Variable Refrigerant Flow (VRF) Market Strategies Report

September 2019

Table of Contents

Acknowledgements

This report reflects the invaluable contributions of multiple individuals.

We would like to recognize the report's lead author, Chris Badger, Senior Consultant of Emerging Technologies, Vermont Energy Investment Corporation (VEIC). Jake Marin and Rachel Mascolino, VEIC supported development of key sections. NEEP staff also served key roles in the development of the report including David Lis, Director of Technology and Marketing Solutions and Giselle Procaccianti, Commercial and Industrial Program Manager. Formatting and edits were provided by Lisa Cascio, Director of Partner Engagement.

NEEP would like to recognize and thank members of its VRF Working Group for their participation in reviewing this report and providing input into the creation of this document.

Finally, as this report follows the form and function of the 2016 Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report, NEEP would like to take this opportunity to reiterate acknowledgement of its authors and contributors – Robb Aldrich, Steven Winter Associates, Inc. and David Lis, Director of Technology and Marketing Solutions, NEEP.

Cover photo courtesy of NEWYORK ENGINEERS, www.ny-engineers.com.

About NEEP

Founded in 1996, NEEP is a non-profit whose goal is to assist the Northeast and Mid-Atlantic region to reduce building sector energy consumption three percent per year and carbon emissions 40 percent by 2030 (relative to 2001). Our mission is to accelerate regional collaboration to promote advanced energy efficiency and related solutions in homes, buildings, industry, and communities. We do this by fostering collaboration and innovation, developing tools, and disseminating knowledge to drive market transformation. We envision the region's homes, buildings, and communities transformed into efficient, affordable, low-carbon, resilient places to live, work, and play. To learn more about NEEP, visit our website at http://www.neep.org.

Executive Summary

Variable refrigerant flow (VRF) heat pumps (VRFs) are a variable capacity, multi split technology primarily targeted at commercial heating and cooling applications. A VRF heat pump is comprised of a single air or water-cooled compressor utilizing refrigerants to supply multiple indoor fan coil units.

Since 2013, NEEP has worked on a regional market transformation initiative to accelerate the market adoption of VRF technology in the Northeast region. The initiative collectively developed and recently updated the Northeast/Mid-Atlantic ASHP Market Transformation Strategies Report to provide a "roadmap" of coordinated regional activities to effectively transform the residential market. The regional initiative and its working group have since advanced many of the key strategies, though there is still active work being done to transform this market. Then in 2017, NEEP's Regional Assessment of Strategic Electrification further underscored the urgent need for market transformation for both residential and commercial heat pumps.

This report takes the framework of the residential ASHP initiative and adds a new focus on commercial application of VRF and the respective market strategies that, if implemented by regional stakeholders, would result in accelerated adoption of commercial VRF heat pumps in the Northeast/Mid-Atlantic region.

Like their smaller residential-scale heat pump technology counterpart, VRFs have continued to improve in efficiency, introducing high performance cold climate versions designed to provide rated heating capacity even in low ambient outdoor temperatures.

In Europe and Asia, market share of VRF heat pumps represent approximately 80-90 percent of installed HVAC systems in commercial buildings. In the United States, however, the technology is still a nascent – but rapidly growing – market. The rapid adoption of VRFs internationally and more recently in the U.S. is due to the technology's energy and non-energy benefits (e.g. efficiency, comfort, space savings, etc.). However, remaining questions and limited field data on VRF installations – notably potential refrigerant leakage and verified energy savings of VRF systems – continue to weigh on broader promotion of the technology.

Increased adoption of VRF offers the potential for significant gains in efficiency for cooling applications. As such, it can become an important technology solution in NEEP's broader ASHP electrification strategy for commercial heating applications. However, increased regional coordination and collaboration is needed to realize the potential for VRF as a GHG mitigation strategy in shifting away from fossil fuels.

This report maps out the critical strategies necessary for VRF market transformation. Like the 2016 NEEP ASHP report, recommendations are framed for the broader community of regional stakeholders and sub-strategies identify specific stakeholders for implementation.

List of Regional Market transformation strategies

1. Increase reporting of VRF performance and costs to improve models for predicting cost-effectiveness, energy and GHG savings
   a) Regional energy efficiency program administrators should introduce reporting requirements to capture project specific details on system design, upfront and operational costs and estimated or modeled savings. Additionally, longer term supplemental field evaluations, verification and pre/post monitoring studies are of critical importance for documentation of field VRF performance - including changes in energy use, ongoing operational performance in relation to changing building loads, supplemental systems and weather conditions.
   b) Regional VRF working group and manufacturers collaborate to assess the opportunity for leveraging existing or additional on-board metering of VRF systems to inform field-verified performance. Identify best practices for metering/monitoring VRF to identify the optimal balance of cost-effectiveness vs. accuracy.
   c) Regional stakeholders collaborate to develop best practices for VRF building energy modeling and share updates to VRF performance curves (e.g. cold-climate models), field verified building models and system costs.
2. Support improved test procedures and performance criteria/standards to enable the promotion of climate-appropriate VRF
   a) NEEP VRF working group should monitor and support development of national test procedures, standards and advanced specifications that improve the correlation and accuracy to real-world and climate-specific applications. The working group should evaluate the benefits of developing regional climate-specific performance reporting requirements and advanced criteria for VRF.
3. Develop a comprehensive regional strategy for addressing the climate and safety risks of refrigerants in VRF systems.
   a) NEEP VRF working group should initiate and collaborate in research aimed at identifying current VRF leakage rates, as well establishing data-informed best practices for VRF installations and servicing.
   b) NEEP VRF working group should invest in early support for industry evaluation of new refrigerants for VRF installations and encourage early market adoption. As new low-GWP refrigerants will potentially require repiping for proper safety or performance, early planning and incentives may be required for avoiding barriers to market growth of VRF.
   c) Efficiency program administrators, state building code officials and industry can collaborate to support training on best practices for VRF design to mitigate safety, as well as reduce refrigerant charge to address leak risks. Similarly, site inspections prior to commissioning and code official enforcement of proper installations will support broader adoption among HVAC contractors.
4. Increase state policy support and program valuation of all energy savings and non-energy benefits of VRF
   a) Regional state policy and efficiency programs should address policy barriers to the full valuation of VRF in reducing fossil fuel use through beneficial

electrification and peak demand reduction. Additionally, the development of VRF case studies installations in a diverse set of building types, as well as increased field performance monitoring, will increase the confidence in VRF as a solution for building owners, and role in state GHG mitigation strategies.

5. Increase HVAC workforce development and training on proper VRF design, installation and maintenance.
    a) Regional stakeholders, including manufacturers and program administrators, should increase the level of investment in HVAC workforce development and training to ensure that a sufficient number of “clean energy contractors” are trained in design, installation and maintenance best practices of new electrification technologies like VRF.
    b) In tandem to workforce development and training, program administrators should require manufacturer certification in the installation of VRF to increase confidence in system performance and reduce risk of refrigerant leaks. The NEEP workgroup can assess existing manufacturer training and value of developing regional best practice guides and standardized certifications for VRF contractors in critical areas (e.g. proper design, system sizing and start-up procedures).
6. Reduce incremental costs and increased VRF market transformation through robust, streamlined and aligned regional, state and efficiency program market promotional actions
    a) Regional VRF working group members should better track and report VRF costs (incremental, installed and avoided), as well as assess the level of incentive necessary to drive sustainable, yet accelerated growth in the VRF market.
    b) Energy efficiency and Renewable heating and cooling programs should evaluate opportunities to align program delivery strategies – notably midstream distributor partnerships, as well as coalescing around regional performance criteria like the success of the ccASHP specification. However, programs should seek to leverage the industry partnerships and conduct standardized surveys to continue to gather detailed cost and system design data to inform program design improvements.
    c) Regional VRF workgroup members should work to develop a multi-year market transformation strategy for increased voluntary building and equipment efficiency standards, as well as education of building professionals, to support VRF adoption and accelerated transition to low carbon state building energy codes.
7. Promote integration of existing building management systems and advanced VRF controls to increase coordination and efficiency between building heating and cooling systems and other occupancy type controls.
    a) Regional VRF workgroup members should invest in increased building operation training, best practices in system design, and assessing program or state building code strategies to increase VRF control and building energy management system integration. These investments and collaboration with industry will help achieve the highest building level HVAC energy savings and comfort in VRF installations.

Introduction

Since 2013, NEEP has led a regional market transformation initiative for air source heat pumps (ASHPs), mainly for residential applications. The region has since seen a dramatic increase in activity focused on addressing the key strategies that were identified by the initiative. Less regional attention has been paid to the commercial application of ASHP technology specifically, VRF technology. Numerous studies, including NEEP's 2017 Northeast Regional Assessment of Strategic Electrification, have highlighted the urgency for the aggressive acceleration of low-carbon space heating and cooling over the next 10-15 years if mid- and long-term carbon reduction targets are to be met. It became clear that it was time to expand the ASHP regional market transformation initiative to include VRF technology.

To launch the initiative, NEEP convened a diverse group of stakeholders to collaborate on further market development of ASHPs. NEEP conducted an initial study[1] of the needs and opportunities associated with low-carbon building technologies; and then commenced a multi-stage process for engaging and soliciting input from VRF stakeholders to best identify and prioritize market barriers and opportunities for growth in the regional market.

NEEP kicked off the new VRF initiative in October 2018 with the VRF working group, consisting of heat pump manufacturers, efficiency program administrators, engineers, contractors, and other interested parties to better understand the persistent barriers in the VRF market. Two initial actions were taken to support the framework for NEEP's variable refrigerant flow (VRF) market strategies report:

- Presentation of the 2018 NYSERDA VRF report[2] findings to the NEEP VRF working group, and assessment of knowledge gaps to inform regional VRF market assessment and strategy development
- Survey regional VRF working group of program activity and prioritize key research focus areas

The results of this initial framing allowed for two primary areas of focus for market research - VRF market development and VRF technology and performance. These focus areas were to be informed by individual research areas important to developing actionable strategies to support the VRF market.

Factors that affect VRF Market Development

- Cost
- Market actors
- Market interventions
- Market size
- Program strategies
- Regional promotion

[1] NEEP Regional Assessment of Strategic Electrification

[2] NYSERDA commissioned an assessment of VRFs in 2018 that identified barriers and opportunities to the heat pump technology and energy savings estimates for commercial office and multifamily buildings. "Market and Technical Analysis of Variable Refrigerant Flow Heat Pump Technology", VEIC. May 2018.

Factors that affect VRF Technology Performance

- Design and installation
- Performance
- Standards & savings
- Refrigerants
- Technology assessment

Following additional research informed by the working group, NEEP prepared draft market transformation strategies. Regional stakeholders provided robust input after review of the draft report that included the market assessment and market strategies.

Informed by the regional input, NEEP finalized this report. NEEP intends to use the strategy report to prioritize regional activity that key market actors should focus on to accelerate the market adoption of VRF technology in the coming years.

VRF Technology and Market Assessment

Framing Assessment of VRF Market, Technology and Performance

NEEP launched its market assessment work by organizing key research questions to more fully understand the market that we were seeking to impact. Table 1 captured the topic areas that were of highest interest. Market research was prioritized in the areas of biggest need.

Table 1 Framework for assessing VRF technology and regional Market

VRF Focus Area	VRF MARKET TOPICS	KEY QUESTIONS FOR NEEP VRF PROJECT	RELEVANT INFO CAPTURED IN NYSERDA VRF REPORT	INPUT RECEIVED DURING KICKOFF WORKING GROUP WEBINAR	ADDITIONAL INSIGHT CAPTURED IN NEEP STAKEHOLDER SURVEY
VRF Technology & Performance	TECHNOLOGY ASSESSMENT	What are the current VRF system applications?	- Benefits of VRF systems over traditional HVAC solutions were covered in the NYSERDA report but tradeoffs were not. - Ideal application of VRF systems with a focus on comfort cooling.	- What are the most recent technological advancements re HVAC systems? Is VRF one of the preferred solutions in this mix? - What are the benefits/tradeoffs of VRF systems against other alternative technologies?	
	DESIGN AND INSTALLATION	How are VRF systems specified/sized?		What are some of the best practices when it comes to design, installation, commissioning and O&M?	Lack of sufficient industry design and installations skills
	PERFORMANCE (Cold Climate)	Have performance specifications for VRF operation and high efficiency in cold climate applications been developed? (Do they allow for differentiation?)	Most of this is covered in the NYSERDA report. Cold climate concerns can be overcome with good design.	How does the industry define "cold-climate" performance of VRF?	Cold climate performance - the more a system can reduce the capacity of the backup heating devices, usually natural gas boilers, the more it can be cost-effective and the more it can reduce GHG emissions.

	STANDARDS & SAVINGS	- What are relevant efficiency metrics, standards & test procedures? - Have performance & energy use deemed savings for VRF and baseline solutions been established? - What are the estimated savings for VRF systems?	- NYSERDA's modeling compares VRF systems' performance to typical baseline systems. - NYSERDA's modeling looked at factors that impact performance like fuel prices, building ages, external electrical loads and shell characteristics.	How does modeled performance compare to actual performance?	There is a lack of real-world performance data, and difficulties in understanding how to design and size one for engineers, as it is different for each manufacturer.
	REFRIGERANTS	Are leaking refrigerants an issue?	Mentioned re ASHRAE standards, but assessment of refrigerant in VRF can be done more comprehensively.	- Can more information on the next generation of refrigerant and refrigerants be provided? - Consider piping reuse, how ASHRAE-34 needs to evolve, how manufacturers can get involved etc.	There is a potential for collision between VRF deployment and HFC phase-out.
VRF Market Development	**COST**	What cost data is available?	VRF systems are more expensive on a per-ton basis than other systems due to additional installation costs of refrigerant lines, condenser costs and other advanced components.	Incremental and installed costs are covered in the NYSERDA report, but perhaps more recent and more comprehensive research can be done on this.	VRF is perceived as having a high cost
	MARKET ACTORS	Who are the key market actors re VRF market adoption?	High level assessment of market actors and their roles in influencing the adoption of VRF technologies.		
	MARKET INTERVENTIONS	What appropriate/critical market interventions can be identified in order to accelerate market adoption?	Highlighted in response to each market/ technical barrier identified. Are there more holistic approaches?		
	MARKET SIZE	How big is the current VRF market?			

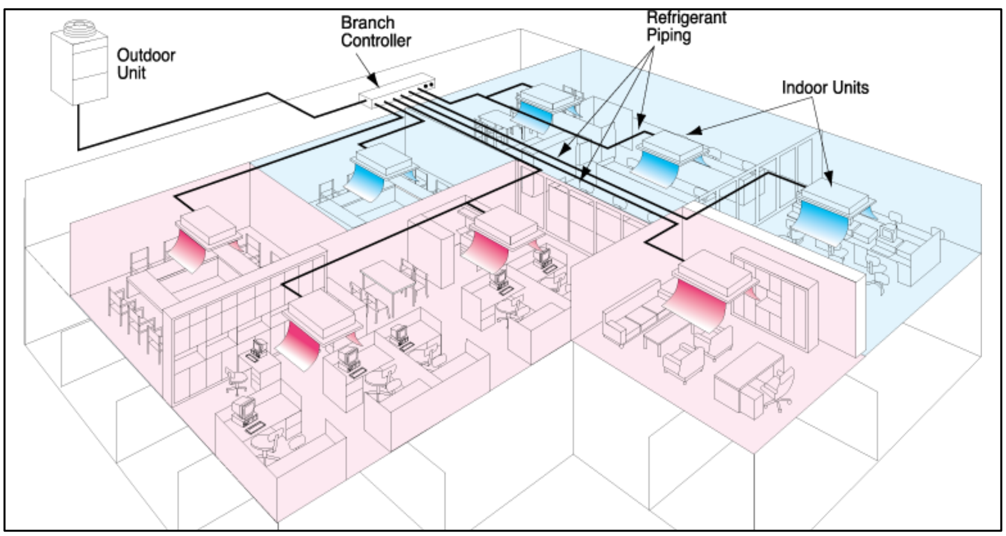
	PROGRAM STRATEGIES	What program strategies for VRF should be developed?	Review of market development and industry engagement strategies relevant to overcome identified barriers	How effective are current mid-stream and down-stream programs?	
	REGIONAL PROMOTION	- How can regional stakeholder communication be maintained? - What are the existing VRF promotional efforts in the region?	Reference to case studies to highlight VRF's applicability to various building types.	How does the northeast compare to other regions? – Is VRF adoption moving at the same speed and in the same direction? – What initiatives are other regions implementing to accelerate VRF adoption?	Broad lack of awareness about VRF technology and the energy and non-energy benefits.

VRF Technology and Applications

VRF was introduced in the 2016 NEEP ASHP Market Strategies report[3], and although VRFs are available for air conditioning use only, this report focuses on VRFs as a comprehensive heating and air conditioning solution for commercial buildings. Increased performance by VRFs is achieved using inverter-driven, variable-speed compressors which "allow heat pumps to operate much more efficiently by varying capacity with building loads". Unlike chillers, VRF systems circulate refrigerant instead of water as the heat transfer medium. The current refrigerant used in VRF systems is R410A, but research on alternative low global warming potential (GWP) and natural refrigerants is ongoing.

As noted in the ASHP report, VRF systems – which have unique design flexibility – are typically installed in applications where there is a central heating and cooling load larger than what is economical to serve with mini split heat pump units. A commercial building with multiple and diversely loaded zones – potentially with simultaneous heating and cooling needs – is an example of where VRF would be a more appropriate application when compared to mini split technology. A single outdoor condensing unit can be connected to multiple indoor evaporators providing efficiency through load matching and heat recovery. Systems selected with a heat recovery module have the added benefit of simultaneously heating and cooling from one condensing unit, transferring energy between zones.

Figure 1: VRF Heat Pump heat recovery building design



(Source: 2012 GSA VRF Systems Report / Mitsubishi)

Achieving simultaneous heating and cooling of zones connected to one condensing unit is not possible without the heat recovery module option, available from all major VRF manufacturers. The additional cost of adding heat recovery technology is justified when there is diversity of heating and cooling needs in the same conditioned space. Potential for heat recovery is best captured in the original system design, understanding that it is not going to increase the system efficiency in all applications.

---

[3] https://neep.org/sites/default/files/NEEP_ASHP_2016MTStrategy_Report_FINAL.pdf

The use of VRF heat recovery is typically best suited for design applications with smaller, separated spaces (e.g. offices, classrooms or conference rooms), with a known diversity of heating and cooling needs.

Based on industry interviews in the 2018 NYSERDA VRF report, VRF systems are well suited for "any space type that provides comfort cooling", including offices (both small and large), multifamily (apartments, residential town homes, dormitories, and condos), assisted living, hotel/motel, and K-12/university. The common attributes of these building types are that they have physically defined zones and variable occupancy rates through the day and week.

The NYSERDA report highlights the attractiveness of VRF in urban areas where building space limitations on the roof and between floors in retrofit and new construction applications is a significant concern. Additionally, as urban applications are typically in buildings with lower natural gas heating costs and higher electricity rates, summer cooling savings and the non-energy benefits of comfort and space savings (e.g. reduced ductwork) can often drive VRF selection. Alternatively, applications in more rural areas not served by natural gas recognize a significant benefit from reductions in higher oil and propane heating fuel costs.

VRF Performance Metrics, Ratings, and Standards

Air-Conditioning, Heating, and Refrigeration Institute *Standard 1230: Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment* (AHRI 1230-2014) establishes the test procedure of VRF equipment. Standard 1230 classifies equipment by nominal capacity stating that for systems < 65,000 Btu/h, the standard measure of efficiency shall be expressed by EER, SEER, and HSPF. For systems ≥ 65,000 Btu/h, the standard measure of efficiency shall be expressed by EER, IEER or IPLV, and COP. The primary focus of this report is on air-cooled VRF greater than 5.4 ton or 65,000 Btu/h; smaller capacity systems less than 5.4 ton and water-cooled criteria are not currently captured.

- **Energy efficiency Ratio (EER)** A ratio of the Total Cooling Capacity in Btu/h to the power input values in watts [W] at any given set of rating conditions expressed in Btu/Wh.
- **EER** $= \frac{total\ heat\ removed\ from\ the\ conditioned\ space\ during\ 95^{\circ}\ F\ test\ (Btu)}{total\ electrical\ energy\ consumed\ by\ the\ heat\ pump\ during\ the\ 95^{\circ}\ F\ test\ (Watt-hours)}$
- **Integrated Energy efficiency Ratio (IEER)** The integrated energy efficiency ratio expressed in Btu/Wh is a metric used to represent the annualized performance of the mechanical cooling system, as well as to serve as a comparative metric for partial load performance of VRFs at (4) different capacities defined in AHRI 1230:
- A = EER at 100% net capacity at 95°F outdoor dry bulb
- B = EER at 75% net capacity at 81.5°F outdoor dry bulb
- C = EER at 50% net capacity at 68°F outdoor dry bulb
- D = EER at 25% net capacity at 65°F outdoor dry bulb

As highlighted in the calculation of IEER below, the full load capacity represents only two percent of the assumed operation of the VRF to reflect typical real building applications.

IEER $= (0.02 * A) + (0.617 * B) + (0.238 * C) + (0.125 * D)$

AHRI 1230-2014 specifically notes "IEER is not intended to be a predictor of the annual energy consumption of a specific building in a given climate zone. To more accurately estimate energy consumption of a specific building an energy analysis using an hour-by-hour analysis program should be performed for the intended building using the local weather data."

- **Coefficient of Performance (COP)** A ratio of the heating capacity in watts [W] to the power input values in watts [W] at any given set of rating conditions expressed in watts/watts [W/W]

Minimum Efficiency Standard for VRFs

Minimum efficiency standards for air, ground, and water source VRF heat pumps are covered under ASHRAE Standard 90.1-2016 Table 6.8.1-10 for both heating and cooling operation. The table below is an excerpt for air-cooled VRF and ≥ 65,000 Btu/h, based on the focus of this report.

Equipment Type	Cooling Capacity	Heating Type	Minimum Energy Efficiency Criteria	
			Cooling Mode	Heating Mode
VRF Air-Cooled Heat Pump	≥ 65,000 Btu/h < 135,000 Btu/h	w/o Heat Recovery	11.0 EER; 12.3 IEER	3.3 COP at 47°F 2.25 COP at 17°F
		w/ Heat Recovery	10.8 EER; 12.1 IEER	
VRF Air-Cooled Heat Pump	≥ 135,000 Btu/h < 240,000 Btu/h	w/o Heat Recovery	10.6 EER; 11.8 IEER	3.2 COP at 47°F 2.05 COP at 17°F
		w/ Heat Recovery	10.4 EER; 11.6 IEER	
VRF Air-Cooled Heat Pump	≥ 240,000 Btu/h	w/o Heat Recovery	9.5 EER; 10.6 IEER	
		w/ Heat Recovery	9.3 EER; 10.4 IEER	

Table 2 ASHRAE Standard 90.1-2016 Table 6.8.1-10 for Air-cooled VRF systems above 65,000 Btu/h

VRF systems have the potential to be highly effective at load matching. The ability of the system to yield savings at part load conditions is highly dependent on the controls algorithms used, and proper design and sizing. This energy benefit is not currently captured in the efficiency standards using the current test procedure.

In January 2018, a VRF multi split air conditioners and heat pumps working group was formed by the U.S. Department of Energy (U.C. DOE) Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) to reach a consensus agreement for updates to federal test procedure and standards for VRF. The current federal standards required for equipment manufactured after January 2010 must meet or exceed the ASHRAE Standard 90.1-2010 Table 6.8.1-10. This working group met on April 17-18, 2019 to review a proposed Controls Verification Procedure Test Plan (CVT)[4] to address advocate concerns around the current test procedure and its ability to properly assess the impact of software controls on the performance of VRF.

The working group came up with a proposed repeatable, reproducible and representative controls verification test (CVT) procedure. To vet this procedure and provide data to inform the finalization of a code-language version, the working group also developed a recommended test plan and guidance document. The test plan recommended by the working group includes the recommendation that DOE consultants be given access to testing and test data under NDA for tests conducted by Original Equipment Manufacturers (OEMs) in-house to

[4] https://www.regulations.gov/contentStreamer?documentId=EERE-2018-BT-STD-0003-0028&attachmentNumber=1&contentType=pdf

verify that the CVT procedure meets the required goal. More updates on this can be found on the ASRAC website[5].

Performance Specifications for VRFs

ASHRAE Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings is typically adopted by states and municipalities to establish minimum efficiency requirements of building design and construction. ASHRAE Standard 90.1 2010 and later includes minimum equipment efficiencies for VRF.

Advanced performance specifications have been developed by two recognized labels - Environmental Protection Agency (EPA) ENERGY STAR™ program and the Consortium for Energy Efficiency (CEE). However, the performance specifications can introduce additional variance and confusion in the market for establishing a uniform set of performance levels for VRF. Additionally, the ENERGY STAR specification does not capture the minimum efficiency COP criteria for heating mode at 17°F.

An excerpt of the current V3.1 Light Commercial HVAC ENERGY STAR minimum performance criteria[6] effective January 2018 for VRF air-cooled heat pumps is outlined below:

Table 3 ENERGY STAR Criteria for Certified Light Commercial VRF Multi-Split Systems

Equipment Type	Cooling Capacity	Heating Type	Minimum Energy Efficiency Criteria	
			Cooling Mode	Heating Mode
VRF Air-Cooled Heat Pump	≥ 65,000 Btu/h < 135,000 Btu/h	w/o Heat Recovery	11.8 EER; 17.4 IEER	3.4 COP at 47°F
		w/ Heat Recovery	11.6 EER; 17.2 IEER	3.4 COP at 47°F
VRF Air-Cooled Heat Pump	≥ 135,000 Btu/h < 240,000 Btu/h	w/o Heat Recovery	10.9 EER; 16.4 IEER	3.3 COP at 47°F
		w/ Heat Recovery	10.7 EER; 16.2 IEER	3.3 COP at 47°F

Consortium for Energy Efficiency (CEE) has developed advanced performance tiers for VRF[7] (applied to both air-source and water source within capacity bins)

5 https://www.energy.gov/eere/buildings/appliance-standards-and-rulemaking-federal-advisory-committee
6 https://www.energystar.gov/sites/default/files/Light%20Commercial%20HVAC%20Version%203.1%20Program%20Requirements_1.pdf
7 https://library.cee1.org/system/files/library/13655/Final_2018_CEE_HECAC_Initiative_Description.pdf

Table 4 CEE Specification for VRF Multi-Split Heat Pump Systems

<table>
<tr><th>Equipment Type</th><th>Size Category</th><th>Subcategory</th><th>Cooling Mode</th><th>Heating Mode</th></tr>
<tr><td rowspan="6">VRF Air Source</td><td rowspan="2">≥65,000 and <135,000 Btu/h</td><td>w/o Heat Recovery</td><td>11.3 EER; 14.2 IEER</td><td rowspan="2">3.4 COP at 47°F
2.4 COP at 17°F</td></tr>
<tr><td>w/ Heat Recovery</td><td>11.1 EER; 14 IEER</td></tr>
<tr><td rowspan="2">≥135,000and <240,000 Btu/h</td><td>w/o Heat Recovery</td><td>10.9 EER; 13.7 IEER</td><td rowspan="4">3.2 COP at 47°F
2.1 COP at 17°F</td></tr>
<tr><td>w/ Heat Recovery</td><td>10.7 EER; 13.5 IEER</td></tr>
<tr><td rowspan="2">≥240,000 Btu/h (Cooling Mode)</td><td>w/o Heat Recovery</td><td>10.3 EER; 12.5 IEER</td></tr>
<tr><td>w/ Heat Recovery</td><td>10.1 EER; 12.3 IEER</td></tr>
</table>

In partnership with the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), CEE maintains a CEE Directory of Efficiency Equipment. This directory of HVAC equipment can searched for the most efficient residential and small commercial equipment on the market. Manufacturers work with AHRI to verify that their equipment meets the criteria established by the federal ENERGY STAR® program and by CEE. This directory leverages the AHRI Directory of Certified Product Performance along standing source of performance certified heating, ventilation, air conditioning, and commercial refrigeration equipment and components.

Regional Efficiency Program VRF Performance Criteria, Incentives and Program Delivery

Commercial scale VRF heat pumps have been introduced into several NEEP member programs in the Northeast and Mid-Atlantic. Incentive and performance criteria, as well as program requirements and delivery (e.g. downstream customer incentives and midstream distributor incentives) vary from state to state – and in the case of Massachusetts - between the utility-led Mass Save® and state-led Massachusetts Clean Energy Center (MassCEC) programs.

Table 5 Regional Efficiency Program VRF Performance Criteria

<table>
<tr><th>State</th><th>Rebate Incentive</th><th>HPSF</th><th>EER</th><th>IEER</th><th>SEER</th><th>COP</th></tr>
<tr><td rowspan="2">Massachusetts (Mass Save)</td><td>For air cooled units ≥5.4 tons = $125/ton</td><td></td><td>≥11.0</td><td>≥18.0</td><td></td><td>≥3.4</td></tr>
<tr><td>For water cooled units ≥5.4 tons = $125/ton</td><td></td><td>≥12.0</td><td>≥20.0</td><td></td><td>≥4.3</td></tr>
<tr><td rowspan="2">Massachusetts (Clean Energy Center)[8]</td><td>For units without heat recovery ≥5.4 tons = $800/ton</td><td colspan="5" rowspan="2">Must meet the minimum efficiency ratings established in the ANSI/ASHRAE/IES Standard 90.1-2016 Energy Standard for Buildings Except Low-Rise Residential Buildings</td></tr>
<tr><td>For units with heat recovery ≥5.4 tons = $1,200/ton</td></tr>
</table>

[8] Award levels for Public/Non-Profit = $1,000/ton without heat recovery, $1,400/ton with heat recovery; Award levels for Affordable Housing = $1,600/ton without heat recovery, $2,000/ton with heat recovery. MA CEC revised incentive levels in early 2019 and plans to sunset the VRF program in June 2019 for a transition to utilities.

State	Rebate Incentive	HPSF	EER	IEER	SEER	COP
	For units without heat recovery <5.4 tons = $800/ton	≥10.0	≥11.0		≥17.0	
	For units with heat recovery <5.4 tons = $1,200/ton	≥10.0	≥11.0		≥17.0	
Rhode Island (Program ensures that efficient equipment is available)	Air-cooled units ≥5.4 tons = $125/ton		≥11.0	≥18.0		≥3.4
	Water-cooled units ≥5.4 tons = $125/ton		≥12.0	≥20.0		≥4.3
New York (NYSERDA)	Flex Tech program: cost-shared energy efficiency technical analyses and strategic energy management assistance to existing facilities, can include investigation of VRF					
PSEG- Long Island	<5.4 tons = $125/ton (Tier 1)	≥8.5	≥12.5		≥15.0	
	<5.4 tons = $230/ton (Tier 2)	≥9.0	≥13.0		≥16.0	
	≥5.4 & <11.25 tons = $125/ton		≥11.3	≥14.2		≥3.4
	≥11.25 tons & <20 tons = $80/ton		≥10.9	≥13.7		≥3.2
	≥20 tons = $80/ton		≥10.3	≥12.5		≥3.2
	Water source unit <11.25 tons = $80/ton		≥14.0			≥4.6
Energy Save PA Custom energy calculations required for VRFs	<5.4 tons = $100/ton	≥9.0			≥16.0	
	<5.4 tons = $150/ton	≥10.0			≥18.0	
	≥5.4 tons and <11.25 tons = $35/ton		≥11.0	≥11.2		≥3.6
	≥11.25 tons and <20 tons = $35/ton		≥10.6	≥10.7		≥3.6
	≥20 tons = $35/ton		≥9.5	≥9.6		≥3.5

Massachusetts Mass Save[9] and Rhode Island[10] are examples of regional efficiency programs supporting VRF through midstream incentives delivered through participating HVAC distributors. One of the primary benefits cited for customers through the upstream programs is the stocking of eligible, efficient products.

The NYSERDA report also highlights the importance of distributors as part of the supply chain and their role in influencing the decision tree for selecting VRF.

"In all project types, the distributor is at the center of the efficiency discussion. This market actor is the vehicle through which VRF equipment is connected to the mechanical engineer, architect, and DB [design-build] contractor. VRF distributors have trained engineers that support market actors in both project types.

[9] https://www.masssave.com/en/saving/business-rebates/upstream-electric-hvac-program/
[10] https://www.nationalgridus.com/media/pdfs/bus-ways-to-save/ee7078-ci-upstream-hvac.pdf

Distributors' sales engineers attempt to connect with decision makers to influence the best HVAC system for the project."[11]

There are two primary sales paths for VRF equipment - "plan and specification" (PS) and "design build" (DB). These two pathways reflect the different key influencers as part of the decision to choose VRF over more conventional and potentially "like-for-like" replace of end of life equipment replacement.

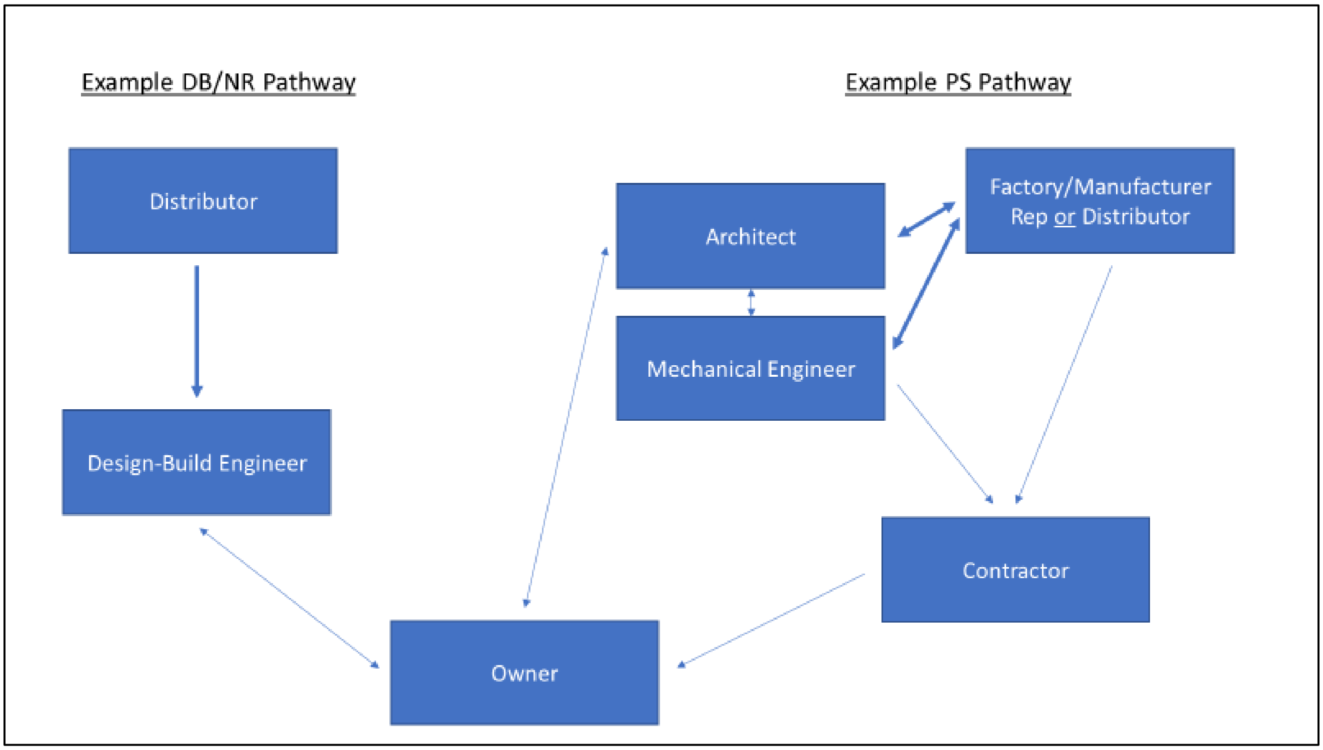


Figure 2 Example of VRF Project Pathways (NYSERDA 2018)

Building Energy Code impacts on VRFs

A key industry concern is the impact of building codes on VRF's due to the economizer requirement in the IECC 2018 that creates a potentially unnecessary design and cost burden for VRF systems.

"Economizers are not a logical pairing with VRF systems because one of the main features of VRF is that heat is transferred via refrigerant, not air. The notion of utilizing mild ambient air in large air ducts does not align with VRF technology. In other HVAC system types, economizers are a great energy saving feature. However, VRF systems provide the code minimum ventilation rates only, and are not designed to provide additional fresh air. The efficiency gains from reducing fan energy are tremendous and outweigh the benefits from economizers."

A recommendation supported by industry suggests an exception be made for VRF in future energy codes and standards to consider the operational and design differences compared to traditional HVAC technologies.

[11] NYSERDA 2018 VRF Report

Savings associated with VRF installations; Energy, Cost, Peak load, and Emissions

Utility programs supporting VRF through commercial HVAC programs typically treat it as a market opportunity in which the prescriptive measure savings are defined as the delta between the baseline VRF equipment efficiency (e.g. ASHRAE 90.1-2016) and the high efficiency VRF meeting (e.g. ENERGY STAR or CEE specification). However, a few regional utility efficiency programs including those in Massachusetts and Rhode Island have established higher VRF IEER requirements (Air-cooled VRF ≥ 18.0) beyond CEE Tier 1 criteria. Custom measure analysis offers the potential for improved targeting of cost-effective opportunities where oil or propane heating fuels can be offset.

Manufacturers are actively releasing new VRF product lines with increased efficiency and capacity at lower outdoor ambient temperatures. Below is an example of a recent advancement in a manufacturer product line without heat recovery (left) and with heat recovery (right). IEER performance increased by up to 28 percent over previous models and achieved up to 29.3 IEER in heat recovery units at eight tons.

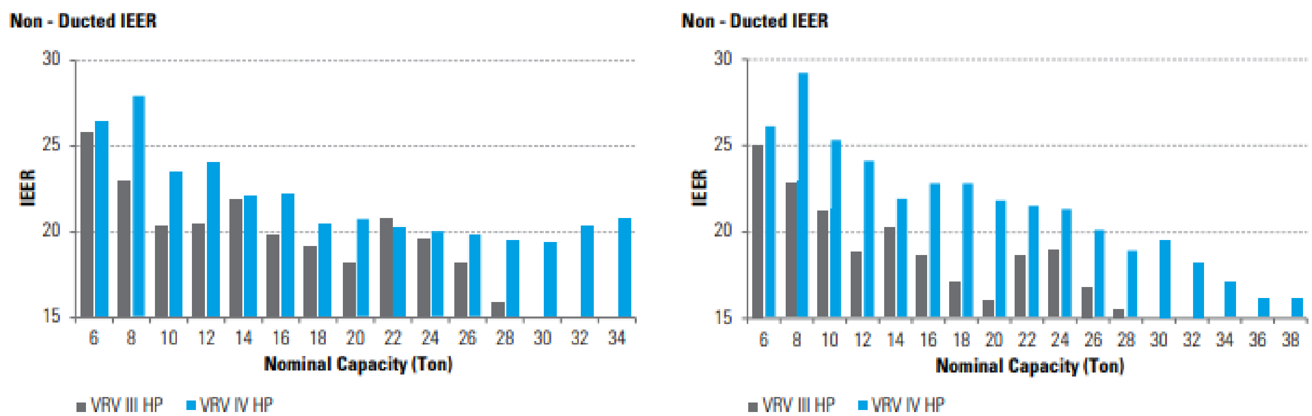


Figure 3 Comparison of Daikin VRV IV to III heat pump performance for systems without (left) and with (right) heat recovery[12]

Manufacturers have dramatically increased VRF heat pump cold climate performance to broaden the applications and performance in northern climates. Leading manufacturers promote strong heating capacity performance down to -13 °F in heat recovery systems and 0 and -4 °F systems where heat recovery is not used. Current ASHRAE heating COP reporting requirements and testing are limited to 47 and 17 °F. Increasing testing and reporting requirements at lower temperatures would improve the ability to compare cold-climate performance, support broader applications to replace conventional heating systems and improve cost-effectiveness for NEEP programs and buildings in the Northeast climate.

The limited number of independent evaluations of VRF performance support robust energy savings in a small sample of diverse heating fuel types, building use and type, and baseline equipment being replaced. Most of the savings estimates are developed pre-installation through energy model simulations of buildings instead of more difficult field monitoring of the HVAC post installation. Comments from NEEP VRF stakeholders highlighted that energy modeling inputs and functionality to properly model VRF systems is lacking in some of the most common

[12] https://www.daikinac.com/content/assets/DOC/Product%20Brochures/CT-VRV-Catalog-08-15.pdf

tools (eQuest, TraneTrace, etc.) and although workarounds are possible, they require significant modeling expertise.

A report published by the Minnesota Department of Commerce in 2015[13] concludes that VRF systems reduced energy use by 30-40 percent compared to conventional HVAC systems and highlighted the partial load benefits of the variable speed compressors in matching the building's heating and cooling load.

In 2012 the General Services Administration (GSA) commissioned a study assessing VRF performance through model simulations against a variety of baseline technologies and fuel types (electric vs. natural gas). The model simulations were based on previous models from independent sources and manufacturer simulations.

Table 6 Potential HVAC Only Energy Savings from VRF Systems Compared to Other Systems (GSA 2012)[14]

Chilled Water, VAV	Packaged VAV	Packaged CAV	Air-Source Heat Pump	Water-Source Heat Pump	Notes	Source
	62%	39%	49%		Independent modeling study. Values shown are averages for 4 climate locations, California, Northwest, Midwest/Northeast, and Southwest. See description in text with Table 4.	Hart and Campbell 2012
36%		49%		13%	Manufacturer modeling study. Values are average savings relative to VRF for five climates for a large office building. See description in text at Table 5.	LG 2011
34%					Average of three savings values. Identified as 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 savings and energy cost savings with electric heat source.	
26%	32%	36%	NA	NA	Average energy cost savings with gas heat – see text.	

The Energy Trust of Oregon designed a pilot through its New Buildings program to capture the costs and savings of VRF projects to support a prescriptive program development. Initial research findings found an average HVAC energy savings of 2.9 kWh/sf/yr or 35 percent, with a range of 13 – 63 percent savings depending on baseline

[13] http://mn.gov/commerce-stat/pdfs/refrigerant-technology-cold-weather.pdf
[14] https://www.gsa.gov/cdnstatic/GPG_Variable_Refrigerant_Flow_12-2012.pdf

equipment and building type. The program implementer modeled existing VRF systems across three primary building types – school, multifamily and office – to support prescriptive savings for the pilot program.

Table 7 Energy Trust VRF pilot program prescriptive savings and incentive (ACEEE 2016)[15]

Building Type	Weighted Average Savings (kWh/sf)	Weighted Average Savings (kWh/ton)	Proposed Incentive
School	2.2	888	$150/ton
Multifamily	2.4	1,047	
Office	3.5	999	

In 2018, NYSERDA commissioned a market and technical study of VRF by VEIC and Energy Solutions to assess the technology opportunity as part of the broader Renewable Heating and Cooling program.[16] VEIC created a building scenario energy model to estimate "energy savings offered by VRF systems installed in key building types in New York City and the Northeast based on a variety of modeling input scenarios – by varying fuel prices, building age, internal electrical loads, and shell characteristics – then applied to the building types and local climate conditions."

For the NYSERDA study, VEIC utilized OpenStudio, an open-source interface with EnergyPlus, an extremely flexible and powerful BEM platform developed by the U.S. Department of Energy (U.S. DOE) and the National Renewable Energy Lab (NREL). EnergyPlus is considered the replacement to the previous DOE-2 platform, on which e-Quest (one of the most popular BEM tools) is built. Program implementers can use building energy models to develop high-level estimates of performance or by capturing actual project specific building and HVAC system details – along with energy use and costs -provide a robust model of VRF performance and savings.

For NYSERDA's purposes to guide the aggressive state goals for emission reductions, GHG impacts were tracked along with that of energy. The GHG impacts serve as alternative lens to assess the total VRF project value in addition to the customer financial economics and program cost-effectiveness. In the case of office buildings, GHG emission reductions from VRF ranged from a maximum of 41 percent for older, large office buildings in NYC to a net increase of 10 percent for older, medium-sized office buildings in upstate New York. It should be noted that the modeling assumed a generic VRF performance and is not necessarily representative of the higher efficiency models being introduced in the Northeast market currently with higher IEER and COP levels. Increases in energy savings and GHG reductions would be expected for the advanced cold-climate models.

In the VEIC analysis, the modeling results found significant heating fuel savings but the electrical savings for cooling in some cases were offset by the increased heating electrical load.

[15] https://aceee.org/files/proceedings/2016/data/papers/3_345.pdf
[16] NYSERDA provided a public version of the "Market and Technical Analysis of Variable Refrigerant Flow Heat Pump Technology" report to the NEEP VRF working group in October 2018.

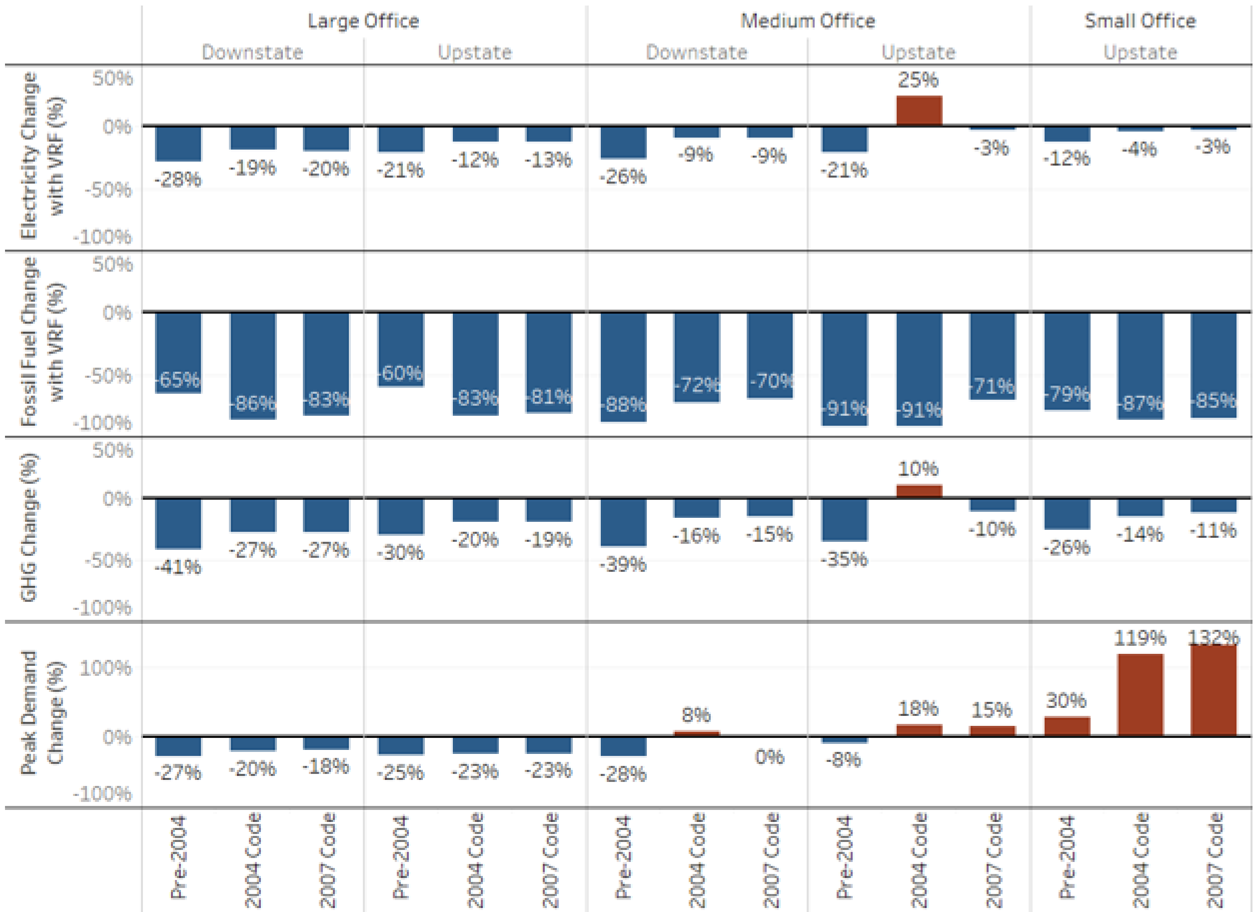


Figure 4 Change in building electric and fossil fuel consumption, GHG and peak demand from VRF installations in office buildings

The NYSERDA study also assessed the significant changes in seasonal peak demand from VRF installations relevant to changing utility peak load profiles. The result is a more significant winter peak increase in the heating dominated, fuel switching multifamily applications. Whereas the VRF installations in office buildings create a more uniform peak between winter and summer, greatly reducing the summer peak for baseline cooling systems.

Not modeled in the NYSERDA report is the potential to more effectively use the variable capacity functionality of the VRF to serve load management purposes to mitigate or shift peak loads during certain times of day or peak events.

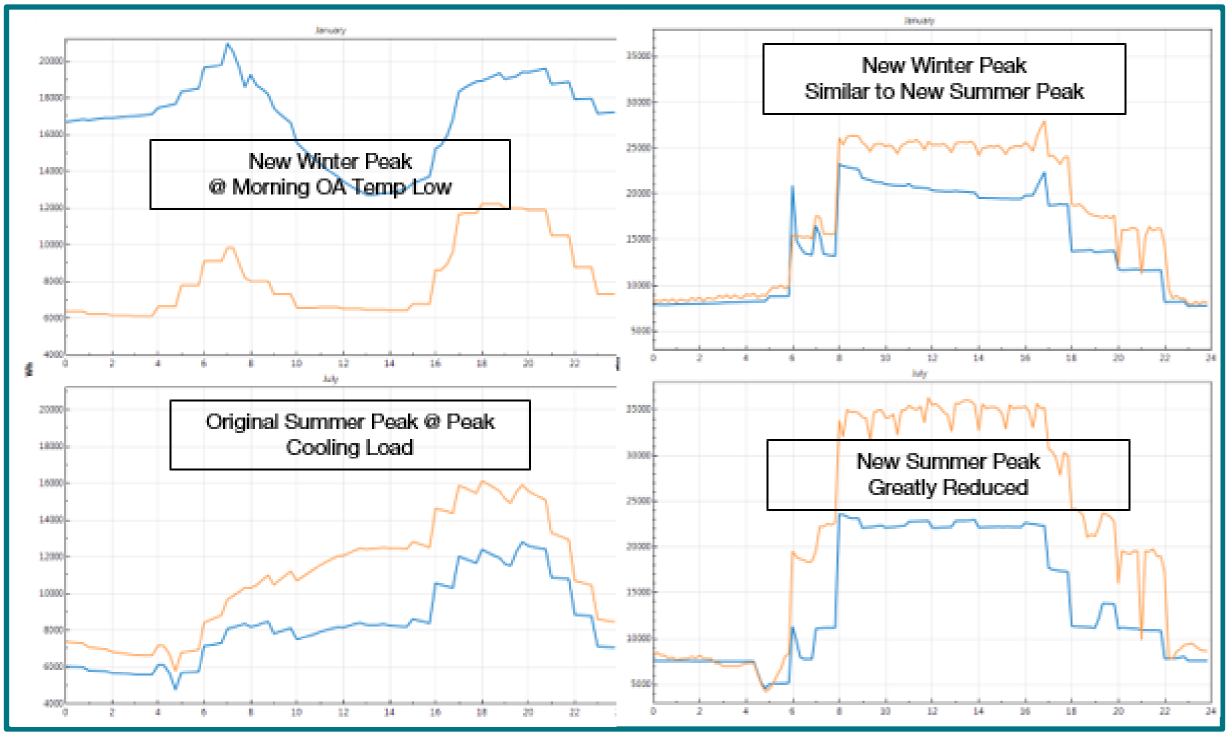


Figure 5 Change in seasonal peak demand in multifamily (left) and office buildings from VRF installations

VRF Market Size and Research Insights

In Europe and Asia, market share of VRF heat pumps represents approximately 80-90 percent of installed HVAC systems in commercial buildings, but in the United States, the technology is still a nascent – but rapidly growing – market.[17]

Recent market reports have identified VRFs as the fastest growing technology in the HVAC market (>15 percent annual growth) and representing 3-5 percent of the total HVAC market in the U.S. Regional sales data is largely limited to fragmented program participation data, however based on industry feedback, market adoption of VRFs has been led by urban areas like New York City in which the space savings of VRFs is a premium benefit.

The AHRI monthly, year-over-year comparisons of shipment data demonstrate the continued growth in U.S. sales of heat pumps in comparison to air conditioners. On an annual basis, heat pumps have experienced more than 12 percent increase in shipments compared to four percent for air conditioners. However, these sales have disproportionately come from residential scale heat pumps, whereas commercial combined heat pump and air conditioner sales in most capacity sizes ranged from -6.8 percent to 3.8 percent growth. One notable exception was in very large commercial systems that are outside of the primary focus of the VRF heat pump market that experienced a double-digit growth – though small in quantities.

[17] Joanna Turpin. *VRF Market Expected to Hit $24B by 2022.* ACHR News. February 2017. https://www.achrnews.com/articles/134465-vrf-market-expected-to-hit-24b-by-2022

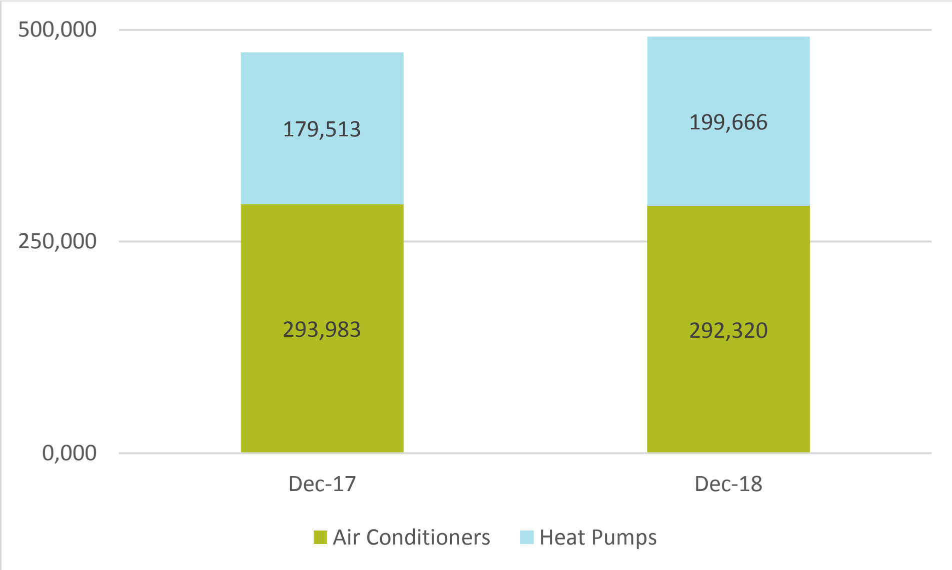


Figure 6 AHRI U.S. Heating and Cooling Equipment Shipment Data for Air Conditioners and heat Pumps in December 2017 and 2018[18]

Historically, VRF has represented a small percentage of the overall HVAC market, but increases in performance, flexibility in design, and broader awareness of the technology and its applications are accelerating its growth. The non-energy benefits (i.e. comfort, space savings, and electrification benefits to a clean-energy electrical grid) of VRF are often neglected at the building design stage with a primary focus on the upfront and operational energy costs compared to traditional heating and cooling technologies.

Commercial air source heat pumps in the United States are comprised of three primary types:

- Packaged rooftop heat pumps
- Split-system heat pumps
- VRF/ductless systems

Commercial VRF represent a small, but growing share of the overall market, dominated by more traditional ducted heating and cooling systems.

[18] AHRI 2018 U.S. Heating and Cooling Equipment Shipment Data. February 2019. http://www.ahrinet.org/App_Content/ahri/files/Statistics/Monthly%20Shipments/2018/December_2018.pdf

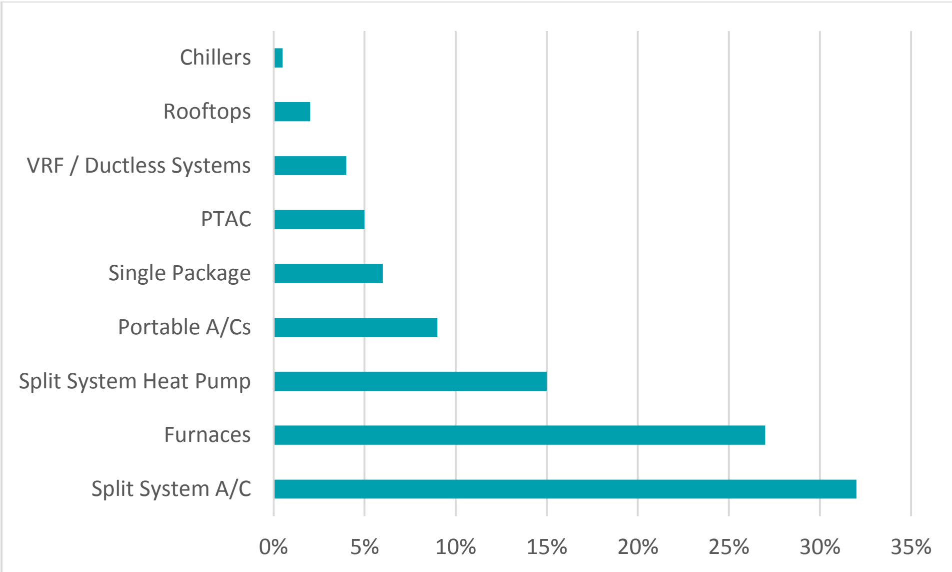


Figure 7 US HVAC Industry volume comparison of Commercial and light commercial HVAC types[19]

Based on CBECS 2012 data, space heating, cooling, and ventilation in Northeast buildings represents approximately 52 percent (36 percent heating, seven percent cooling and nine percent ventilation) of all energy used in buildings or 50 kBtu per square foot of building area - a significant opportunity for efficiency and greenhouse gas (GHG) mitigation. Within the NEEP region, as would be expected, buildings in New England have a higher energy intensity for heating, while Mid-Atlantic buildings have a higher cooling and ventilation load.

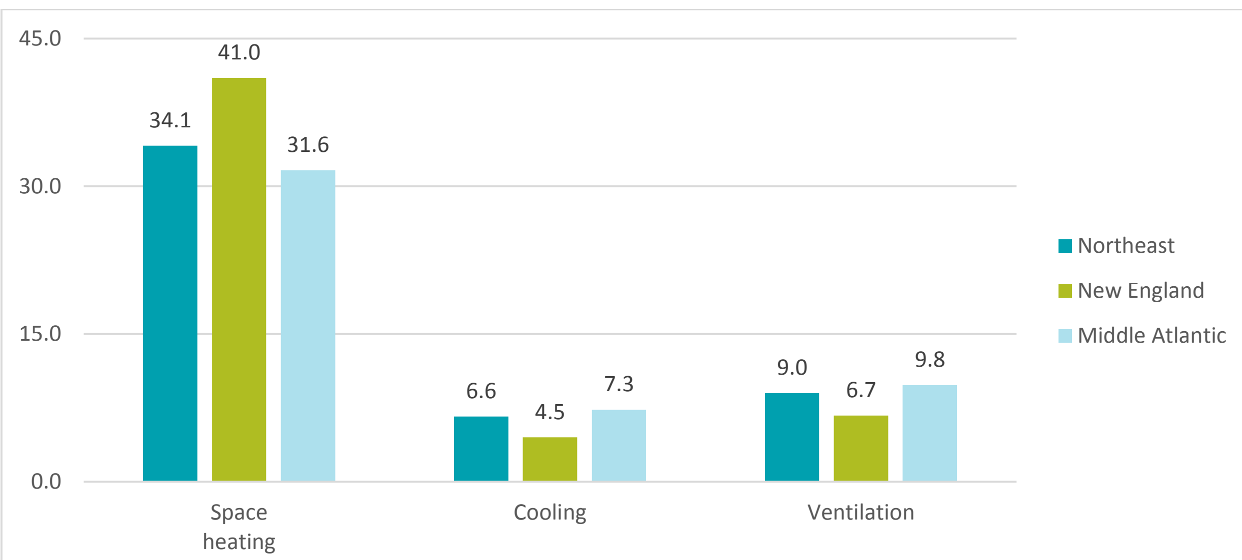


Figure 8 Buildings energy intensity with existing heating system types in Northeast Commercial Buildings (CBECS 2012)

However, existing buildings and the HVAC market in general is characterized by a diverse set of conventional heating and cooling technologies, with a significant amount incorporating non-heat pump technology. This

[19] Steve Jones. Mitsubishi presentation at Texas Utility Innovations - Source AHRI and BSRI September 2012.

creates both barriers and opportunities for market growth of VRF in relation to displacing the existing heat transfer medium (e.g. ductwork or water piping) with new refrigerant piping.

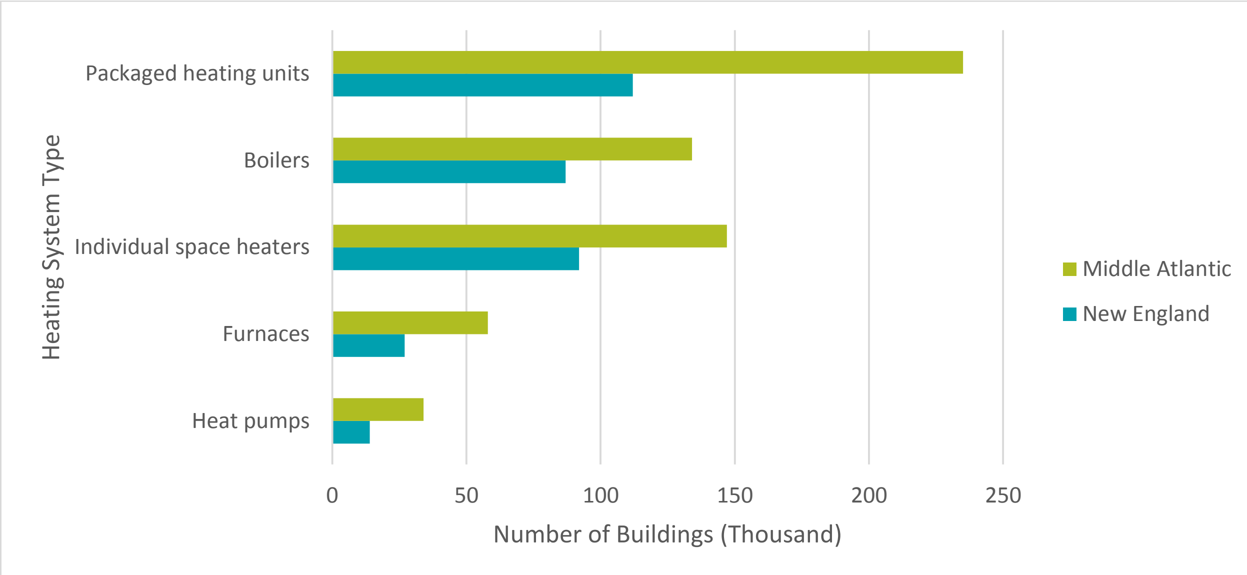


Figure 9 Existing heating system types in Northeast Commercial Buildings (CBECS 2012)

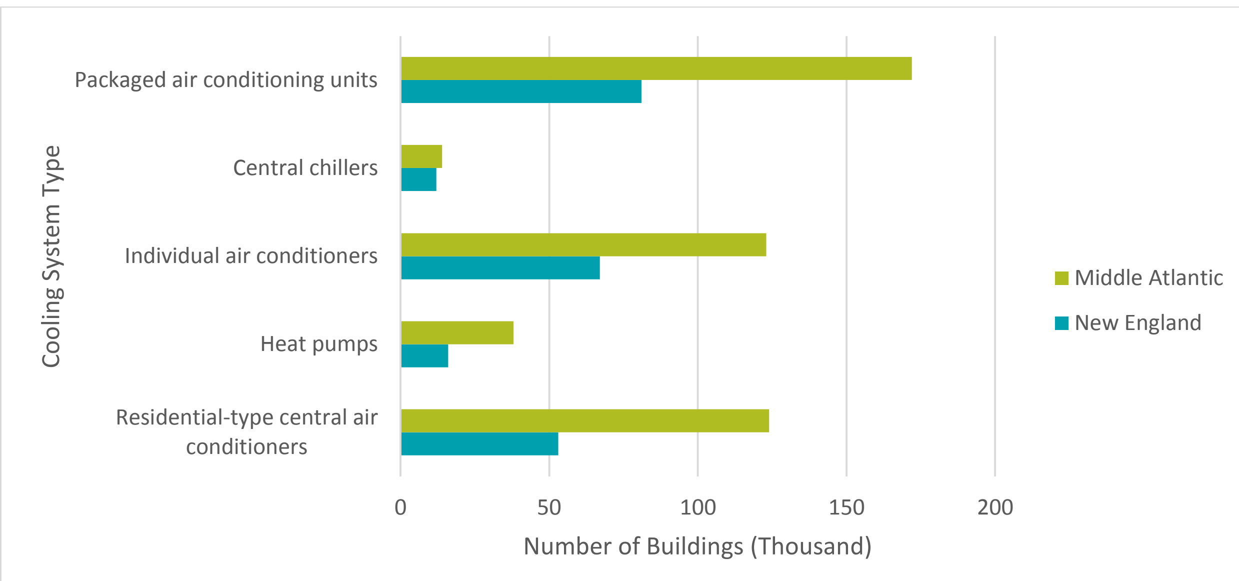


Figure 10 1 Existing cooling system types in Northeast Commercial Buildings (CBECS 2012)

Forthcoming commercial building studies commissioned by NYSERDA[20] and other states will bring valuable regional data to the potential market size for VRF. As part of this effort, NYSERDA will conduct a commercial building baseline study, potential study, and market assessment for commercial unitary air conditioner systems.

[20] https://www.nyserda.ny.gov/About/Publications/Building-Stock-and-Potential-Studies/Commercial-Statewide-Baseline-Study

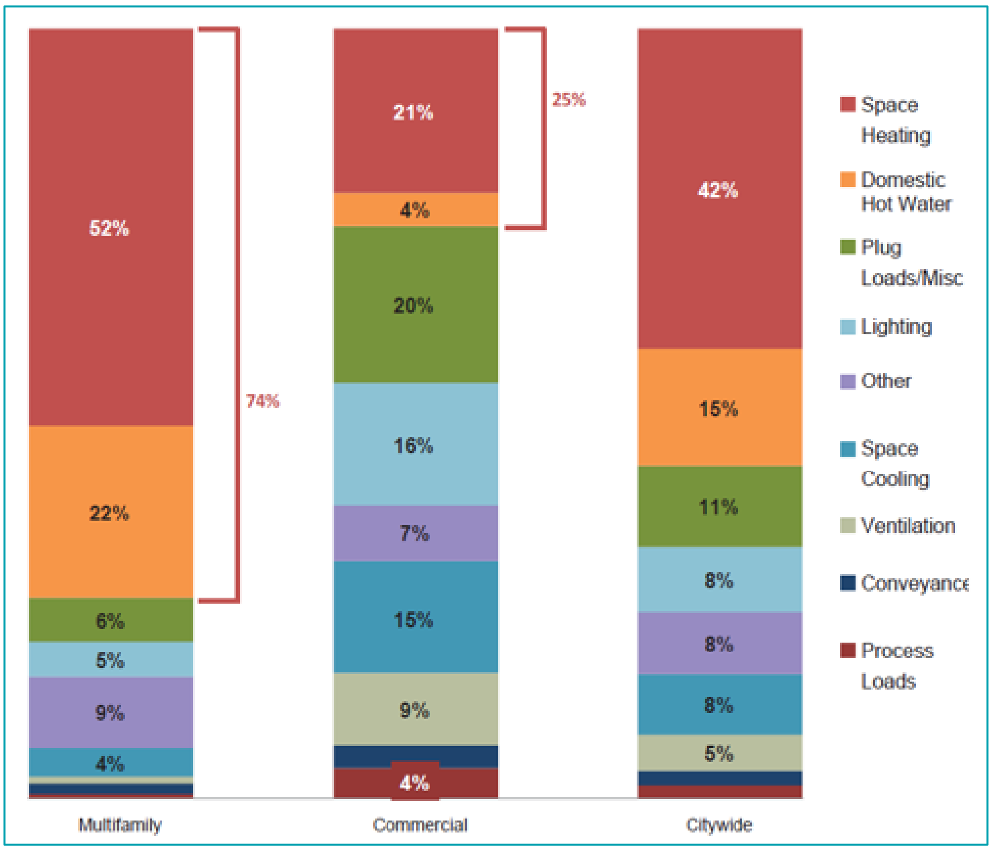
However, a compilation of market assessments and baseline studies would be of value in developing a regional estimate of the potential VRF market.

In 2014, New York City (NYC) committed to an 80 percent reduction in GHG emissions by 2050 (80 x 50) with an interim goal of 40 percent reduction by 2030. The NYC 80 x 50 roadmap[21] highlights the important role of improving the city buildings as they represent 68 percent of total GHG emissions. To achieve an 82 percent reduction in building GHG emissions (52 percent by 2030), two primary actions related to building are identified:

- Shift to a 70-75 percent renewable-based electric grid
- Achieve deep energy retrofits in 100 percent of buildings, with 50-60 percent implementing high efficiency electric heating systems

A focus on high efficiency electric heating systems reflects the fact that space heating and domestic hot water (DHW) production represent 74 percent of multifamily and 25 percent commercial NYC building emissions.

Figure 11 New York City Building GHG Emissions by End Use[22]



Source: 2013 and 2014 Local Law 87 Submissions

[21] New York City's Roadmap to 80 x 50 (2016)
[22] Presented at NEEP NYC in-Person VRF Meeting (December 2018)

To advance efforts in addressing GHG emissions in buildings, the NYC Sustainability Office has developed a partnership program to pilot deep energy retrofits through a new High Performance Retrofit Track. The deep energy retrofits are to target all major building systems and the building envelope, but also advance strategies for increased tenant engagement and building operator operation and maintenance (O&M) training.

Table 8 Multi-path deep energy retrofit strategies in NYC High Performance Retrofit Track partnership program

<table>
<tr><th colspan="10">Building Block Systems</th></tr>
<tr><th></th><th colspan="2">Heating</th><th>Cooling</th><th>Ventillation</th><th colspan="5">Envelope</th></tr>
<tr><th></th><th>Equipment</th><th>Distribution</th><th>Equipment</th><th>Equipment</th><th>Air Sealing</th><th rowspan="5">Choose at least 2</th><th>Windows</th><th>Roof</th><th>Walls</th></tr>
<tr><td>Retrofit Path 1 - Existing System Optimization</td><td rowspan="2">Boiler replacement and right sizing at end of life</td><td>Upgrade steam system + O&M</td><td rowspan="2">High efficiency cooling</td><td rowspan="2">1) Upgrade existing system, or 2) Evaluate installation of new system</td><td rowspan="2">Common area and tenant spaces</td><td rowspan="2">High efficiency windows</td><td rowspan="2">Roof deck or cavity insulation</td><td rowspan="2">Add interior or exterior wall insulation</td></tr>
<tr><td>Retrofit Path 2 - Hydronic Conversion</td><td>Hydronic conversion</td></tr>
<tr><td>Retrofit Path 3 - Electrification + Heating Load Reduction</td><td rowspan="2">Air source or ground source heat pump</td><td rowspan="2">Remove or keep existing system as backup</td><td rowspan="2">Air source or ground source heat pump</td><td rowspan="2">1) Upgrade existing system, or 2) Evaluate installation of new system</td><td rowspan="2">Common area and tenant spaces</td><td rowspan="2">High efficiency windows</td><td rowspan="2">Roof deck or cavity insulation</td><td>Interior wall insulation</td></tr>
<tr><td>Retrofit Path 4 - Elecrification + Major Envelope Improvement</td><td>Exterior wall insulation</td></tr>
</table>

<table>
<tr><th colspan="6">Additional Systems</th></tr>
<tr><th>Domestic Hot Water</th><th>Lighting</th><th>Solar PV</th><th>Electric Loads
Required in commercial
Encouraged in residential</th><th>Tenant Engagement</th><th>O&M Training</th></tr>
<tr><td>Options Include:
- Low-flow fixtures
- Air source heat pump for hot water
- On-demand electric resistance</td><td>Options Include:
- Install LEDs
- Upgrade fixtures
- Install controls and sensors</td><td>Options Include:
- Install PV on roof
- Community shared solar</td><td>Options Include:
- Upgrade fans and motors
- Appliance efficiency
- Data center/server room optimization</td><td>Determined based on building needs</td><td>Building operators to receive Operations & Maintenance training</td></tr>
</table>

The multi-path strategy is designed to align with a capital planning schedule for building upgrades and allow for flexibility based on the specific building needs. The combination of efficiency, building shell improvements and electrification of heating loads with air and ground source heat pumps serve as a comprehensive solution for achieving the city GHG emission targets.

VRF Refrigerants and Regulation

VRF systems contain significant amounts of refrigerant due to increased heating and cooling capacities and significantly increased refrigerant piping lengths in commercial buildings. In VRF systems, refrigerant is the transfer media in vapor-compression style heat pumps and flows from the outdoor condenser unit to the various indoor fan coil units and back through an extensive piping network. Refrigerant therefore moves throughout the entire system, going through a cyclical phase change process to absorb and reject thermal energy.

Refrigerants are regulated by the Environmental Protection Agency (EPA) under section 608 of the Clean Air Act[23] and given an "R" number to designate the molecular structure of the substance - some of which are "pure" while others are "blends". The most common type of refrigerant used in VRF systems is R-410A. This refrigerant

[23] https://www.epa.gov/section608/managing-refrigerant-stationary-refrigeration-and-air-conditioning-equipment

is a near-azeotrophic mix of R-32 and R-125. It was introduced by Carrier Corporation in 1996 and is considered the current primary replacement for R-22.[24]

The quantity of refrigerant in a VRF system is dependent on a variety of factors such as system capacity, length of distribution piping, heat recovery functionality, among others. Systems tend to average 3-6 lbs. per cooling ton (12,000 btu/h), therefore an "average" 30-ton system would contain 90-180 lbs. of refrigerant once the system is fully charged and operational.

From the 1930s-1990s, predominant refrigerants were chlorofluorocarbons (CFCs). Due to concerns around impact of these refrigerants on ozone depletion, the Montreal Protocol was signed in 1987, which phased out the use of these substances in refrigerant systems.[25] Following the phase out of CFCs, hydrochlorofluorocarbons (HCFCs) were introduced as a replacement. HCFCs have significantly reduced impact on ozone depletion. However, these substances were additionally phased out, both for ozone impact as well as a growing concern about the role of these substances in contributing to global warming. In the 2000s, HCFCs were replaced with hydrofluorocarbons (HFCs), which are the predominant refrigerant type used in air conditioning/heat pump systems today. Although this class of refrigerant has 0 Ozone Depletion Potential (ODP), their Global Warming Potential (GWP) is high.

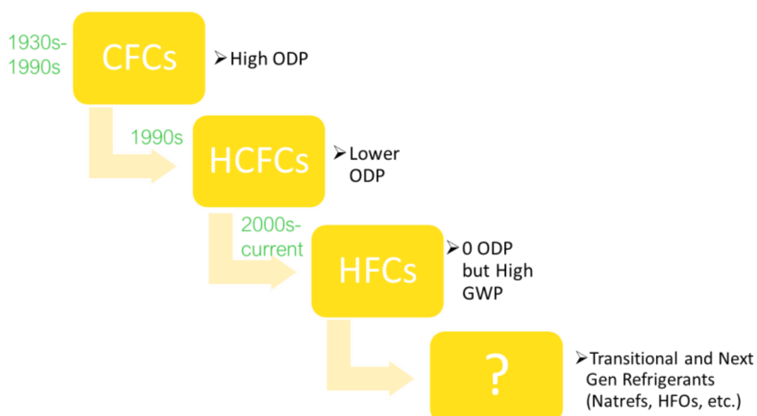


Figure 12 Evolution of ozone depletion and global warming potential impacts of refrigerants in air conditioning & heat pump systems

Although VRFs represent a very small portion of the use of refrigerants compared to the larger refrigeration and conventional air conditioning market, efficiency program administrators and energy advocates are concerned about investing in a technology with associated risks of potential non-energy climate impacts. The risks are categorized into three categories:

1. Global Warming Potential
2. Safety
3. System Obsolescence

Each of these refrigerant risk categories is explored further as part of the market strategy section of the report.

---

[24] "About Refrigerant R410A (HFC), http://www.toshibacca.com/en/learn-more/refrigerant-r410a-hfc
25 "The Montreal Protocol on Substances That Deplete the Ozone Layer", https://www.state.gov/e/oes/eqt/chemicalpollution/83007.htm

VRF Market Adoption Barriers and Opportunities

The following table captures the VRF market barriers that were highlighted by NEEP's VRF working group. The regional market transformation strategies in this report were developed to assist in overcoming these barriers.

Table 9 Barriers to the Regional Development of the VRF Market

Climate-specific Barriers	Need for the development of performance specifications for VRF system operation and high efficiency in cold climate applications. Metrics have to be proved - show the math, using real numbers on upfront costs, fuel savings, etc.
Consumer Barriers	Lack of awareness that heat pumps even exist, or if there is awareness, there is especially a sense that "they don't work in cold climates", or "they don't work below freezing".
	Costs vary significantly, with a large range in pricing for the installed cost of essentially the same system. In general, VRF is perceived as having a high cost.
	With the drop in oil prices, comfort cooling was the main reason to buy in 2016. These issues are becoming less significant.
Design and Installation Barriers	Installers are available, but may not themselves yet trust or be willing to recommend this technology for primary heat.
	Many installers in Northeast have limited experience with ducted heat pumps and don't offer them as an option.
	Poor informational feedback on how efficiently VRF units operate once installed, therefore there is a lack of readily available accurate information on system economics relative to oil and gas-fired systems.
	A general need to improve industry design and installation skills for VRF systems.
Policy Barriers	Need for regulators to allow electric utilities to promote fuel switching - this is the easiest way to get greater heat pump adoption. Doing this will create the larger carbon savings than energy efficiency programs, at no additional cost. Furthermore, the incremental electric sales will reduce electric rates. Regulators very rarely understand that electricity, when used in efficient heat pumps, is by far the cleanest heating fuel in terms of carbon emissions. Heat pumps in New England reduce natural gas home heating CO_2 emission by 40 percent and oil emission by 60 percent. There is considerable policy misalignment between the jurisdiction with climate change response mandates and utility regulatory bodies' rules.
Program Barriers	General inability to develop savings calculations without believable seasonal COP values.
	Need for better models for savings for different types of equipment or in differing installation use cases.
Promotion Barriers	Broad lack of regional awareness about the VRF technology, and its related non-energy benefits.
Refrigerant Barriers	Potential for collision between VRF deployment and HFC phase out.
Standards Barriers	Lack of real-world performance data, and difficulties in understanding how to design and size a VRF system, as it is different for each manufacturer.
Technology Opportunity	CO2-based systems may be available in the near future with 1/2000 of the global warming potential of today's refrigerants.

Regional Market Transformation Strategies

The Variable Refrigerant Flow (VRF) Market Strategies Report is intended to serve as a framework for increasing shared regional knowledge, and streamline and align market strategies with a focus on addressing identified barriers to this specific new clean energy technology.

This section describes seven key regional market transformation strategies, including tactical details for each of them. While they are framed as recommendations to the broad community of regional stakeholders, the sub-strategies identify specific stakeholders for implementation. Earnest deployment of the recommended market strategies outlined here should produce the necessary market conditions for accelerated and sustained uptake of VRF systems throughout the Northeast and Mid-Atlantic regions.

List of Regional Market transformation strategies

1. Increase reporting of VRF performance and costs to improve models for predicting cost-effectiveness, energy, and GHG savings.
2. Support improved test procedures and performance criteria/standards to enable the promotion of climate-appropriate VRF.
3. Develop a comprehensive regional strategy for addressing the climate and safety risks of refrigerants in VRF systems.
4. Increase state policy support and program valuation of all energy savings and non-energy benefits of VRF.
5. Increase HVAC workforce development and training on proper VRF design, installation, and maintenance.
6. Reduce incremental costs and increased VRF market transformation through robust, streamlined, and aligned regional, state, and efficiency program market promotional actions.
7. Promote integration of existing building management systems and advanced VRF controls to increase coordination and efficiency between building heating and cooling systems and other occupancy type controls.

Strategy #1: Increase reporting of VRF performance and costs to improve models for predicting cost-effectiveness, energy, and GHG savings

Industry and efficiency programs utilize a variety of proprietary and open-source building modeling tools to assist in selection, system design, prediction of performance, and cost savings of VRF installations. However, the limited amount of field-verified data, limitations of existing test procedures and standards, as well as minimal documented installed, incremental, and avoided costs serve as a barrier to increased confidence in VRF as a cost-effective measure for efficiency programs and their customers. Below are examples of the impact on different stakeholders due to the absence of established performance of ASHPs from the NEEP 2016 report:

- For consumers, it remains difficult to assess investing in VRF without knowing the likely savings;
- For contractors, it is challenging to provide accurate projections for savings in comparisons to the systems currently operated;
- For regulators and program administrators, it is very difficult to establish proper policies, programs, and incentive levels if savings and other benefits are in question. There is inadequate data to support one-size-fits-all deemed savings estimates.

Due to nascent market of VRF and its broad applications across different commercial building types, fuel sources, building-specific size and system requirements, as well as the variety of conventional HVAC alternatives, it is important to increase reporting of both the technical design and costs accessible to programs and industry partners.

Strategy 1a) Regional energy efficiency program administrators should introduce reporting requirements to capture project-specific details on system design, upfront and operational costs, and estimated or modeled savings. Additionally, longer-term supplemental field evaluations, verification, and pre/post monitoring studies are of critical importance for documentation of field VRF performance - including changes in energy use, ongoing operational performance in relation to changing building loads, supplemental systems, and weather conditions.

Ideally, data should be captured at a regional level and with standardized reporting and field evaluation protocols to serve to provide the most value to a variety of stakeholders. As highlighted earlier in the report, this field-verified data can be instrumental in improving the accuracy of the building energy models that industry and efficiency programs rely on to inform savings and system design decisions.

One attribute of the advanced controls native to VRF systems is the ability for industry to monitor and track real-time performance of installed systems, potentially reducing the typically high cost of adding supplemental metering and increasing the accuracy of evaluating system performance. This functionality of certain manufacturer VRF controls was highlighted at the December 2018 in-person NEEP VRF workgroup meeting as a supplemental area of focus for collaboration.

Strategy 1b) Regional VRF working group and manufacturers collaborate to assess the opportunity to leverage existing or additional on-board metering of VRF systems to inform field-verified performance.

Pinpoint best practices for metering/monitoring VRF to identify the optimal balance of cost-effectiveness vs. accuracy.

As noted earlier in the report, there are existing proprietary and non-proprietary building energy modeling software currently being utilized by industry and efficiency program administrators to evaluate VRF design tradeoffs and estimate energy savings based on building-level and locational parameters. The existing building and HVAC models continue to improve in function and accuracy, but increasing confidence and investment in VRF will require ongoing collaboration for improvements. With the recent introduction of new, high efficiency cold climate VRF models, it will be necessary to update models with a diverse set of VRF performance curves to reflect the wide variation in heat pump and heat recovery performance.

Strategy 1c) Regional stakeholders collaborate to develop best practices for VRF building energy modeling and share updates to VRF performance curves (e.g. cold-climate models), field-verified building models, and system costs.

On-board VRF control systems may serve as a valuable source of data to improve building energy modeling tools for VRF at different building load and weather conditions.

Strategy #2: Support improved test procedures and performance criteria/standards to enable the promotion of climate-appropriate VRF

The current federal standard and test procedure VRF working group will be instrumental in identifying where national collaboration efforts are succeeding or falling short in accurately reflecting real-world system performance – notably with a new focus on including an assessment of VRF control systems.

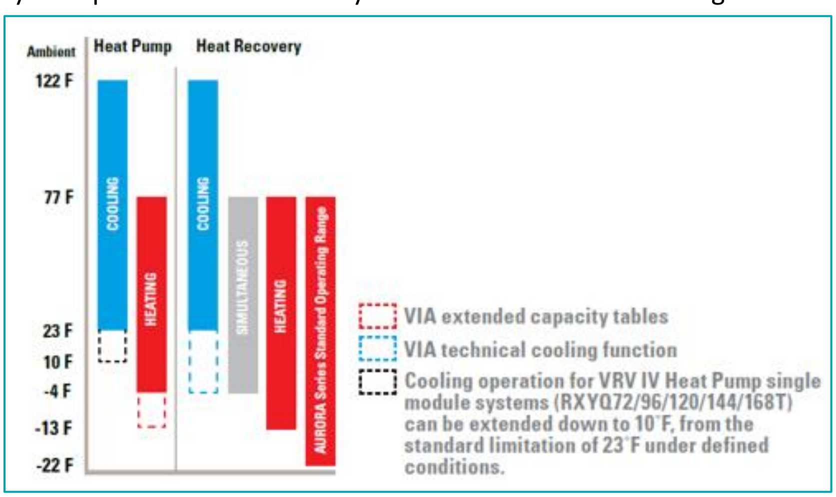


Figure 132 Daikin product brochure demonstrating broader operational range of new VRF/VRV models[26]

[26] Daikin brochure VRV Applications in Extreme Cold Conditions (2017)

There are a lot of commonalities between the federal, ASHRAE, ENERGY STAR, and CEE standards and specifications for VRF heat pump products. However, new VRF models – notably cold-climate models – are demonstrating operational capacity to a wider range of design temperature and operational conditions that are not currently tested under current standardized test procedures.

NEEP stakeholders emphasized the need to work with AHRI in "creating the next generation of standards in VRF" to better reflect and align with the manufacturer focus on properly optimizing the overall performance and life cycle cost of the unit. The current set of test procedures and standards reflect a more traditional focus on IEER and full load COP.

NEEP has demonstrated a successful role in developing and maintaining a cold-climate specification and eligible product list for residential-scale ASHPs, addressing a critical need for manufacturer reporting of ASHP performance at temperatures below that required for AHRI 1230 (Cold Climate Air Source Heat Pump Specification (Version 3.0) at 5°F). Leveraging NEEPs established working group and partnership on the current cold climate specification might serve as a template for developing similar standardized reporting for commercial VRF products at a wider range of temperatures. However, any future developments from the federal working group on VRF will be important to monitor and inform any future efforts in this area.

Strategy 2a) NEEP VRF working group should monitor and support development of national test procedures, standards, and advanced specifications that improve the correlation and accuracy to real-world and climate-specific applications. The working group should evaluate the benefits of developing regional climate-specific performance reporting requirements and advanced criteria for VRF.

Strategy #3: Develop a comprehensive regional strategy for addressing the climate and safety risks of refrigerants in VRF systems.

Global Warming Potential (GWP) is a metric used to describe the relative impact of a compound's contribution to global warming. GWP is given as a value relative to the baseline of CO2, which has a GWP of 1. On an equal mass basis, a substance with a GWP of 2 would therefore have two times the impact of CO2. R-410A has a GWP of 2090. In effect, this means that one pound of R-410A released into the atmosphere would have the same impact on global warming as 2090 pounds of CO2. Based on our characterization of an "average" VRF system, the refrigerant contained within has the *potential* impact of 188,000-376,000 pounds CO2 if it were all to be released.

Table 10 ODP and GWP for Various Refrigerants[27]

REFRIGERANT	TYPE	ODP	GWP (100yr)
R-12	CFC	0.820	10,600
R-22	HCFC	0.034	1,700
R-404A	HFC	0	3,800
R-410A	HFC	0	2,000
R-290 (Propane)	Natural	0	~20
R-717 (Ammonia)	Natural	0	<1
R-744 (CO_2)	Natural	0	1
HFO-1234yf	HFO	0	4

Source: Calm & Hourahan, 2001

VRF systems are a key strategy being utilized for CO2 reduction in commercial buildings and by design are not intended to leak refrigerants. However, the number of field connections of refrigerant lines and lengths of piping potentially exposed to physical damage from external elements increases the chance of a system leak. Properly designed and installed, VRF can displace aging fossil fueled heating systems and inefficient air conditioning, saving money, energy and significantly reducing the CO2 associated with space conditioning. However, there is a concern that the targeted CO2 reduction benefits of VRF will not be realized if a high rate of refrigerant leak exists.

The net CO2 impact of VRF is dependent on a variety of factors. These factors include:

- VRF system performance
- Baseline fuel type and system performance
- Carbon content of electricity
- GWP of refrigerant
- Refrigerant leakage rate

VRF system performance is addressed elsewhere in this report. Baseline fuel type and system performance need to be calculated on a case by case basis. However, higher carbon fuels, such as oil and propane, and older, inefficient heating systems will present a larger opportunity for carbon offset than newer heating equipment burning low-carbon fuels (such as natural gas or wood). Carbon content of the electricity being utilized for VRF operation is beyond the scope of this report but does have significant impact on the potential for carbon reduction through any electrification measure.

Given the high GWP of currently utilized refrigerants (such as R-410A), concerns around leakage rates are a high priority as we evaluate the CO2 impact of VRF. Unfortunately, very little data exists on the average leakage rates for VRF systems. Some basic modeling demonstrates that over 35 percent of all refrigerant would have to leak

[27] Nick Martineau. *CO2's Stage a Comeback. August 2015.* http://koretechnical.com/rca-ti-tips/2015/8/14/the-comeback-of-co2-as-a-refrigerant

out every year to break even on CO2 if the VRF system is replacing #2 fuel oil. However, if that same system were replacing natural gas, the break-even level would only be 15 percent per year.

During the NEEP in-person December 2018 working group meeting, Steven Winter Associates presented modeled greenhouse gas (GHG) footprints for several buildings in New York City with VRF installations. The modeled results included an assumed 10 percent leakage rate and suggested an equal to larger carbon impact when compared to gas heated buildings.[28] The results did not include additional performance related to cooling compared to conventional air conditioning systems. Although limited, additional reports have been cited by the U.K. Department of Energy & Climate Change, which identified a 3.5 percent leakage rate (8-10 percent of buildings leaking at a 40-50 percent rate)[29] and another report by the U.S. Department of Defense identified leakage rates as high as 25 percent.[30]

It is important to collect additional data on the percentage of installations and rate of leakage that is occurring, as the concern about refrigerant leakage is rooted in the fact that VRF systems require extensive piping field connections. Systems can contain hundreds of connections, each one representing a risk for leakage. As with all emerging technologies that require a highly trained workforce, there is a learning curve that we must address to ensure quality and dependable installations.

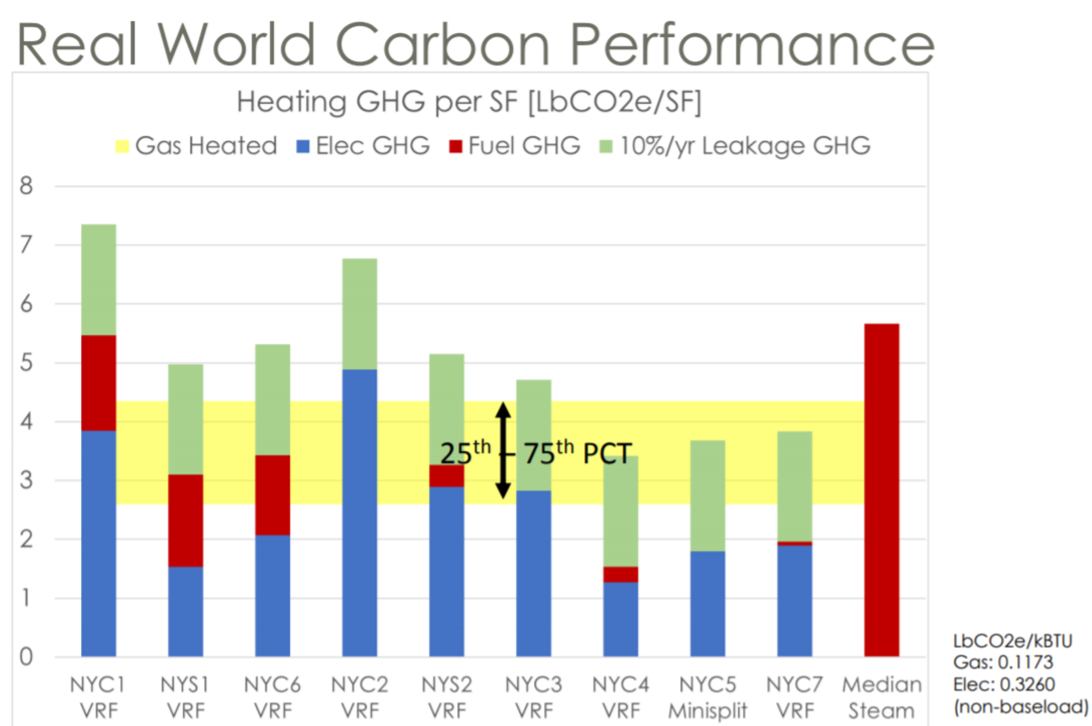


Figure 14 Modeled NYC GHG emissions assuming a 10% per year leakage[31]

[28] Zuluga, Marc, "VRF: A Little Bit of Data & A Few Questions"
[29] UK Department of Energy & Climate Change, "Impacts of Leakage from Refrigerants in Heat Pumps", March 2014
[30] US Department of Defense, "Heating, Ventilating, and Air Conditioning Systems", November 2017
[31] Zuluga, Marc, "VRF: A Little Bit of Data & A Few Questions"

Until we understand the baseline condition, we will not be able to address the issue of VRF refrigerant leakage. A large-scale assessment of leakage rates for different manufacturers and building types across a broad geographic area will provide the much-needed information to make informed policy decisions going forward. There is potential for getting this data remotely as some manufacturers report the ability to track this utilizing on-board diagnostics which can upload data remotely. This would require manufacturer engagement and customer sign-off to access this data.

Through improvements in training programs, manufacturers and industry partners can work with installers to ensure that best practices are employed in the field. Clear recommendations about which field connections are acceptable and the best way to conduct these connections as well as QC and pre-charge field inspections by trained staff will go a long way to ensuring quality installation and lower lifetime leakage rates.

Evidence of refrigerant leaks should be addressed through remediation and repair rather than periodic addition of refrigerant. Industry partners should educate customers to proactively engage with their service contractor on this practice. Customers should look for charges related to added refrigerant and question why the system is leaking.

During the 2018 NEEP in-person meeting, industry participants highlighted that manufacturers have supplemental on-board diagnostic equipment designed to detect refrigerant leakage, as well as internal reporting of cases of refrigerant leakage that might serve as critical information to best understand the number of reported leakage events, amount leaked and ideally the reason for the leakage.

Strategy 3a) NEEP VRF working group should initiate and collaborate in research aimed to identify current VRF leakage rates, as well establish data-informed best practices for VRF installations and servicing.

There are a variety of low GWP refrigerant options that are being developed, tested, and anticipated to come on the market soon. However, initially these new refrigerants may come with increased costs, lower performance (efficiency), or difficulty in entering the market due to existing building safety codes with respect to flammability.[32]

- R-32: Most market attention has been focused on R-32 as a viable alternative to 410A, as it has a moderate GWP value of 675, or about 1/3 that of 410A. However, R-32 is classified as an A2 for flammability, making it “moderately flammable” according to regulatory prohibitions. As a result, this refrigerant is not a viable alternative to 410A.
- HFOs: A new class of refrigerants being tested for replacement of HFCs is hydrofluoroolefins (HFOs), which have ultra-low GWP values while maintaining 0 ODP.
- Natural refrigerants (NR): Compounds such as propane (R-290) and CO2 (R-744) are included as potential alternatives and although new VRF products (and existing installations) are not currently commercially available utilizing these refrigerants. Other technology sectors such as

[32] https://dms.hvacpartners.com/docs/1001/Public/0E/ENG_NEWS_3_2.pdf
https://www.ashrae.org/technical-resources/bookstore/standards-15-34

commercial refrigeration and air-to-water heat pumps are beginning to take advantage of these refrigerants and their unique performance characteristics.

Another recommendation is to utilize equipment with lower charge levels. By utilizing water, or another transfer medium on the distribution side, the amount of refrigerant needed in the system is reduced, thereby reducing the GWP of the system. Air-to-water or other technologies provide much of the benefit of traditional VRF while reducing the refrigerant impact.

Due to the ever-changing regulatory environment of refrigerants, there are concerns around access to phased-out refrigerants and stranded distribution piping.

The EPA, under the Trump administration, has rolled back adoption of Significant New American Policy (SNAP) rules that would have begun phase-down of HFC refrigerants. However, several states such as California, New York, Connecticut and Maryland (among others), have opted to adopt the SNAP rules at a state level. It is anticipated that many other states will follow suit. These rules require a refrigerant phase-down of targeted high-GWP refrigerants. Similar rules are being adopted in Canada, France, and other countries around the world. For the industry, sweeping changes in refrigerant regulation are expected, and although the timing on when HFC refrigerants will no longer be available is unclear, most agree that a shift away from HFCs is inevitable.

For customers that install 410A systems, access to refrigerants, whether as a leak replacement or for service reasons, is critical for ensuring that the equipment does not become a stranded asset. Another concern is that when new refrigerants are introduced, existing installed piping distribution systems may very well be made obsolete. Refrigerant piping size plays a critical role in system design with different refrigerants having different operating parameters. For example some operate at much higher pressures than others, requiring stronger piping materials/joints, while others require larger or smaller piping diameters for proper system performance. A change in refrigerant (unless considered a “drop-in replacement”) will potentially require a complete replacement of the distribution piping and fan coils.

Based on historical regulatory changes and resulting phase-outs, we can confidently assume that R-410A will be available for the life the current VRF equipment. Phase-outs generally affect new installations long before they become unavailable for addition to existing systems. Costs will be expected to increase as a phase out nears full transition, however, it is unlikely that 410A will become entirely unavailable at any point in the foreseeable future.

Although it is possible to develop a low GWP “drop-in” replacement to 410A which can utilize existing piping, there is significant uncertainty if the next generation of refrigerants will be able to utilize existing infrastructure. Installing piping in accessible locations whenever possible may be a potential opportunity to reduce anticipated costs of re-piping, but it is more likely that the piping be considered as a temporary, perishable portion of the VRF system that will need to be replaced.

Strategy 3b) NEEP VRF working group should invest in early support for industry evaluation of new refrigerants for VRF installations, as well as incentivizing their early-market adoption. As new low-GWP refrigerants will potentially require re-piping for proper safety or performance, early planning and incentives may be required for avoiding barriers to market growth of VRF.

Safety standards have been developed by ASHRAE to govern the management of refrigeration systems:

- ASHRAE Standard 15 defines the requirements for refrigerant system design, construction, installation, and operation of refrigeration systems
- ASHRAE Standard 34 establishes a refrigerant safety classification system including flammability and toxicity

Together, these standards, when properly adhered to, provide a clear and conservative framework for refrigerant safety. R-410A, for example, is considered a non-toxic substance, however it does have oxygen displacement characteristics that necessitate careful design and installation of VRF systems. High concentrations of R-410A in confined spaces can result in severe threat to human life, which requires certain changes to piping layout and system sizing to ensure adherence to ASHRAE 15. As noted earlier, current ASHRAE 15 standards prohibits the use of flammable refrigerants in occupied spaces, and until further updates to the standard currently proposed for allowing refrigerants classified as 2L (including R-32).

These standards are clear, easy to understand, and widely accepted as the way to manage refrigerant safety for VRF systems. All municipalities and utility programs should reinforce the compliance with Standards 15 & 34. They establish the Refrigerant Concentration Level (RCL) maximum based on the oxygen deprivation limit. This is calculated based on the refrigerant characteristics and the volume of space the refrigerant passes through. The assumption is that all the refrigerant could, in theory, drop directly into the smallest space on the refrigerant circuit. This "worst case scenario" must still be within safety parameters. By following these standards carefully, safety of all building inhabitants in ensured.

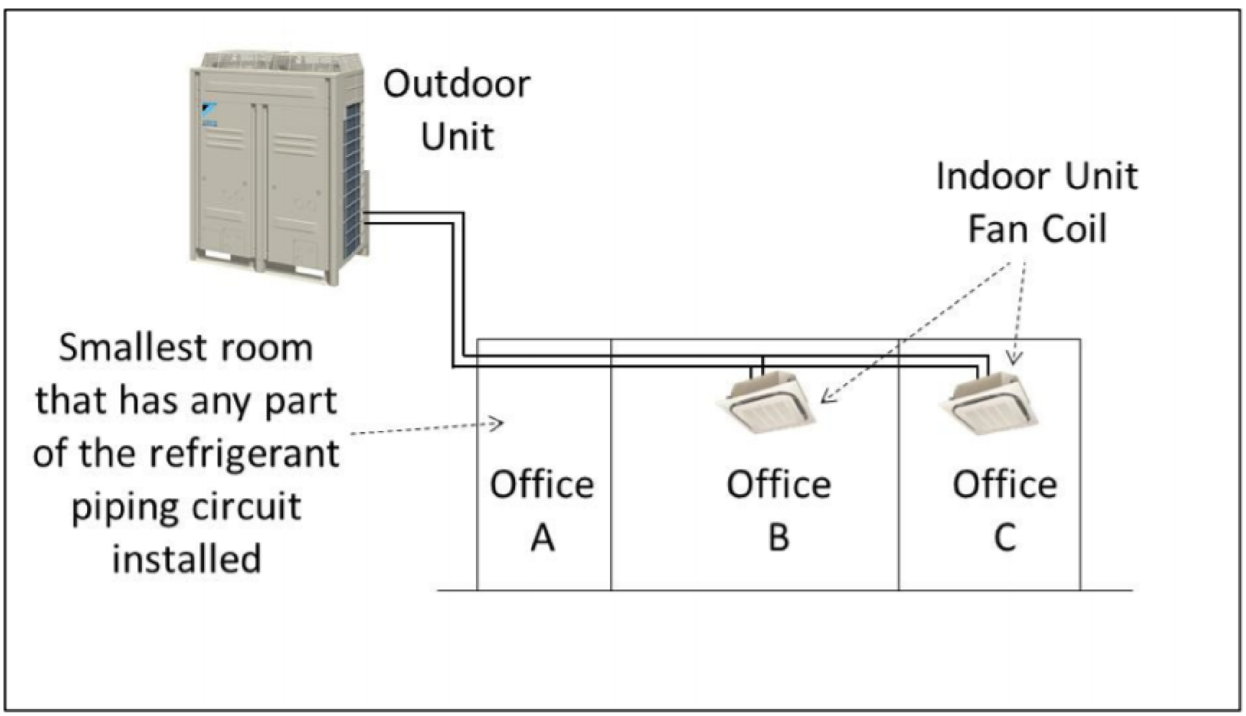
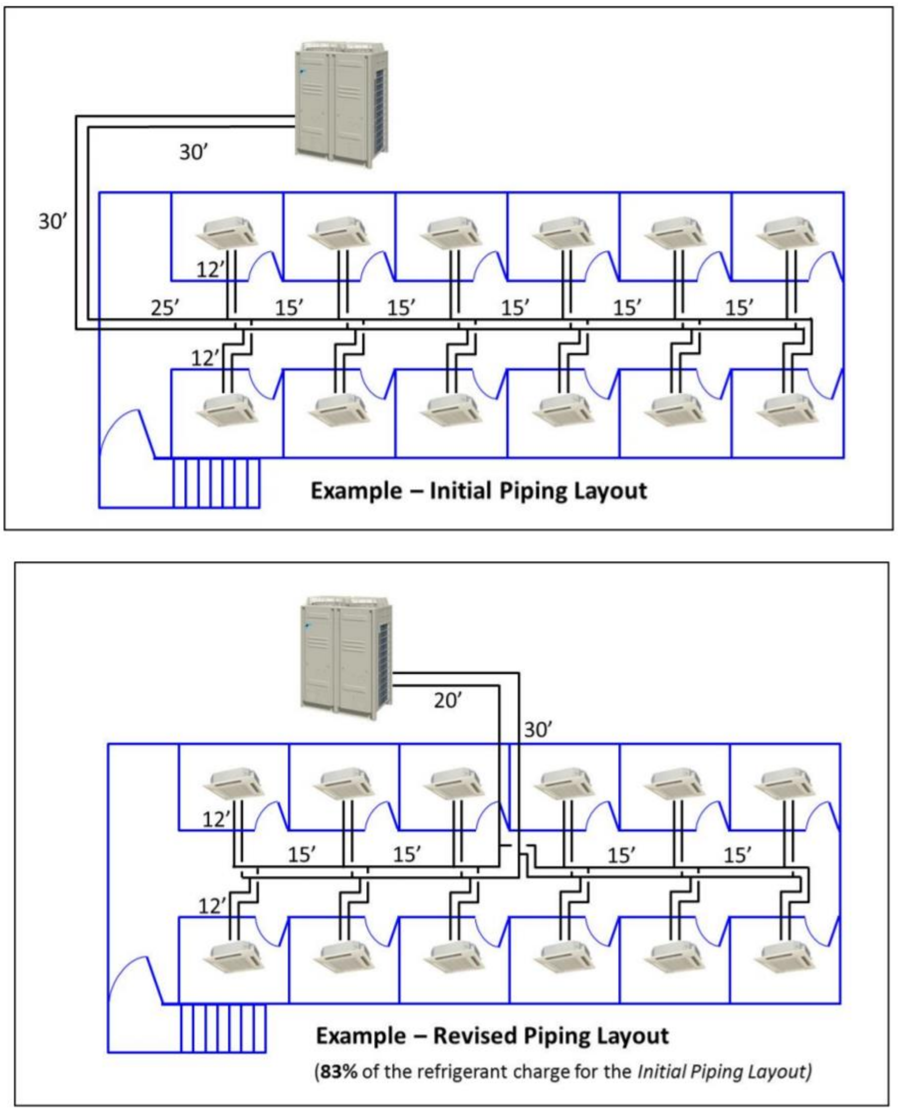


Figure 15 Illustration of ASHRAE 15 safety requirements for minimum occupied space to refrigerant volume[33]

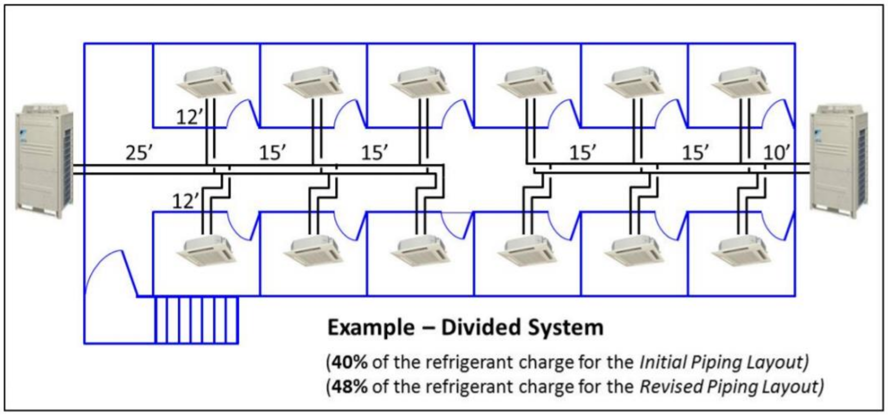
[33] https://www.daikinac.com/content/assets/DOC/White-papers-/TAVRVUSE13-05C-ASHRAE-Standard-15-Article-May-2013.pdf

There are several design strategies that can be employed to ensure that compliance is maintained. The smallest space that the refrigerant runs through is generally the bottleneck. By running lines through larger, more open spaces, the amount of refrigerant in the circuit is less important. Additionally, rooms can be interconnected using louvers or other cross-ventilation techniques to connect room together. Refrigerant circuit size is another variable to control in design. By creating multiple, smaller circuits as opposed to fewer, larger circuits, there is less need to be concerned about room volume. Simply re-routing refrigerant lines away from smaller spaces can assist in compliance.

Figure 16 Rerouting of refrigerant lines to satisfy ASHRAE 15 safety requirements for minimum occupied space to refrigerant volume[34]



[34] https://www.daikinac.com/content/assets/DOC/White-papers-/TAVRVUSE13-05C-ASHRAE-Standard-15-Article-May-2013.pdf



Strategy 3c) Efficiency program administrators, state building code officials and industry can collaborate to support training on best practices for VRF design to mitigate safety, as well as reduce refrigerant charge to address leak risks. Similarly, site inspection, commissioning and code official enforcement for proper installations will support broader adoption among HVAC contractors.

Strategy #4: Increase state policy support and program valuation of all energy savings and non-energy benefits of VRF

VRF is experiencing double digit growth in the HVAC market in part due to the potential energy savings for customers, but more commonly as a recognition of VRF providing comfort, space, and design improvements over conventional technologies. With additional verification of performance – as highlighted earlier in the report – case studies of applications of VRF can serve to educate and support broader adoption of the technology.

However, most efficiency program administrators are currently limited in program activities to support and/or claim electric only (kWh) savings from VRF installations and, in some cases, are not allowed to support or claim for fuel switching applications (e.g. natural gas to VRF electric heating). This frequently creates a misalignment between state GHG reduction goals tied to fossil fuel use and electric utility ratepayer funded programs.

Recent regulatory orders in individual states have begun to address this market barrier, directing utilities to prioritize beneficial electrification and peak demand reduction. In Massachusetts, 2019-2021 energy efficiency plans include plans to support the switch to renewable energy and other clean energy technologies – though all are required to meet cost-effectiveness requirements.[35]

However, as part of the cost-effectiveness calculations, assessing the incremental costs of VRF equipment, as well as the avoided costs associated with less material improvements – including space savings and increased comfort cooling – will continue to be an area of increased reporting and studies.

[35] https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/10317061

To improve the effectiveness of the broader industry message, regional stakeholders should develop a comprehensive strategy to support new clean energy technologies like VRF.

Strategy 4) Regional state policy and efficiency programs should address policy barriers to the full valuation of VRF in reducing fossil fuel use through beneficial electrification and peak demand reduction. Additionally, the development of VRF case studies to show installations in a diverse set of building types, as well as increased field performance monitoring, will increase the confidence in VRFs as a solution for building owners and highlight their important role in state GHG mitigation strategies.

Strategy #5: Increase HVAC workforce development and training on proper VRF design, installation and maintenance.

Workforce development is a critical area of focus for states in achieving aggressive goals in GHG reduction in buildings, as the growth of trained HVAC contractors needs to keep pace with the scale of deployment of new clean energy technologies. New partnerships between manufacturers, states, and efficiency program administrators are looking to address barriers to a growing and well-trained HVAC workforce.

NYSERDA has recently committed $70 million over the next 10 years to increasing clean energy workforce development and training strategies and resources.[36] The NYSERDA Clean Energy Workforce Development program includes the targeted opportunities:

- Energy Efficiency and Clean Technology Training
- On-the-job Training
- Internships
- Building Operations & Maintenance

Strategy 5a) Regional stakeholders, including manufacturers and program administrators, should increase the level of investment in HVAC workforce development and training to ensure that a sufficient number of "clean energy contractors" are trained in installation best practices of new electrification technologies like VRF.

In the United States, VRF is disrupting a traditional commercial rooftop and Variable Air Volume (VAV) market that has required contractors and building professionals to have specific skills to design, install, and maintain the necessary ductwork and plumbing. Increases in adoption of VRF will require workforce training and demand for contractors with the experience and skills for designing, installing and maintaining refrigerant-based systems.

[36] https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Workforce-Development

Strategy 5b) In tandem to workforce development and training, program administrators should require manufacturer certification in the installation of VRF to increase confidence in system performance and reduce risk of refrigerant leaks. The NEEP working group can assess existing manufacturer training and value of developing regional best practice guides and standardized certifications for VRF contractors in critical areas (e.g. proper design, system sizing and start-up procedures).

Strategy #6: Reduce incremental costs and increased VRF market transformation through robust, streamlined, and aligned regional, state, and efficiency program market promotional actions

Various studies and reporting of VRF costs have demonstrated a significant incremental cost of the VRF equipment, and more importantly, the final installed system cost. There is an important role for more traditional efficiency program administrators and local and state organizations to influence the selection of not only VRF – but increasingly the highest efficiency VRF models for commercial new construction and HVAC retrofit opportunities.

Although incremental costs of VRF over alternative conventional HVAC solutions can be obtained through inquiries with factory representatives and distributors, capturing the full incremental costs (and avoided costs) of the system design are typically only available at the project completion phase. For this reason, it is equally important that programs encourage the final reporting of system costs for evaluating the cost-effectiveness of the VRF energy savings, as well as ensuring that incentives are set appropriately to achieve the desired outcomes. Reporting from the Massachusetts Clean Energy Center (MassCEC) program in May 2019[37] highlighted the following VRF program performance:

- 80 projects, with average capacity 544 kBTU/hr
- Seven participating manufacturers and 45 different designer/installer companies
- Over $4.8M in incentives – approximately 45 percent for affordable housing projects
- Approximately 50/50 split of new construction and retrofit projects
- 62 percent of projects incorporated heat recovery
- Project costs average $8,600 per 17F heating ton ($6,400 per cooling ton)
- Program anticipated to sunset in June 2019

The MassCEC VRF program provides incentives at a tiered rate based on building ownership type and incorporation of heat recovery. It is also important to note that the incentives are based on equivalent heating ton of the system vs. a more common capacity rating based on cooling ton.

[37] MA CEC program performance and findings reported by Peter McPhee to NEEP. May 9, 2019.

Table 11 Massachusetts CEC VRF program tiered incentive table for building ownership type and incorporation of heat recovery[38]

Entity Type	VRF without Heat Recovery *per 12,000 BTU/hr**	VRF with Heat Recovery *per 12,000 BTU/hr**	Maximum Grant per Project*
Private	$800	$1,200	$180,000
Public/Non-Profit	$1,000	$1,400	$210,000
Affordable Housing	$1,600	$2,000	$250,000

***Grants are based on AHRI-rated heating capacity at 17°F.** Maximum grants are based on 1,800 kBTU/hr of capacity. The grant maximums in the table assume heat recovery equipment; systems without recovery will have lower maximums.*

It is important to highlight that the MassCEC incentives are in some cases approximately an order of magnitude greater than those provided through regional efficiency programs, enabled in part by the primary goal of GHG reduction over electricity savings. MassCEC developed incentives based on the following guiding criteria:

- Incentive level sufficient to change minds of project decision makers to upgrade from traditional heating and cooling to VRF
- Incentive should move the payback for some projects from unattractive to attractive
- VRF incentives are in line with our incentives for less expensive mini-splits ($625/12,000 BTU/hr) (5° F) and more expensive ground-source heat pumps (about $3,000/12,000 BTU/hr)

Strategy 6a) Regional VRF working group members should better track and report VRF costs (incremental, installed, and avoided), as well as assess the level of incentive necessary to drive sustainable, yet accelerated growth in the VRF market.

The table of regional efficiency program promotional activity for VRF earlier in the report (and referenced in the ***Error! Reference source not found.Error! Reference source not found.***) reflects a somewhat diverse approach and level of investment in supporting VRF. There are notable differences in the VRF performance criteria, incentive levels, and program delivery (project level, customer-oriented downstream incentives, and equipment-level, distributor-oriented midstream incentives). Although midstream HVAC programs are a relatively new advancement in program delivery for regional HVAC programs, the results from increased program participation and streamlined incentive delivery and industry promotional partnerships are getting strong recognition in the industry. However, as distributors are frequently operating at a regional level, increasing the level of coordination of program strategies, performance criteria and less critical incentive levels can increase the market impact and efficiency. One important element often lost in shifting away from downstream incentives is

[38] MA CEC rebates were reduced recently from these original levels, and the program incentives are anticipated to end on June 30,2019 with a transition towards utility program implementation. https://files-cdn.masscec.com/get-clean-energy/business/clean-heating-cooling/VRF_Program_Manual_EFFECTIVE_FEB_2019.pdf

the level of detailed project-level data and building owner engagement that is important for informing early program decisions.

Performance-based incentives may offer another future mechanism for long-term building investments in VRF systems. NYSERDA is introducing a pay-for-performance (P4P) for residential and small commercial buildings,[39]; nationally and regionally, P4P and other market-based solutions are anticipated to play a critical role in the build out of efficiency in buildings.

Strategy 6b) Energy efficiency and renewable heating and cooling programs should evaluate opportunities to align program delivery strategies – notably midstream distributor partnerships – and coalesce around regional performance criteria similar to the success of the ccASHP specification. Programs should also seek to leverage industry partnerships and conduct standardized surveys to continue to gather detailed cost and system design data to inform program design improvements.

Increasing confidence in VRF performance and reducing risk/impacts of refrigerants will give greater emphasis to adopting VRF as a standard technology in sustainable/high performance building programs, voluntary programs (i.e. ENERGY STAR Commercial Buildings, LEED, etc.), and future building energy codes. NEEP VRF stakeholders have emphasized the need for educating architects, engineers, contractors, designers, and other building professionals on the existence of VRF, opportunities, costs, and so on. These building professionals are the "decision-makers in building design" and an increased awareness of VRF systems, along with their attributes and advancements in performance, will improve acceptance and installation rates.

Strategy 6c) Regional VRF working group members should work to develop a multi-year market transformation strategy for increased voluntary building and equipment efficiency standards, as well as educate building professionals, to support VRF adoption and accelerated transition to low-carbon national and state building energy codes.

Strategy #7: Promote integration of existing building management systems and advanced VRF controls to increase coordination and efficiency between building heating and cooling systems and other occupancy type controls.

Although not all VRF projects require interaction between VRF controls and other building systems, the majority, especially in relation to maximizing the efficiency of the VRF and separate building ventilation systems and other occupancy driven controls (e.g. lighting), benefit from integrated controls.

A whitepaper on VRF and Building Integrations (Mitsubishi 2017)[40] breaks down VRF building integration into several options:

---

[39] https://www.recurve.com/blog/nyserda-and-dps-announce-plans-for-pay-for-performance-efficiency-in-new-york
[40] "VRF and Building Integrations - Options and How to Choose Among Them". Mitsubishi August 2017. https://www.esmagazine.com/ext/resources/images/WhitePapers/Building-Integrations.pdf

- Non-integrated Standalone Building Controls System
- Third-party Integration
- Third-party Integration… With a Boost From the VRF Manufacturer's Controls Engineers
- Manufacturer-specific Controls That Can Handle Other Manufacturers' Products

Each option includes benefits and "pitfalls" that may be driven in magnitude by the complexity of the building systems and the level of comfort, efficiency, and control that building owners or managers require.

The report earlier highlighted the importance of current federal working group efforts to better assess VRF controls impact on system performance and the need to develop appropriate test procedures and standards to reflect real-world operation. It is equally important for regional VRF stakeholders to prioritize integration of VRF and building energy management system controls to achieve the highest efficiency performance at a building level. Including building control integration with VRF would be an important metric to capture as part of any verification or study of VRF performance in building installations.

Strategy 7a) Regional VRF working group members should invest in increased building operation training, best practices in system design, and assessing program or state building code strategies to increase VRF control and building energy management system integration. These investments and collaboration with industry will help achieve the highest building level HVAC energy savings and comfort in VRF installations.

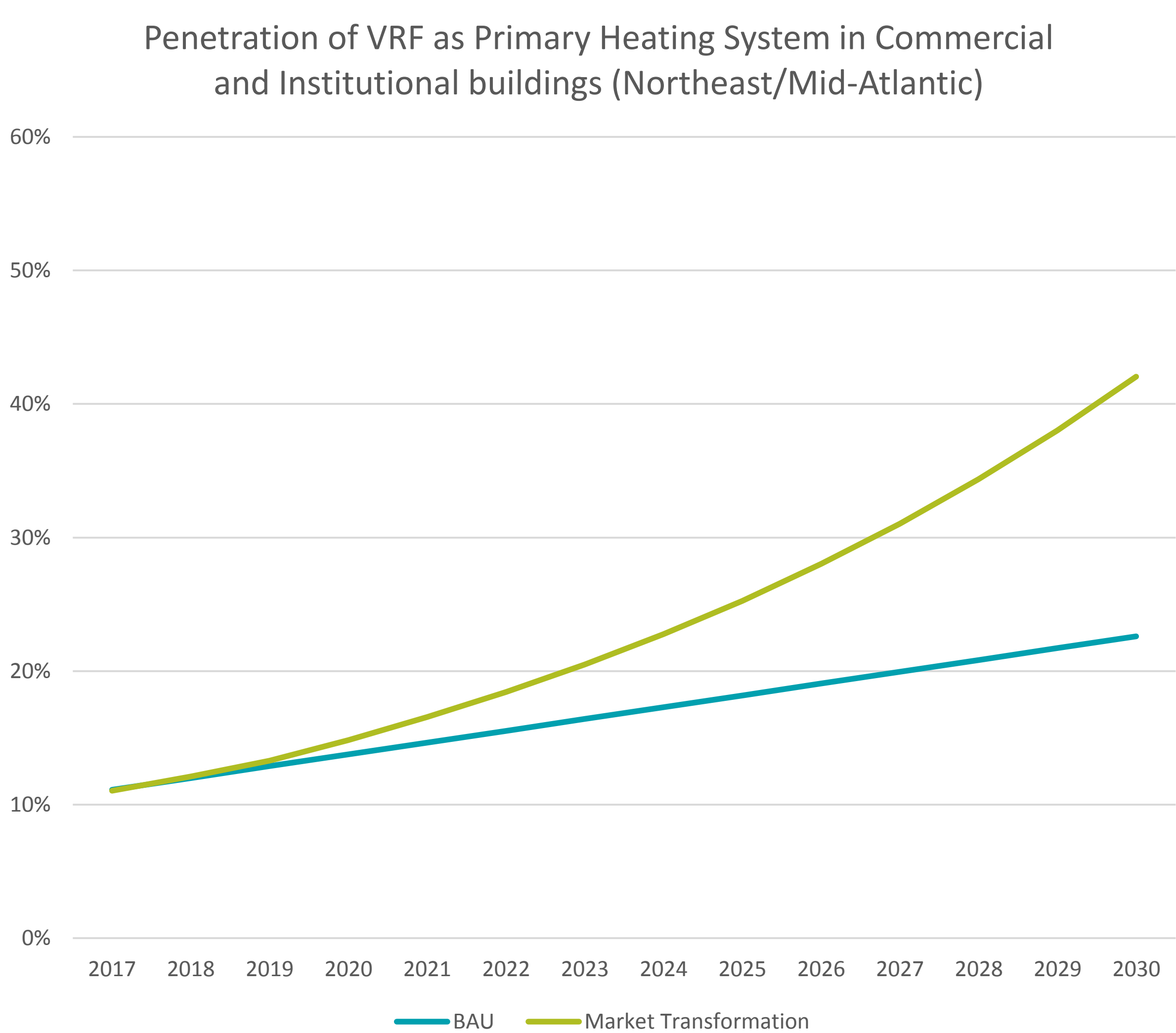
Regional Market Transformation Goal

Based on our assessment of the regional VRF market, it is clear that while VRFs have established a viable and growing market, there remains a significant opportunity to further accelerate adoption of the technology and, in the process, achieve exciting energy, cost, and carbon savings to the Northeast/Mid-Atlantic region. In the previous section, seven key market strategies were presented that we project will collectively accelerate the adoption of ASHPs in the region.

NEEP projects that earnest implementation of the recommended market strategies outlined in the Regional Market Transformation Strategies section will produce the necessary market conditions in order for accelerated and sustained uptake of VRFs throughout the Northeast and Mid-Atlantic region.

The following graph suggests what a projected market trajectory would will look like if the region is successful in implementing the key strategies identified in the report. The market transformation scenario is in relation to a business as usual scenario.

Figure 3: Market Transformation for VRFs in the Northeast/Mid-Atlantic Region



Appendix A

2018 VRF Heat Pump Incentive Summary

Below is an Incentive Summary of Variable Refrigerant Flow (VRF) Heat Pump Promotional Activities that are in place throughout the region. *(July 2018)*

Incentive and Requirement Summary

State	Rebate Incentive	HPSF	EER	IEER	SEER	COP
Massachusetts (Mass Save)	For air cooled units ≥5.4 tons = $125/ton		≥11.0	≥18.0		≥3.4
	For water cooled units ≥5.4 tons = $125/ton		≥12.0	≥20.0		≥4.3
Massachusetts (Clean Energy Center)[41]	For units without heat recovery ≥5.4 tons = $800/ton	Must meet the minimum efficiency ratings established in the ANSI/ASHRAE/IES Standard 90.1-2016 Energy Standard for Buildings Except Low-Rise Residential Buildings				
	For units with heat recovery ≥5.4 tons = $1,200/ton					
	For units without heat recovery <5.4 tons = $800/ton	≥10.0	≥11.0		≥17.0	
	For units with heat recovery <5.4 tons = $1,200/ton	≥10.0	≥11.0		≥17.0	
Rhode Island (Program ensures that efficient equipment is available)	Air-cooled units ≥5.4 tons		≥11.0	≥18.0		≥3.4
	Water-cooled units ≥5.4 tons		≥12.0	≥20.0		≥4.3
New York (NYSERDA)	Flex Tech program: cost-shared energy efficiency technical analyses and strategic energy management assistance to existing facilities, can include investigation of VRF					
PSEG- Long Island	<5.4 tons = $125/ton (Tier 1)	≥8.5	≥12.5		≥15.0	
	<5.4 tons = $230/ton (Tier 2)	≥9.0	≥13.0		≥16.0	
	≥5.4 & <11.25 tons = $125/ton		≥11.3	≥14.2		≥3.4
	≥11.25 tons & <20 tons = $80/ton		≥10.9	≥13.7		≥3.2
	≥20 tons = $80/ton		≥10.3	≥12.5		≥3.2
	Water source unit <11.25 tons = $80/ton		≥14.0			≥4.6
Energy Save PA	<5.4 tons = $100/ton	≥9.0			≥16.0	

[41] Award levels for Public/Non-Profit = $1,000/ton without heat recovery, $1,400/ton with heat recovery; Award levels for Affordable Housing = $1,600/ton without heat recovery, $2,000/ton with heat recovery. MA CEC revised incentive levels in early 2019 and plans to sunset the VRF program in June 2019 for a transition to utilities.

State	Rebate Incentive	HPSF	EER	IEER	SEER	COP
Custom energy calculations required for VRFs	<5.4 tons = $150/ton	≥10.0			≥18.0	
	≥5.4 tons and <11.25 tons = $35/ton		≥11.0	≥11.2		≥3.6
	≥11.25 tons and <20 tons = $35/ton		≥10.6	≥10.7		≥3.6
	≥20 tons = $35/ton		≥9.5	≥9.6		≥3.5

Appendix B

Excerpt from NRDC Commissioned 2018 Report - "Ramping Up Heat Pump Adoption in New York State"[42]

VRFs are not currently promoted by NYSERDA, but they excel in serving buildings requiring "comfort cooling" (e.g. offices, multifamily) and have enormous potential to reduce energy use in New York City. Continued efforts are needed to reduce the soft and upfront costs of ground source heat pumps (GSHPs), which provide highly efficient cooling and heating and can contribute to peak load reductions (GSHPs exhaust heat to the absorbent, cool ground as opposed to hot outdoor air).[43] NYSERDA should consider the following steps to support emerging heat pump technologies and applications:

- **Develop VRF case studies and marketing materials.** NYSERDA can help to educate the commercial building market on the improved performance characteristics of VRFs and best practices for meeting building standards. Case studies, testimonials, and marketing materials are needed to counter misconceptions and raise awareness of many of the non-energy benefits of VRF. Case studies and examples should address a variety of applications, given the wide variation in climate and building stock between upstate New York and the New York City metro region.
- **Aggressively promote VRFs in commercial and residential new construction and building codes,** consistent with an overarching strategy to encourage all-electric heating equipment in new construction.
- **Evaluate and support accelerated transition of heat pumps to lower global warming potential (GWP) refrigerants.** Although not unique to heat pumps, risk of refrigerant leaks could reduce the significant climate benefits of the technology. Developing a multi-faceted approach to mitigating refrigerant leaks includes support for proper design and installation practices, compliance with existing refrigerant safety standards, and advancement of natural refrigerants to replace use of higher GWP refrigerants.
- **Explore distributor incentives for VRF technology.** As previously discussed, upstream and midstream program approaches that engage wholesale distributors are effective because the distributors control stocking and upselling and directly engage and train contractors, mechanical engineers, and architects.
- **Develop regional standards for VRFs in the Northeast.** New York stakeholders should work with NEEP to develop a regional performance specification to promote the highest efficiency VRFs, while supporting a diverse mix of technologies and manufacturers.
- **Review building code barriers to VRF technology.** Recent IECC 2015 code adoption has inadvertently increased costs for VRF applications with requirements for economizers. NYSERDA and state should review building codes to avoid creating barriers or unnecessary costs for new heat pump technologies.
- **Consider creating a VRF "Clean Energy Challenge"** as NYPA and NYSERDA did for GSHP technology, to encourage state buildings to "lead by example" in adopting VRFs.[44]
- **Accelerate NYSERDA's soft cost reduction strategy for GSHPs** and maximize the proposed targeted cost-shared technical assistance for larger projects to address the higher pre-development costs.[45]
    - **Develop and fund demonstration projects** that explore the potential for GSHPs to promote grid flexibility, such as improved load factor or peak demand reduction.

---

[42] https://www.veic.org/documents/default-source/resources/reports/veic-ramping-up-heat-pump-adoption-in-new-york-state.pdf
[43] Heat & Cool: Heat Pump Systems, https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems
[44] NYPA. https://www.nypa.gov/about/geothermalchallenge.
[45] NYSERDA, 2017. "Clean Energy Fund Investment Plan: Renewable Heating & Cooling Chapter." https://www.nyserda.ny.gov/-/media/Files/About/Clean-Energy-Fund/cef-renewable-heating-and-cooling-chapter.pdf.