

Variable Refrigerant Flow Basics



Philadelphia ASHRAE - 9/11/2014

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What is it.....

Introduced overseas 30 years ago, for the sole purpose of providing superior thermal comfort at the least possible energy expense.

System of choice in 65-75% of commercial buildings in some parts of the world.

Manufactured by approx 25 overseas companies....marketed by even more through private labeling agreements and joint ventures.

In the US, about 10 have entered the market since introduction here in the early 2000's.

Manufacturers have exhibited a real commitment to the US market by investing in substantial infrastructure and developing product improvements specifically to suit our needs.

Some of the leading VRF manufacturers are bonafide HVAC companies, with a full portfolio of other applied products.

Why and how.....

Advanced multi-zone air source heat pump technology that is capable of providing comfort heating/cooling at a wide range of outdoor conditions. -20 - 130F

Up to 64 IDUs on a single system

Heating leaving air temperatures >104F

Continuous rated heating performance down to -13F. Still operates below that, but delivered capacity is typically reference data.

If heating in harsh winter climates is a concern.....

Capable of integrating control of external supplementary heating sources. Some ducted indoor units have slip-in electric heat kits.

Water Source/Geothermal versions available also

Size each system to the larger of the highest simultaneous peak loads of the zones being served...variable capacity operation will dial in to handle the smaller load efficiently.

A VRF heat pump system is a single refrigerant circuit with:

- One Outdoor Unit (ODU)
 - Single, Double or Triple frame - Heat Pump or Heat Recovery
 - 3 to 36 tons - larger sizes on the horizon
- Multiple Indoor Units (IDUs)
 - 5kbtu to 8 tons
 - Electronic Expansion Valves (EEV)
 - Varying styles





Features

Controls

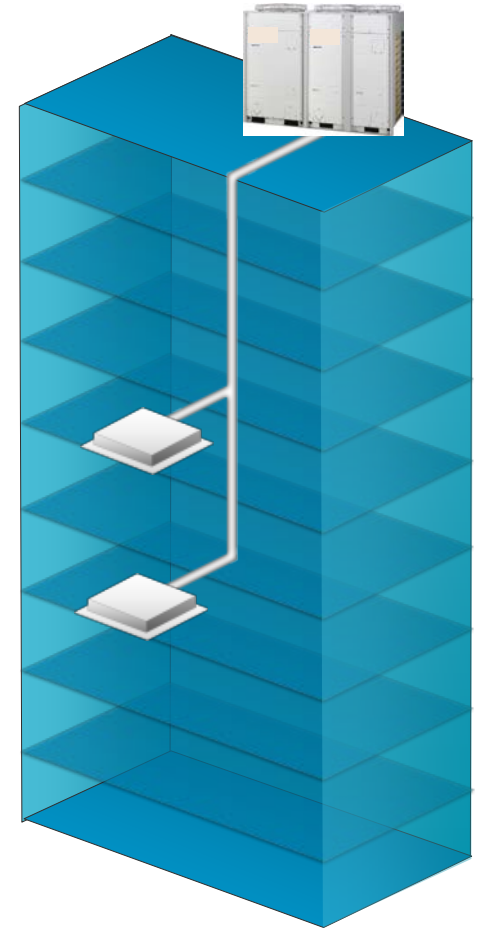
- DDC controls – simplified serial bus control wiring
- Central controls
- Gateways (LonWorks and BACnet)

Long piping capabilities

- Up to 3280 total equivalent feet
- Up to 738 equivalent feet of longest run
- Up to 360 feet elevation difference

Heat Recovery Units (HR Units)

- For simultaneous heating and cooling systems



Modular Design

Install & commission in stages

- By floor or zone

No downtime for cut-in

- Additions are decoupled from existing system

Fits in most service elevators

- Reduce equipment placement cost
 - Cranes
 - Helicopters
 - Disassembly/Reassembly



Energy Savings

Few system losses

- No water piping or pumps
- Little or no duct work
- No distribution duct

Load Matching

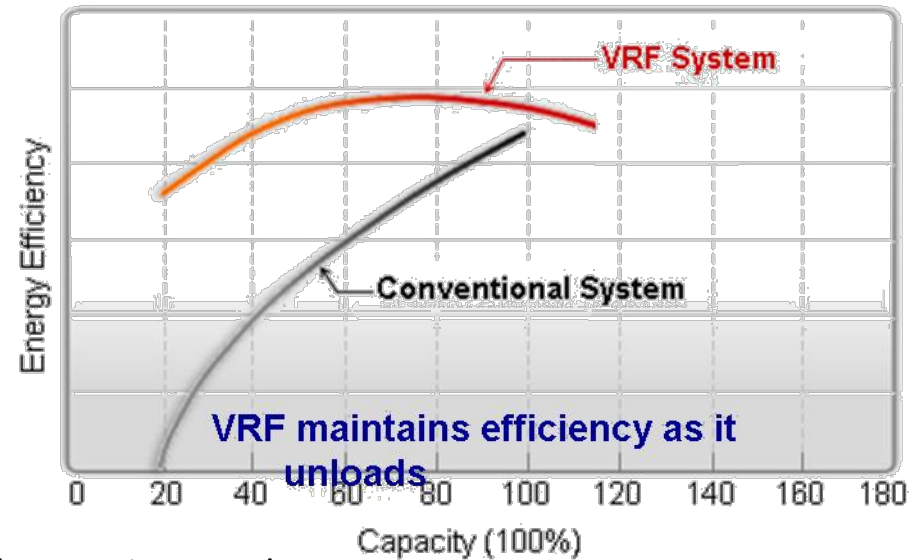
- Inverter compressors
- Dual compressors

Zone Control

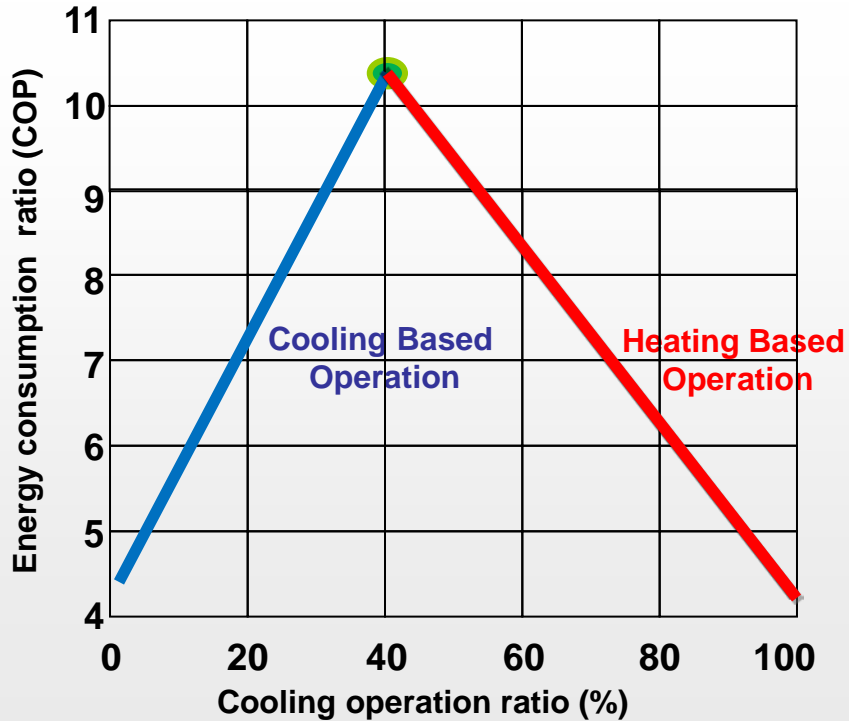
- Condition only needed zones rather than entire envelope
- Set back or turn off units in unoccupied spaces

Heat Recovery

- Move heat from zones needing cooling to zones that need heating without additional compressor energy.
- Water Source VRF Heat Recovery - Double dip on heat recovery benefits.



Heat Recovery - Simultaneous Savings



System Efficiency Example

- 40% Cooling - 60% Heating
10.21 COP = 34.8 EER = .34 kW/Ton
- 50% Cooling - 50% Heating
9.09 COP = 31.0 EER = .39 kW/Ton
- 60% Cooling - 40% Heating
8.17 COP = 27.9 EER = .43 kW/Ton

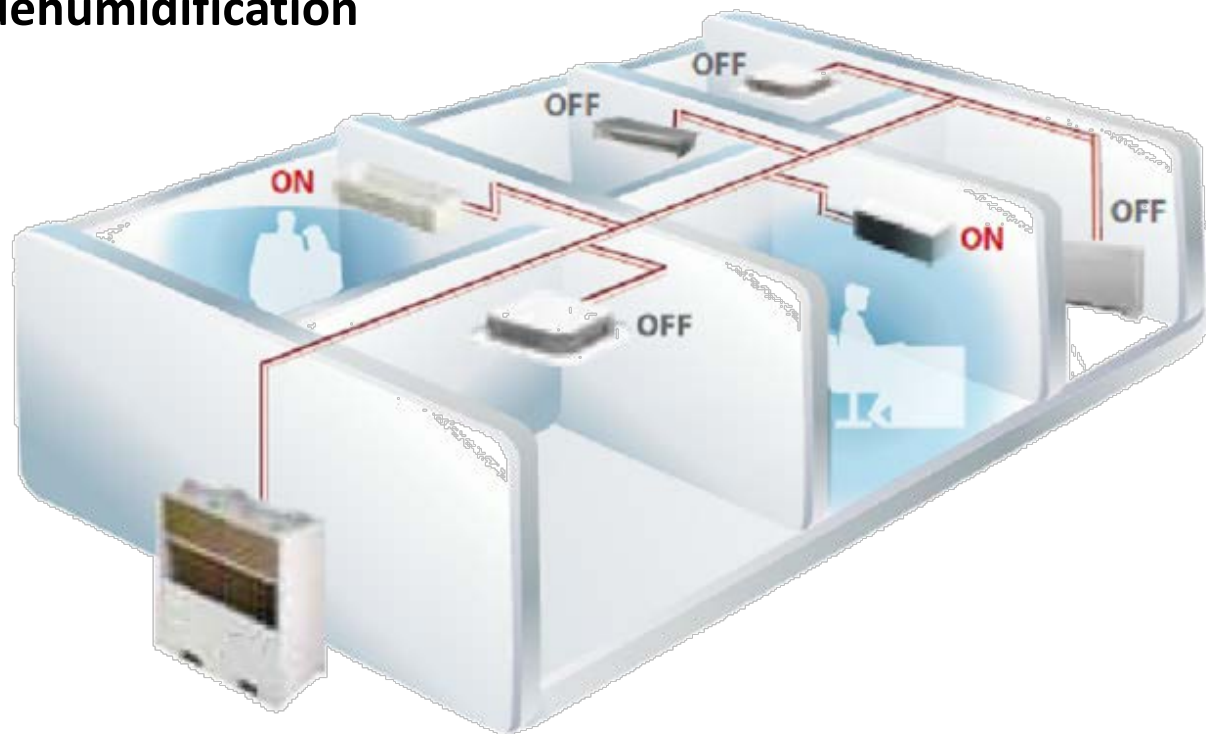
Optimum Occupant Comfort

Quiet

- 58-60 dBA per ODU frame
- As low as 23 dBA

Individual zone control - on/off, varied setpoints

Excellent dehumidification



Flexibility

Less space required:

Smaller plenums

- Potential to reduce building cost

No utility closets, equip rooms, or vertical chases

- No floor space

No horizontal duct chases

- Ceiling fur downs eliminated

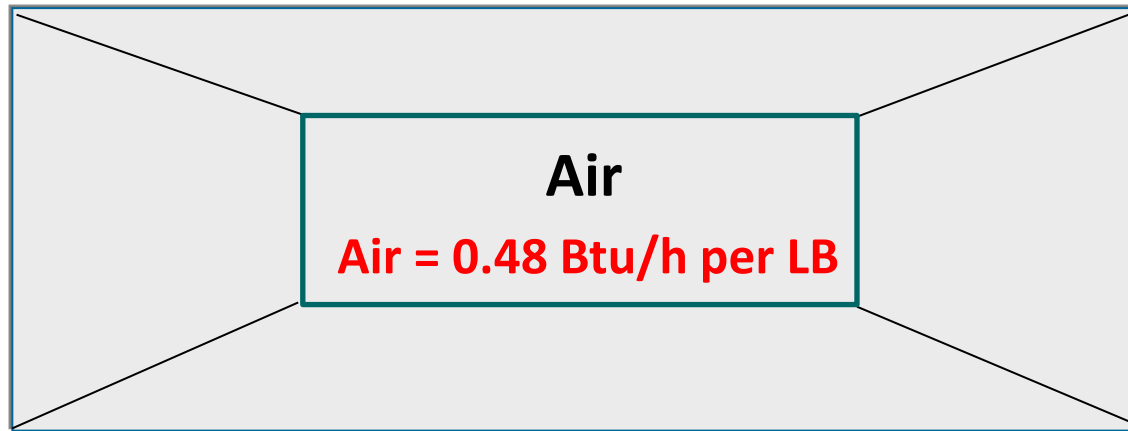


Refrigerant Piping

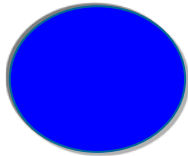


Air Duct

Heat transfer fluid efficiency and relative conduit size comparison....



Water



Water = 8.88 Btu/h per LB

Refrigerant



Refrigerant = 85.38 Btu/h per LB

Reliability and Ease of Service

System by One Vendor

- Commission the system as one

Integral Safeties

- Oil Management
- Refrigerant Management

Redundancy

- Multiple compressors
- Isolated circuits (modular systems)

Simplified Maintenance and Troubleshooting

- PC connection provides all operating data
- Extensive fault code (FDD) capability reduces repair time

30 Year Old Technology



Maintenance Cost Considerations

VRF

- Filters/Coil Cleaning
- Condensate Drains



Rooftop VAV

- Fan Failures
- Belts
- Staging of constant speed compressors



Chiller

- Water Treatment
- Compressor Teardowns
- Rental Chillers
- Chiller Annuals



Applications

Historical buildings

- Never had air conditioning
- Minimal structural impact

Retrofit projects

- Seal and abandon asbestos in place
 - Avoid disturbing existing asbestos by installing alongside it
 - Save Removal Cost
- Leave existing equipment/duct in place
 - Save demolition cost in renovations

New buildings

- Reduced plenum space requirements
 - Lower cost of construction materials and improve payback
- May reduce electrical load on the building

Buildings that require independent control for occupants

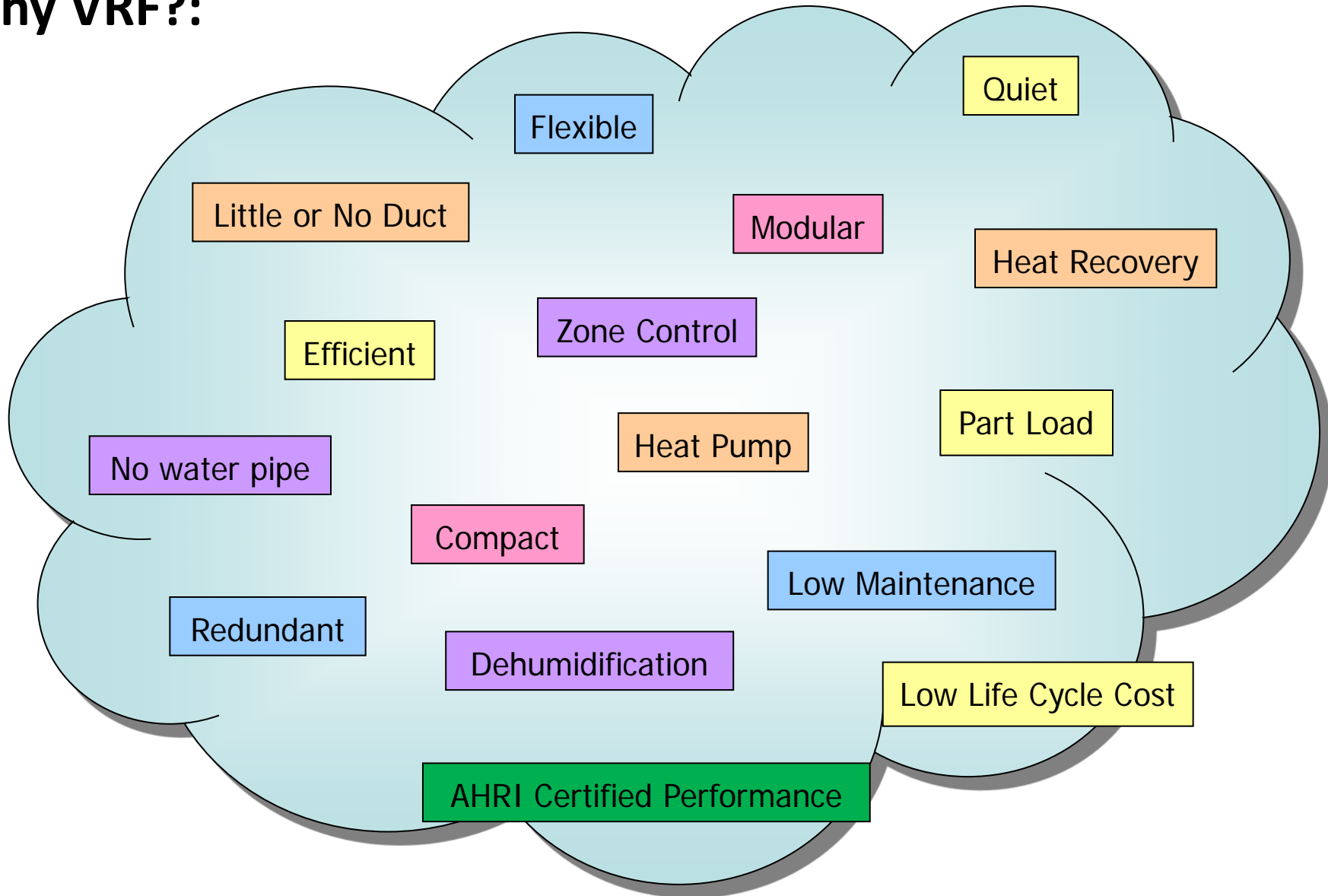
- Hotels, Offices, Schools, Assisted Living, etc...



AHRI STANDARDS & COMPLIANCE

- Data for rated products is now available in the AHRI Directory (www.ahridirectory.org).
- AHRI 1230 Certification Program includes VRF Multi-Split and Heat Recovery VRF Multi-Split systems up to 300,000 Btu/h. Refer to the AHRI Certification Directory for the Single Module components of larger VRF Multi Split systems.
- Today's VRF systems can achieve IEERs over 30

Why VRF?:



So isn't it expensive?....

	Air Source VRF	DX Splits	DX RTU w/ VAV	AC CHW w/ VAV	WC CHW w/ VAV	WSHP
Cost \$/Sq Ft	\$20-25	\$15-18	\$16-21	\$23-28	\$28-32	\$26-30
System Eff kw/ton	.6 -.8	1.5	1.25	1.25	.6 -.9	.8 -.9
Maintenance	\$	\$ ^c	\$	\$ ^c	\$\$\$	\$\$\$
Building Type	0-400 Tons	< 50 Tons	0-200 Tons	75-400 Tons	> 300 tons	0-400 Tons
Total Life in Years	15-20	10-15	15-20	15-20	25-30	15-20

Consider the installed costs of....

	Ductless		DX VAV		4 Pipe
	VRF	Unitary	w/Reheat	GSHP	Fan Coil
Compressor bearing unit	X	X	X	X	X
Air handling unit	X	X	X	X	x
Refrigerant piping	X	X	X	X	X
Controls	*	X	X	X	X
Heat Recovery Box	X				
Duct heater			X		
Ductwork & Insulation		X	X	X	X
Dampers & Airflow Accessories		X	X	X	X
AHU Water Loop Piping					X
Condenser Water Loop Piping				X	X
Pumps & Expansion Control				X	X
Boiler					X
Chiller					X
Well/Field Area				X	
Test & Balance		X	X	X	X
Environmental Studies				X	

* VRF central control possible without added expense of 3rd party controls or integration

Piping Design & Installation Concerns

The manufacturer's design software tool sizes piping, provides performance data, etc...

Equivalent length of piping as input will determine pipe sizing. There is an EL point in main piping runs that will cause an upsize in pipe diameters. It is important to know where the initial design length is in relation to the point of upsize, and avoid a layout that is on the edge.

Field changes to pipe routing need to be checked by the designer for suitability before proceeding with installation.

Thermal expansion of copper piping must be considered....more so in branch lines where temperature variations can be significant and rapid. For this reason, soft ACR copper tubing or pre-made linesets are recommended for these runouts.

No traps or special considerations needed for oil control.

Contractors need no specialized skill sets to install VRF as compared to conventional, but manufacturer's training prior to installation is a must.

So how does it work?

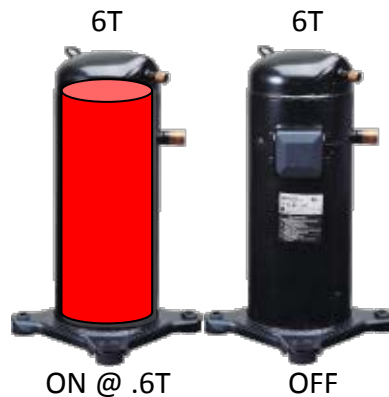


Digitally Commutated (DC) Inverter Compressors



Infinite turndown as low as 10:1 – enable superior load matching

Consider a 36T system with two inverter compressors in each 12T chassis.....



$$.6T \div 36T = 1.66\% \text{ or } 60:1$$

Electronic Expansion Valves



Up to 1500 steps

Used in every IDU and/or heat recovery box port for individual superheat/subcooling control

Used in ODU for

- Superheat control of main coil in heating mode

- Subcooling control in cooling mode

- Other purposes vary by mfr

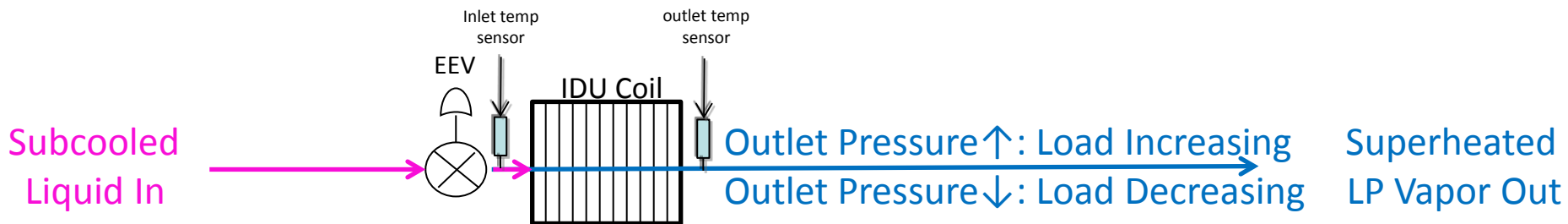
COOLING MODE

The EEV modulates slowly to maintain precise superheat of each IDU

Coil outlet temp – inlet temp = superheat

EEV open = outlet pressure increase

EEV close = outlet pressure decrease



In cooling mode, the aggregate suction pressure is measure by the ODU, and the target to actual pressure error is what drives compressor capacity.

The speed of the outdoor fan(s) are modulated independently of the compressor control to maintain target high pressure.

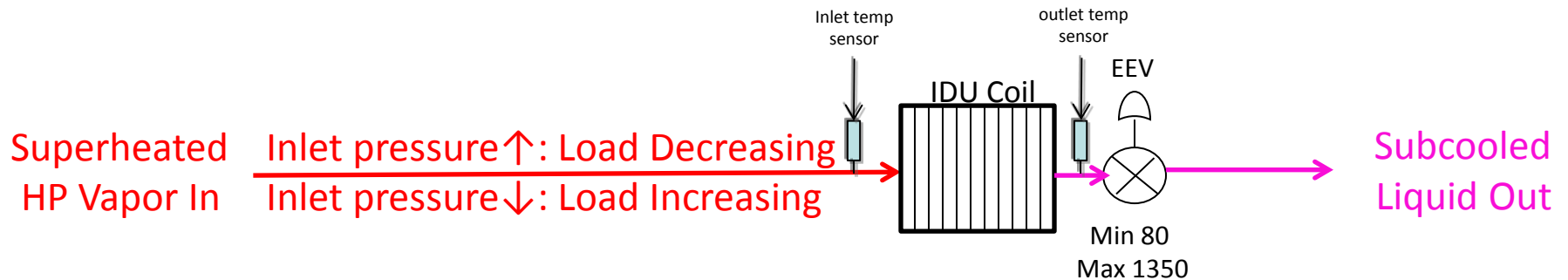
HEATING MODE

The EEV modulates slowly to maintain precise subcooling of each IDU

Coil inlet temp – outlet temp = subcooling

EEV Open = inlet pressure decrease

EEV close = inlet pressure decrease



In heating mode, the compressor discharge pressure is measured by the ODU, and the target to actual pressure error is what drives compressor capacity.

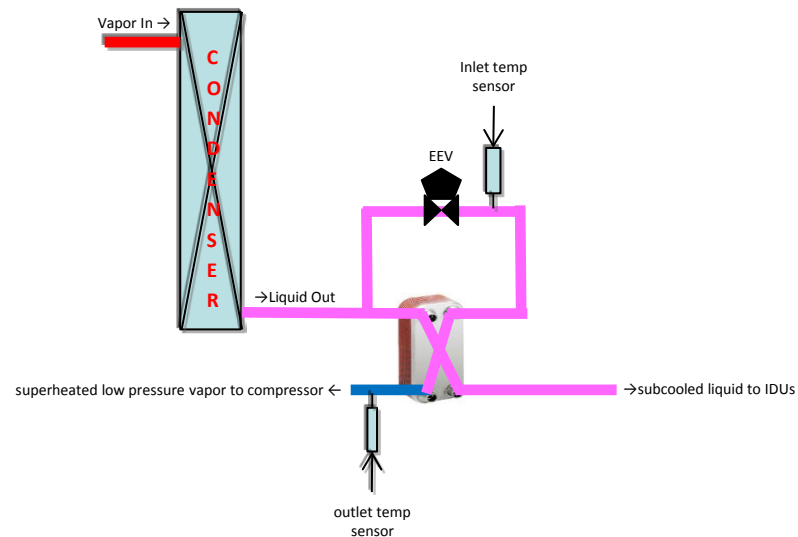
The speed of the outdoor fan(s) are modulated independently of the compressor control to maintain target low pressure.

LIQUID SUBCOOLING CONTROL (cooling mode)

A VRF system must maintain significant liquid subcooling to insure a solid column of liquid refrigerant is supplied to every IDU, at the furthest reaches of the system. VRF subcooling is typically 25-30F.

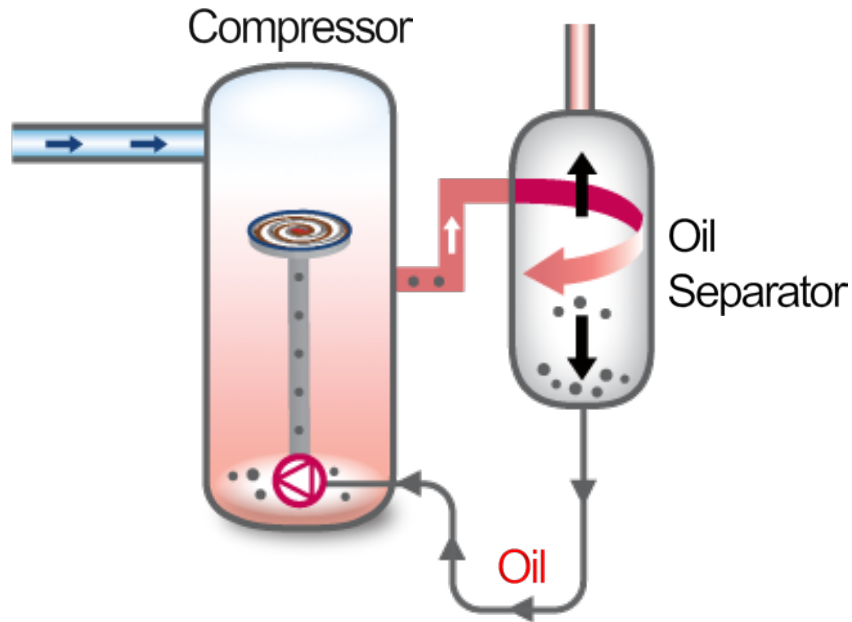
Due to variable nature of the system, it is impossible to design an outdoor heat exchanger with a predetermined saturation point and remaining fixed subcooling circuitry as in constant speed equipment.

For this reason, a separate subcooling HX in the ODU is used.



OIL CONTROL

Oil separators trap and return >90% of oil to compressor



Oil return cycles then bring back any oil that made its way into the system

Time interval based
Crankcase level based

Heat Pump Operation

Heating or Cooling in all zones at the same time.

- 2 pipes from ODU
 - Low pressure vapor
 - Liquid

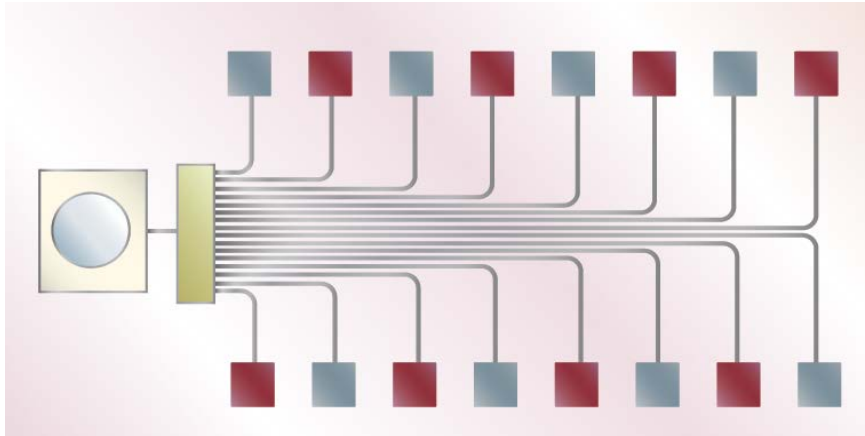


Why and where to use?

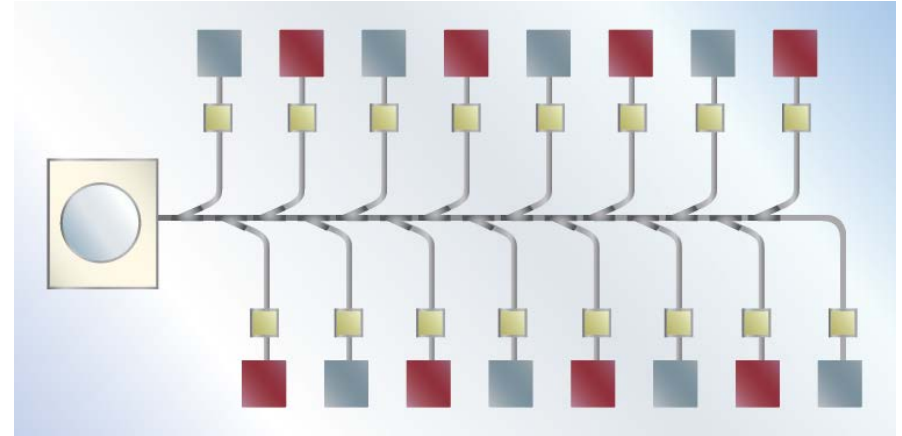
Heat Recovery

Different manufacturers use different methods....

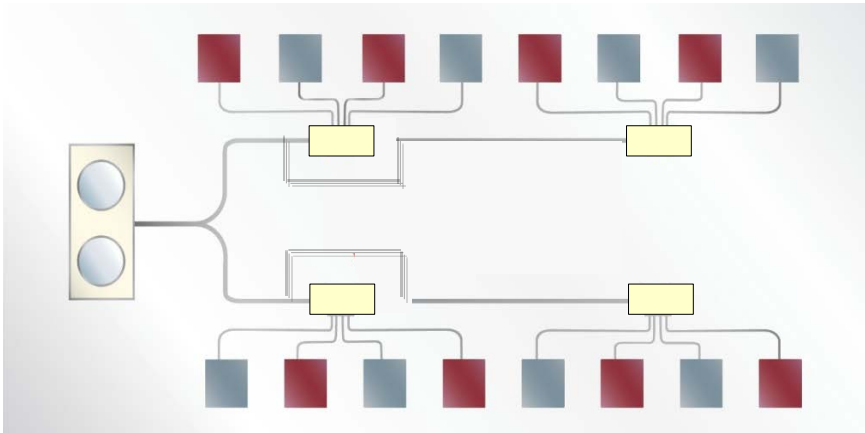
2 Pipe Multi Port Home Run



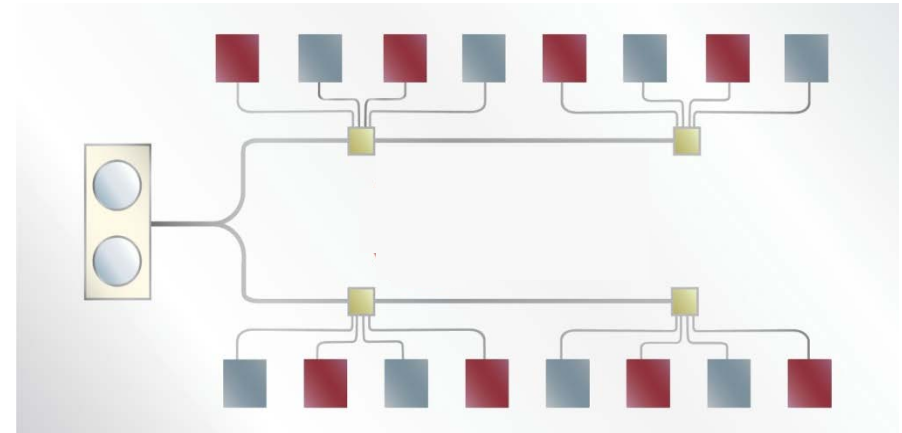
3 Pipe Single Port Parallel



3 Pipe Multi Port Parallel



3 Pipe Multi Port Series/Parallel



Why and where to use?

Heat Recovery

Different manufacturers use different methods.....

Difference considerations

- Condensate drains

- Refrigerant connection type – flare vs braze

- Total feet of pipe

 - Installation labor/material

 - Refrigerant charge – ASHRAE 15

- Heat recovery unit redundancy

- Control and power wiring connections

Most, if not all manufacturers, also permit multiple IDUs on the same port, but may have different capacity limits per port.

Typical 3Ø ODU Offerings

208/230, 460 & 575v

Air Source
6 - 36 Tons



Water Source
6 - 48 Tons



Typical 1Ø HP ODU Offerings

3-5T 208/230v

Air Source



Water Source



Other Typical Indoor Products

All indoor products are 208/230v 1Ø

ERV



Refrig to Water HX



DOAS



Typical Control Products



Wireless
Remote



Simple
Remote



Programmable
Remote



Touchscreen Central
Controller



Basic Central
Controller



Dry
Contact



Heat/Cool
Selector



Remote
Sensor



BMS Gateway



Advanced Central
Controller



Power Distribution
Controller

Energy Modeling

Can energy modeling software model VRF properly?

- Energy Pro is the only modeling program certified by the VRF manufacturers.
- Can be modeled in others (Trace, HAP, Equest etc...) but can have difficulties modeling part load conditions. Use of VRF manufacturer's published modeling guidance is strongly recommended.

[illegible]

Example Analysis

- 6 floor office building
- 133,600 sq ft
- 145 zones
- 0 CFM Infiltration
- Walk-out basement level
- Each zone served by a single indoor fan coil unit (except CV RTU)
- Utilized Energy Pro Software
- Building properties were assigned as indicated below:

Roof Construction U-Factor	0.048
Slab-on-Grade F2-Factor	0.730
Underground Wall U-Factor	0.360
Exterior Wall U-Factor	0.084
Window U-Factor	0.6/0.71
Window SHGC (Non-North)	0.250
Window SHGC (North)	0.250
Window to Wall Ratio	32.78%

System Breakdown

- **VRF**
 - 11 (12-20 Ton) Outdoor Units, 145 Indoor Units (1-6 Tons Per)
- **DX Water Source Heat Pumps**
 - 300 Ton Closed Loop with Tower, 145 WSHPS, Gas Fired Boiler for Heating
- **DX Splits**
 - 145 1-6 Tons Standard DX Splits
- **Constant Volume Rooftop Units**
 - 11 (15-20 Ton) Rooftop Units Standard Efficiency
- **Water Cooled Chiller**
 - Two 150 Ton Constant Screw Chillers, Constant Speed Pumps, 145 Fan Coils, HW Boiler
- **Air Cooled Chiller**
 - Two 150 ton Air Cooled Scroll Chillers, Constant Speed Pumps, 145 Fan Coils, HW Boiler

RESULTS

	VRF	WSHP	DX Splits	CV RTU	4-pipe (WC)	4-pipe (AC)
Atlanta	\$0.72	\$0.81	\$0.88	\$0.91	\$1.04	\$1.11
Chicago	\$0.80	\$0.92	\$0.99	\$1.02	\$1.15	\$1.23
Dallas	\$0.82	\$0.86	\$0.97	\$1.02	\$1.12	\$1.23
LA	\$1.05	\$1.22	\$1.33	\$1.27	\$1.47	\$1.56
Miami	\$0.94	\$1.01	\$1.15	\$1.23	\$1.30	\$1.39
New York	\$1.22	\$1.36	\$1.51	\$1.48	\$1.73	\$1.85
Seattle	\$0.53	\$0.61	\$0.66	\$0.66	\$0.80	\$0.86
Avg Cost/sq ft	\$0.87	\$0.97	\$1.07	\$1.08	\$1.23	\$1.32

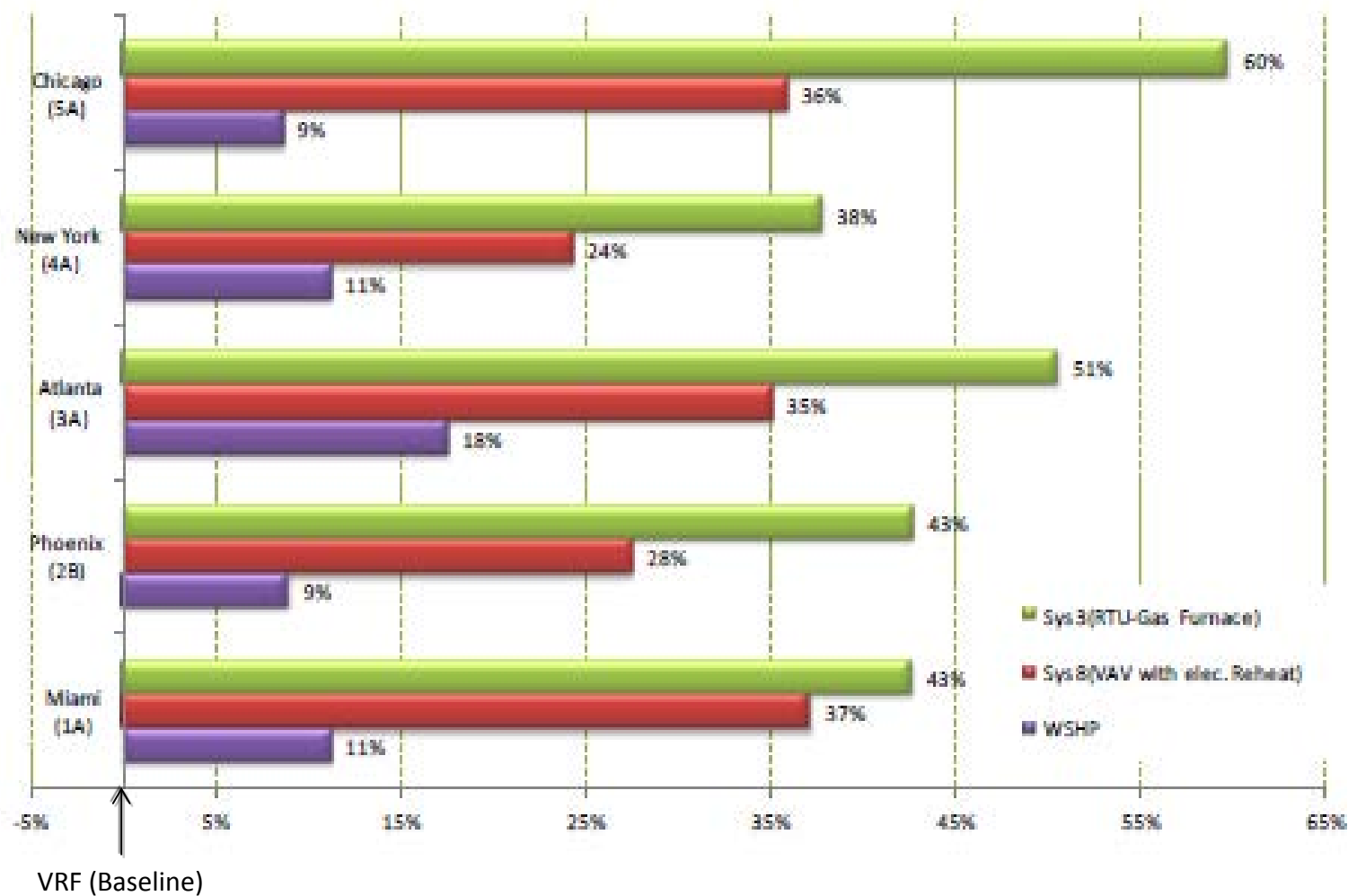


Table 13: Atlanta Estimated Annual Energy Use and Cost

		ASHRAE Standard 90.1-2007			Proposed
		Sys 8 (VAV with elec. Reheat)	Sys 3 (RTU- Gas Furnace)	WSHP	VRF
Whole Building Energy Consumption	Electricity (kWh)	2,367,333	2,573,684	2,057,423	1,998,900
	Gas (therms)	2,638	34,970	13,692	2,638
	Total(kBtu)	8,341,476	12,278,775	8,389,419	7,084,330
Whole Building Energy Cost	(\$)	206,088	244,851	179,675	162,589
	(\$/ft ²)	1.54	1.83	1.34	1.22
HVAC Energy Usage	Electricity (kWh)	1,353,901	1,560,252	1,043,991	985,468
	Gas (therms)	-	32,332	11,054	-
	Total (kBtu)	4,619,702	8,557,001	4,667,645	3,362,556
HVAC Energy Cost(\$/ft ²)	(\$)	123,905	162,668	97,492	80,406
	(\$/ft ²)	0.93	1.22	0.73	0.60

U.S. Green Building Council

LEED "Credits" Groups All Rating Systems

- Sustainable Sites (SS)
- Water Efficiency (WE)
- Energy & Atmosphere (EA)
- Material Resources (MR)
- Indoor Environmental Quality (IEQ)
- Innovation in Design/Operations (ID)



LEED® is a registered trademark of the U.S. Green Building Council

Table 2 Potential LEED points available using VRF

Category	Point ID	Certification Paths					Point Description
		NC	CS	K12	CI	O&M	
WE	CR-4			1	1	1-2	Process Water Use Reduction
EA	PR-1	0	0	0	0		Basic Building Commissioning
EA	PR-3	0	0	0	0	0	Refrigerant does not contain CFC's
EA	CR-1	1-19	3-21	1-19		1-18	Optimize Energy Performance
EA	CR-1.3				5-10		Optimize Energy Performance - HVAC
EA	CR-2				5		Enhanced Commissioning
EA	CR-2.3					2	Exist Bldgs - Ongoing Commissioning
EA	CR-3	2	2	2			Enhanced Commissioning
EA	CR-3.1					1	Perf Measurement - Bldg. Automation
EA	CR-3.2					1-2	Perf Measurement - Sys. Level Metering
EA	CR-4	2	2	1			Enhanced Refrigerant Management
EA	CR-5					1	Enhanced Refrigerant Management
EA	CR-3				2-5		Measure & Verify - Tenant Submetering
EA	CR-5.1		3				Measure & Verify - Base Building
EA	CR-5.2		3				Measure & Verify - Tenant Submetering
MR	CR-1.1				1		Tenant space - Long-term commitment
MR	CR-1		1-5				Maintain exterior walls, floor, roof
MR	CR-1.1	1-3		1-2			Maintain exterior walls, floor, roof
MR	CR-1.1				1-2		Maintain non-structural elements
MR	CR-1.2	1		1			Maintain non-structural elements
IEQ	PR-2			Yes			Minimum Acoustical Performance
IEQ	1.4					1	Reduce particulates - Occupied space
IEQ	1.5					1	Reduce particulates - Construction area
IEQ	3.1				1		Reduce particulates in air distribution
IEQ	CR-6		1				Controllability - Thermal Comfort
IEQ	CR-6.2	1		1	1		Controllability - Thermal Comfort
IEQ	CR-7		1				Thermal Comfort Design
IEQ	CR-7.1	1		1	1		Thermal Comfort Design
IEQ	CR-7.2	1		1	1		Thermal Comfort Verification
IEQ	CR-9			1			Enhanced Acoustical Performance
IEQ	CR-10			1			Mold Prevention
ID	1-5	1-5	1-5	1-4	1-5	1-4	Innovations in Design or Operations

Definitions: PR=Prerequisite; CR=Credit; WE=Water Efficiency; EA=Energy and Atmosphere; MR=Materials and Resources; IEQ=Indoor Air Quality; ID=Innovations in Design; RP=Regional Priority; CR=Credit; PR=Prerequisite; NC=New Construction; CS=Core and Shell; CI=Commercial Interiors; K12=K-12 Schools; O&M=Existing Building Operations and Maintenance (formerly Existing Buildings (EB))
Disclaimer: Each LEED point credit typically relates to numerous building design variables and building system parameters that as a whole allows the point to be earned and no one product including LG can guarantee point credits.

ASHRAE Standard 15 & 34

- Covers aspects of occupant refrigerant safety
 - Most common question is...What if I have a leak?
 - Must determine the volume of the smallest space served
 - A refrigerant leak could dump the entire charge
 - In an emergency...
 - ...the system cannot automatically pump down
 - ...the HR Unit cannot close off the flow of refrigerant
 - ASHRAE 34 maximum allowable R410A is 26lb/1000ft³
 - Institutional applications reduce max to 13lb/1000ft³

- What defines the smallest space?
 - How is equipment applied?
 - Ducted return or plenum return?
 - Plenum return may greatly increase the size of the space
 - Are there transfer grilles or other conjoined spaces?
 - May be able to count hallways, neighbouring rooms
 - Determination of suitability is entirely up to the engineer and/or AHJ until such time that ASHRAE provides calculation guidance.

- What if the design exceeds ASHRAE 34 limits?

- Consider...

- splitting larger refrigerant circuits into smaller ones
 - i.e. 1 Dual frame ODU circuit → 2 Single frame ODU circuits
- using a ducted unit to supply the smallest space with a neighbouring space
- removing the smallest space from the system and serving it with a mini split
- refrigerant leak detection if acceptable to engineer and/or AHJ

ASHRAE 15 Interpretations.....

15-2007-1 Only height of sleeping area (ie; 3' AFF) should be used in room volume calcs

False

15-2007-2 Volume of hotel room bathrooms with doors should not be added

True

15-2007-3 Dilution from forced ventilation air should not be considered

True

15-2007-4 RCL in hotel sleeping rooms should be reduced by 50%

False

15-2007-5 Deduct volume of fixtures, casework etc...from room volume

False

Outdoor Air

A) Natural Ventilation – Operable Windows or louvers operated manually by occupant

Disadvantages:

Humidity levels from outdoor air may be difficult to control

Advantages:

May be used with full lineup of VRF indoor units



Outdoor Air

B) Unconditioned Outdoor Air (non-Ducted, Fan Assisted)

Disadvantages:

- Humidity levels may be difficult to control

- Indoor units have to be oversized for added loads

- Hot and cold spots due to uneven distribution of outdoor air

Advantages:

- May be used with full lineup of VRF indoor units



Outdoor Air

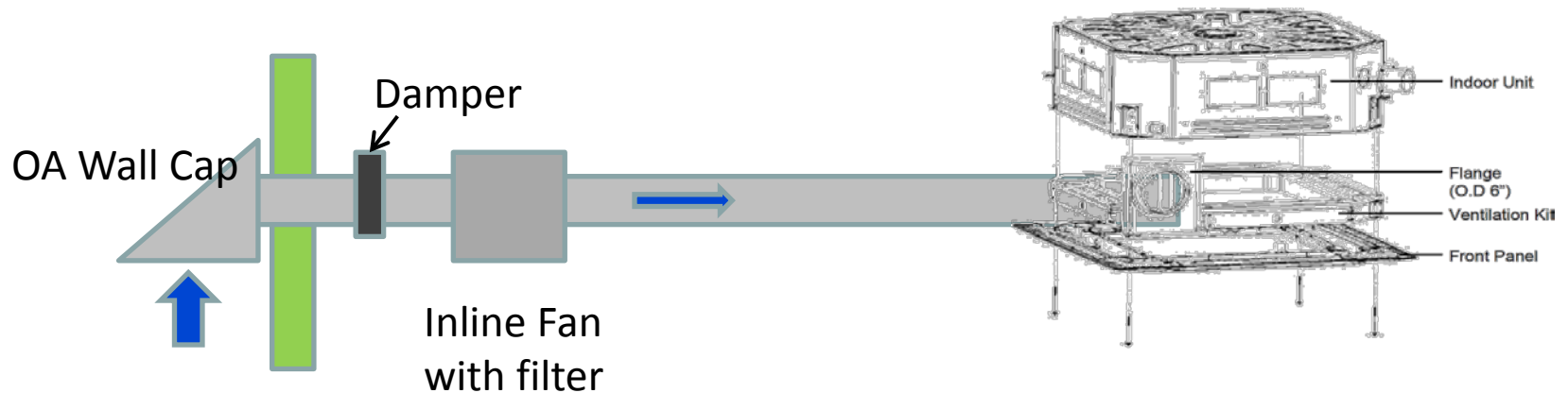
C) Unconditioned Outdoor Air Ducted to Indoor Units

Disadvantages:

- Factory installed return air thermistor cannot be used
- Must add additional air filter and damper for outdoor air duct
- Fan required to push outdoor air to the indoor unit
- Limited types of indoor units can be used.

Advantages:

- Third party ventilation controls like CO2 sensors can be added



Outdoor Air

D) Coupled Dedicated Outdoor Air

Disadvantages:

Ceiling space required for ductwork

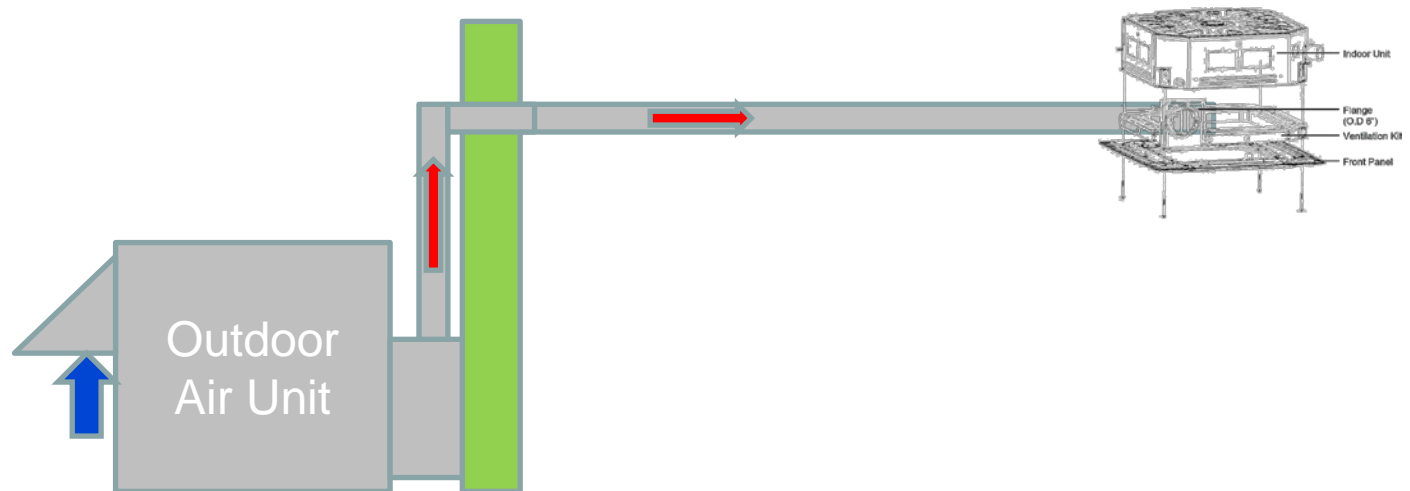
Failure of outdoor air unit may impact operation of indoor unit

Limited types of indoor units can be used

Advantages:

Indoor unit capacity may not be increased by outdoor air

Fan and filter system is centralized to main outdoor air unit



Outdoor Air

E) Decoupled Dedicated Outdoor Air

Disadvantages:
None

Advantages:

Does not add heat/cool loads to indoor units

May be used with full lineup of indoor units

Failure of outdoor air unit does not impact operation of indoor unit

Easier to detect when outdoor air unit is not working properly

