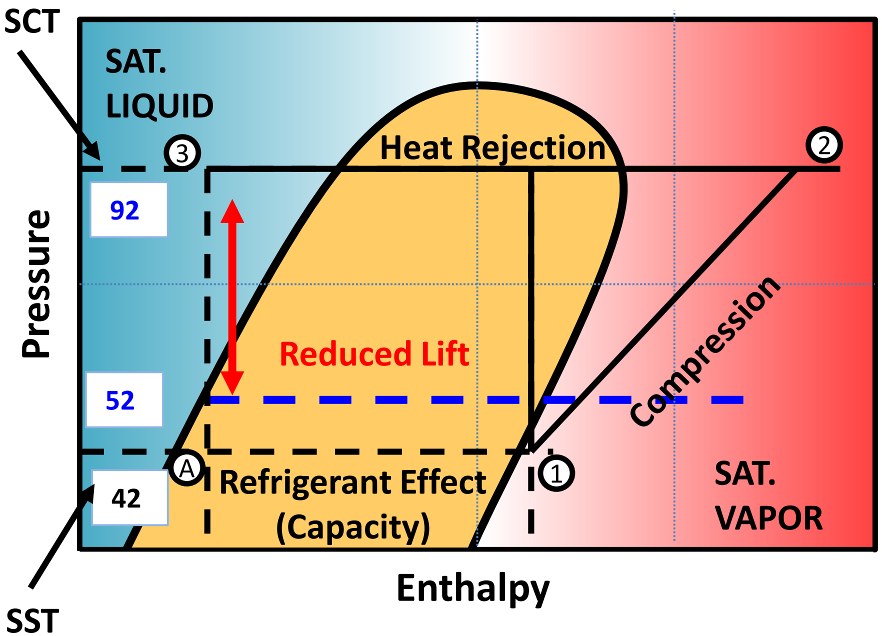


What if We Control the Refrigerant Temp?

Now



The Future??



Lower Lift = Less Work = Lower power input

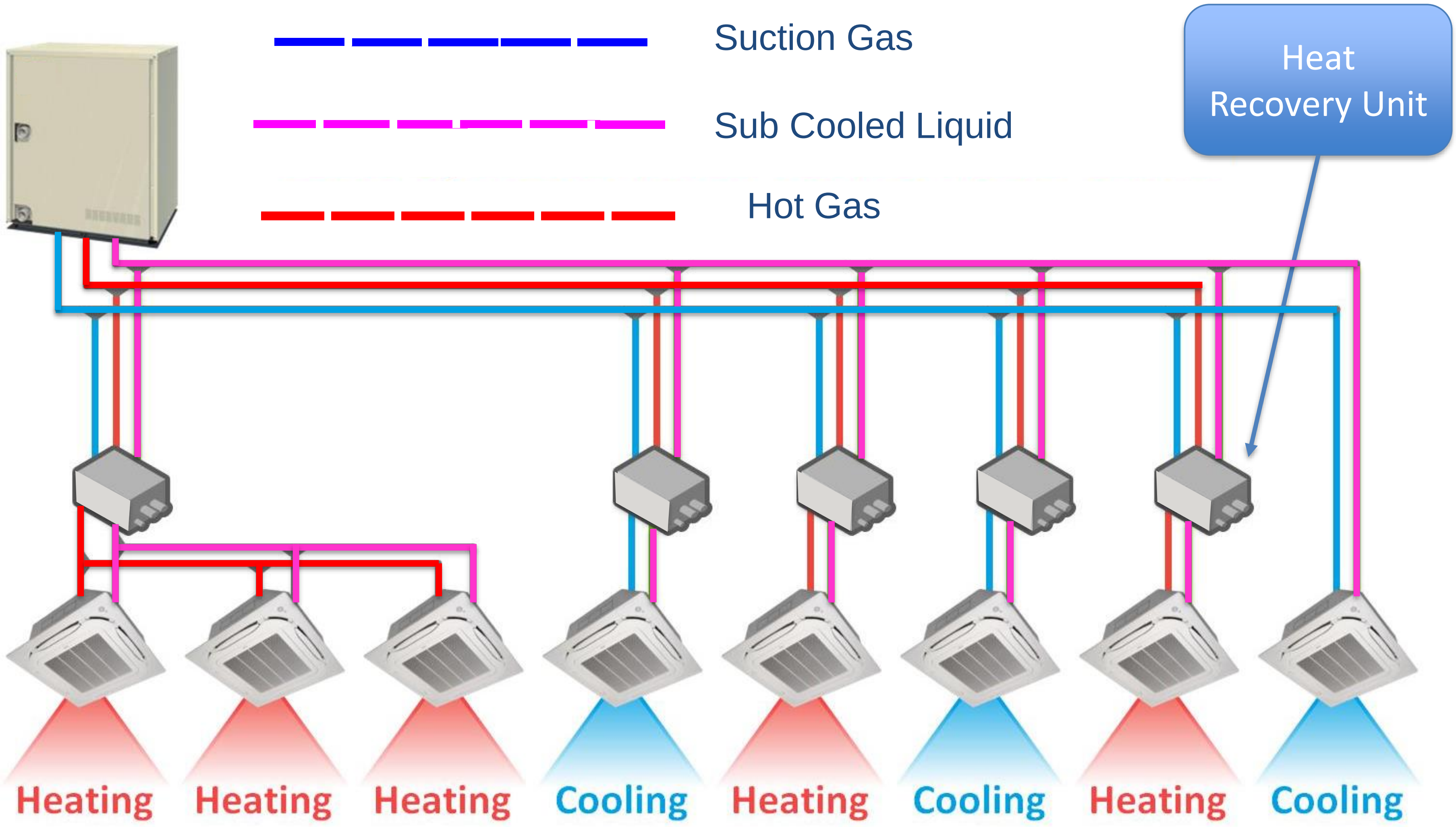
Think Chilled Water or Boiler temperature reset function

Sequence of Operations- Mode Changeover

Heat Recovery

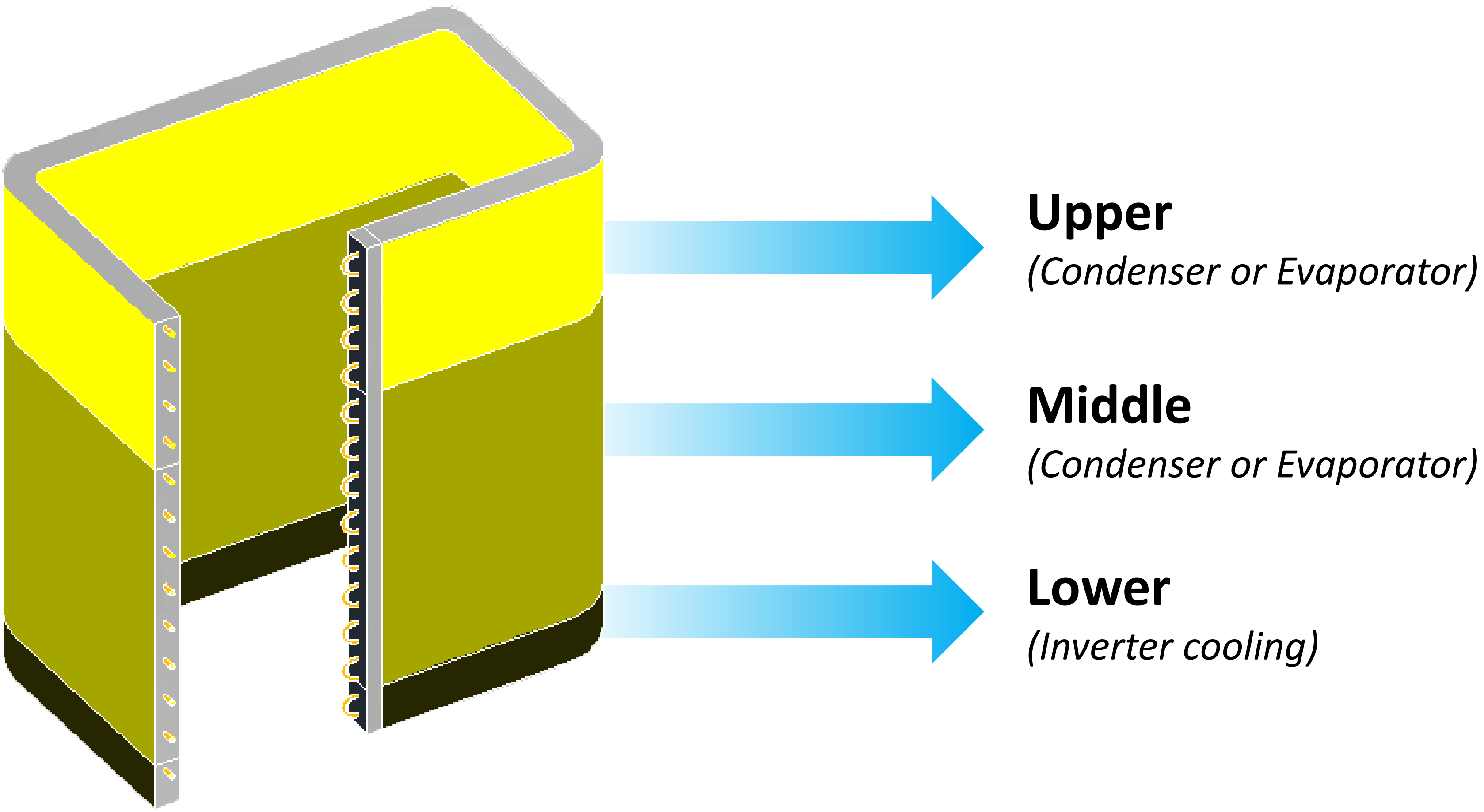
- System provides simultaneous heating/cooling (heat recovery)
- Changeover zone is at each heat recovery control unit
  - Or zone port on a multi port box
- Indoor unit will operate in “Fan Only” when there is no demand
- Mode changeover can be accomplished based on
  - Outside ambient/ Calendar
  - Averaging temperatures from all units on system
  - Weighted vote from all units based on demand and priority
  - Critical zone unit (aka “Master Unit”)

Heat Recovery- Three Pipe



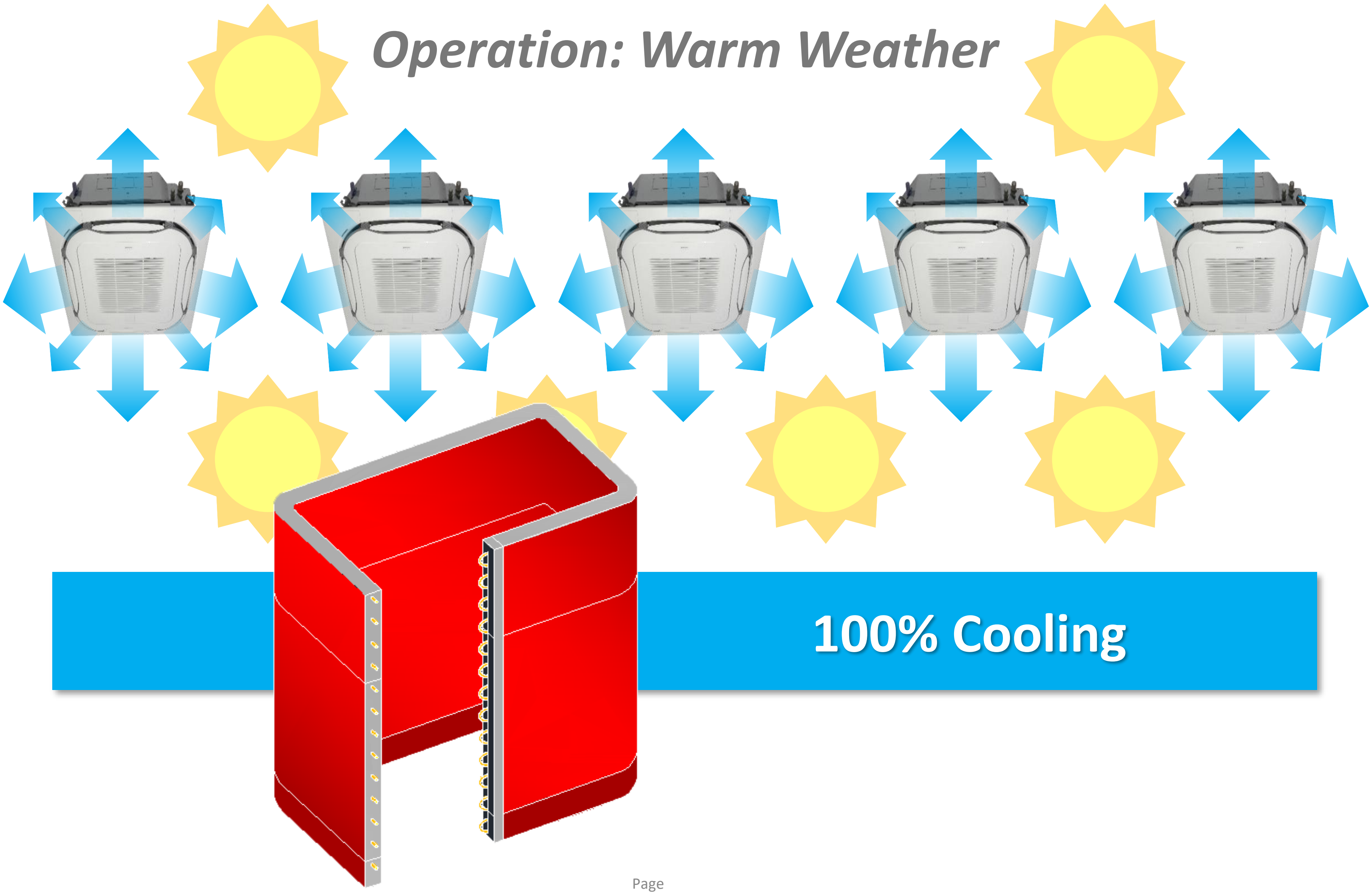
Heat Recovery Unit Control- Three Pipe

- The Heat-Exchanger is Divided in Three Circuits



Heat Recovery Unit Control- Three Pipe

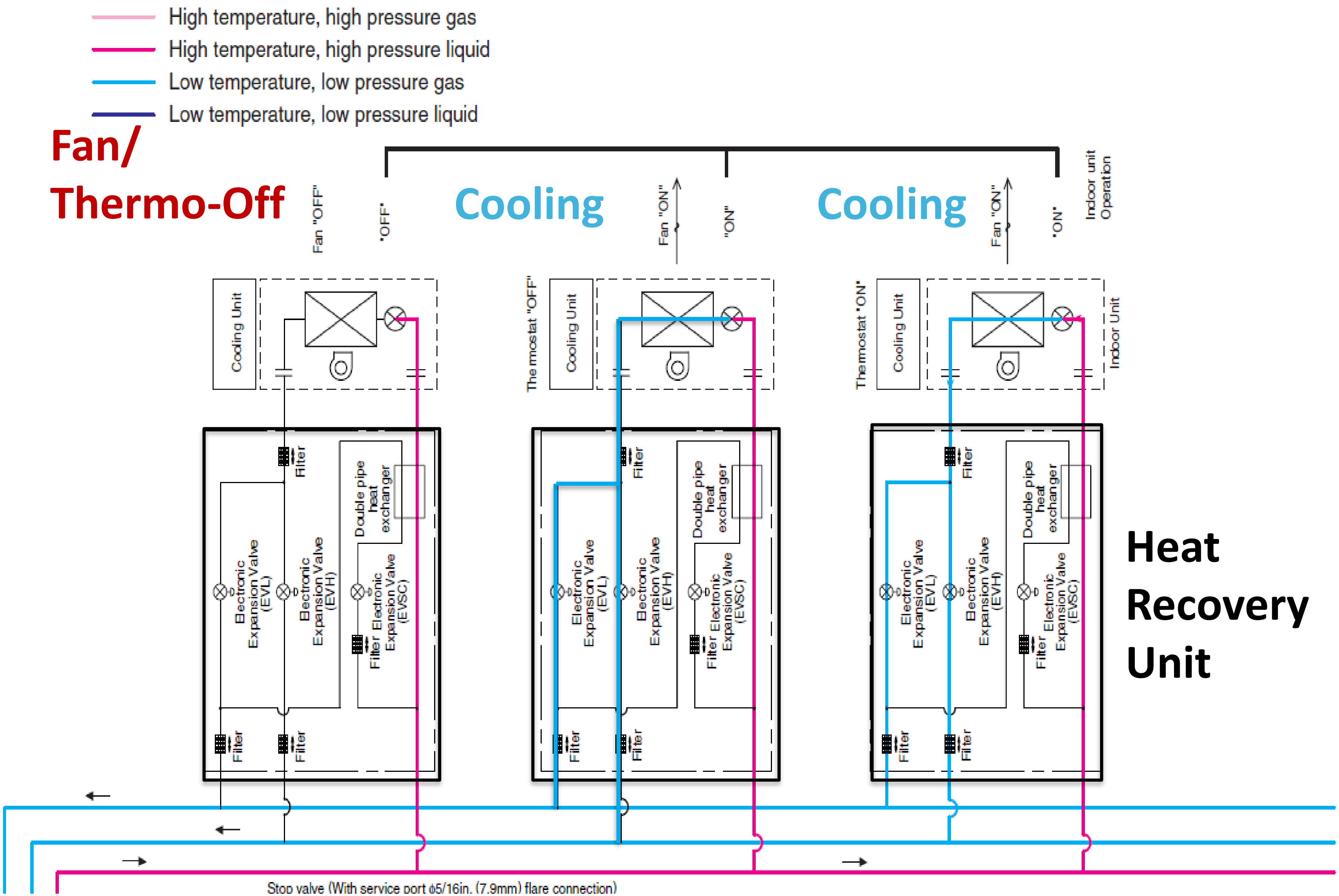
Operation: Warm Weather



Heat Recovery Unit Control- Three Pipe

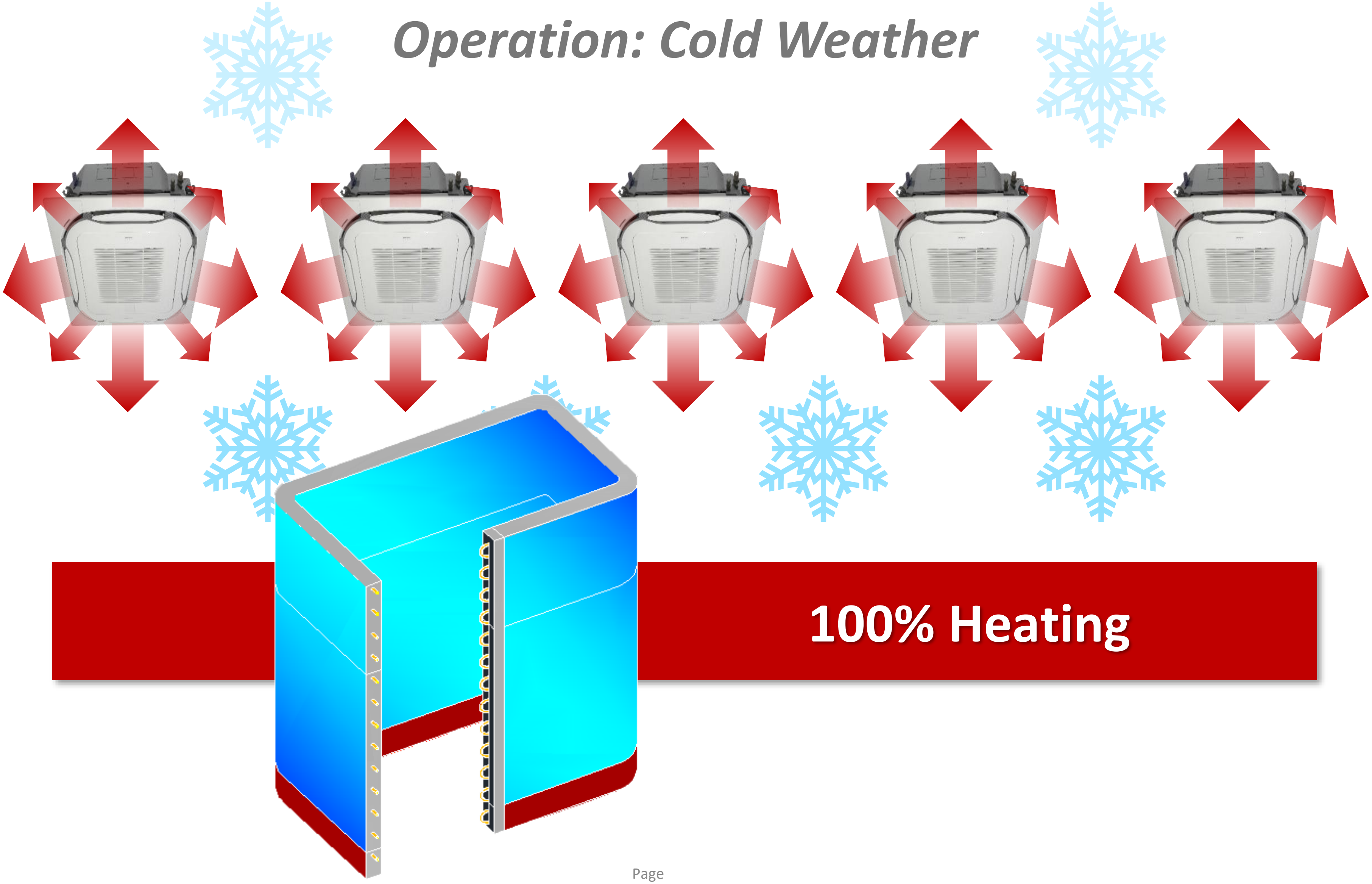
3.1.1 Cooling Operation

Shown in 100% cooling operation



Heat Recovery Unit Control- Three Pipe

Operation: Cold Weather

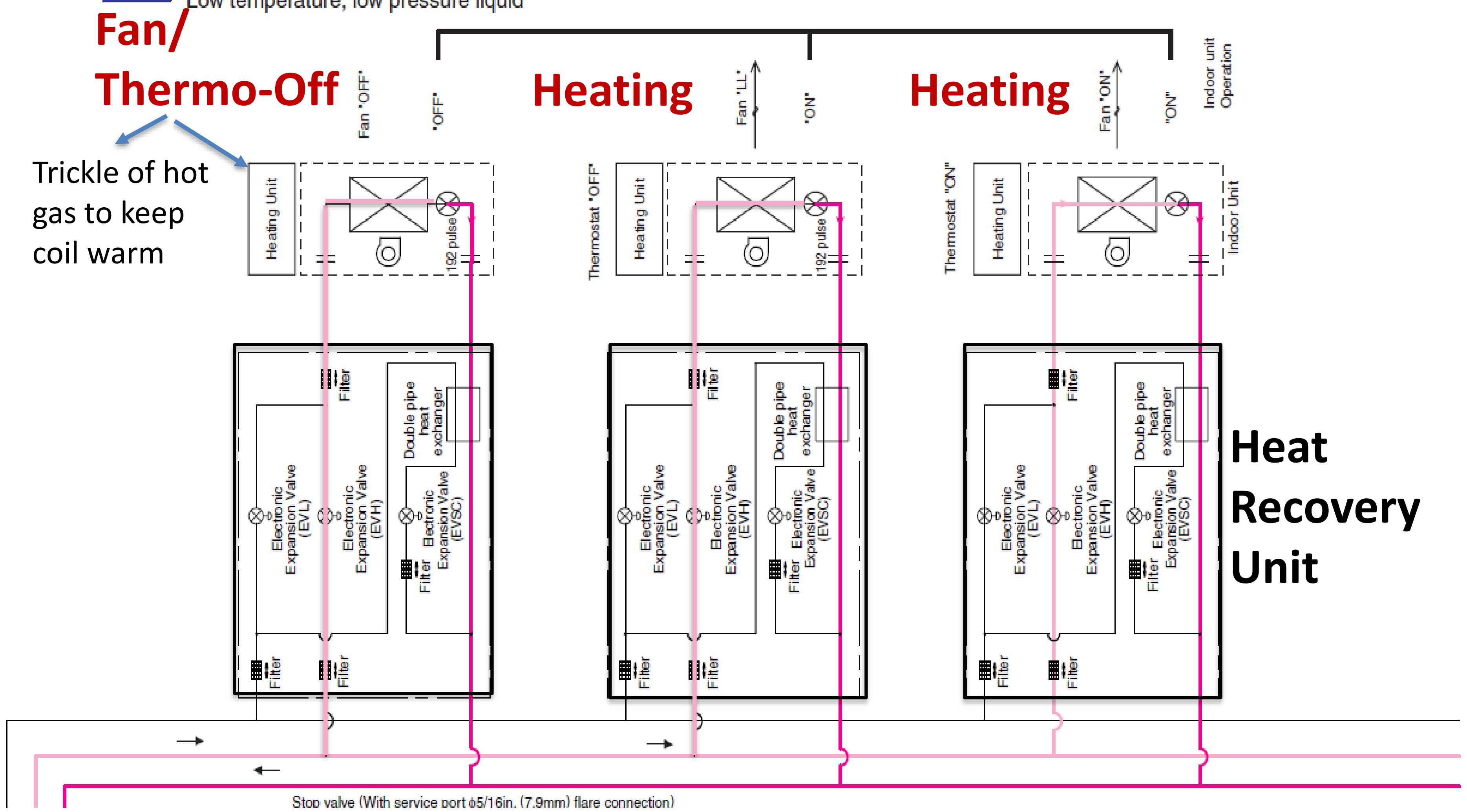


Heat Recovery Unit Control- Three Pipe

3.1.2 Heating Operation

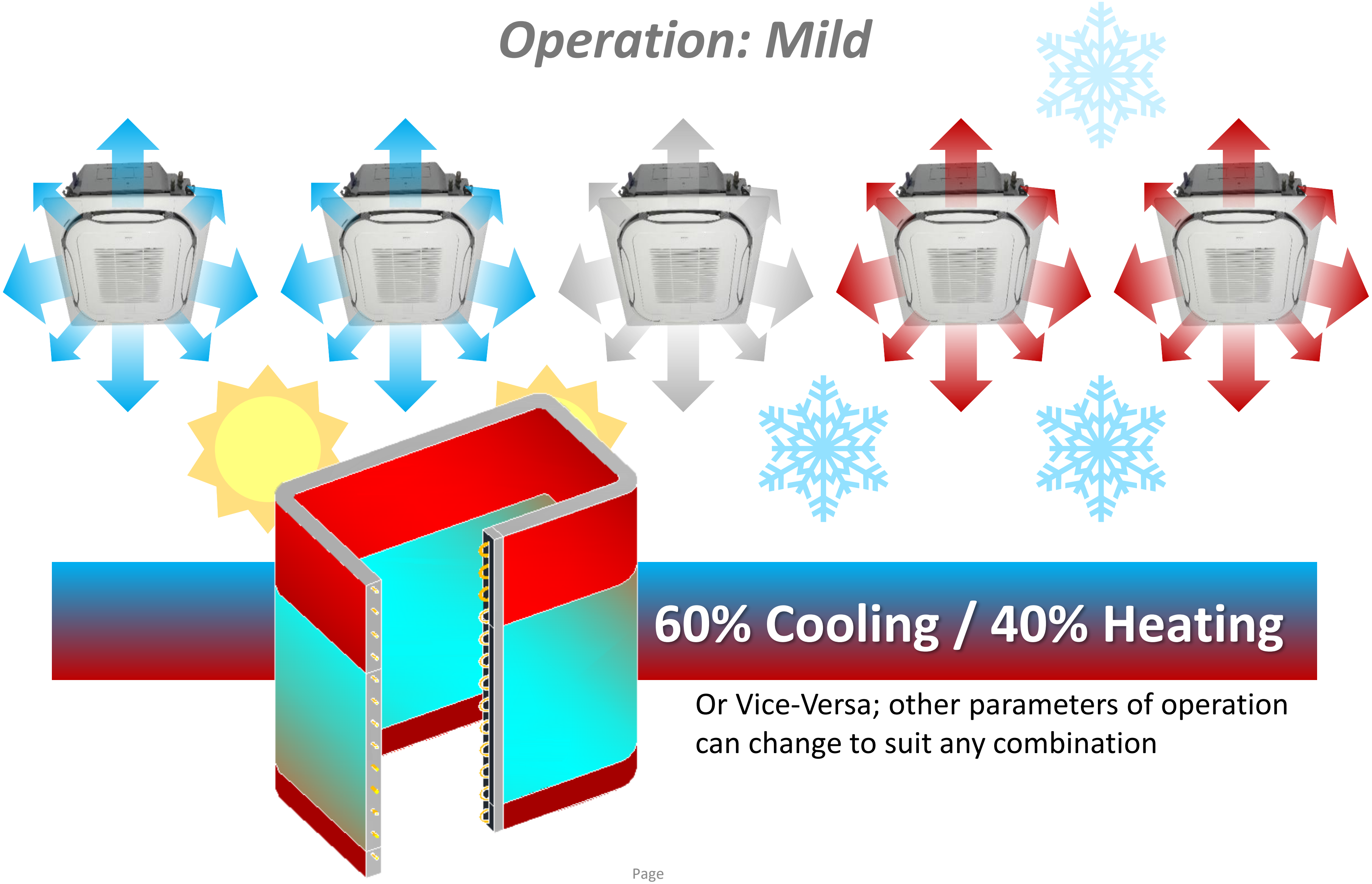
Shown in 100% Heating operation

- High temperature, high pressure gas
- High temperature, high pressure liquid
- Low temperature, low pressure gas
- Low temperature, low pressure liquid



Heat Recovery Unit Control- Three Pipe

Operation: Mild



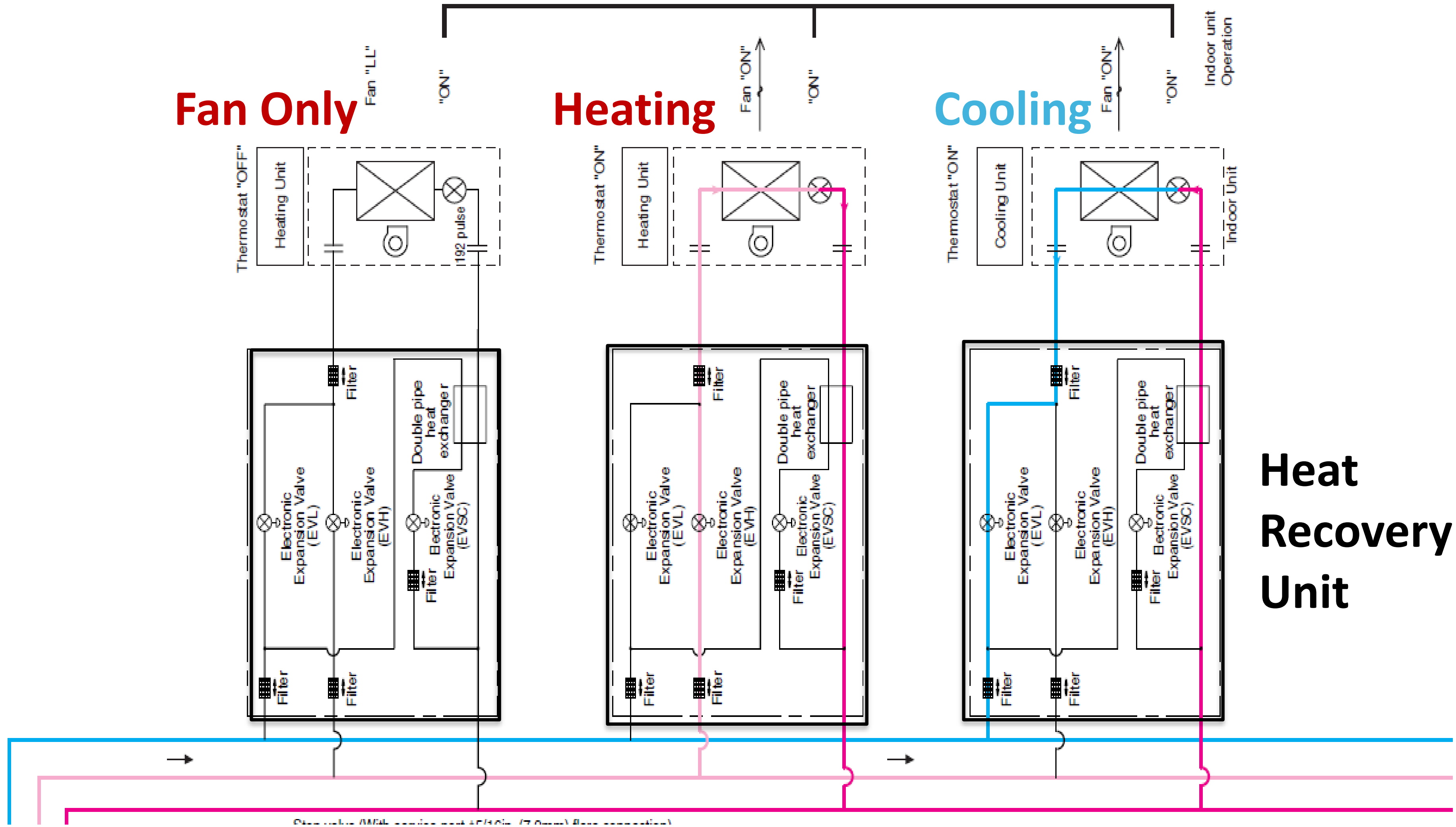
60% Cooling / 40% Heating

Or Vice-Versa; other parameters of operation can change to suit any combination

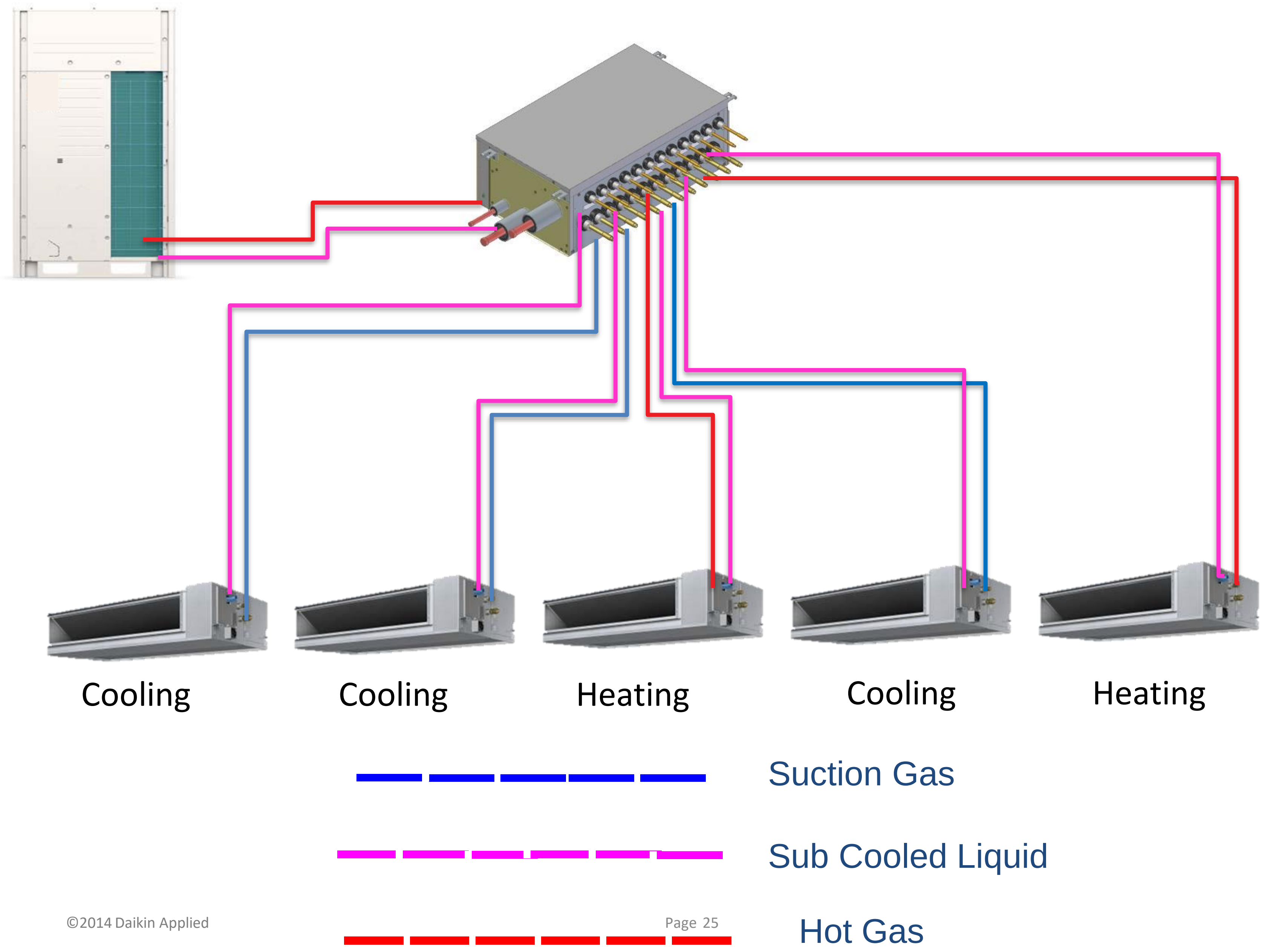
Heat Recovery Unit Control- Three Pipe

- High temperature, high pressure gas
- High temperature, high pressure liquid
- Low temperature, low pressure gas
- Low temperature, low pressure liquid

Shown in simultaneous heating and cooling operation



Heat Recovery- Two Pipe



Sequence of Operations- Defrost

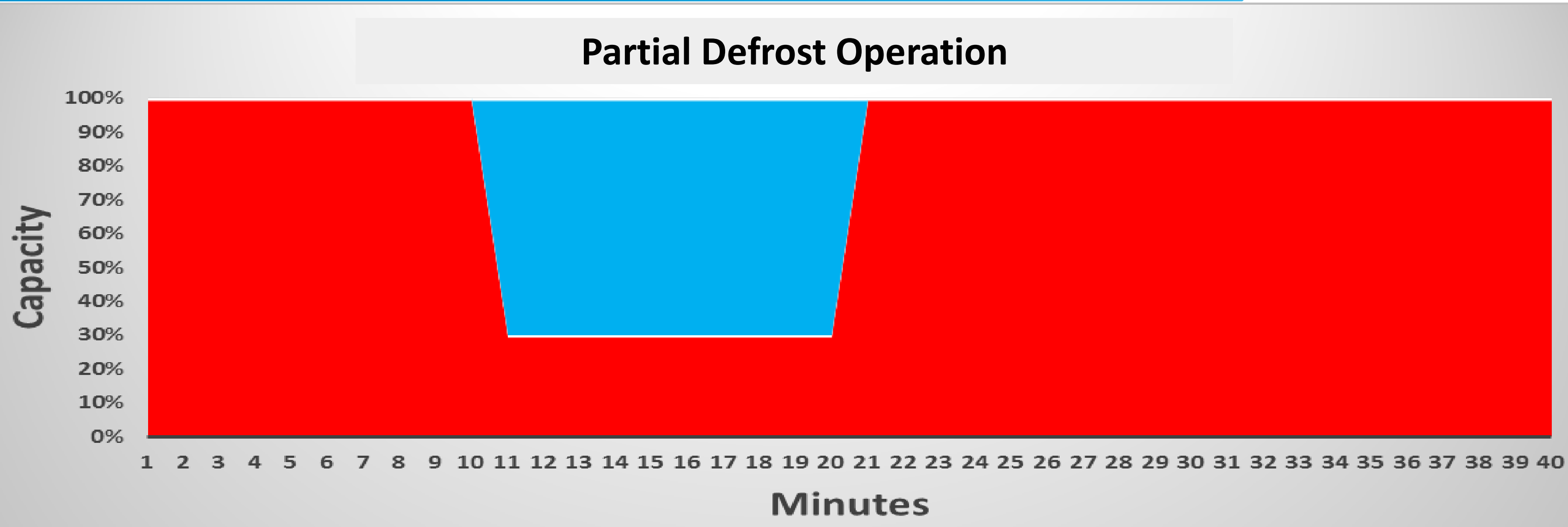
Condenser Defrost Control

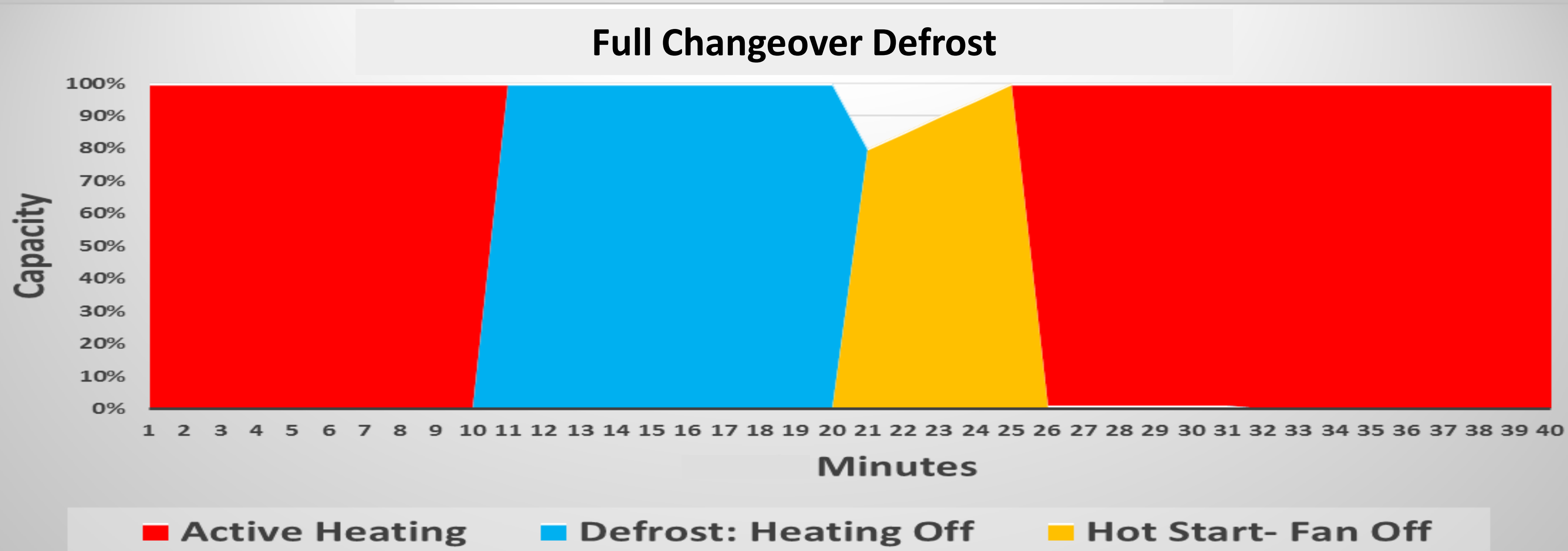
- Demand Based (Time and/or Temperature)
- Actual SOO varies with OEM
- Sequences for HP and HR
  - Full Changeover (All Heat Pump, Most Heat Recovery)
  - Partial Changeover/Continuous Heating (Some Heat Recovery Models)
  - Combination Defrost (Some Heat Recovery Models)
    - Partial defrost with full defrost every 3rd cycle

Indoor Unit Defrost Control

- Full Changeover
  - Fan off, or Fan-on plus supplemental backup
- Partial Defrost
  - Fan goes to lowest speed

Sequence of Operations- Defrost





Application and Design Considerations for Selecting a VRF System

Efficiency Metrics

How are we going to measure this?

EER (95F)	IEER	COP (47°F)	COP (17°F)	SCHE
System full load cooling operation	System seasonal cooling efficiency	Full Load Heating Performance at 47°F	Full Load Heating Performance at 17°F	Simul-taneous Cooling and Heating Efficiency (approx 50-50%)

In 2010, IEER (Integrated Energy Efficiency Ratio) replaced IPLV (Integrated Part Load Performance) as the means to measure part load performance of commercial HVAC systems over 65,000 Btu/h

Efficiency Requirements- NYCECC

VRF Systems <65MBH are tested to AHRI 210/240

- AHRI Directory Listing:
  - Variable Speed Mini-Split and Multi-Split Air Conditioners and Heat Pumps

TABLE C403.2.3(2)
MINIMUM EFFICIENCY REQUIREMENTS:
ELECTRICALLY OPERATED UNITARY AND APPLIED HEAT PUMPS

EQUIPMENT TYPE	SIZE CATEGORY	HEATING SECTION TYPE	SUBCATEGORY OR RATING CONDITION	MINIMUM EFFICIENCY	TEST PROCEDURE[a]
Air cooled (cooling mode)	< 65,000 Btu/h[b]	All	Split System	14.0 SEER	AHRI 210/240
			Single Packaged	14.0 SEER	
Through-the-wall, air cooled	≤ 30,000 Btu/h[b]	All	Split System	14.0 SEER	
			Single Packaged	14.0 SEER	
Single-duct high-velocity air cooled	< 65,000 Btu/h[b]	All	Split System	13.0 SEER	

Efficiency Requirements- NYCECC

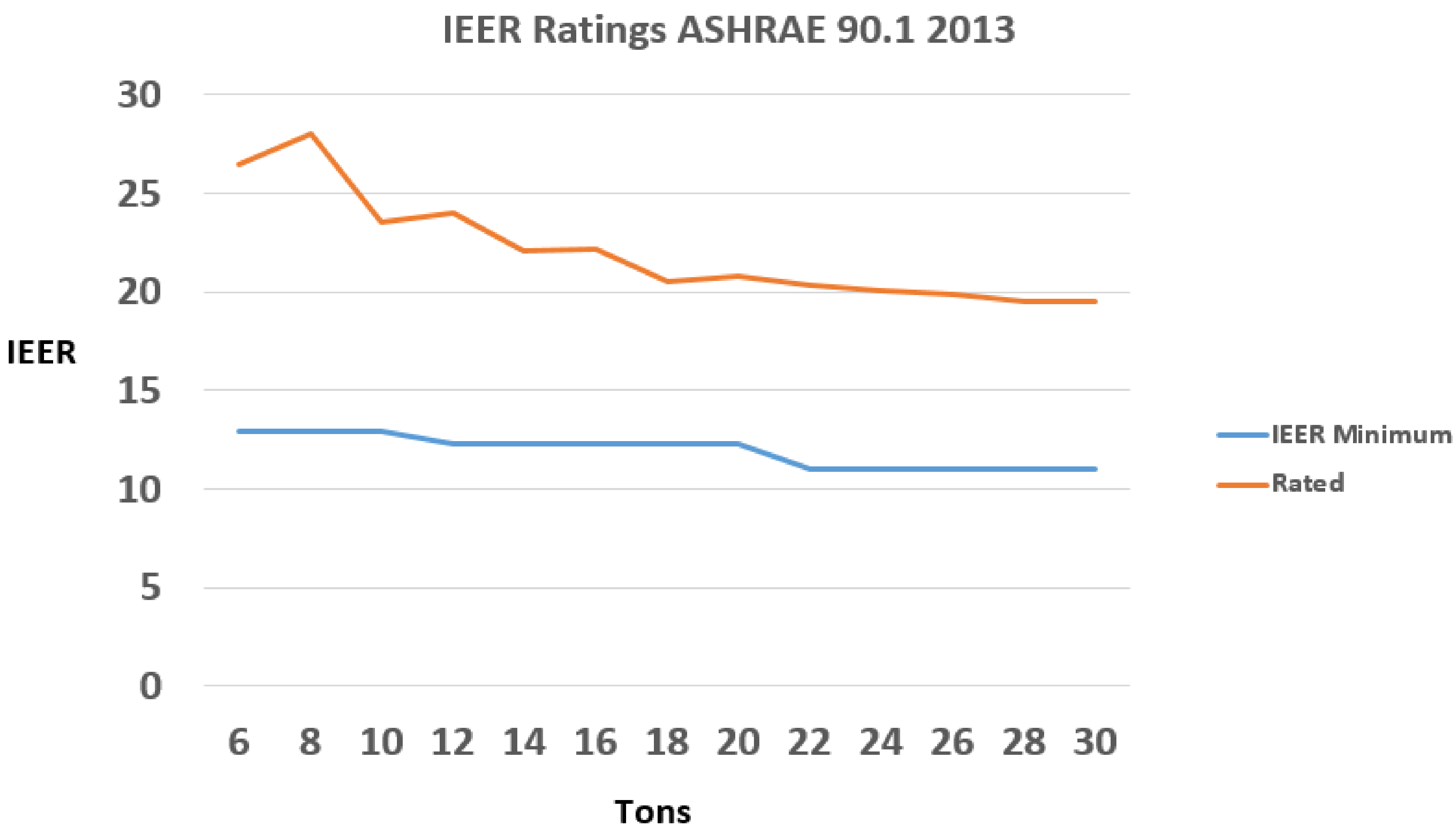
VRF Systems >65MBH are tested to AHRI 1230

- AHRI Directory Listing:
  - VRF Multi-Split Air Conditioning and Heat Pump Equipment
  - Table C403.2.3(12)

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency	Test Procedure
VRF air cooled (cooling mode)	< 65,000 Btu/h	All	VRF multisplit system	13.0 SEER	AHRI 1230
	> 65,000 Btu/h and < 135,000 Btu/h	Electric resistance (or none)	VRF multisplit system	11.0 EER 12.9 IEER(before 1/1/2017) 14.6 IEER (as of 1/1/2017)	
	> 65,000 Btu/h and < 135,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	10.8 EER 12.7 IEER (before 1/1/2017) 14.4 IEER (as of 1/1/2017)	
	> 135,000 Btu/h and < 240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	10.6 EER 12.3 IEER (before 1/1/2017) 13.9 IEER (as of 1/1/2017)	
	> 135,000 Btu/h and < 240,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	10.4 EER 12.1 IEER (before 1/1/2017) 13.7 IEER (as of 1/1/2017)	
	> 240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	9.5 EER 11.0 IEER (before 1/1/2017) 12.7 IEER (as of 1/1/2017)	
	> 240,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	9.3 EER 10.8 IEER (before 1/1/2017) 12.5 IEER (as of 1/1/2017)	

VRF Efficiency Comparison- 90.1 2013

Current VRF systems in the US market tend to significantly exceed the minimum efficiency requirements set for electrically operated air to air VRF systems



Basics

- VRF systems can be "over connected" (130-200% as rule of thumb) to take advantage of diversity
  - Connection Ratio: Sum of total indoor unit capacity (nominal)/ Condenser capacity (nominal)
    - Based on nominal cooling capacities
    - Some unit configuration limits based on OEM guidelines
    - This is not a reason to ignore rated capacity at design conditions

- Peak: Largest sum of all simultaneously occurring zone/space loads (aka building peak or Diversified load)
- Space Load: Largest load requirement per individual zone or space

Loads and System Sizing

- Indoor units sized for zone or space load
- Condenser sized for Peak (diversified) load
- Size based on dominant load
- Consider minimum turn-down requirements
- Consider need for simultaneous heating/cooling

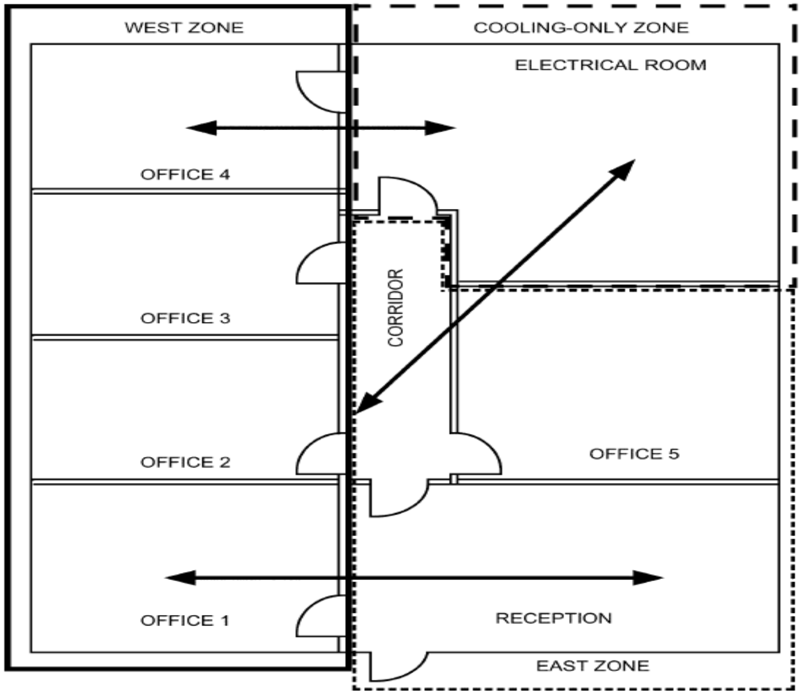


Fig. 13 System Design

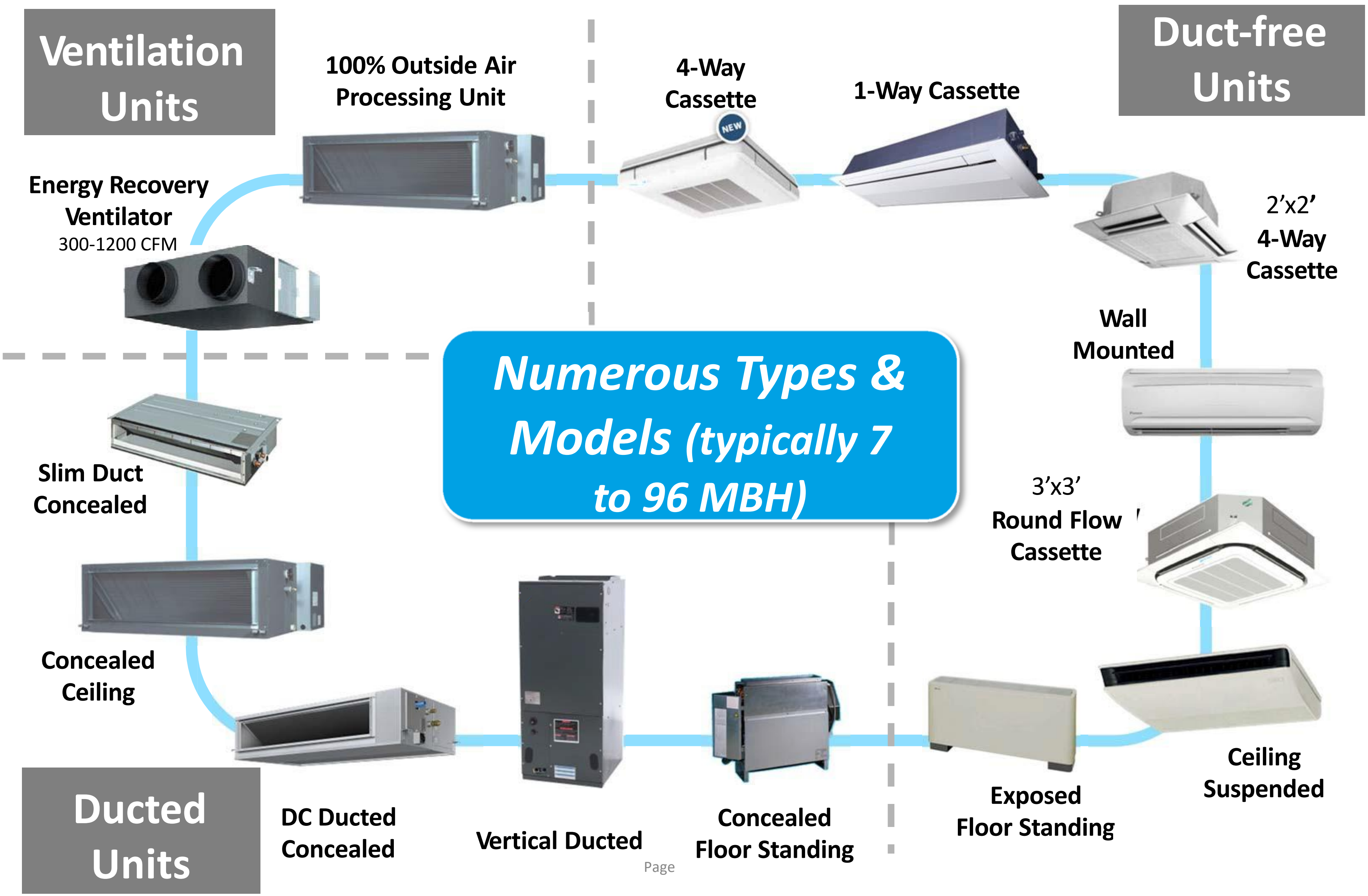
Connected Load: 109MBH (10 Tons)
Peak Load: 93.7MBH (8 Ton)
Diversity Factor= .86
Connection Ratio= 125%

Table 3 Peak Load Profile

Zone	Cooling at 3 PM in August, Btu/h	Cooling at 11 AM in August, Btu/h	Heating at 8 AM in January, Btu/h	Indoor Unit Capacity, Btu/h
Office 1	14,580	8,748	15,240	15,000
Office 2	10,429	6,257	10,023	12,000
Office 3	10,429	6,257	10,023	12,000
Office 4	12,874	7,724	11,420	15,000
Reception	13,457	22,429	18,789	24,000
Office 5	4,717	7,862	7,500	8,000
Corridor	1,265	2,109	1,000	N/A
Electrical Room	26,075	28,045	N/A	36,000
Total Peak	93,797	89,432	73,995	—

Indoor Unit Selection Considerations

Standard Indoor Unit Options



Indoor Unit Selection Criteria

Standard Unit Characteristics

Coil Design

- ~3 Row, 13-15FPI
- Downstream of fan (blow-through)
- Electronic Expansion Valves

Fan and Drive Design

- Centrifugal, synthetic material
- Direct Drive
- Mostly ECM motors, some PSC
  - .1 to .35kW input power

Sound Information

- Typically only sound pressure data available
- Typically rated to ISO standard or OEM specific criteria

Indoor Unit Selection Criteria

Recommended Operating Range

Cooling:

- 58FWB to 82FWB

Heating:

- 58FDB to 80FDB
  - 50FDB EAT allowed for short-term warm-up period

Nominal Capacity Entering Air Conditions

- Cooling nominal EAT 80FDB/67FWB for all types
- Heating nominal EAT is 70FDB

Selection Criteria

Capacities

- Size for dominant load (heating v. cooling)

Sensible Heat Ratio

- Between .70 to .82 at nominal conditions
  - Unit type
  - Model and OEM
  - Capacity to cabinet size

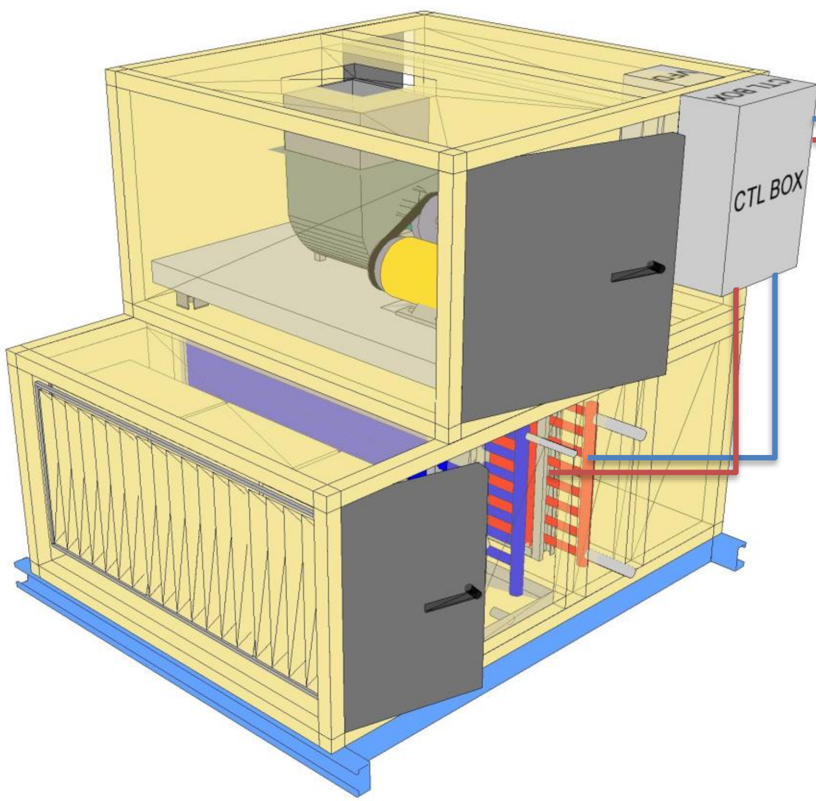
Airflow

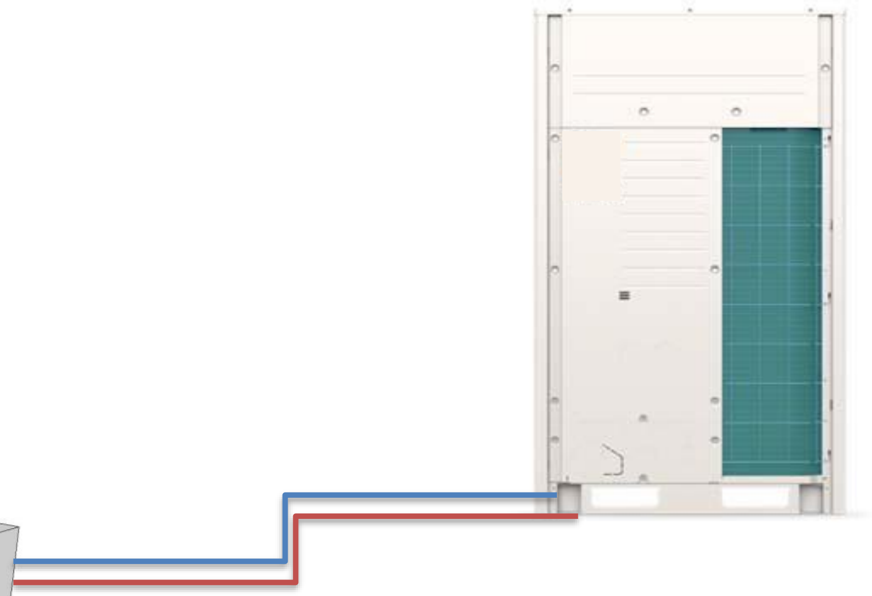
- 350 to 450CFM/Ton
  - Same variables as SHR
  - Must factor in ESP" for accurate rating

Configurable & Custom Air Handler Integration

Discharge Air Temperature Control

- SZVAV
- VAV
- CV+RH





Recent Project Spec:

- MERV 8/13 Pre and Final Filter
- HW Coil
- 3000 CFM
- Stainless Steel Liner
- Double-Wall R-13
- 3.45”TESP (2”ESP)

Outside Air Considerations

Direct Method: Mix a percentage of OA with return air at unit. OA is not pretreated, application conditions apply. Must be rated on MA temp

Integrated Method: OA is pretreated by DOAS or ERV units before being supplied with indoor units. Must be rated on MA temp.

Decoupled Method: DOAS provides 100% conditioned OA direct to space. VRF only has to handle space loads; DOAS can handle some or all space latent

Outside Air Considerations

Direct Method: Mix a percentage of OA with return air at unit. OA is not pretreated, application conditions apply. Indoor units must be rated on MA temp

Example:

Total Supply= 1375 CFM
OA= 275 CFM at 95FDB/75FWB
Return= 1,1100 CFM at 75FDB/64FWB
Mixed Air= 78FDB/66FWB

Outside Air Considerations

Integrated Method: OA is pretreated by DOAS or ERV units before being supplied to indoor units. Indoor units must be rated on MA temp.

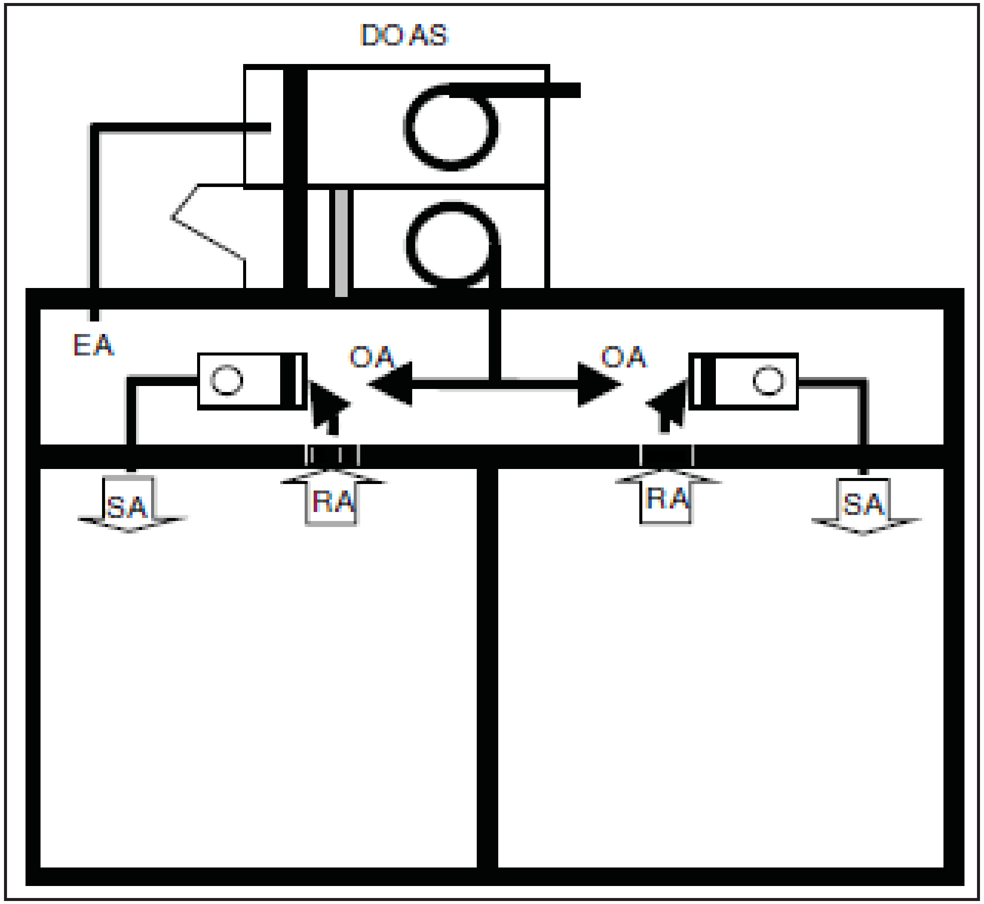


FIGURE 1. Series arrangement of DOAS and terminal equipment.

DAT Temperature and Distribution

SECTION MC 403

MECHANICAL VENTILATION

403.3.2.3.2 System ventilation efficiency.

The system ventilation efficiency (Ev) shall be determined using Table 403.3.2.3.2 or Appendix A of ASHRAE 62.1.

TABLE 403.3.1.2
ZONE AIR DISTRIBUTION EFFECTIVENESS[a,b,c,d,e]

Air Distribution Configuration	E_z
Ceiling or floor supply of cool air	1.0[f]
Ceiling or floor supply of warm air and floor return	1.0
Ceiling supply of warm air and ceiling return	0.8[g]
Floor supply of warm air and ceiling return	0.7
Makeup air drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup air drawn in near to the exhaust and/or return location	0.5

Outside Air Considerations

Decoupled: DOAS provides 100% conditioned OA direct to space. VRF only has to handle space loads; DOAS can handle some or all space latent

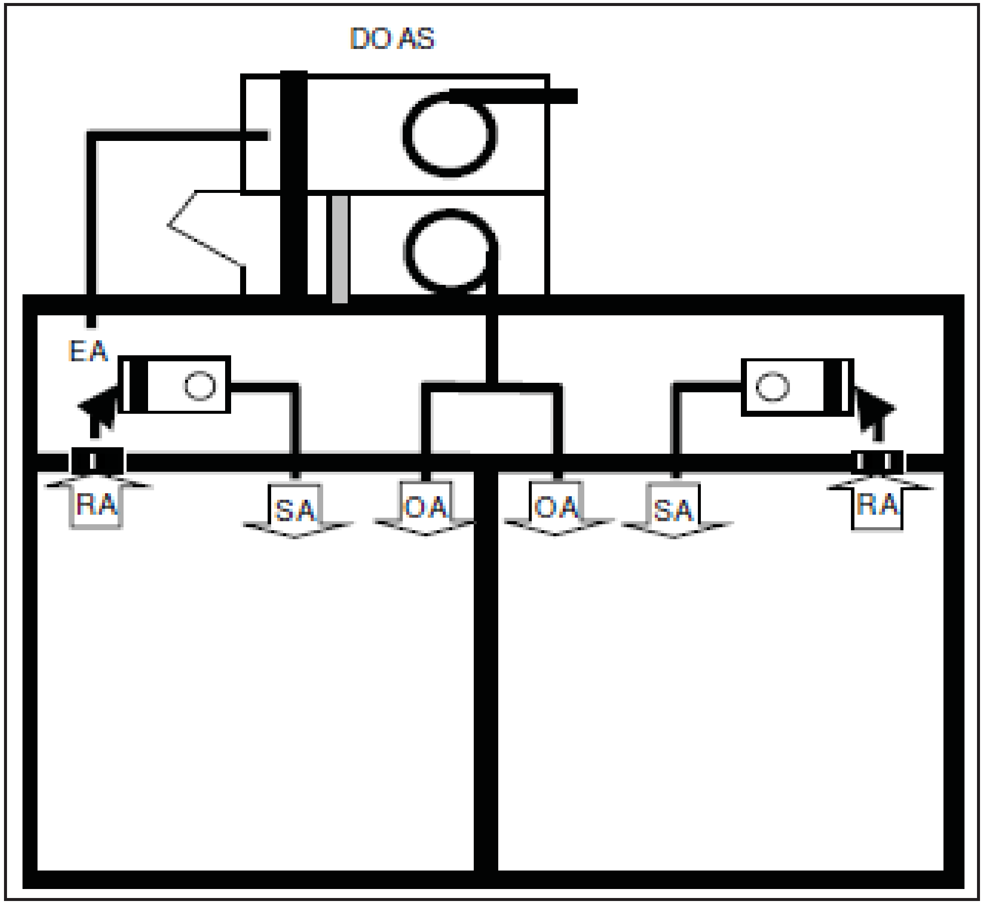


FIGURE 2. Parallel arrangement of DOAS and terminal equipment with individual SA and OA diffusers, a false paradigm.

Condenser Selection Considerations

Outdoor Unit Range

	Heat Pump	Heat Recovery	Heat Pump (Single Phase)
Air Cooled	 *6 - 42 tons*	 *5 - 48 tons*	 *3-5 tons*
Water Cooled	 *5 -~40 tons*	 *5 -~40 tons*	

Air Cooled Unit Characteristics

Compressor(s)/Condenser Modules

- Mostly inverter, some digital scrolls and constant volume
- Single or dual compressors
- Single modules up to 14+tr, manifold for higher

Fan and Drive Design (Air Cooled)

- Propeller, synthetic material
- Direct drive, ECM, variable speed

Sound Information

- Typically only sound pressure data available

Typically rated to ISO standard or OEM specific criteria

Foot Print

- Single modules range from 36” to 48”W x 30”D x 66”H

Electrical Characteristics

Air Cooled Reference:

6 Ton Module MCA= 30A

14 Ton Module MCA= 61A

Water Cooled Reference:

6 Ton Module MCA= 22A

14 Ton Module MCA= 44A

208v -3ph

Input Horsepower Reference

Air Cooled

12TR Heat Pump= 8HP

20TR Heat Pump= 13.5HP

30TR Heat Pump= 20HP

Air Cooled

12TR Heat Recovery= 9.5HP

20TR Heat Recovery= 15HP

30TR Heat Recovery= 24HP

Water Cooled

12TR Heat Pump= 9HP

18TR Heat Pump= 13.5HP

Water Cooled

12TR Heat Recovery= 9HP

18TR Heat Recovery= 13.5HP

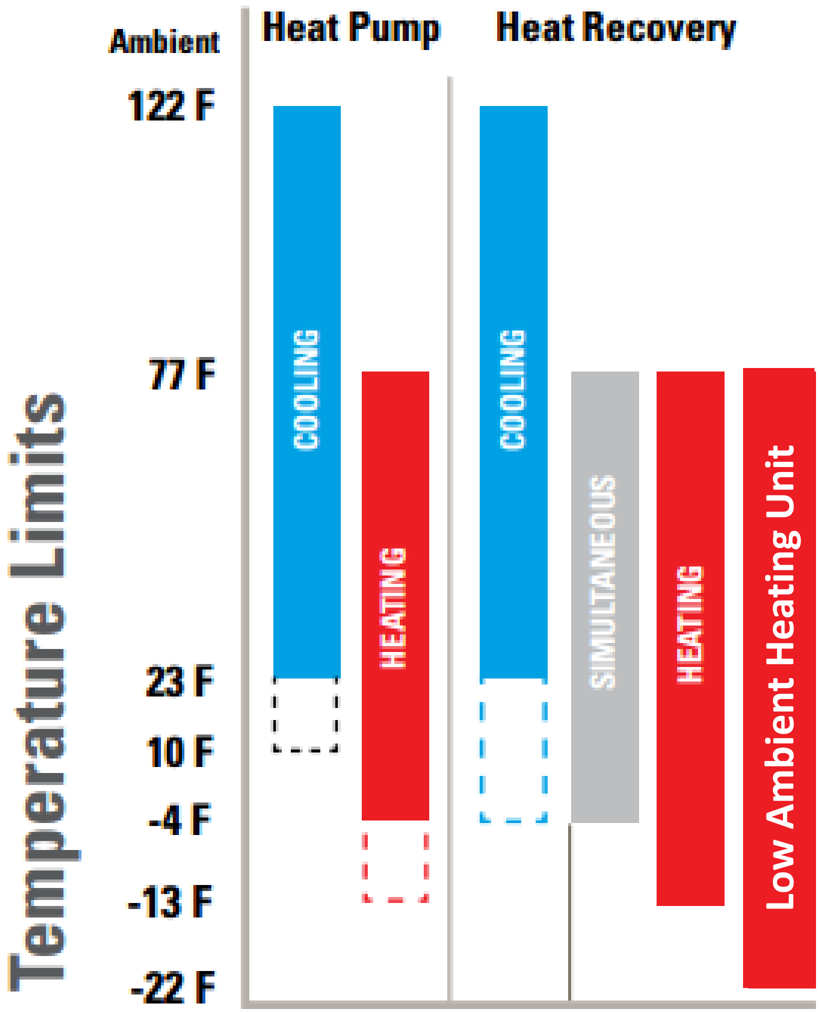
THESE ARE APPROXIMATE- BASED ON ONE OEM. Always verify with OEM rep for actual

Condenser Operating Ranges

Air Cooled Operating Ranges

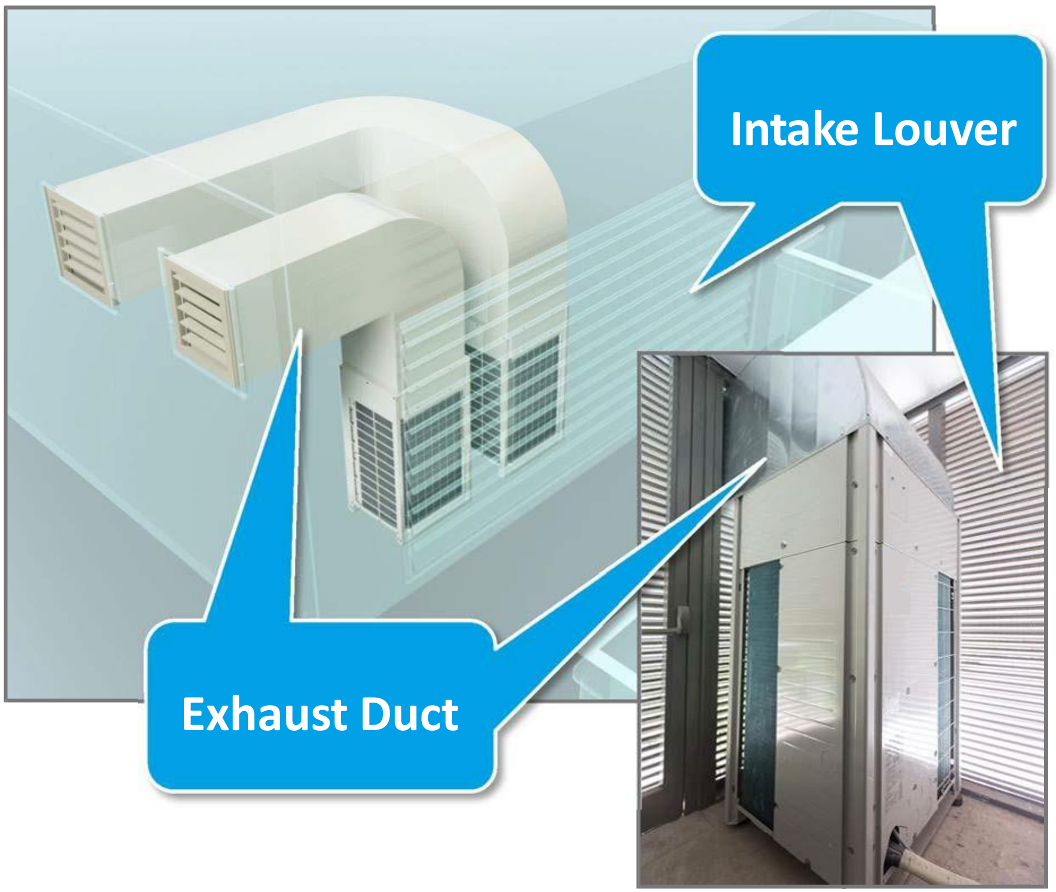
Nominal Capacity Conditions

- Cooling
  - 95FDB
- Heating
  - 47FDB/ 43FWB



Air Cooled Condenser Installation Flexibility

- Rated airflow at ESPto 0.32WG
- Internal/Restricted installs possible
- Noise, sight or location issues mitigated



Condenser Selection Criteria

Water Cooled Unit Characteristics

Compressor(s)/Condenser Modules

- Mostly inverter
- Single or dual compressors
- Single modules up to 18tr, manifold for higher

Heat Exchanger

- Up to 285PSIG (640')
- BPHE- NOT CLEANABLE
- Allowed flow rate and flexibility varies with OEM
  - 13 to 39GPM per module
  - ~10F ΔT at 13GPM, 5F ΔT at 25GPM

The Water Flow Head Loss						
Water Volume	gpm	13.2	15.9	25.4	31.7	39.6
Head Loss	FT HD	3.1	4.3	10.3	15.8	24.2

*This value shows the amount of head loss per one unit

Water Cooled Unit Characteristics

Water Side Controls

- Interlocks for pump or control valve
  - Can be used per module or per system
  - Can be on/off or modulating

Condenser Relief

- 12 Ton condenser with 12 tons of operating connect load

85F EWT and 25GPM
Input Power= 8.4kW

85F EWT and 13GPM
Input Power= 9.5kW

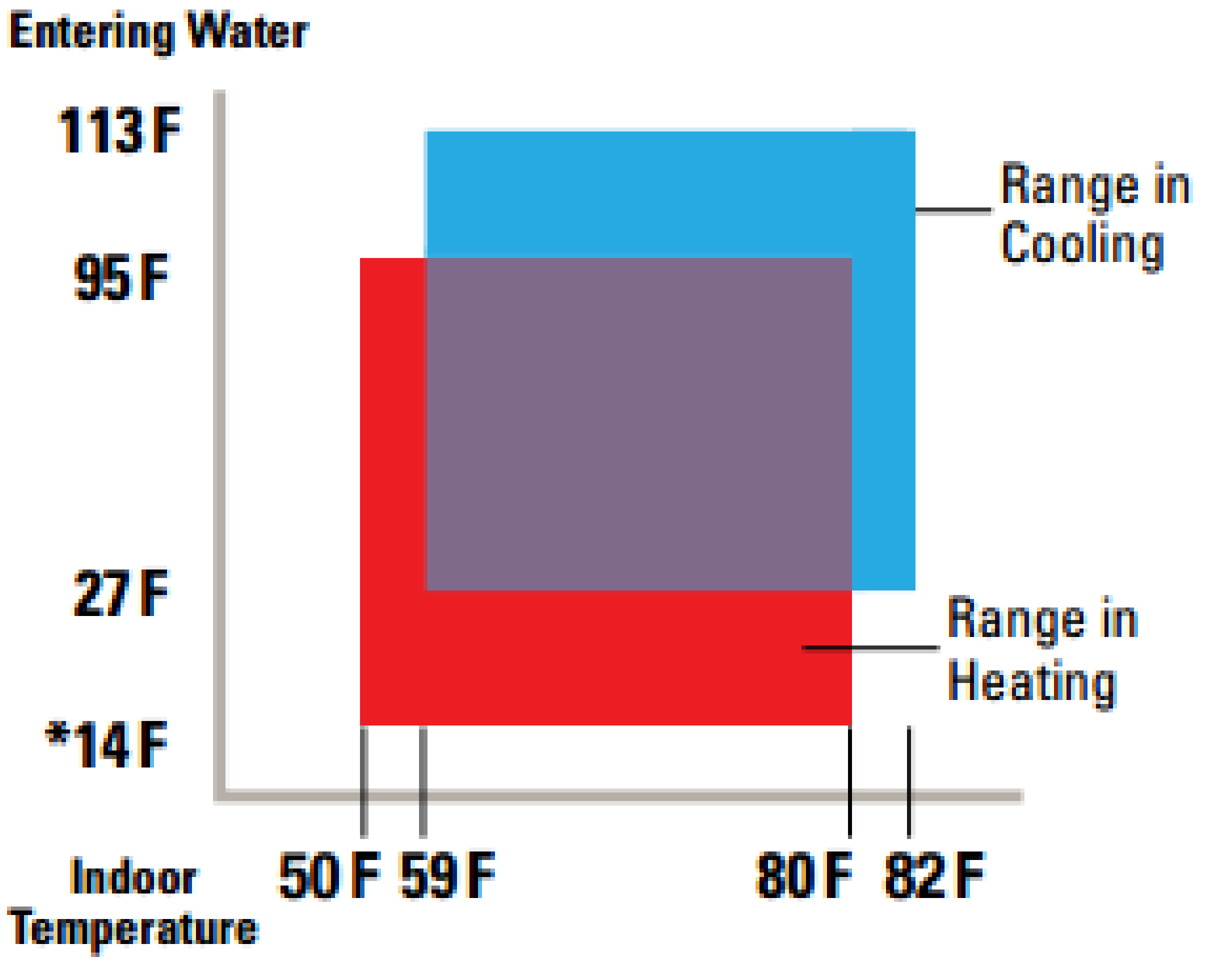
67F EWT and 25GPM
Input Power= 6.0kW

67F EWT and 13GPM
Input Power= 6.5kW

Nominal Capacity Conditions

- Cooling
  - 86F EWT
- Heating
  - 68F EWT

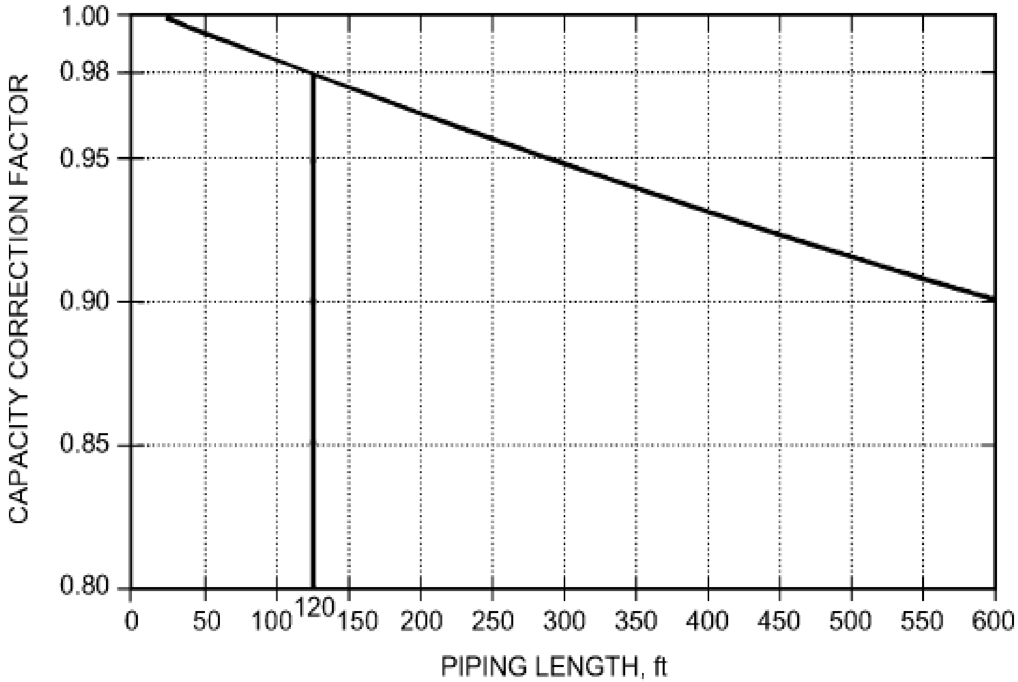
Water Cooled Operating Ranges



Capacity Corrections

The following capacity corrections should be considered:

- Corrected indoor unit capacity
- Non-AHRI outdoor temperatures (or EWT/Flow)
- Piping length correction factor
- Defrost correction factors
- Altitude (if applicable)



Note: Representative data. Not specific for each manufacturer.

Nominal Versus Design Conditions

If you are allowing substitutes or alternates, these must be done with apples to apples comparisons to include all correction factors and refrigerant charge changes.

Manufacturer No. 1									
System Tag	Required Cooling Capacity (Btuh)	Required Heating Capacity (Btuh)	Nominal Cooling Capacity (Btuh)	Nominal Heating Capacity (Btuh)	Design Cooling Outdoor Temp DB (°F)	Design Heating Outdoor Temp WB (°F)	Corrected Cooling Total Capacity (Btuh)	Corrected Heating Capacity (Btuh)	Total Refrigerant Charge
ACCU-1	144,032	152,460	216,000.0	243,000.0	93.0	10.9	155,305.4	120,475.4	90.7
ACCU-2	120,000	146,900	192,000.0	215,000.0	93.0	10.9	143,413.0	120,716.0	78.5

Manufacturer No. 2									
System Tag	Required Cooling Capacity (Btuh)	Required Heating Capacity (Btuh)	Nominal Cooling Capacity (Btuh)	Nominal Heating Capacity (Btuh)	Design Cooling Outdoor Temp DB (°F)	Design Heating Outdoor Temp WB (°F)	Corrected Cooling Total Capacity (Btuh)	Corrected Heating Capacity (Btuh)	Total Refrigerant Charge
ACCU-1	144,032	152,460	216,000.0	243,000.0	93.0	10.9	206,866	171,319	45.6
ACCU-2	120,000	146,900	192,000.0	215,000.0	93.0	10.9	183,899	152,460	35.9

Figure 6 A schedule comparison of two VRF manufacturers' outdoor units at nominal vs. design ratings.

Comparing Alternate Systems- Indoor Units

Manufacturer No. 1												
System Tag	Room Name	Required Total Cooling Capacity (Btuh)	Required Heating Capacity (Btuh)	Nominal Cooling Capacity (Btuh)	Nominal Heating Capacity (Btuh)	Cooling Design Entering Temp DB/ WB (°F)	Heating Design Entering Temp DB (°F)	Corrected Capacity			Peak Fan Air-flow (cfm)	Max Fan ESP Setting 208V/ 230V (in. wc)
								Cooling Total Capacity (Btuh)	Cooling Sensible Capacity (Btuh)	Heating Capacity (Btuh)		
ACCU-1	Core 1	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	29,866.4	20,957.0	23,329.8	883	0.6/0.6
	Core 2	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	29,866.4	20,957.0	23,329.8	883	0.6/0.6
	Core 3	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	29,866.4	20,957.0	23,322.1	883	0.6/0.6
	Core 4	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	29,866.4	20,957.0	23,214.6	883	0.6/0.6
	North Perimeter	36,200	39,100	36,000.0	40,000.0	78.0/66.0	72.0	35,839.7	27,031.1	27,279.0	1165	0.6/0.6
ACCU-2	East	41,600	49,800	48,000.0	54,000.0	78.0/66.0	72.0	47,804.3	34,525.0	40,424.6	1412	0.6/0.6
	South	37,300	47,600	48,000.0	54,000.0	78.0/66.0	72.0	47,804.3	34,525.0	40,145.7	1412	0.6/0.6
	West	41,100	49,500	48,000.0	54,000.0	78.0/66.0	72.0	47,804.3	34,525.0	40,145.7	1412	0.6/0.6

Manufacturer No. 2												
System Tag	Room Name	Required Total Cooling Capacity (Btuh)	Required Heating Capacity (Btuh)	Nominal Cooling Capacity (Btuh)	Nominal Heating Capacity (Btuh)	Cooling Design Entering Temp DB/ WB (°F)	Heating Design Entering Temp DB (°F)	Corrected Capacity			Peak Fan Air-flow (cfm)	Max Fan ESP Setting 208V/ 230V (in. wc)
								Cooling Total Capacity (Btuh)	Cooling Sensible Capacity (Btuh)	Heating Capacity (Btuh)		
ACCU-1	Core 1	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	28,951	21,466	32,720	1,094	.08
	Core 2	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	28,951	21,466	32,720	1,094	.08
	Core 3	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	28,951	21,466	32,720	1,094	.08
	Core 4	27,297	32,950	30,000.0	34,000.0	78.0/66.0	72.0	28,951	21,466	32,720	1,094	.08
	North Perimeter	36,200	39,100	36,000.0	40,000.0	78.0/66.0	72.0	34,741	25,960	38,520	1,130	.08
ACCU-2	East	41,600	49,800	48,000.0	54,000.0	78.0/66.0	72.0	46,344	32,501	51,997	1,377	.08
	South	37,300	47,600	48,000.0	54,000.0	78.0/66.0	72.0	46,344	32,501	51,997	1,377	.08
	West	41,100	49,500	48,000.0	54,000.0	78.0/66.0	72.0	46,344	32,501	51,997	1,377	.08

Figure 7 A schedule comparison of two VRF manufacturers' indoor units at nominal vs. design ratings. The selected units are all ducted units. Notice the difference in capacities compared to design ratings.

Low Ambient Design Considerations

VRF Primary Heating- Indoor Unit Selection

- **Indoor Unit Sizing**
  - Select based on heating conditions if dominant
  - Grossly oversizing unit can lead to over heating
  - Verify MA/EAT temp is within unit operating range
    - 58FDB to 80FDB
    - 50FDB EAT allowed for short-term warm-up period

Example:

Total Supply= 1375 CFM
OA= 275 CFM at 10FDB (20%)
Return= 1,100 CFM at 70FDB
Mixed Air= 59FDB

VRF Primary Heating- Indoor Unit Selection

- **Additional Considerations**
  - Interlocks available to enable backup heat sources
    - Differential set-point
    - Enable/disable interlock based on error code
  - Factor air-side heat sources into fan ESP
  - Do not use unit return air sensor
    - Use sensor in controller or remote sensor
      - Coil temp may influence reading of return sensor
  - 100% OA coils and ERVs have lower minimum EAT
    - ~23FDB and 14FDB respectively

VRF Primary Heating- Condenser Selection

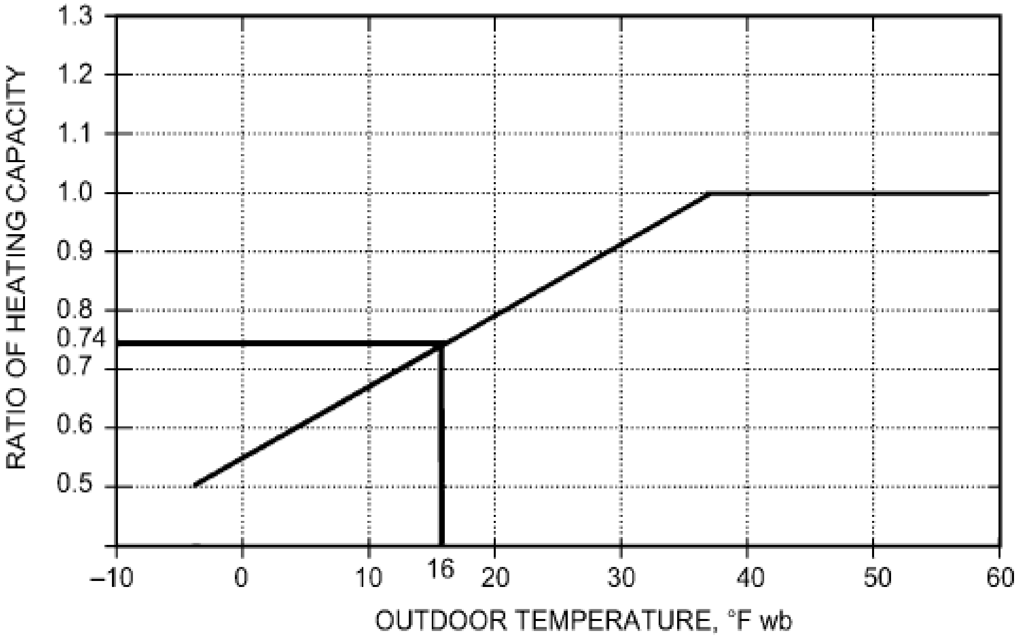
Air Cooled Unit Characteristics

Compressor(s)/Condenser Modules

- Condenser must be sized to include:
  - Defrost Correction (.80 to .95- wet bulb driven)
    - Verify OEM includes in selection software calculation
  - Piping Correction
  - Ambient Temperature Correction

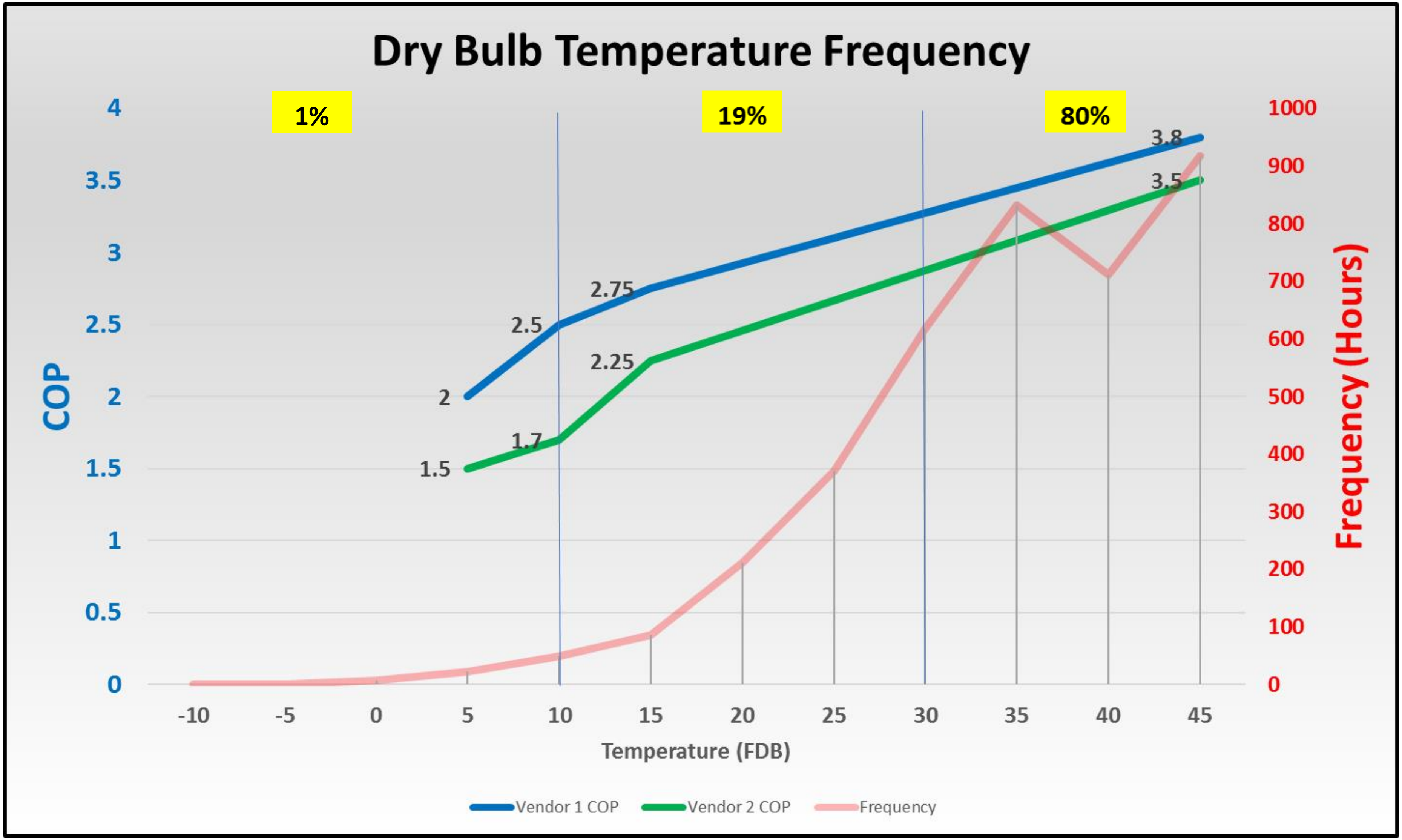
Efficiency

- COP@47FDB= ~3.8
- COP@17FDB= ~ 2.75
- COP@10FDB= 1.5- 2.5



Note: Representative data. Not specific for each manufacturer.

VRF Primary Heating- Condenser Selection



VRF Primary Heating- Condenser Selection

Air Cooled Unit Characteristics

Low Ambient Heating Performance

- Methods of increasing capacity at low ambient
  - Increase mass flow rate
    - Run the compressor at faster speed
    - Use a larger compressor and HX
- LOOK AT PERFORMANCE, NOT MARKETING HYPE

COOLING CAPACITY	
Btu/hr	AMBIENT DESIGN (^{O}F DB)
206,431	95
167,897	95

HEATING CAPACITY	
Btu/hr	AMBIENT DESIGN (^{O}F DB / WB)
199,840	10.0 / 8.9
187,141	10.0 / 8.9

Sound Power (dBA)
87
NA

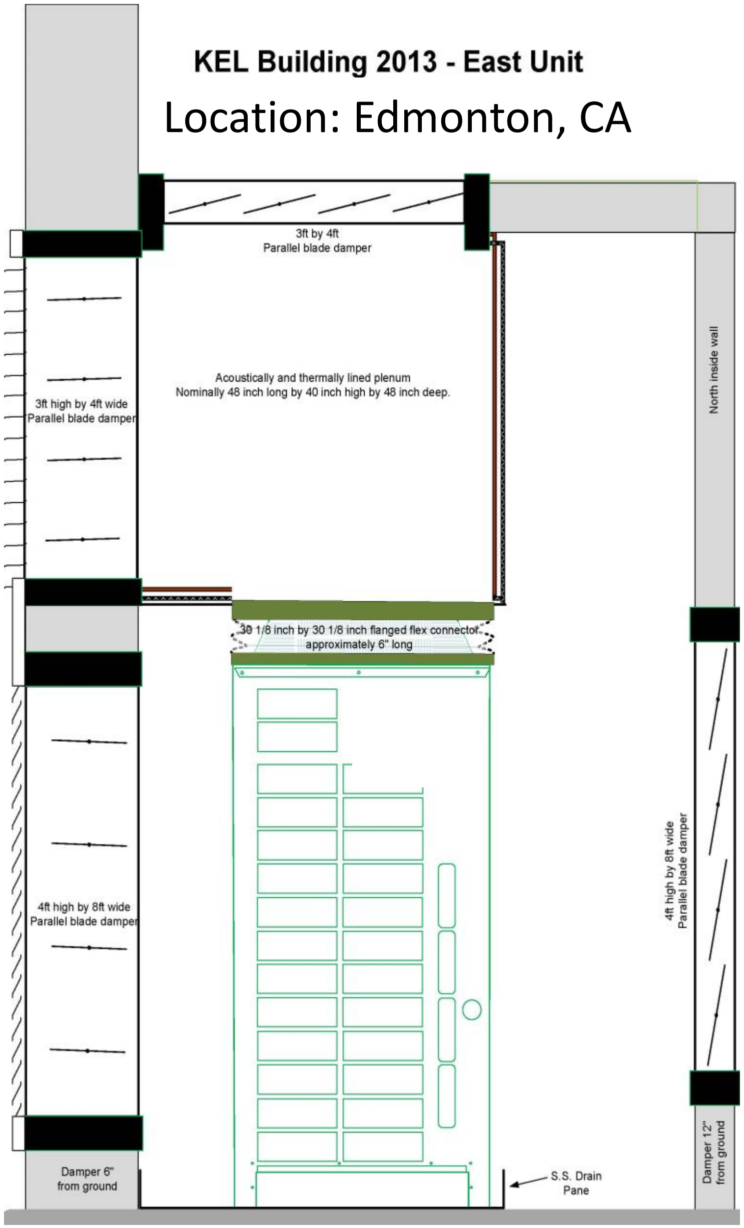
REFRIGERANT CHARGE	ELECTRICAL (PER MODULE)		DIMENSIONS	EFFICIENCY (NonDucted/Ducted)			NOMINAL TONNAGE
Field+ Factory	VOLTAGE-PHASE	MIN CIRCUIT AMPS (MCA)	Sq Ft	IEER	COP17	SCHE	
119.7	230V 3ph	55 / 38	20.4	21.9/19.2	2.48/2.31	25.6/22.7	[redacted]
123.5	230-3	60 / 60	20.0	16.6/16.1	2.12/2.12	21.4/16.9	

VRF Primary Heating- Condenser Selection

Air Cooled Unit Location

Manipulate Ambient Conditions

- Move condenser into MER/Enclosure
- Use additional heat source to maintain balance point temperature
- Remember condensate!



VRF Primary Heating- Condenser Selection

Consider Water-Cooled

- Tower/Boiler loop
  - Eliminates ambient de-rates
  - Less refrigerant piping
  - Higher VRF COP

Efficiency

- COP@68F EWT= ~5.0
- Cost per MM/BTU ($.22/kWh / $1.05 Therm)
- VRF @ 5.0 COP= $12.90
  - includes fan energy per AHRI 1230
- Natural Gas (90% AFUE)= $13.33
  - Does not include pump power or additional fans

VRF Secondary Heating

Condenser Sizing

- Size for changeover balance point
  - VRF capacity
  - Footprint
  - Efficiency

Sequence of Operations

- Newer controls allow indoor unit to stage base systems/other heat sources as primary
  - VRF heating can be used as a backup or in shoulder seasons

VRF Low Ambient Cooling

Considerations

- Check with OEM for ambient condition de-rates and operating ranges
- Use manufacturer snow hoods to prevent snow drift and prevailing winds
- If using for "comfort heating + process cooling", verify process load is greater than minimum turndown
- Unit may take up to 20 minutes to get back to capacity after power loss

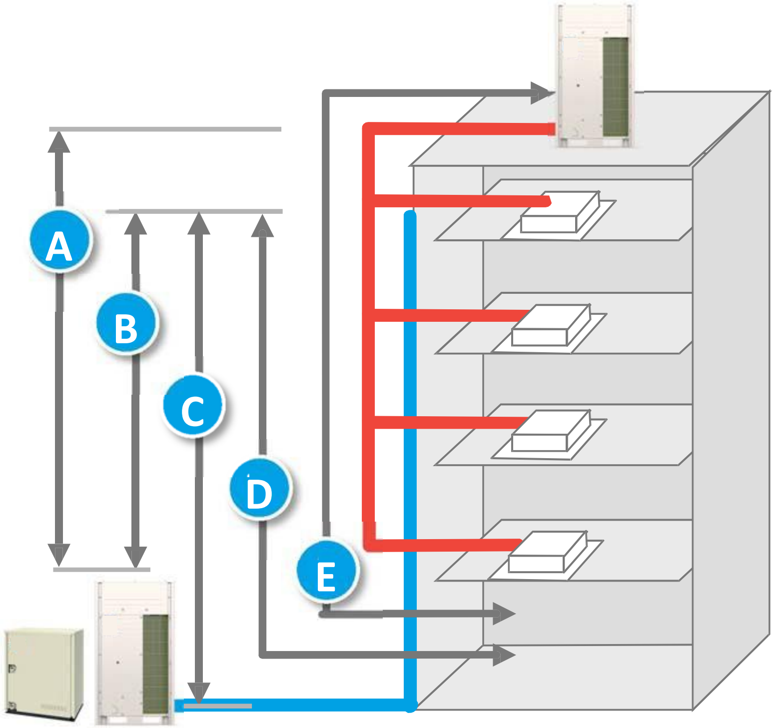
Piping Considerations

Piping Considerations

- Minimize Total Effective Length (TEL)
- OEM Piping guidelines exist to provide a balanced piping system
  - Minimum distances between longest and shortest branches, etc.
  - Selection software incorporate these rules
- Avoid traps in piping
  - Do Not Trap Gas Lines on Risers or Indoor Units
  - Follow OEM Guidelines for traps at condensers
- Provide means for expansion and contraction

Refrigeration Piping Limits

- Piping limits are far in excess of traditional DX systems
- Advanced oil return techniques allow this
- No oil traps are required



Liquid Line Max (feet)	Heat Pump	Heat Recovery	Water Cooled
A Vertical Drop	295	295	164
B Between IDU	100	49	49
C Vertical Rise	295	295	130
D From 1st Joint	130 (295)*	130 (295)*	130 (295)*
E Linear Length	540	540	390
Total Network	3280	3280	980

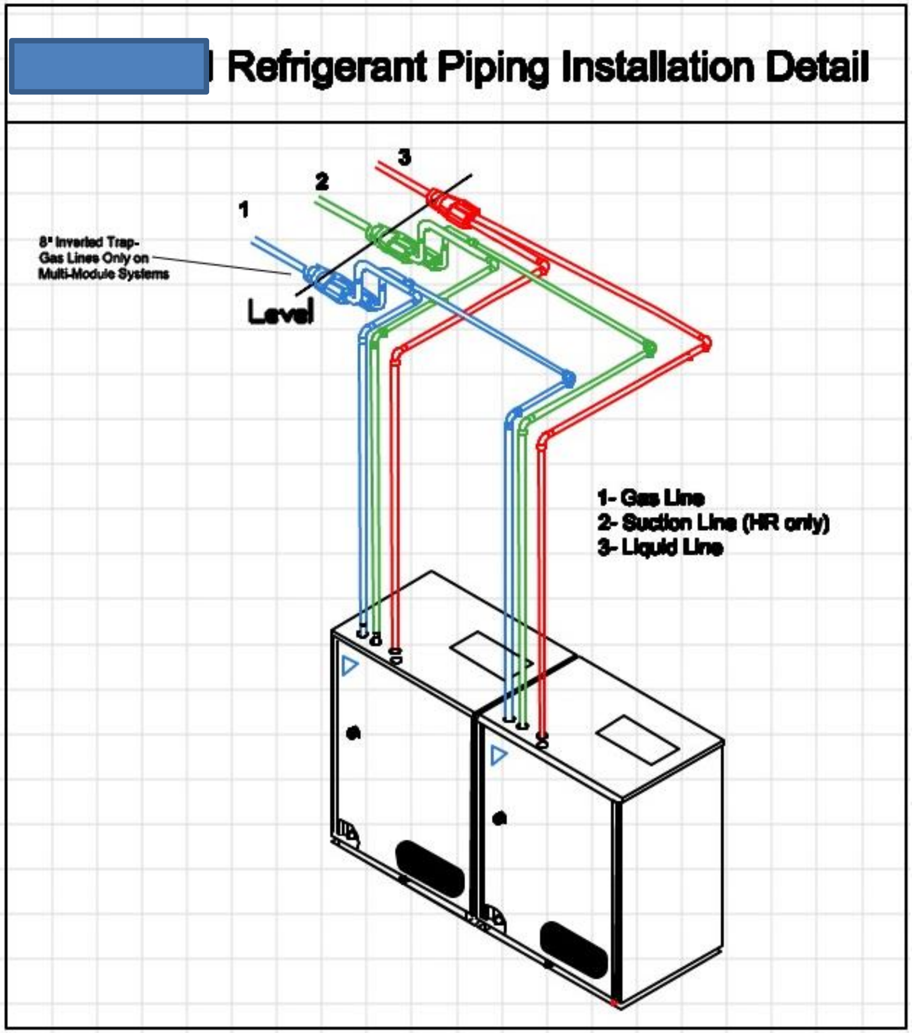
* Fan coil distance differentials need to be met

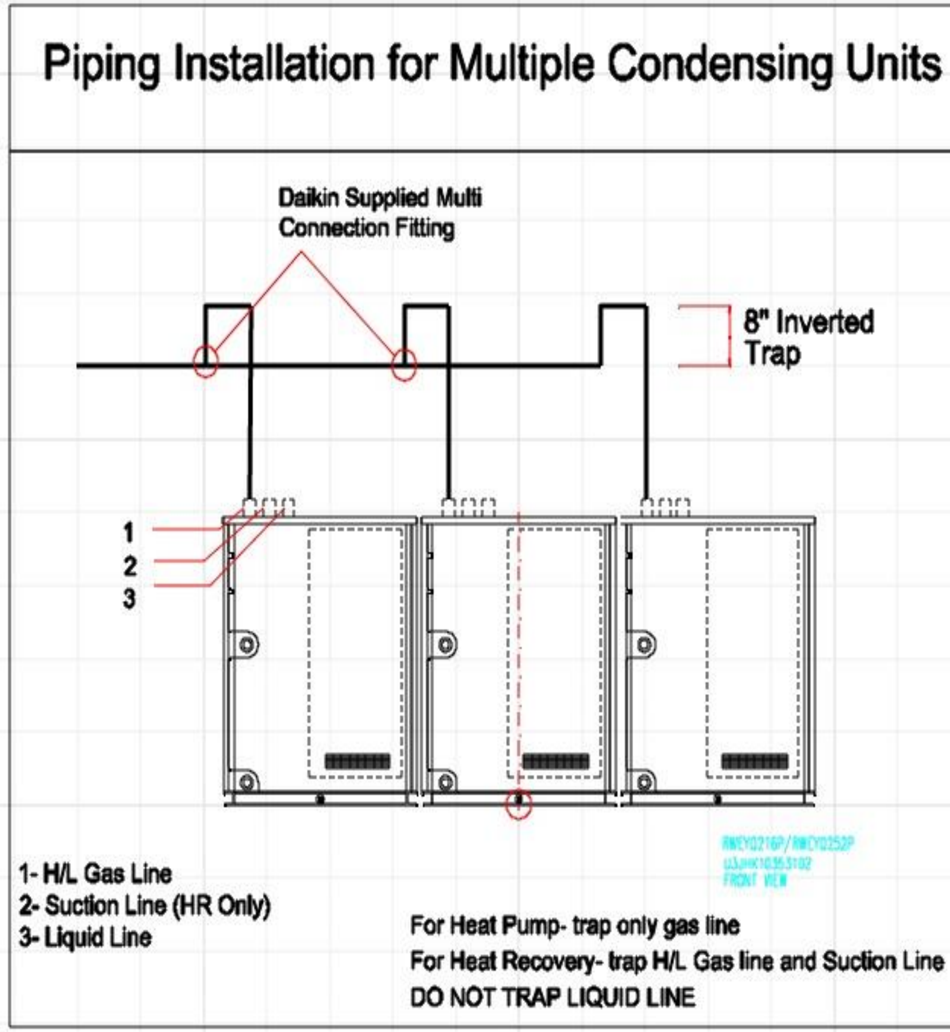
Detail Drawings

- What to include:
  - Fitting details
  - Condenser pipe connections
  - Heat Recovery Unit pipe connections

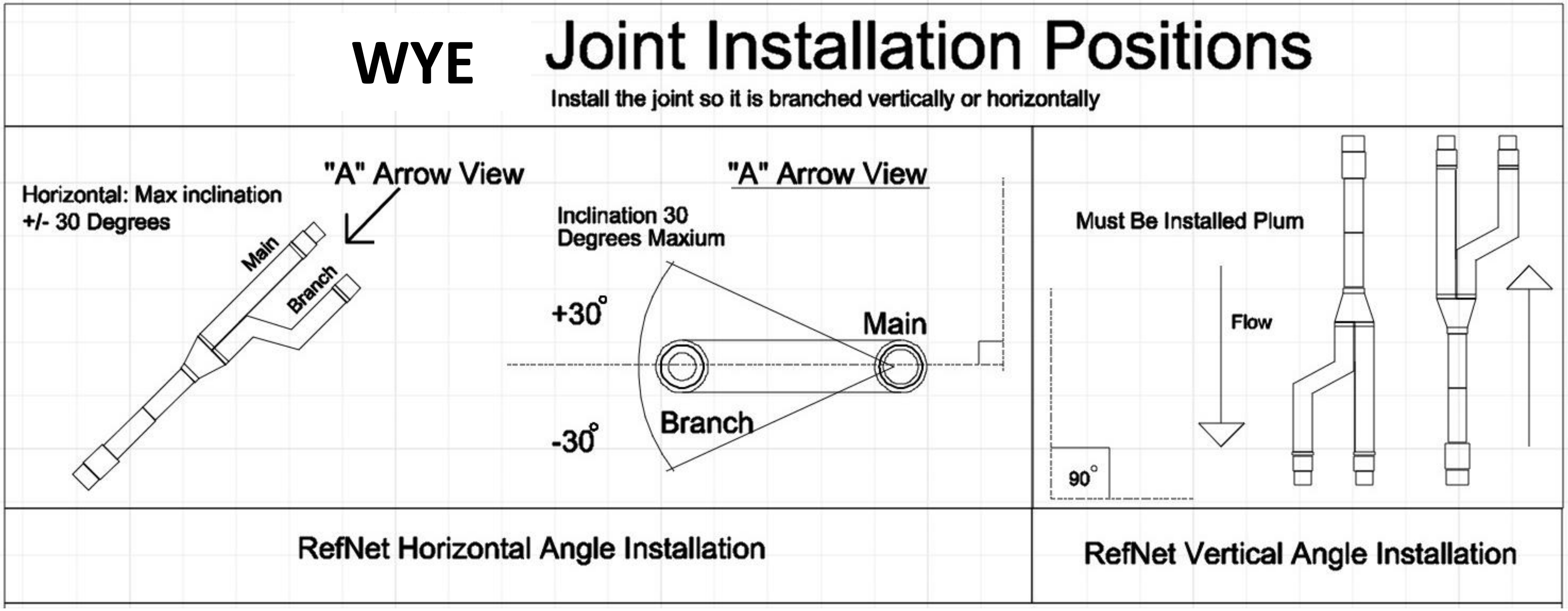
- If it’s not possible to add to drawings, ask OEM or rep to provide in a “systems installation manual” for use during installation.

Condenser Pipe Connections

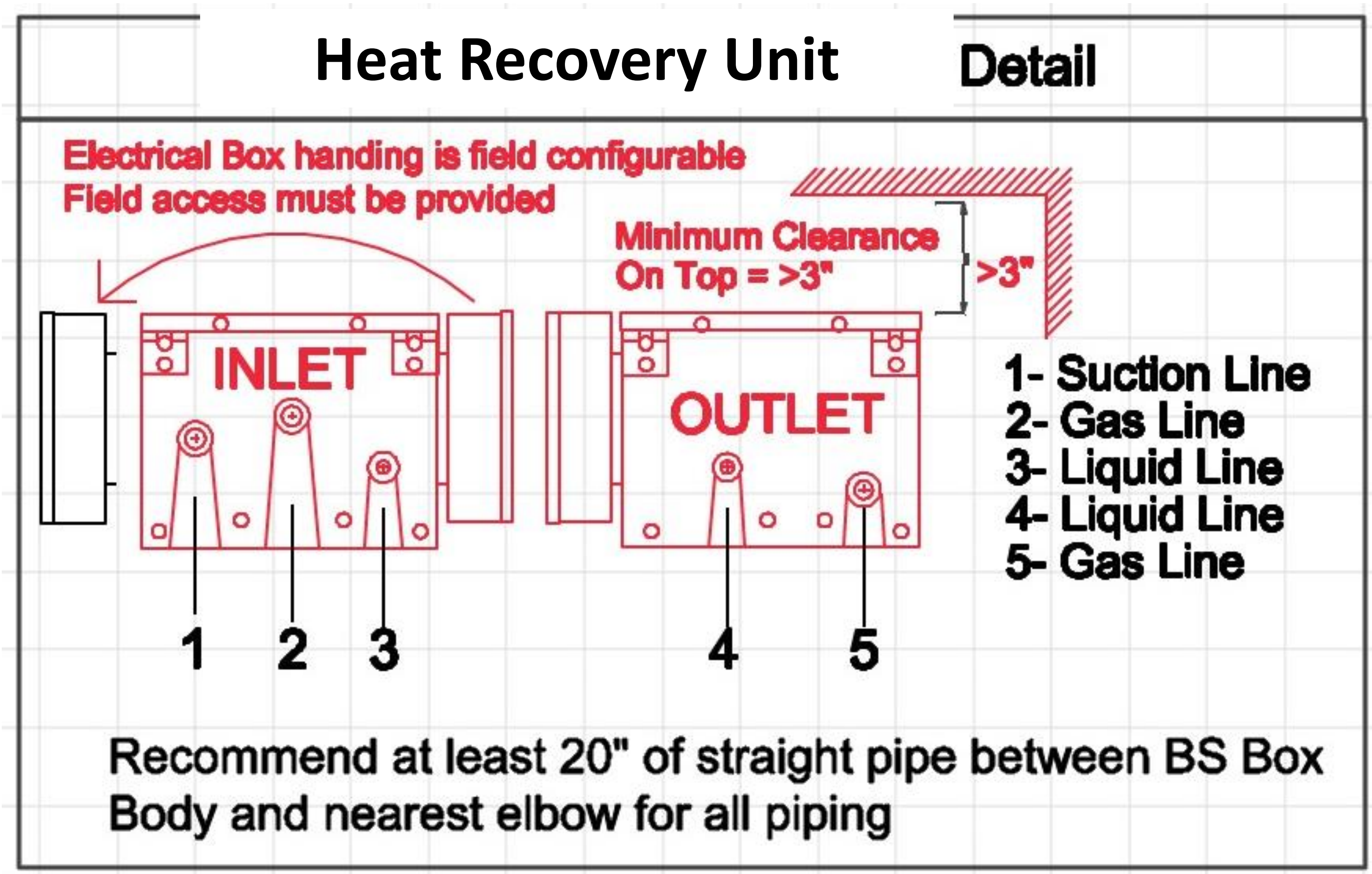




Wye Fitting/ Header Installation Detail



Heat Recovery Unit Piping Detail



Pipe Insulation- NYCECC 2016

SECTION ECC C403

BUILDING MECHANICAL SYSTEMS

<u>C403.2.8 Piping Insulation:</u>

All piping serving as part of a heating or cooling system shall be thermally insulated in accordance with Table C403.2.8.

Exceptions:

1. Factory installed piping within HVAC equipment tested and rated in accordance with a test procedure referenced by this code.

3. Piping that conveys fluids that have a design operating temperature range between 60°F (15°C) and 105°F (41°C).

Pipe Insulation- NYCECC 2014/2016

VRF Piping Operating Temperatures:

<u>Liquid Pipe:</u> Falls in 60F to 105F range (default to OEM requirements, ¾” typ.)

<u>Hot Gas Line:</u> Falls in the 141F to 200F range (condensing temp 115F, typ.)

<u>Dedicated Suction Line:</u> Falls in the 40F to 60F range

TABLE C403.2.8
MINIMUM PIPE INSULATION THICKNESS (thickness in inches)[a]

FLUID OPERATING TEMPERATURE RANGE AND USAGE (°F)	INSULATION CONDUCTIVITY		NOMINAL PIPE OR TUBE SIZE (inches)				
	Conductivity Btu · in./(h · ft² · °F)[b]	Mean Rating Temperature, °F	< 1	1 to < 1½	1½ to < 4	4 to < 8	≤ 8
> 350	0.32 – 0.34	250	4.5	5.0	5.0	5.0	5.0
251 – 350	0.29 – 0.32	200	3.0	4.0	4.5	4.5	4.5
201 – 250	0.27 – 0.30	150	2.5	2.5	2.5	3.0	3.0
141 – 200	0.25 – 0.29	125	1.5	1.5	2.0	2.0	2.0
105 – 140	0.21 – 0.28	100	1.0	1.0	1.5	1.5	1.5
40 – 60	0.21 – 0.27	75	0.5	0.5	1.0	1.0	1.0
< 40	0.20 – 0.26	75	0.5	1.0	1.0	1.0	1.5

a. For piping smaller than 1½ inch (38 mm) and located in partitions within conditioned spaces, reduction of these thicknesses by 1 inch (25 mm) shall be permitted (before thickness adjustment required in footnote b) but not to a thickness less than 1 inch (25 mm).

b. For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows:

$$T = r\{(1 + t/r)^{K/k} - 1\}$$

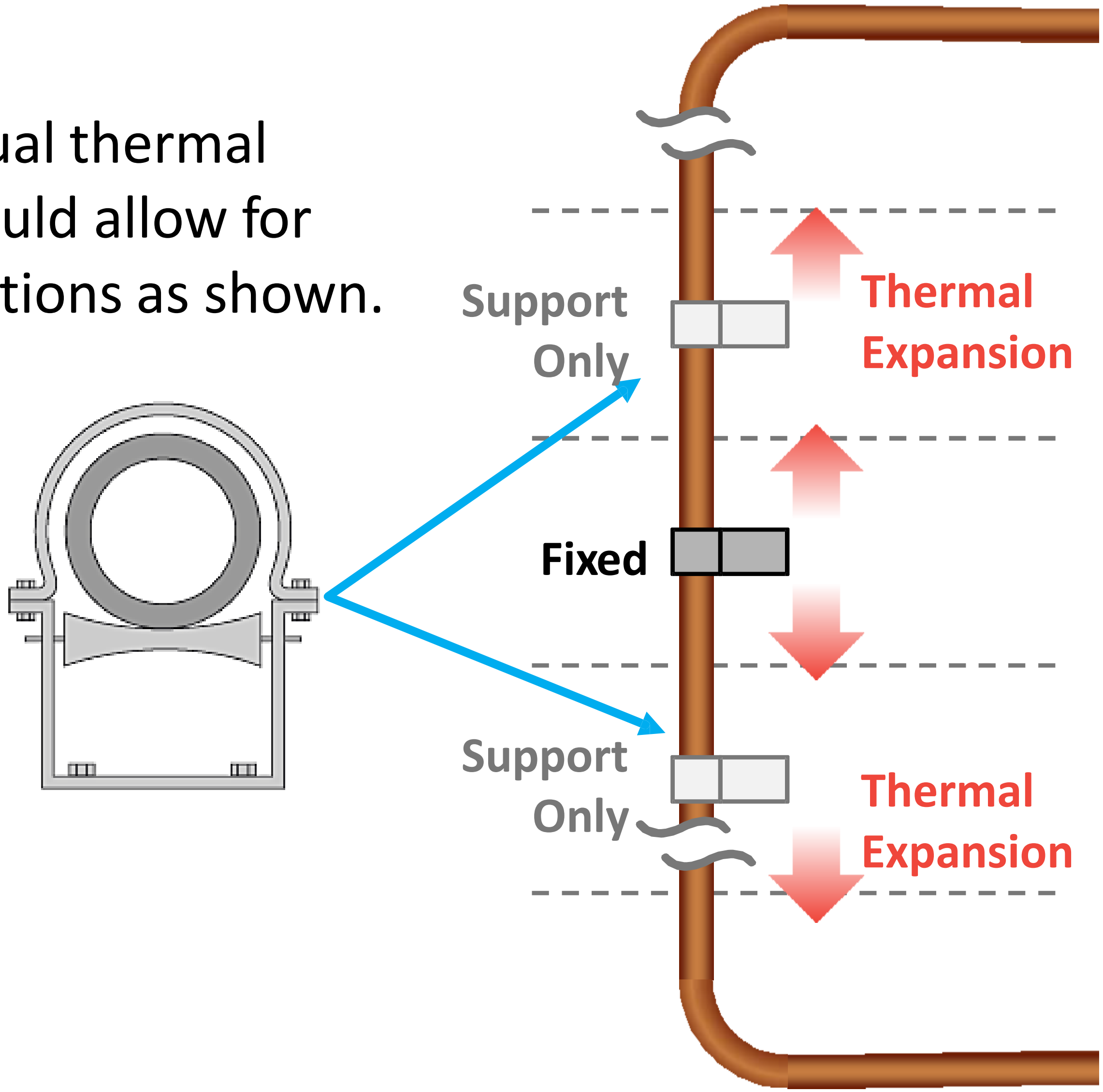
where:

T = minimum insulation thickness,
r = actual outside radius of pipe,
t = insulation thickness listed in the table for applicable fluid temperature and pipe size,
K = conductivity of alternate material at mean rating temperature indicated for the applicable fluid temperature (Btu × in/h × ft² × °F) and
k = the upper value of the conductivity range listed in the table for the applicable fluid temperature.

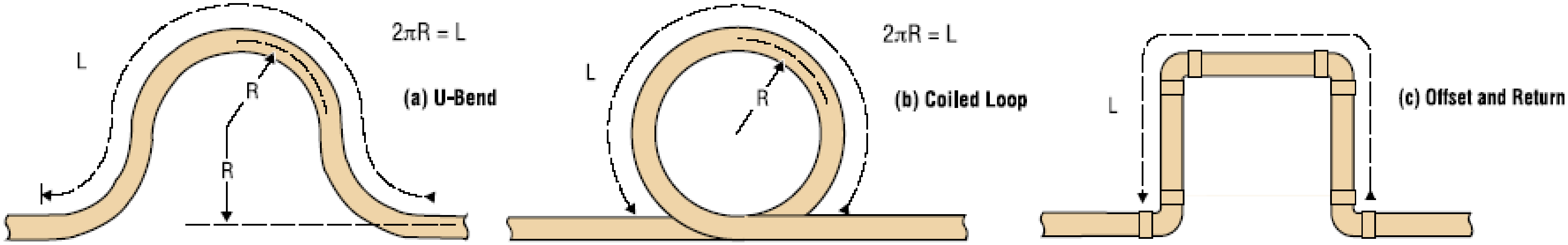
c. For direct-buried heating and hot water system piping, reduction of these thicknesses by 1½ inches (38 mm) shall be permitted (before thickness adjustment required in footnote b but not to thicknesses less than 1 inch (25 mm).

Vertical Piping Support

- To account for any residual thermal expansion, supports should allow for movements in two directions as shown.



Expansion and Contraction

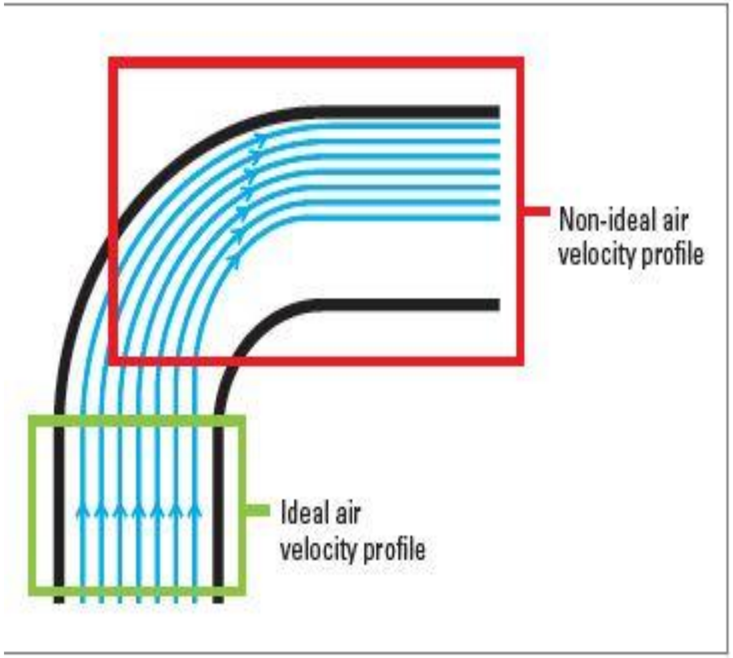


Reference The Copper Tube Handbook for information on pipe expansion and designing expansion loops

Airflow Considerations

Airflow Considerations

- CFM/Ton varies by unit type
  - Not 400 CFM/Ton
- System Effect
  - Fan system effect usually not an issue
  - Duct system effect results in higher pressure drop through fittings
    - Often overlooked



Airflow Considerations

- Consider distribution impact on occupant comfort
  - Consider plaque diffusers for overhead warm air heating if DAT is greater than 15FDB above room temperature
  - Higher CFM and lower ΔT configurations possible
    - Adjust airflow through ESP not unit size
  - Consider drafts on perimeter walls/floor-ceiling glass
  - Buoyancy and stratification effects are difficult to remedy in the field

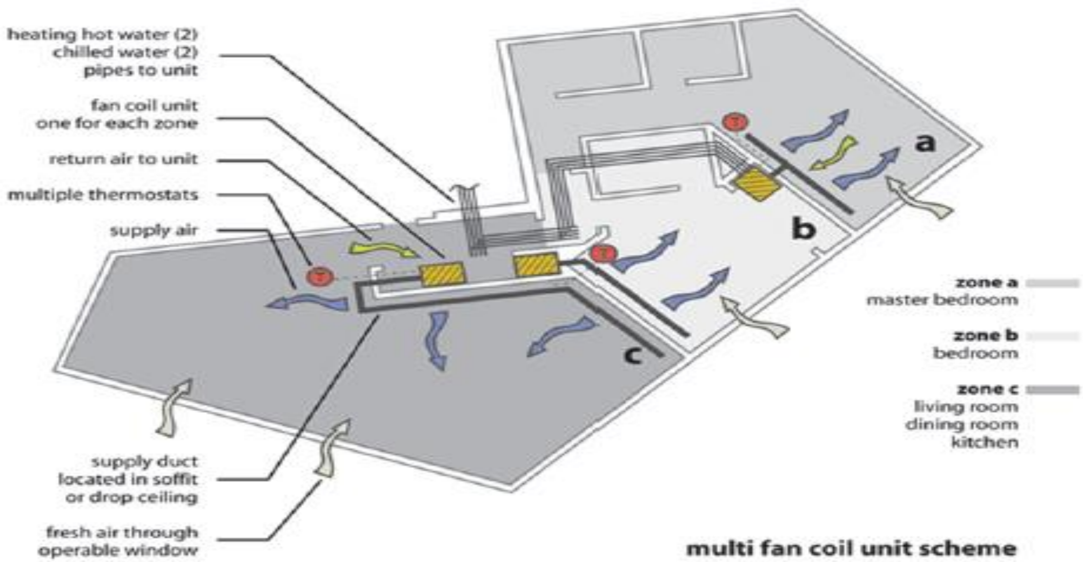


Figure 14.5 A multiple-fan-coil system for a residence.

How does the 2014 NYC Mechanical Code Impact VRF Piping Installation and System Design?

Refrigerant Piping- Mechanical Code

<u>**Section 7**</u>

<u>**Restrictions on Refrigerant Use**</u>

7.1 General. The occupancy, refrigerating system, and refrigerant safety classifications cited in this section shall be determined in accordance with Sections 4, 5, and 6, respectively.

7.2 Refrigerant Concentration Limits.

- The concentration of refrigerant in a complete discharge of each independent circuit of high-probability systems shall not exceed the amounts shown in Table 1 or 2 of ASHRAE Standard 34, 1 except as provided in Sections 7.2.1 and 7.2.2 of this standard. The volume of occupied space shall be determined in accordance with Section 7.3. <u>***(R-410A= 26 lb/ 1000 Cu Ft)***</u>

7.2.1 Institutional Occupancies.

- The amounts shown in Table 1 or 2 of ASHRAE Standard 341 shall be reduced by 50% for all areas of institutional occupancies. Also, the total of all Group A2, B2, A3, and B3 refrigerants shall not exceed 550 lb (250 kg) in the occupied areas and machinery rooms of institutional occupancies. <u>***(R-410A= 13 lb/ 1000 Cu Ft)***</u>

Refrigerant Piping- Mechanical Code

7.3 Volume Calculations.

- *"The volume used to convert from refrigerant concentration limits to refrigerating system quantity limits for refrigerants in Section 7.2 shall be based on the volume of space to which refrigerant disperses in the event of a refrigerant leak."*

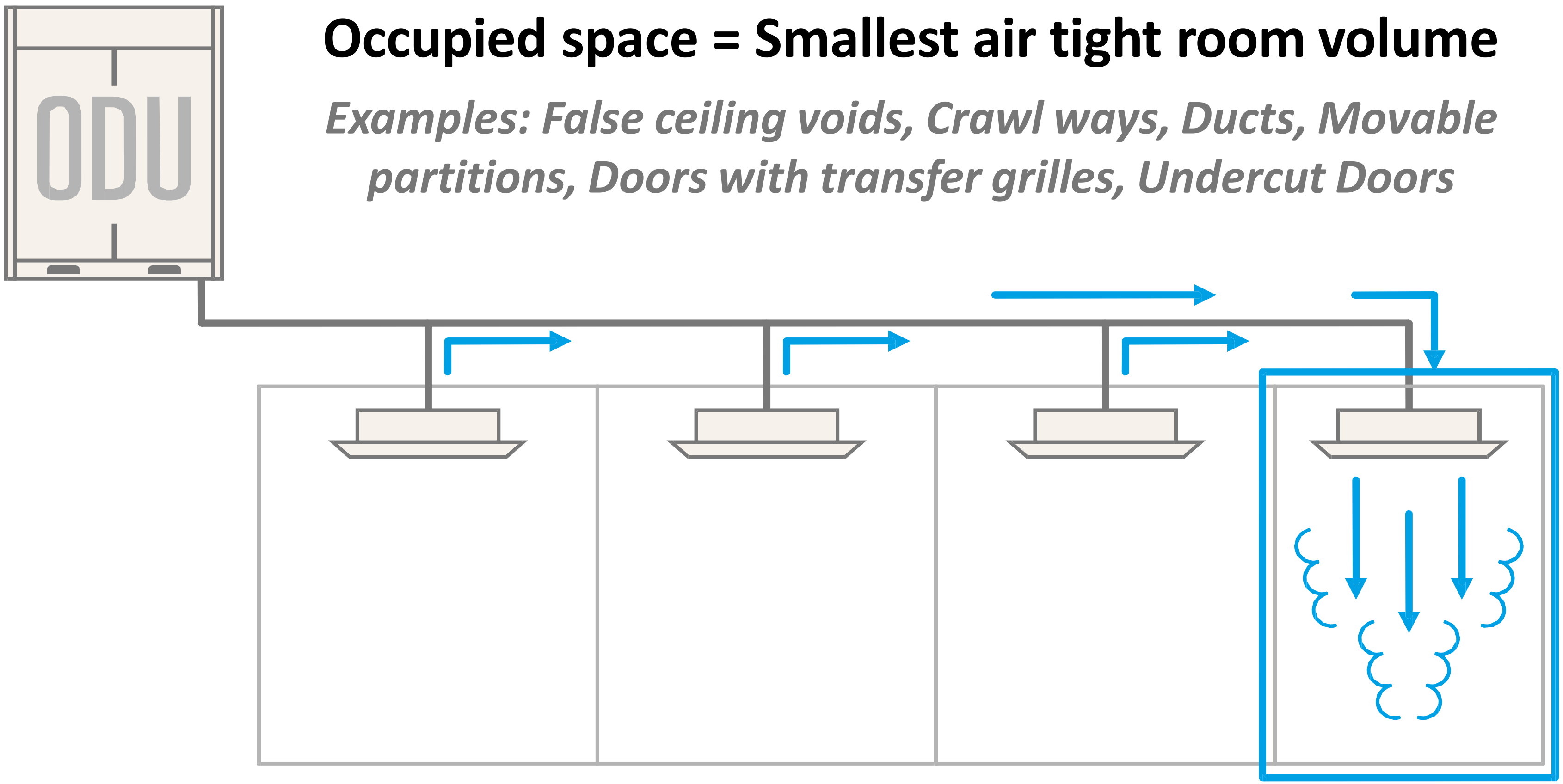
7.3.1 Non-connecting Spaces.

- *Where a refrigerating system or a part thereof is located in one or more enclosed occupied spaces that do not connect through permanent openings or HVAC ducts, the volume of the smallest occupied space shall be used to determine the refrigerant quantity limit in the system...*

OCCUPIABLE SPACE:

- An enclosed space intended for human activities, excluding those spaces intended primarily for other purposes, such as storage rooms and equipment rooms, that are only intended to be occupied occasionally and for short periods of time

Refrigerant Piping- Mechanical Code



Occupied space = Smallest air tight room volume

Examples: False ceiling voids, Crawl ways, Ducts, Movable partitions, Doors with transfer grilles, Undercut Doors

Other spaces not air tight to the smallest room are considered as part of it

Refrigerant Piping- Mechanical Code

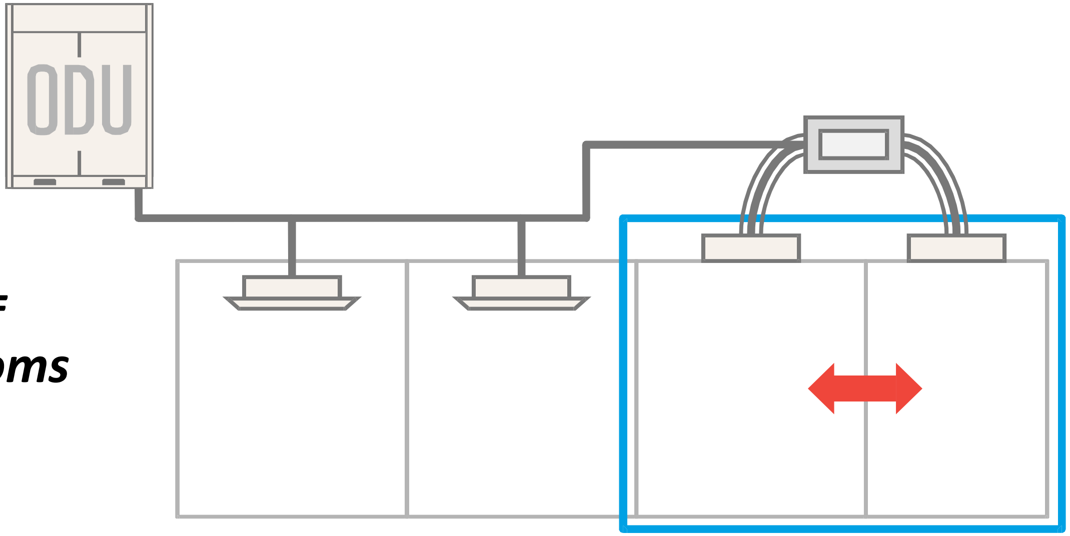
Connecting the Spaces:

- For ducted units, the supply and return duct volume as well as the volume of the spaces served can be counted as being connected.
    - Exception: Space cannot be counted if there is a damper that can close to reduce airflow to 10% or less. Dampers to close in emergency don't count

- For units using an open return via the ceiling plenum, the plenum counts towards to volume
    - Permanent opening is not defined and open to interpretation
        - ASHRAE 15 Users Manual makes a reference to air tightness

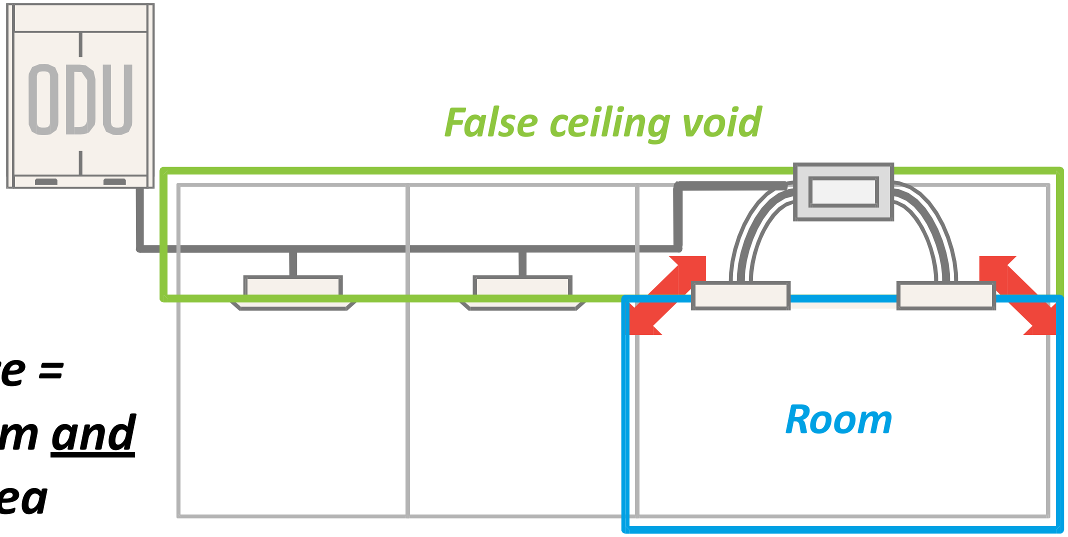
What is smallest 'occupied space' ?

Ducted Units



Occupied space = Volume of all rooms served by unit

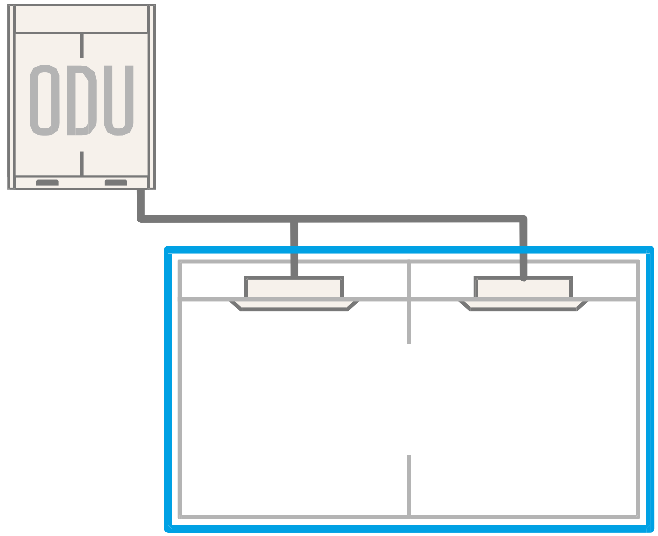
False Ceilings



Occupied space = Volume of room <u>and</u> ceiling void area

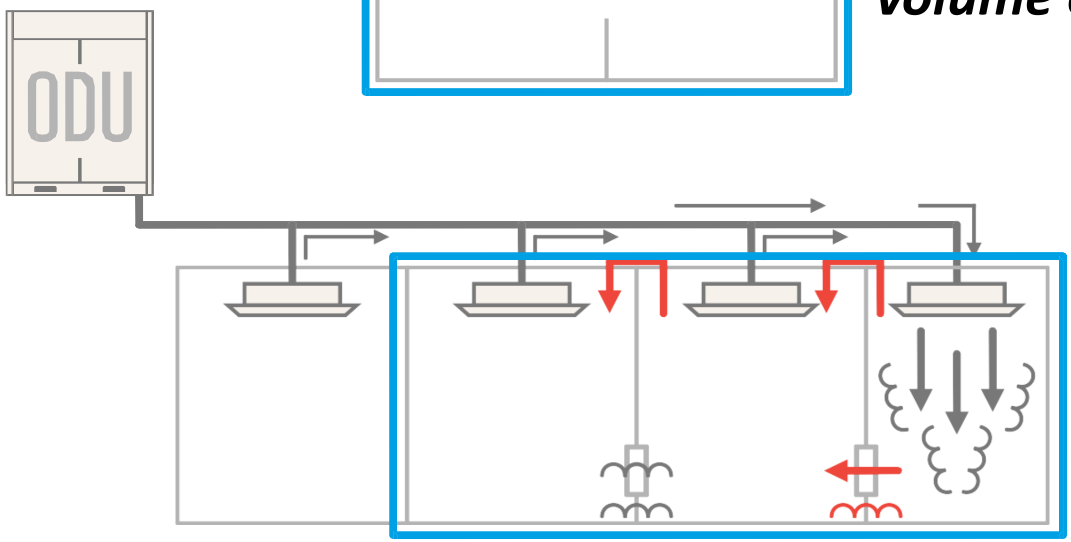
What is smallest 'occupied space' ?

Partitioned Spaces



Occupied space = Volume of both rooms

Transfer Ducts



Air transfer ducts between adjacent rooms

Door Grille

Door undercut (Depends on AHJ)

Occupied space = Volume of all connected areas

(including unconditioned corridors)

Refrigerant Piping- Mechanical Code

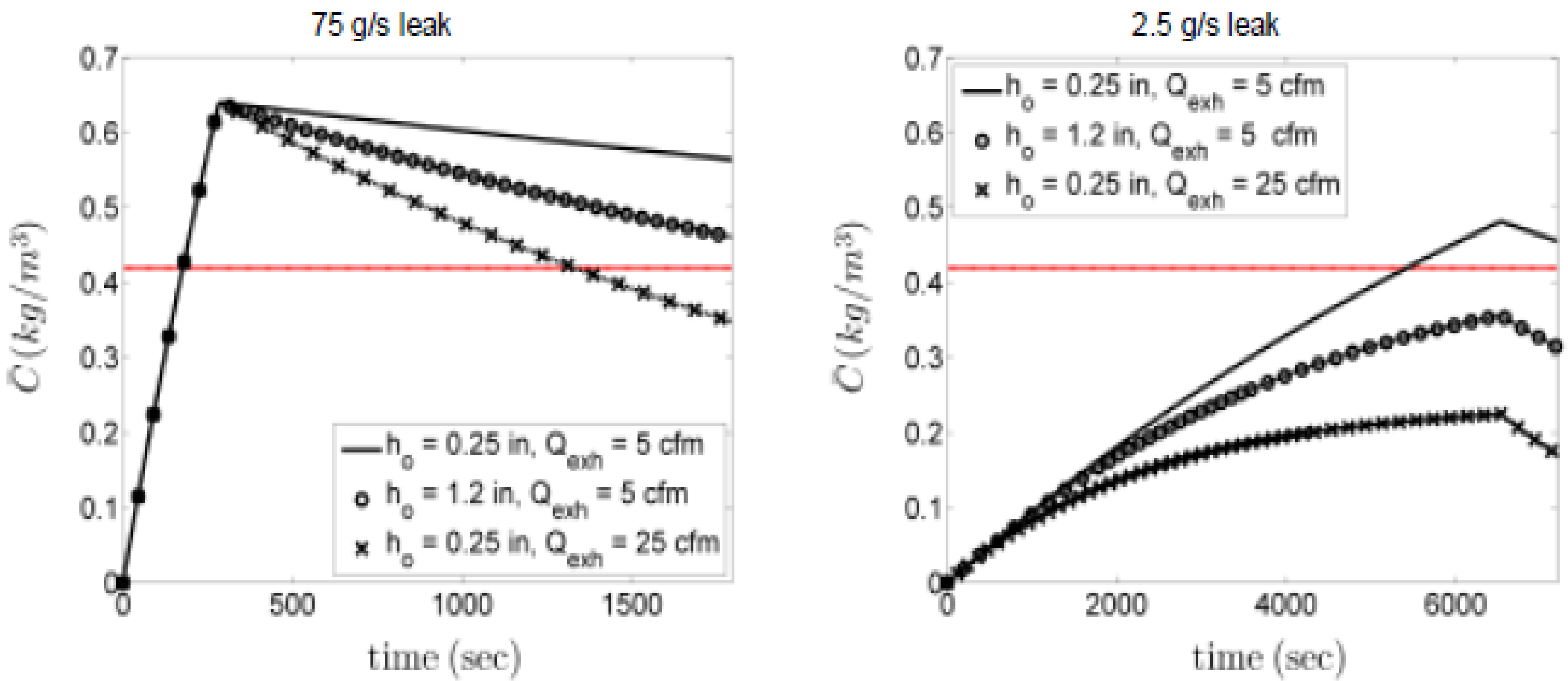
SECTION MC 1107

REFRIGERANT PIPING

- Refrigerant piping most be protected
- Must be leak checked before insulated
- Must be 7’3” AFF unless mounted to ceiling
- Shall not be placed in shafts with moving objects
- Shall not be installed in enclosed stairwell, landing or exit/means of egress
- Shall not be installed in public corridors
  - Specific exception are very restrictive but allow piping in corridors
  - Separate piping from corridor with fire rated enclosure
    - Numerous Multi-Tenant and Hotel projects in NYC with piping in public corridors

Other Considerations:

"A Study of Refrigerant Dispersion in Occupied Spaces under Parametric Variation"- Laughman 2015



Questions?

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- Simmonds, Peter, 2015. “ASHRAE design guide for Tall, Supertall, and Megatall building systems” pages 170-171
- ASHRAE Handbook: Systems and Equipment, Ch 18, 2016
- Mumma, Stanley A. 2008. “Terminal Equipment with DOAS: Series vs. Parallel.” *Engineered Systems* 45(5).
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- “Commercial Air Conditioning Systems (VRF) Market - U.S. Industry Analysis, Size, Share, Growth, Trends and Forecast, 2013 - 2019.”