GPG Outbrief 14

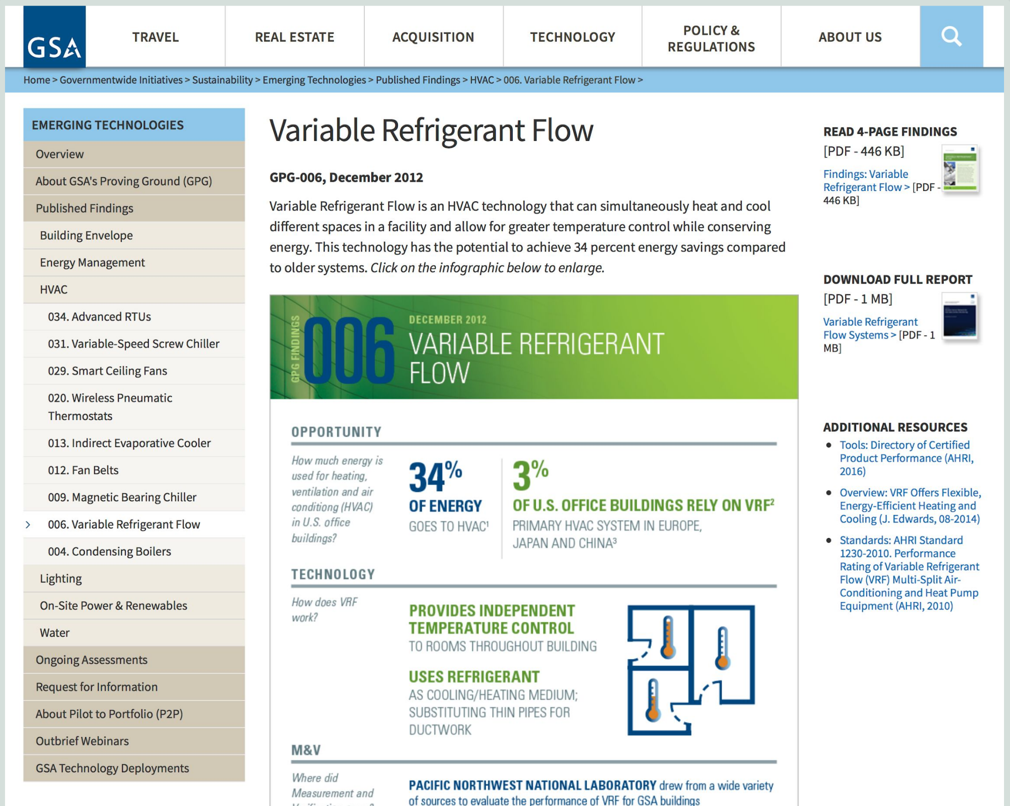
Variable Refrigerant Flow

Emerging Building Technologies, GPG Program | U.S. General Services Administration | June 7, 2018

GSA

GPG-006 Variable Refrigerant Flow @ gsa.gov/gpg

- Infographic
- 4-page Findings
- Full Report
- Additional Resources



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How to Ask Questions

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Introduction

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Webinar Agenda

- ❏ Introduction (5 minutes)
  Kevin Powell, Program Manager, Emerging Technologies
- ❏ Variable Refrigerant Flow Report (15 minutes)
  Anne Wagner, Pacific Northwest National Laboratory
- ❏ On-the-ground Feedback R1, Moakley Courthouse (10 minutes)
  David Johnson, Sustainability Program Manager
- ❏ On-the-ground Feedback R8, Wayne Aspinall (15 minutes)
  Jason Sielcken, Architect/Senior Project Manager; Roger Chang, Energy+Engineering Principal, DLR Group
- ❏ On-the-ground Feedback R9, Bakersfield Courthouse (10 minutes)
  Robert Moctezuma, Building Management Specialist
- ❏ On-the-ground Feedback R10, Vancouver Federal Building (15 minutes)
  Joe Seufert, Regional Mechanical Engineer
- ❏ Q & A (20 minutes)

Introduction

Kevin Powell
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Emerging Building Technologies’ two programs – GSA Proving Ground (GPG) and Pilot to Portfolio (P2P) – enable GSA to make sound investment decisions in next generation building technologies based on their real world performance

Multiple Perspectives on VRF

- PNNL, 2011, VRF technology review and guidance on where it is best suited
- R1: Moakley Courthouse, 2011, need for simultaneous heating/cooling
- R8: Wayne Aspinal FB, 2014, limited room for ductwork changes in historic retrofit
- R9: Bakersfield Courthouse, 2012, separate data center spaces running 24x7
- R10: Vancouver Federal Building, 2017, courthouse with need for independent temperature control

Measurement & Verification

Anne Wagner
Senior Research Engineer, CEM, PMP
Pacific Northwest National Laboratory

GPG-006

Variable Refrigerant Flow

General Services Administration
Public Buildings Service

GSA

GPG-006 | DECEMBER 2012

VARIABLE REFRIGERANT FLOW

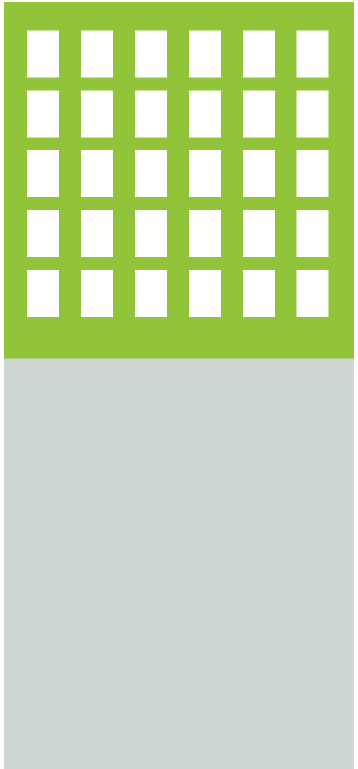
VRF Systems Promise Savings in Targeted Building Types and Climates

Variable Refrigerant Flow (VRF) heating, ventilation, and air conditioning (HVAC) systems use refrigerant as their cooling/heating medium. A compressor unit, typically located on a roof, is connected through refrigerant lines to multiple indoor fan coil units, each individually controllable by its user. The system is capable of simultaneously cooling one area while heating another, and can transfer heat from spaces being cooled to spaces being heated and vice versa. Also, they are small, modular, and can be installed without the use of a crane. This high-performance HVAC technology was invented in Japan more than 20 years ago and has large installed bases in several countries but it's a relative newcomer to the U.S., which, according to a major VRF manufacturer, can claim only 3.4% of the market[1]. However, because VRF has proven to be effective under certain circumstances, particularly in retrofits of older buildings where room for additional ductwork is limited, and because it promises

Opportunity

44%

of energy in commercial buildings goes to HVAC*



3%

OF U.S. OFFICE BUILDINGS RELY ON VRF

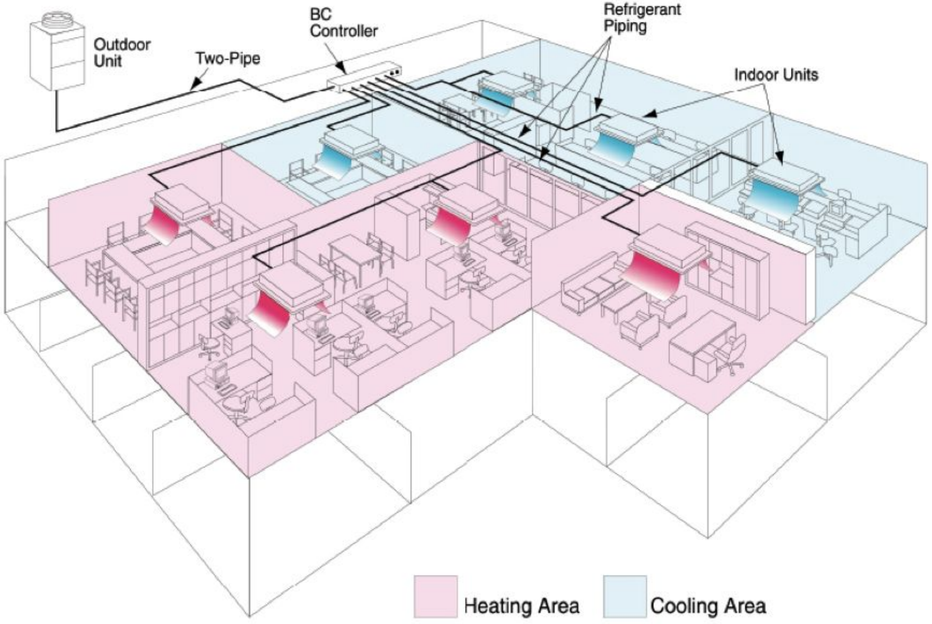
PRIMARY HVAC SYSTEM IN EUROPE, JAPAN AND CHINA

*Commercial Buildings Energy Consumption Survey (CBECS)

Independent Temperature Control

Provides Independent Temperature Control to Rooms Throughout a Building

Simultaneous heating & cooling systems afford substantial energy savings



Engineered System

Major Components: Compressors, Indoor Fan Coil Units and Controller

- Modular
- 2- or 3-pipe
- Proprietary
- Designed before built

How VRF Differs from Other HVAC Systems

	VRF	**Conventional System** Air-handlers (boilers, chillers, DX)	**Conventional Decentralized System** Water Source Heat Pump, Split systems
Capacity range	Broad capacity range (10 – >100%)	Capacity range typically 50–100%	Capacity range typically 50–100%
Centralized/decentralized	Decentralized	Centralized	Decentralized
Heat transfer medium	Refrigerant	Water or air	Water or air
Ductwork distribution system	None/minimal ductwork (–5’)	Extensive ductwork	None — ductwork (usually <50’)
Outside air	Provided by separate system	Outside air supply incorporated	Outside air supply incorporated
System & Controls	Proprietary: All components from same manufacturer	Various component manufacturers	Various component manufacturers
Equipment footprint	Compact	Larger than VRF system	Larger than VRF system

M&V: No GSA Installations; Evaluated Wide-variety of Sources

Potential HVAC Energy Savings for VRF Compared to Other Systems

Chilled Water VAV	Packaged VAV	Packaged CAV	Air-Source Heat Pump	Water-Source Heat Pump	Notes	Source
	62%	39%	49%		Independent modeling study. 4 climates: California, Northwest, Midwest/Northeast, & Southwest	Hart and Campbell 2012
36%		49%		13%	Manufacturer modeling study. Five climates, large office building	LG 2011
34%					Average of three savings from simulations or literature review	Goetzler 2007
33%	29%		33%		Multiple sources—literature,manufacturers' information	EES Consulting 2011 - from Aynur 2010, Amarnath and Blatt 2008
	43%		23%		Average of Mitsubishi simulations for multiple buildings in Seattle, WA	EES 2011
		55%			LG energy study, generic small retail store, average of multiple climates	LG 2012
34%	**45%**	**48%**	**35%**	**13%**	**Average energy/cost savings vs. electric heat systems**	
26%	**32%**	**36%**	**NA**	**NA**	**Average energy cost savings vs. gas heat systems**	

Estimated VRF Energy Cost Savings

Energy Usage	Cost	Minimum[1]	Average[1]	Maximum[1]	Standard 90.1-2010
Total Energy Usage, kBtu/ft^2	–	48.1	60.7	79	55
Heating	–	10.4	13.1	17.0	9
Cooling	–	5.8	7.3	9.5	6.9
Fans	–	4.3	5.5	7.1	5.2
HVAC, kWh/ft^2	–	4.0	5.1	6.6	3.8
HVAC, therms/ft^2	–	0.09	0.12	0.15	0.08
HVAC energy Cost, $/ft^2	$0.08/kWh $0.66/therm	$0.32	$0.41	$0.53	$0.36
VRF 34% energy cost savings $/ft^2	$0.08/kWh $0.66/therm	**$0.11**	**$0.14**	**$0.18**	**$0.12**
HVAC energy Cost, $/ft^2	$0.10/kWh $0.89/therm	$0.41	$0.52	$0.67	$0.45
VRF 34% energy cost savings $/ft^2	$0.10/kWh $0.89/therm	**$0.14**	**$0.18**	**$0.23**	**$0.15**
HVAC energy Cost, $/ft^2	$0.16/kWh $1.22/therm	$0.64	$0.80	$1.05	$0.71
VRF 34% energy cost savings $/ft^2	$0.16/kWh $1.22/therm	**$0.22**	**$0.27**	**$0.36**	**$0.24**

[1]GSA Portfolio Regional Average EUI, kBtu/ft^2/yr

34%

ENERGY SAVINGS

PROJECTED RELATIVE TO CODE-COMPLIANT HVAC

Advantageous for Historic Buildings

Dropped ceilings & ductwork in old postal lobby of Wayne Aspinall FB

THIN

PROFILE

ADVANTAGEOUS IN HISTORIC BUILDINGS WITH LIMITED ROOM FOR DUCTWORK

Simple Payback

Cost-effective When the Additional Cost Is <$4 ft^2 Compared to Code-compliant HVAC

Reasonable paybacks are achievable (shown in white)

VRF vs VAV (HW reheat) or CAV (gas heat)

34% Projected Energy Cost Savings

Energy Cost Savings, $/ft²

Added Cost $/ft²	$.10	$.14	*$.18	$.22	$.26	$.30	$.34	$.38
$1	10	7	6	5	4	3	3	3
$2	20	14	11	9	8	7	6	5
$3	30	21	17	14	12	10	9	8
**$4	40	29	22	18	15	13	12	11
$5	50	36	28	23	19	17	15	13
$6	60	43	33	27	23	20	18	16

VRF vs VAV with Electric Reheat

45% Projected Energy Cost Savings

Energy Cost Savings, $/ft²

Added Cost $/ft²	$.13	$.19	*$.24	$.29	$.34	$.40	$.45	$.50
$1	8	5	4	3	3	3	2	2
$2	15	11	8	7	6	5	4	4
$3	23	16	13	10	9	8	7	6
**$4	30	22	17	14	12	10	9	8
$5	38	27	21	17	15	13	11	10
$6	45	32	25	21	17	15	13	12

* Average GSA Portfolio Energy Cost Savings (based on GSA average usage of 60.7 kBtu/ft², GSA average cost of $0.89/therm, and EIA average cost of $0.10/kWh)

** Average Added Cost

Barriers to Implementation

SUPPLIERS

Manufacturers provide VRF through an integrated supply system. GSA will have difficulty reconciling this with the design/bid/build approach it uses for procurement.

FIRST COSTS

First costs can be relatively high compared to conventional alternatives.

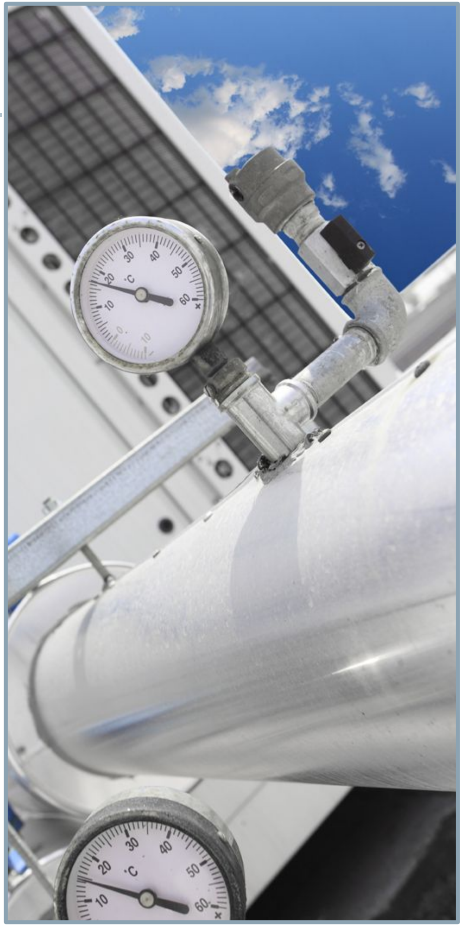
UNCERTAINTY ABOUT THE ENERGY SAVINGS

Because there is a scarcity of thorough case studies and a heavy reliance on model estimates, questions remain about the magnitude of energy savings that can be realized with VRF.

Deployment

Not one-size fits all. Target facilities with:

- Need for HVAC upgrades with limited room for ductwork changes
- Buildings with enclosed spaces that would benefit from independent temperature control
- Buildings with electric reheat, supplemental heat, or primary heating
- Buildings with simultaneous heating and cooling needs
- 5,000 to 100,000 ft^2
  larger buildings can be evaluated on a case-by-case basis



GSA Feedback—Moakley Courthouse

David Johnson
Sustainability Program Manager
GSA Region 1

VRF Installation at the Moakley Courthouse

Chosen for Simultaneous Heating/Cooling in Response to Tenant Complaints

- 8–10% energy use reduction and 6-year payback estimated in original ECMS
- Planned for entire 9 and 10th floors but installation more expensive than anticipated because of after hours installation; ½ the 9th and 10th floors were completed in 2011

10-story, 945,000 GSF, constructed in 1999

VRF Installation at the Moakley Courthouse

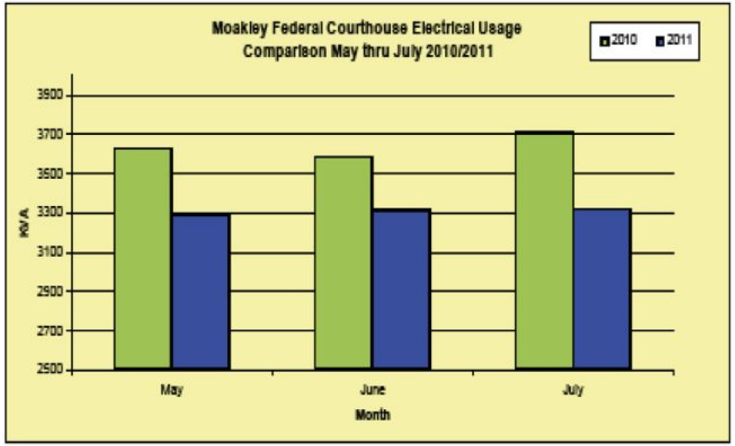
Water-Cooled Instead of Air-Cooled

- Water-cooled VRF selected instead of air-cooled
  - Security concerns (roof openings)
  - Easier for O&M access and avoided potential corrosion due to marine conditions
  - Slightly better payback
- Used existing cooling towers and duct work
- Refrigerant pressure differentials (hi/low) at CUs used for leak detection; occupied space leak detection not required per ASHRAE 15
- Washable filters replaced with MERV-8
- Boxes come with liner for sound attenuation

Reduction in Energy and No Complaints from Tenants

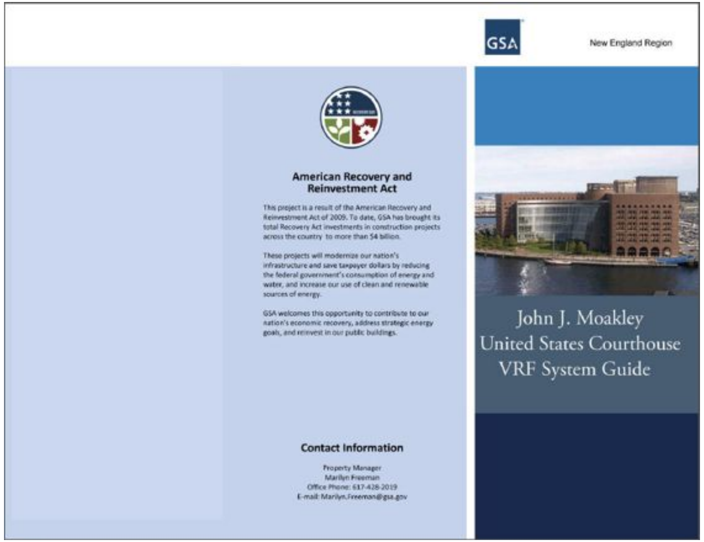
No News Is Good News

- Have seen 12% reduction in overall utility spend (includes other upgrades like BAS and lighting)
- No news is always good news, no complaints from tenants
- Controls are proprietary but that's not any different from dealing with other controls manufacturers
- One condenser has been replaced and Mitsubishi has been responsive to issues



Lessons Learned

- Utilize manufacturer's control interface; BAS has only limited control and monitoring of VRF
- Perform site verification during design phase to ensure sufficient physical spacing of AC's



GSA

New England Region

American Recovery and Reinvestment Act

This project is a result of the American Recovery and Reinvestment Act of 2009. To date, GSA has brought its total Recovery Act investments in construction projects across the country to more than $4 billion.

These projects will modernize our nation's infrastructure and save taxpayer dollars by reducing the federal government's consumption of energy and water, and increase our use of clean and renewable sources of energy.

GSA welcomes this opportunity to contribute to our nation's economic recovery, address strategic energy goals, and reinvest in our public buildings.

Contact Information

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John J. Moakley United States Courthouse VRF System Guide

Moakley HVAC Upgrade Project

In 2010, the US General Services Administration undertook a detailed retro-commissioning study of the John J. Moakley Federal Courthouse to identify key energy conservation measures that would have a measurable and distinct impact on energy consumption at this federal facility.

The Moakley Federal Courthouse has a complex heating, ventilation, and air conditioning system with considerable and major equipment designed to operate in unison to provide the comfort of the occupants. Any improvement would also need to accommodate a fully occupied building. The replacement of the air terminal units with Variable Refrigerant Flow (VRF) AC Units was identified as a major energy conservation measures affecting energy usage.

TheHVACupgradeprojectwhichentailedthereplacement of the existing fan terminal units with the state-of-the-art VRF system on the ninth and tenth floors was funded through the American Recovery and Reinvestment Act. This HVAC improvement was designed to reduce the energy consumption of the two floors by $4,327,669 over a twenty year period.

Type of Upgrade

The energy upgrade of the system was achieved by installing VRF units above the ceilings on the ninth and tenth floors which replaced existing fan terminal units. Each VRF unit essentially serves the same zones or rooms that the previous variable volume unit served, yet at considerable energy savings.

The VRF system consists of variable refrigerant units distributed above the upper level office ceiling with their respective condensing units located throughout the two floors. The individual units are connected with refrigerant lines through a branch circuit controller to each condensing unit. There are a significant number of days when the system takes advantage of simultaneous operation, while maximizing comfort, allowing for significant energy savings. This innovation results in virtually no energy wasted by being expelled outdoors. A make-up air unit will provide outside air in accordance with ASHRAE 62.1

Zone/Space Control

The sensors or zone thermostats for each VRF unit are located in the same offices as before hence the control of each space or zone has not changed. Heating or cooling of each zone is achieved by the ceiling mounted VRF unit which is controlled by the zone /space temperature controller. This controller allows the required amount of cooling or heating energy to be distributed to the space by transferring varying amount of refrigerant through each unit. Ventilation air for each space is maintained by existing air handlers located in the mechanical rooms.

Adjusting Space Controller

The space or zone controller can be adjusted locally (+/- 2°F) or remotely by request through a computer application controlled by the building management. By request, temperature can easily be adjusted beyond the +/- 2°F range by the building management. Set points have been set to maintain each zone at 72°F.

Building Controller

The VRF units use a two-pipe system and a Building Controller to cool and heat different zones in the same building simultaneously.

Sensor/Zone Temperature Controller

Conclusion

- **Energy efficiency:** simultaneously heat and cool, virtually eliminating heat loss – Low LCC
- **Zone comfort:** system delivers right amount of refrigerant to precisely meet the load in each space
- **Quiet operation:** condensing units as low as 51dB(A) and indoor units as low as 22dB(A)
- **Low maintenance:** change filters and clean coils
- **Safety:** no recirculate air into other zones, reducing the spread of airborne contaminants and allergens
- **Flexibility:** zone by zone installation while the rest of the building remains in operation

GSA Feedback—Wayne Aspinall Federal Building & U.S. Courthouse

Jason Sielcken
Sr. Project Manager
GSA Region 8

Roger Chang
Energy + Engineering Principal
DLR Group

Wayne Aspinall Federal Building and Courthouse

2014 ARRA Modernization Project, 41,562 ft^2


Design Build RFP/System Considerations

OPTIONS:

1. VAV Baseline
2. 4-Pipe Fan Coil Units
3. Radiant Cooling & Heating
4. Air Source | Water Source VRF

METRICS:

1. Footprint (VRF | Radiant)
2. Efficiency (VRF | Radiant)
3. Zoning Flexibility (All)
4. Indoor Environmental Quality (VRF | Radiant)
5. Response Time (FCU | VRF)
6. Controls Complexity (VRF)

VRF System Summary

VRF FAN COIL UNITS

Primarily Clg. Ducted Units

Basement: 13 | Level 1: 19 | Level 2: 23 | Level 3: 17

VAV Ventilation Air Control Boxes

Basement: 4 | Level 1: 11 | Level 2: 7 | Level 3: 7

VRF CONDENSING UNITS

Six (6) Twinned Sets

12-20 tons nominal capacity; 12.4 EER, 21.6 IEER

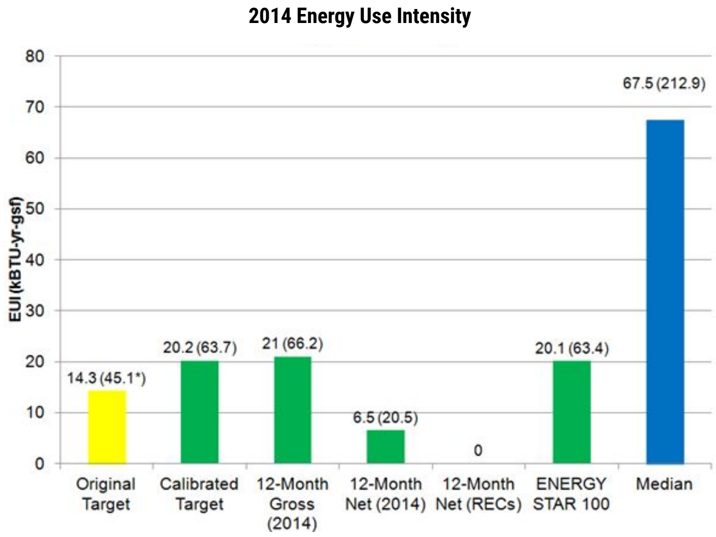
REFRIGERANT PIPING

Brazed Copper, 2-pipe

Ten (10) Total Branch Controllers; 8-16 nodes - Heat Recovery

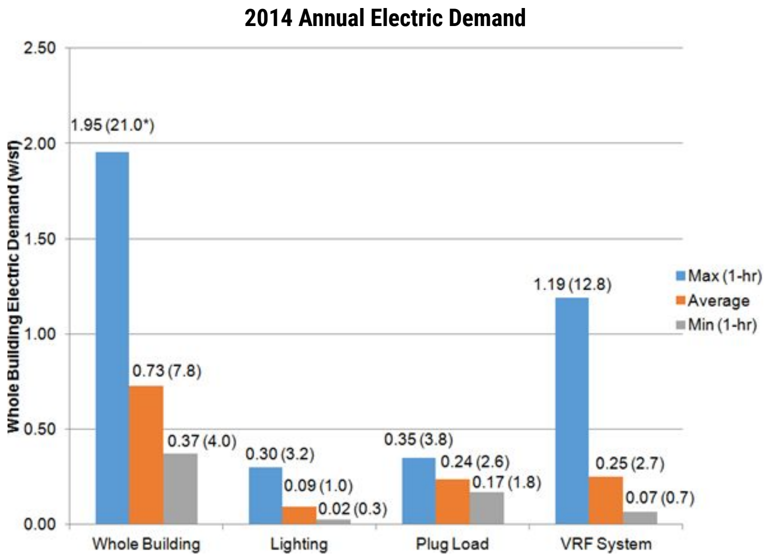
Lessons Learned

1. **Highly proprietary technology:** black box
2. **Not able to measure heat/cool delivery:** like a hydronic system
3. **System operates in steps:** not true variable
4. **Controls integration can be challenging:**
    a. Output: Auto, Cool, Heat | Temperature | Scheduling
    b. Input: Status | Space Temperature
    c. System optimized for stand-alone control
    d. Have seen installs with parallel set of space sensors



Lessons Learned

1. **No benefit to twinning:** if one compressor fails, the whole unit goes down.
2. **AHRI rating:** does not address <25% load condition.
3. **Sizing was more conservative than needed:** apply more diversity.
4. **Energy modeling:** derating needed for pipe length, fittings, altitude, defrost/oil return cycle.



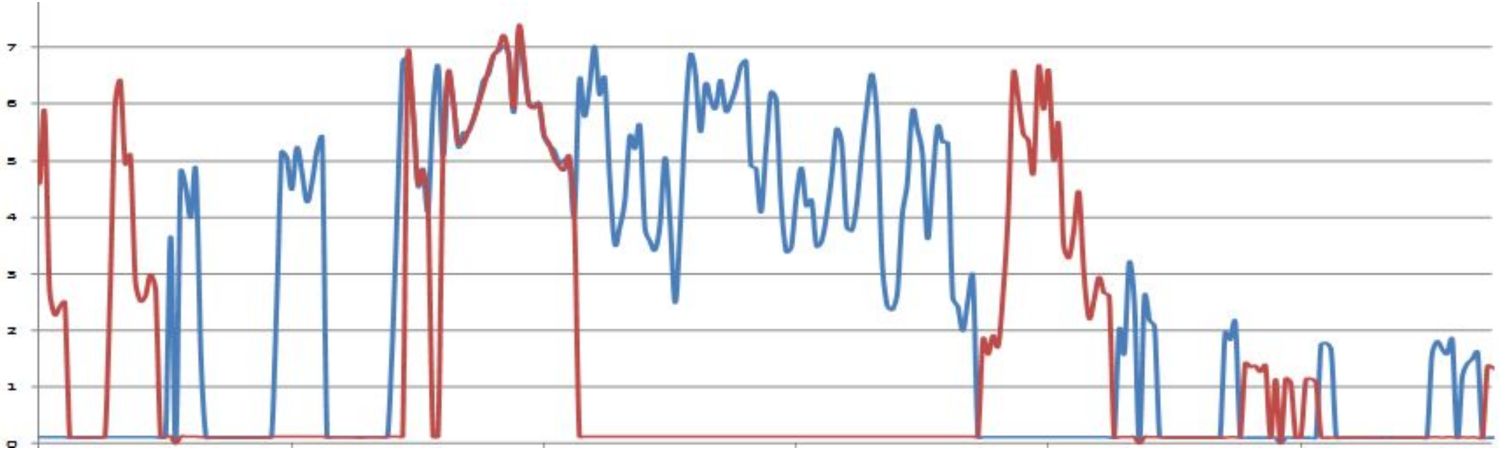
Considerations for Future Use

1. **3-pipe vs. 2-pipe system:** significant industry discussion. 3-Pipe is common to all vendors except Mitsubishi. Higher efficiency potential with 3-Pipe heat recovery application.
2. **Air-source systems have higher reliability potential:** no external system influence on performance | Packaged System.
3. **Fan coil unit filter change is a concern:** provide MERV 13+ filtration at Dedicated Outdoor Air System (DOAS).
4. **Use water-source systems with care:** due to the complexity of the refrigeration cycle, a special controller card is needed for some manufacturers for true variable condenser water loop flow operation.

Image source: Childcare facility Camp LeJeune, Joe Seufert

Considerations for Future Use

1. Plan commissioning and M&V process early in design phase.
2. Equipment stand-by performance not always available.
3. Determine temperature set-point ranges early and set on day one.



24 Hour Twinned VRF Electric Demand

GSA Feedback—Pacific Rim Region 9

Robert Moctezuma
Building Management Specialist
GSA

VRF at the Bakersfield Courthouse

- New construction 2011, 35,000 total ft^2
- VRF used for 4 server/equipment rooms, spread out around the building ~325 ft^2
- Master/slave air-cooled outdoor units on the roof, 4 indoor units
- 2-pipe system design
- Only used for cooling; operational 24x7

Benefits of VRF at the Bakersfield Courthouse

- Bakersfield courthouse is a good application of VRF due to dispersed location of rooms served and small footprint
- Some level of redundancy, while slave unit was down, master was able to continue running
- 1 outdoor unit serves 4 different agencies
- More efficient than standard system due to high turndown (20-100%)

Limitations of VRF at the Bakersfield Courthouse

Repairs

- Limited access to troubleshooting and repair information for non-factory certified personnel
- Repairs can be costly if factory rep is needed

Control sequences

- Weakness in the system, failures/faults have been electronic in nature i.e. communication between the master and slave unit
- Limited BAS integration

GSA Feedback—Northwest Arctic Region 10

Joe Seufert
Regional Mechanical Engineer
Northwest Arctic Region 10

VRF in R10—Vancouver and Richland Federal Buildings

Issues to Consider with VRF

- Limited visibility into BAS
- Condensate piping may require insulation
- Refrigerant lines have a limit on length
- Training of O&M is critical

Great Technology, *If* Applied Correctly

Challenges With Original Installation in Vancouver

Note lack of continuous insulation

Lack of continuous insulation on refrigerant line

Great Technology, *If* Applied Correctly

PVC Pipe Replaced with Copper Pipe but Pumps Need Monitoring/Alarm

PVC pipe condensate installed with loosely installed metal strap

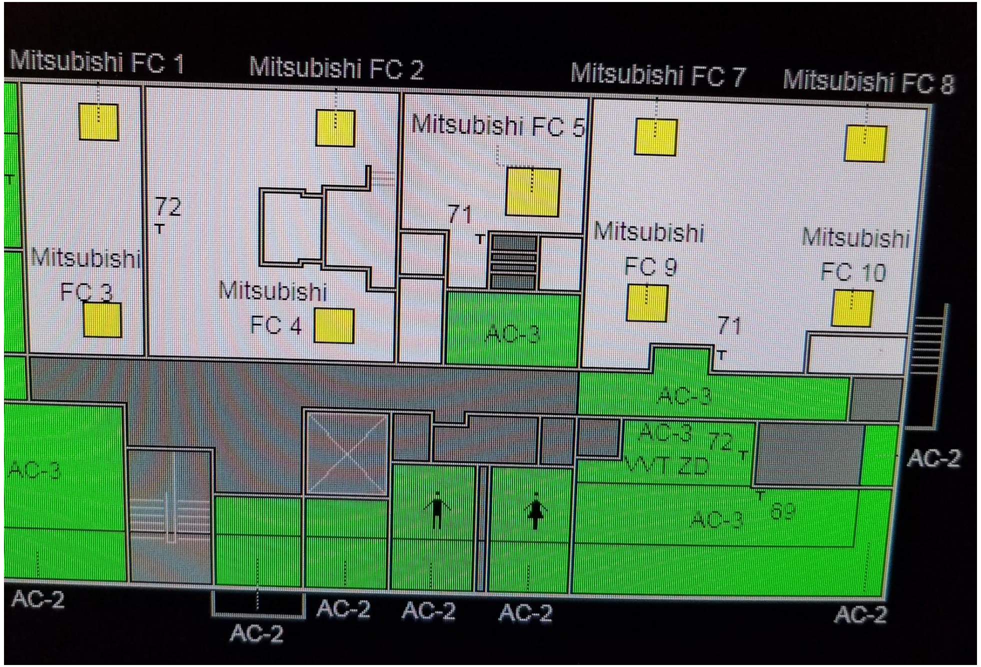
Copper pipe replaces PVC but booster condensate pumps not monitored

VRF at the Vancouver Courthouse

- VRF selected for independent temperature control
- Air-cooled, Mitsubishi system installed in 2017
- 5,500 ft^2 Courtroom, judge's chambers & bankruptcy hearing rooms
- Additional ductwork wasn't necessary

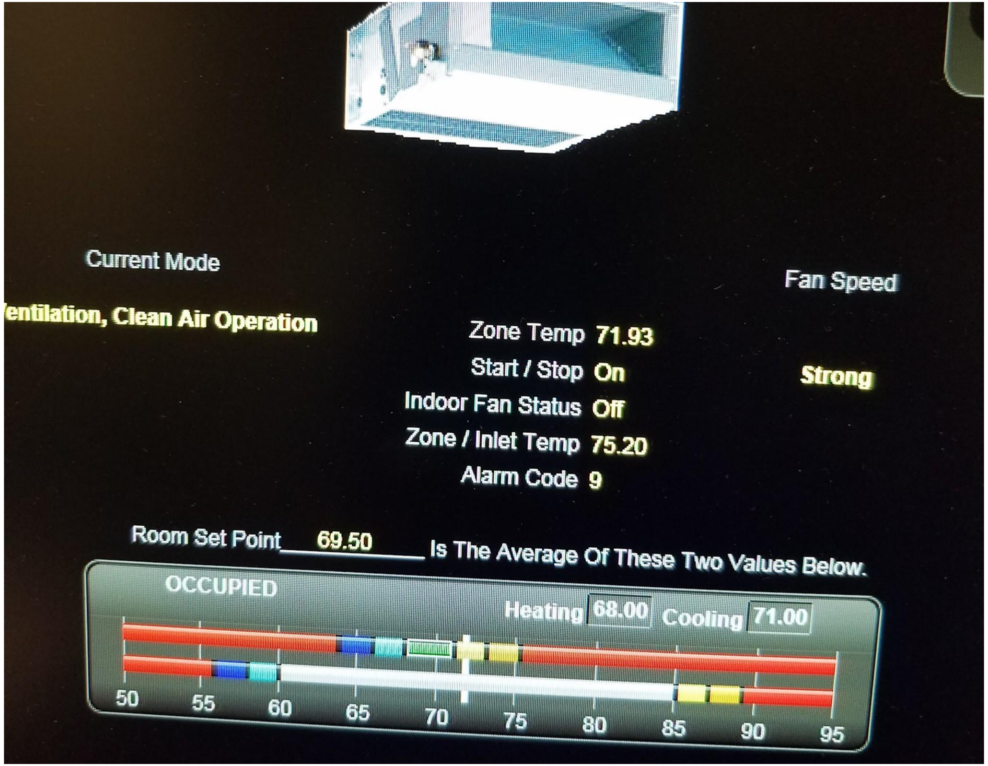
More Efficient & Improved Tenant Comfort

- No longer overcooling people on 1st floor when the courtroom is in use
- System is so quiet that tenants initially thought it wasn't working
- Used mostly for cooling but energy recovery system can transfer heat & cooling from one area to another



Tied to the BAS (Automated Logic)

- Can change and monitor setpoints
- Process to tie into BAS was straightforward
- Minimal control programming but system is autonomous so haven't needed to change controls

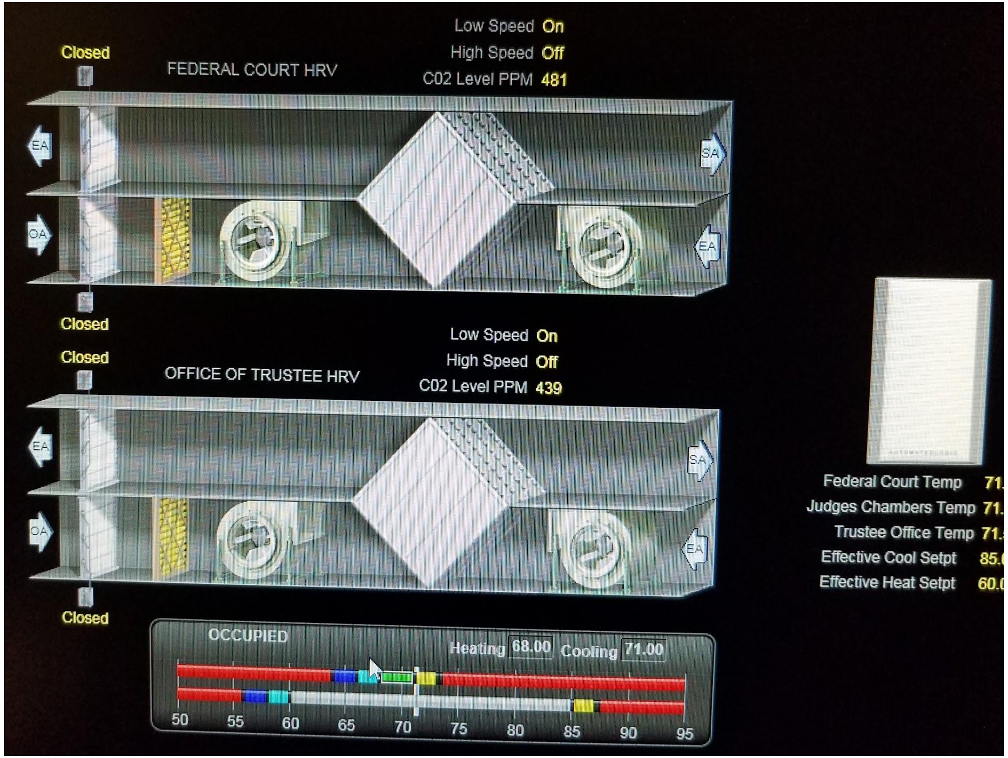


Lessons Learned

- Exhaust & intake don't meet 15 ft. separation required in P-100 Table 5.2
  - General contractor and engineer say in compliance with building codes
  - Recycles exhaust air and recovers heat & cooling from exhaust
- Condensate drain tanks don't have an alarm in the BAS which could be problematic.
- In retrofit, make sure you disconnect and cap ductwork.

VRF Recommendations

- Need VRF design guide
- Maintain built records so you know where joints in ductwork are, once insulation is installed leaks can be hard to locate
- Understand limitations and use cases
- Learn more from other implementations of VRF, the US Army Corps has been using VRF for awhile
- Key is to design for simultaneous heating/cooling



Q & A

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AIA Number

Your answer

First and Last Name

Your answer

The information presented in the Outbrief webinar was helpful.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

I am interested in installing variable refrigerant flow.

- ○ Yes, in the next 2 years.
- ○ Yes, in the next 5 years.
- ○ Maybe
- ○ No

Thank you

For more information: gsa.gov/GPG

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