Market and Technical Analysis of Variable Refrigerant Flow Heat Pump Technology

Prepared For
NYSERDA

Prepared By
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May 15, 2018

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1 Introduction/Background

Vermont Energy Investment Corporation (VEIC) and Energy Solutions were contracted by the New York State Energy Research and Development Authority (NYSERDA) to conduct a market and technical analysis for Variable Refrigerant Flow (VRF) heat pump technology. This analysis will help NYSERDA forecast the technical and market potential of VRFs and provide guidance to NYSERDA based on regionally focused research to help the Products and Digital Solutions team design a prescriptive or hybrid incentive program that would significantly influence the supply chain and increase adoption of VRFs throughout New York State. This analysis is intended to provide foundational information and outputs to assist NYSERDA in the development of effective market-based solutions for VRF technology.

2 VRF Market Barriers and Opportunities

The VEIC team researched and identified major market barriers to VRF heat pump technology in the Northeast and those specific to the New York City (NYC) market. The VEIC team conducted interviews to obtain insights from the VRF supply chain to inform the impetus or drivers behind VRF projects in the Northeast and identify points of potential intervention that would allow NYSERDA to influence the supply chain and spur wider adoption of VRF technology. The team then identified recommended counteractions and resulting benefits to accelerate market adoption.

The research team enlisted senior decision makers from two major VRF manufacturers to support the NYSERDA VRF research. Each manufacturer assembled a Northeast-focused group consisting of senior sales engineers, utility programs directors, and general managers. The research team conducted separate phone interviews with each group. In introductory calls, the research team identified key personnel in each manufacturer's distribution network, and conducted one-on-one interviews with those individuals as well. Finally, the research team conducted numerous follow-on phone interviews and email exchanges to clarify all questions regarding statements made by industry actors. The market research findings in this report are based on observations and statements made by market actors, the research team's firsthand experience implementing programs supporting VRF technology, and other secondary research and sources as cited.

The market research provided in-depth insights on decision-making processes and variability based on VRF project type. The two main project types identified are "plan and specification/spec" (PS) and "design-build" (DB). Detailed descriptions of these two project types are in section 2.1.3. The research team also identified misconceptions that exist about VRFs and opportunities for NYSERDA to address the barriers to broader market acceptance of the technology.

2.1 Major Market Barriers

2.1.1 Broad range of technical and market experience with VRF technology

Barrier Description	VRF manufacturers have varied levels of technical and market experience with VRF technology. Certain manufacturers have been developing VRF technology for decades and have a well-developed training and support infrastructure to complement their equipment sales. Other manufacturers are either newer entrants into the market or do not focus as heavily on the VRF product line within their larger HVAC offerings. Lastly, some manufacturers are newer entrants to the market and are less experienced with VRF technology. The notion of "quality" is subjective and difficult to define. Quantitative metrics such as AHRI EER and IEER ratings are easy to sort by manufacturer, but other factors such as persistence of energy efficiency over time and quality of installation and components are also important factors. As a proxy for attempting to rank manufacturers by quality, factors such as longevity in the industry and contractor training infrastructure may be used to gain an understanding of quality.

Possible solution or counteraction	Education of market actors (including architects, mechanical engineers, and contractors) could help reduce uncertainty and confusion about the variations in quality between VRF manufacturers.
How NYSERDA can address	NYSERDA could create literature that highlights certain VRF features, focusing specifically on installation and design practices, assistance, and training to the HVAC community (architects, mechanical engineers, and contractors). This would help reduce confusion among the design and contractor community with regards to the differences between premium and economic VRF options. However, NYSERDA must be careful to maintain vendor neutrality and simply focus on highlighting positive attributes that higher tier VRF manufacturers deliver.
NYC/Northeast-specific insights	A New York based HVAC company believes that New York City is unique in the level of competition between VRF manufacturers. Because New York City is an ideal location for VRF (mainly due to space constraints, an area where VRF excels), there is a lot more focus on this market than there is in upstate New York. In cities like Albany or Buffalo, not every manufacturer is going to have as heavy a presence in those markets. Daikin, Mitsubishi, and LG are all very active in the NYC market, as well as Fujitsu, Toshiba, and Samsung.

2.1.2 Applicability of VRFs to varying building types and uses

Barrier Description	VRF is an option for all building types that require “comfort cooling.” Comfort cooling is defined as any HVAC application that serves regularly occupied spaces. When dealing with unoccupied or very large open spaces, VRF is not a good option. One manufacturer cited the following conditioned space characteristics as the poorest fit: Unoccupied zones, large spacious zones, and “technical cooling” (servers & data centers). The building types cited above have either much steadier (data centers) or steep peak (assembly) loads. VRFs excel in applications with highly zoned indoor units because of superior part load performance due to the multispeed compressor and multispeed fans, the combination ratio between indoor/outdoor units, and VRF’s ability to move heat between zones. These technical advantages of VRF are explained in sections 3.2.1 and 3.2.5. Applications that have very large or very few zones will play less to VRFs’ strengths than other space types. However, if these space types represent a minority of the building’s load, the engineer may specify VRF anyway for simplicity. These space types would most likely be specified with VRF heat pumps without heat recovery (see section 3.2.5).
Possible solution or counteraction	VRF technology is not the best option for every space type. VRFs excel in “comfort cooling” applications.
How NYSERDA can address	The market appears to understand this barrier and we do not recommend any further interventions by NYSERDA at this time.
NYC/Northeast-specific insights	N/A

2.1.3 Key points of influence for VRF technology selection

Barrier Description	In order to better understand points of influence for VRF technology selection, the VEIC team interviewed manufacturers, factory representatives (FRs), and distributors. The responses were varied but a few consistent threads emerged.

Two main transaction types for VRF projects are "plan and specification" (PS) and "design build" (DB). The decision makers for the two project types are different.

PS projects tend to be more highly engineered and complex than DB projects. In PS, the decisions are made mainly by a mechanical engineer, with the architect, general contractor, and building owner involved. All the parties need to be on board with an HVAC system type, but the mechanical engineer is typically using their experience and preferences to decide which type of system to specify. Various market actors can influence these projects. The breakdown by market actor is: owners-15%, architects-25%, and mechanical engineers-60%. In the PS project delivery, the heating and cooling system type is specified and can be a result of a direct request from the owner. In some cases the exact equipment to be used is specified and in other cases they will site an "equivalent option".

The DB contractor has the most influence on these project types. In most cases, DB Contractors have mechanical engineers on staff. The DB contractor is typically hired by the owner and is the final decision maker for which HVAC systems get installed. It is typically the distributor that would have the most contact and influence over the DB contractor and DB mechanical engineer. The DB contractor market actor tends to have significant flexibility in recommending HVAC systems to the owner.

Contractors, distributors' sales engineers, mechanical engineers (for larger or complex projects), and to a lesser extent building owners have influence over the direction of the HVAC system specifications on DB projects. *When given the choice, DB contractors are pressured to make decisions that result in recommending lower price and lower efficiency equipment.* The reason for this is that most DB contractors are responding to request for proposals or project cost proposals (single contractor bid) that historically result in the low bid winning the work. Distributors have significant influence with DB contractors and mechanical engineers to influence decisions that would typically result in low bid and specify low efficiency equipment.

Also, *most DB contractors do not understand "energy efficiency"* and can be driven by margins and completing projects quickly. A majority of contractors do not focus on upselling efficiency in DB projects. A minority of DB contractors that actively encourage high efficiency products and designs. Building owners are typically concerned with first costs and frequently cancel energy efficient options, ignoring or not understanding life cycle costs advantages.

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 contractor. VRF distributors have trained engineers that support market actors in both project types. Distributors' sales engineers attempt to connect with decision makers to influence the best HVAC system for the project. *The distributor is "in the driver's seat" when it comes to offering incentives for stocking and upselling of VRF equipment.* Manufacturers do reach out and offer technical support to distributors as well as having direct contact with mechanical engineers and architects.

In conclusion, both PS and DB projects have opportunities to influence energy efficient decision making.

Possible solution or counteraction	The distributor/FR will have the best understanding of the market and will be motivated to drive the conversation toward VRF. Distributors are located "upstream" in the market chain. Distributors will compete with one another and

	have successfully transformed markets by pushing (via stocking and upselling) high efficiency options. The mechanical engineer is a highly influential market actor in PS projects and can also influence DB projects. It is essential to eliminate all misconceptions that the engineering community may have about VRFs (see section 2.1.5). NYSERDA should consider supporting distributors and manufacturers in educating the engineering community about VRF's benefits. Contractors and distributors influence small ROB (replace on burn out) and NR (normal replacement) projects. Distributors and mechanical engineers can influence large ROB and NR projects.
How NYSERDA can address	Distributor incentives are an attractive option for NYSERDA to increase the sales of VRF technology. Distributors control stocking and upselling and directly engage and/or train contractors, mechanical engineers, and architects. Once engaged and effectively incented, distributors can play a significant role in both PS and DB projects.
NYC/Northeast-specific insights	N/A

2.1.4 Different market channels for VRF technology sales

Barrier Description	Depending on whether the project is PS or DB, the equipment may move through different market actors before being installed at the project site. There are two distinct upstream market actors – FRs and distributors. They behave slightly differently from one another. Reported by one manufacturer, PS jobs will go to FRs. DB projects will occasionally go to FRs, but mainly go to distributors. Some manufacturers may only work with either a FR or a distributor, whereas others have experienced success with both strategies to influence HVAC system designs and specification. One reason suggested is that the distributor is seen as being more responsive and faster to react. Distributors will stock VRF equipment while the FR typically "upsells" high efficiency equipment. DB projects tend to have a quicker turnaround and the distributor can satisfy that need through stocking of high efficiency equipment. One major manufacturer estimates that 65% of their VRF projects are PS, and about 35% are DB. Our research indicates that this breakdown by project type is fairly representative of both the Northeast and NYC specifically. When accounting for the FR/distributor breakout, roughly 70% of projects go to FRs, and 30% go to distributors. A high-level illustration of project pathways is shown in Figure 1. It should be emphasized that this is based on feedback for common VRF projects and does not apply in every case.
Possible solution or counteraction	Manufacturer FRs and distributors operate on the same "level" in the supply chain and equally important market actors with whom to partner.
How NYSERDA can address	Since most VRF projects are not replace on burnout (ROB) situations they involve more long-range planning. In an ROB project, we expect that the building owner would replace the existing failed system with a "like-for-like" new system. In planned out, non-ROB projects (PS), a distributor incentive will likely be passed down to the building owner, assisting with the issue of up-front costs and increasing the likelihood of a more efficient equipment choice. In DB, a distributor incentive will promote stocking and upselling of VRF equipment to

	the contractor. In all cases, the "free market" is the best and most efficient determinate of how it will leverage the incentive depending the many different transactions types, size of building, on-site conditions, and complexity of design solutions. This has proven itself over many years of intervention strategies.
NYC/Northeast-specific insights	The research team is not aware of differences between NYC and upstate NY projects with regards to market channels at this time.

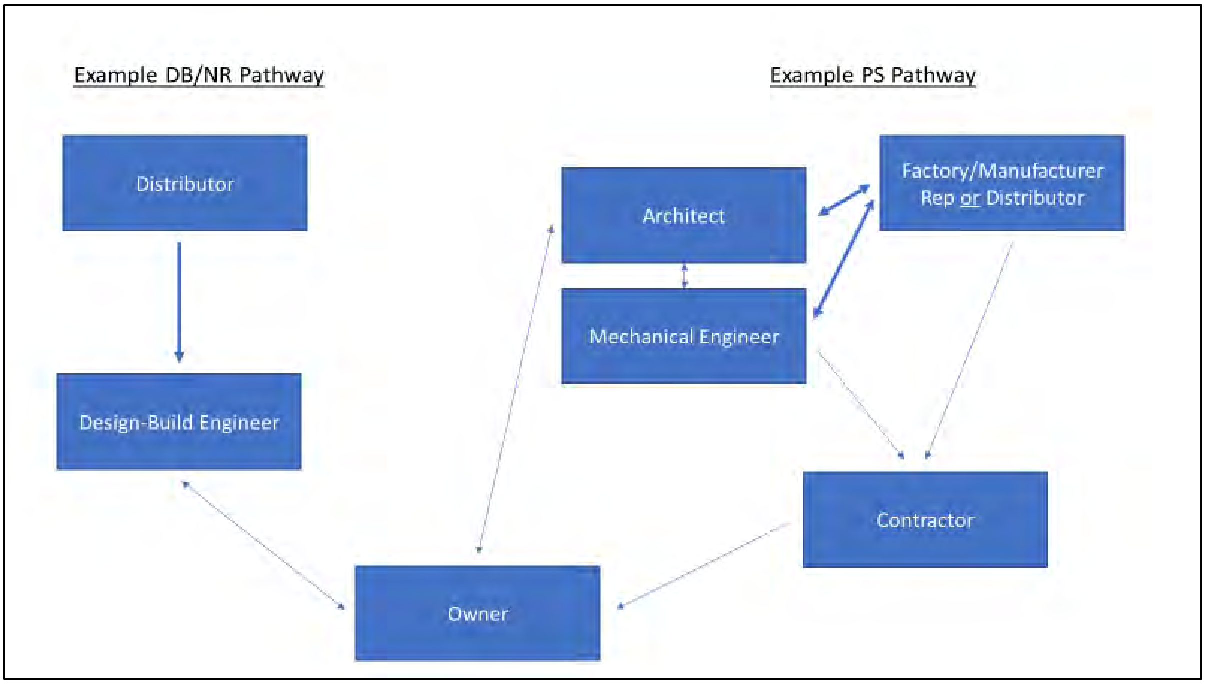

Figure 1: Example VRF Project Pathways

2.1.5 Misconceptions about VRF technology and applications

Barrier Description	The technical heating issues of VRF are explained in more detail in section 3.1.2. There are perceived barriers that can be categorized as outdated notions about the heating capabilities of VRFs and, more generally, heat pumps as compared to fossil-fuel based heating. This is a market issue because market actors (including customers) are not relying on recent developments or data, but rather on vague and outdated notions of the inadequacy of heating with VRF equipment. While heat pumps may have had issues with heating at low ambient temperatures 15-30 years ago, the technology has advanced and today heating needs can be met with modern heat pump equipment and proper sizing. The specific numbers vary by model and manufacturer, but product literature shows that cold climate VRF equipment can operate at 100% capacity down to 0°F, and at reduced capacity down to -25°F. According to ASHRAE design-day data, NYC's 99.0% heating design temperature is 17°F and clearly fits within the operational range of VRFs. There is also the misconception that heating with natural gas is the cheapest option. Economics are dependent on the cost of electricity and the performance of the heat pumps vs. the cost of natural gas on a $/MMBtu basis. VRF and heat pumps in general will be most commonly be superior to oil-fired space heating, followed by propane heating, and finally natural gas heating in that order. A high performing natural gas heating system can be less expensive

	than VRF, but the market has overstated the degree to which natural gas is superior to heat pumps. Other misconceptions relate to skepticism about the benefits and advantages of VRF. For example, some individuals think that the long refrigerant piping runs would preclude energy efficient operation. Others perceive code compliance barriers to VRF installation (such as the need to comply with ASHRAE 15 or ASHRAE 62), when in fact it is possible to overcome them in every VRF installation.
Possible solution or counteraction	The commercial building market needs to catch up with the improved performance characteristics of VRF and best practices for meeting building standards. An effective counteraction to these misconceptions could be to highlight the facts through case studies, testimonials, and marketing materials.
How NYSERDA can address	NYSERDA should highlight outdated misconceptions about VRF and why they are inaccurate. This could involve fact sheets and other marketing materials. NYSERDA should focus on decision makers/building operators and design engineers, with training materials targeted to each specific market actor.
NYC/Northeast-specific insights	The climate differences between NYC and upstate New York will impact what heat pumps are capable of, so materials should be tailored to specific markets. For example, cold climate condensers should be highlighted in upstate New York (see section 3.1.2), while standard condensers can be featured in NYC.

2.2 Major Market Benefits/Opportunities

2.2.1 Effective in Many Building types

Opportunity Description	Manufacturers suggested that VRF projects will work well in any space type that provides comfort cooling. Offices (both small and large), multifamily (including apartments, residential town homes, dormitories, and condos), assisted living, hotel/motel, and K-12/university are all good building types for VRF. Energy Solutions' data from other programs also supports this assessment. The common attributes of these building types are that the zoning tends to be smaller, the occupancy ranges from low to high throughout the day (creating lots of opportunities for part-load and heat recovery operations), and of course, they are all comfort cooling applications.
How NYSERDA can address	NYSERDA could highlight, through case studies, exceptional VRF projects that could serve as a model for what NYSERDA would like to see in its incentive programs.
NYC/Northeast-specific insights	NYC has many more appropriate building types than the rest of New York State because of the very limited space availability in the city (both on the roof and between floors, see section 3.2.2) and the prevalence of existing water piping in buildings for water-source VRF retrofits. That said, New York State does have appropriate building types for VRF retrofit and new construction projects.

2.2.2 Extensive training network/requirements from top manufacturers

Opportunity Description	The top VRF manufacturers offer extensive design (focused on Architects and Mechanical Engineers) and installation training (focused on Contractors). Contractor training is a requirement before VRF installation can take place at a given location. This takes the form of multi-day training classes, including lectures and hands-on activities that lead to certification.

	Top VRF manufacturers believe these trainings support high quality installations which exceed that of competitors who may not hold contractors to as rigorous standards.
How NYSERDA can address	NYSERDA could consider encouraging projects be installed by contractors who have received a manufacturer's training class. This would ensure that only high quality VRF projects are incentivized by a potential program. Through close partnerships with distributors and regional contractors, NYSERDA could place an emphasis on long term program investments to justify individual contractors having to miss a day of work to attend training. As industry, notably manufacturers, typically address this need, it is not a necessary program requirement.
NYC/Northeast-specific insights	NYC has a greater concentration of training facilities than the rest of the state.

2.2.3 Manufacturers and distributors perform daily outreach to engineers & contractors

Opportunity Description	A point that was emphasized to the research team during manufacturer interviews is the fact that VRF manufacturers and distributors have very close relationships with design engineers and contractors. Manufacturers and distributors call on mechanical engineers and contractors daily to continually educate these actors on VRF benefits and good applications. Manufacturers and distributors state that this persistence leads to more VRF projects and better ongoing service of existing projects. The manufacturers try to stay on the architects' radar as well by attending AIA events. Manufacturers perform more outreach to architects than they have in the past.
How NYSERDA can address	NYSERDA can amplify distributors' messages to mechanical engineers, architects, and contractors by providing branded content that lends credibility and authority to the stated benefits of VRF.
NYC/Northeast-specific insights	No regional insights were discovered.

2.2.4 VRF excels in partial load applications and should be reflected in program design

Opportunity Description	Though the specifics of VRF's part load performance is described in further detail in section 3.2.4, it should be noted that from a program design/market perspective, *it is the Integrated Energy Efficiency Ratio (IEER) metric that should be emphasized in VRF systems rather than the Energy Efficiency Ratio (EER) metric*. The IEER metric utilizes test data at four points meant to simulate the varying conditions that mechanical equipment experiences throughout the year, whereas EER is only measured at peak ambient conditions and at the equipment's rated capacity. Though EER is important for sizing & electric grid capacity considerations, IEER is much more relevant from an energy efficiency standpoint. The EPA ENERGY STAR specification for VRFs includes a stringent EER and IEER requirement. VRF manufacturers have indicated that some of their equipment has difficulty meeting the EER requirement, and is therefore is excluded from the ENERGY STAR program as a result. See Table 1 for the full ENERGY STAR VRF specifications.
How NYSERDA can address	Because the federal standards and ASHRAE 90.1 contain EER requirements for VRF equipment, there is a "backstop" that prevents the equipment from placing too much strain on the electric grid during peak periods. A program should focus instead on high performing IEER equipment. Another option

	would be to simply require ASHRAE 90.1-2016 IEER levels (that took effect 1/1/2017) and design the program around the notion of switching from inefficient traditional HVAC (such as code minimum DX or PTACs) and fossil fuel heating to VRF. Either way, EER should not be a focus for program design.
NYC/Northeast-specific insights	No regional insights were discovered.

Table 1: ENERGY STAR VRF Specifications

Equipment Type	Size Category	Heating Section Type	Minimum Energy Efficiency Criteria
Air-Source Central Air Conditioner	≥65,000 Btu/h to <135,000 Btu/h	All	20 IEER, 13 EER
Air-Source Central Air Conditioner	≥135,000 Btu/h to <240,000 Btu/h	All	18.5 IEER, 12 EER
Air-Source Heat Pump	≥65,000 Btu/h to <135,000 Btu/h	Without Heat Recovery	20 IEER, 13.0 EER, 3.7 COP*
		With Heat Recovery	19.8 IEER, 12.8 EER, 3.7 COP*
Air-Source Heat Pump	≥135,000 Btu/h to <240,000 Btu/h	Without Heat Recovery	18.5 IEER, 12.0 EER, 3.5 COP*
		With Heat Recovery	18.3 IEER, 11.8 EER, 3.5 COP*

*COP rated at 47°F
Source: https://www.energystar.gov/sites/default/files/LC%20HVAC%20V3%20Draft1_160512.pdf

3 VRF Technical Barriers and Opportunities

The VEIC team researched and identified major technical barriers to VRF heat pump technology in the Northeast and those specific to the New York City market through a combination of industry interviews, secondary research and leveraging the program engineering experience on the VEIC team. The team then identified recommended counteractions and resulting benefits to address these technical barriers.

The research team interviewed VRF engineers with two major VRF manufacturers about VRF's technical benefits and barriers. These interviews served as a starting point, and the follow-up research in this section was more focused on internet research into resources such as the International Energy Conservation Code (IECC), AHRI Standard 1230-2010 "Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment," ENERGY STAR Specifications, ASHRAE standards 15, 34, and 62, and the 2016 ASHRAE Handbook of HVAC Systems and Equipment Chapter 18, "Variable-Refrigerant Flow Systems." The research team also relied on experience with VRF equipment and incentive programs in Vermont, Massachusetts, and California.

VRF's technical benefits should be highlighted by NYSERDA in marketing materials to engineers, architects, and owners. Information disseminated from an unbiased neutral party such as NYSERDA will lend credibility to the efficiency and non-energy benefits of VRF. Similarly, VRF's technical barriers should also be highlighted to prevent the misuse of VRF equipment in applications that are not appropriate.

3.1 Major Technical Barriers

3.1.1 Economizer requirements in IECC 2015

Barrier Description	A point made among every market actor interviewed for this project is the fact that the latest update to the New York State Energy Code (based on IECC 2015,

effective as of 10/3/2016[1]) includes an economizer requirement that doesn't have an exception for VRFs in NYC's climate zone.

A comparative review of IECC 2012 and IECC 2015 reveals that the language was altered in the prescriptive economizer requirement section to now include VRF equipment. In IECC 2012, economizers were required for equipment that was included in specific tables in the code (tables C403.2.3(1) through C403.2.3(8)), which did not include VRF equipment. In IECC 2015, the economizer requirement is a blanket requirement for all HVAC equipment. For reference, in both editions of the code, the economizer requirement is section C403.3.

IECC 2015 section C403.3 contains nine exceptions that eliminate the economizer requirement. The ones relevant to VRFs are exceptions 2 and 7 and are discussed below.

Exception 2 states (note that climate zones 1A and 1B are "very hot – humid" and "very hot – dry," respectively, and not applicable to any location in New York State):

"In climate zones other than 1A and 1B, where individual fan cooling units have a capacity of less than 54,000 Btu/h (15.8 kW) and meet one of the following:

"2.1 Have direct expansion cooling coils.

"2.2 The total chilled water system capacity less the capacity of fan units with air economizers is less than the minimum specified in Table C403.3(1).

"The total supply capacity of all fan-cooling units not provided with economizers shall not exceed 20 percent of the total supply capacity of all fan-cooling units in the building or 300,000 Btu/h (88 kW), whichever is greater."[2]

This means that only for VRF installations less than 25 tons, indoor units need to be 4.5 tons or less. For VRF systems at 25 tons or less, 100% of the load can be met without economizers. For VRF systems from 25 to 125 tons, only 25 tons worth of the load can be met without economizers. For VRF systems greater than 125 tons, only 20% of the building load can be met without economizers.

Exception 7 allows for efficient HVAC systems in certain climate zones to avoid the economizer requirement. However, this currently does not apply to New York City's climate zone (ASHRAE CZ 4A). The climate zones that could potentially qualify for exception 7 include 2B, 3B, and 4B (note that any climate zone with the suffix "B" refers to a dry climate which does not apply anywhere in New York State).

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 (see section 3.2.1 for a detailed discussion on how VRFs reduce fan energy consumption).

[1] https://www.energycodes.gov/adoption/states/new-york
[2] https://up.codes/viewer/new_york/iecc-2015/chapter/CE_4/ce-commercial-energy-efficiency#C403

Possible solution or counteraction	Designers can simply design the DOAS system large enough to provide airside economizing, though this is an expensive option. Also, prescriptive requirements can be circumvented through utilizing "performance paths" like ASHRAE 90.1-2013 to meet code. This involves tradeoffs between different elements of the design to meet an overall energy target. In terms of adjusting the code, ideally exception 7 would be expanded to include more climate zones, at efficiency improvement percentages appropriate for the specific climate zone. The California Energy Commission has researched the viability of "refrigerant-side economizers"[3] in unoccupied cooling space types (such as data centers), but per section 2.1.2, these are not the best space types for VRF. Further investigation may be required.
How NYSERDA can address	NYSERDA can assist by proposing an exception to section C403.3 that appropriately credits energy efficient systems in CZ 4A. The efficiency improvement would likely be an addition to exception 7. The exact improvement would be determined through energy modeling in software such as EnergyPlus. NYSERDA should also investigate the potential for allowing heat recovery VRF systems to qualify from an economizer exemption, because this type of VRF system does optimize heat sources and sinks like an economizer. The opportunity to influence IECC 2018 has passed, but NYSERDA can get involved over the next year in the changes to IECC 2021. IECC codes typically contain typos and closer attention to cross-references would vastly improve the quality of the code language.
NYC/Northeast-specific insights	New York State has adopted IECC 2015, so technically this issue applies to the entire state. The NYC Department of Buildings strictly enforces the energy code. Code enforcement throughout the rest of the state may vary which could provide some flexibility. Additional research would be required to assess code enforcement outside NYC.

3.1.2 Installing VRFs in cold climates

Barrier Description	Air-source VRFs will experience a "de-rate" at low ambient temperatures. This is an inevitable result of the fact that cold air contains less energy than warmer air. Therefore, when installing VRF in a cold climate, attention must be paid to the system performance at the location's design ambient temperature. It should be noted that this "barrier" has received an extensive amount of attention within the industry and can be easily overcome with good design. The true barrier is the misconceptions around VRF performance in cold ambient conditions, which is further outlined in section 2.1.5. It should be noted that there can be a tendency to oversize heating/cooling loads which will cause a drop in performance throughout the year or alternatively install a backup system incorrectly perceived as needed. New construction applications require collaboration between the architect and the MEP so that there is confidence in the thermal shell to "fly wheel" through some colder temperature periods. If a backup system is proposed, the cost can double, often resulting in the VRF system being value engineered out. In a retrofit application, the existing heating system can be left in place (often it is

[3]http://www.energy.ca.gov/business_meetings/2015_packets/2015-09-09/Item_10_Refrigerant_Economizer_Staff_Paper_FINAL.pdf

	hydronic) even if it is not is peak condition, only to be used on an emergency basis.
Possible solution or counteraction	There are multiple possible solutions to this issue. Manufacturers now make cold-climate optimized VRF outdoor units, for example Daikin's is the Aurora system, and Mitsubishi's is the Hyper-Heating system and have stated full heating capacity at 0°F. Other options include simply sizing a standard VRF model to the appropriate design heating temperature, installing the VRF condensers in the mechanical room or "dog house," or using water-cooled VRF condensers. The popularity of these relative options tends to vary based on the geographical location of the project (see NYC/Northeast-specific insights). The bottom line is that VRF equipment is extremely capable to operate as the sole heating source in cold climates using one of the strategies identified above.
How NYSERDA can address	Consider setting different incentive rates for cold-climate specific equipment as compared to standard VRF equipment.
NYC/Northeast-specific insights	The design day temperature for heating drives which model is used for VRF condensers. If the design day temperature is relatively mild (such as NYC or Long Island), then the standard VRF unit may simply be "upsized" by an appropriate amount. This means the unit is sized for the heating load instead of the cooling load. For reference, the ASHRAE 99% heating design temperature is 15 °F for Long Island and 17 °F for NYC. For colder sites (such as upstate New York), cold climate equipment is more typically used. For reference, the ASHRAE 99% heating design temperature is 3 °F for Albany and 6 °F for Rochester. And for the coldest sites (such as Canada), water-source VRF is the most efficient option.

3.1.3 ASHRAE 62 Compliance (code ventilation levels)

Barrier Description	Because VRF moves heat throughout the building using refrigerant piping, and not air ducts, ASHRAE Standard 62 "The Standards For Ventilation And Indoor Air Quality" is satisfied when additional steps are taken. Typically, this solution is a dedicated-outdoor air system (DOAS), but in some projects natural ventilation may qualify. This is not a "major barrier" because the solution has been so thoroughly developed. However, it is an important aspect of VRF commercial projects and should be noted. Also, it comes into play with the IECC 2015 economizer requirements (section 3.1.1) and must be understood. ASHRAE 62.1 requires that a certain amount of fresh outdoor air be provided to the indoor conditioned spaces. The exact amount varies by space type. For offices, the amount is 5 cfm/person and 0.06 cfm/ft^2. As a first approximation, ASHRAE 62.1 fresh air rates are about 20% of the amount of air needed for a traditional Package VAV solution that utilizes air ducts to provide all heating and cooling.
Possible solution or counteraction	As mentioned above, DOAS is the primary method to address this barrier. Using smaller air ducts for fresh air ventilation than standard HVAC air ducts is possible because the fan power required to move ventilation air in the DOAS system is a small fraction of the fan power required to move "supply" air in a standard HVAC system. This phenomenon is a result of the fan affinity laws that state that air power is proportional to the cube of cfm. If one assumes only 20% of the supply air cfm is required for ventilation air, then even less than 20% of

	fan motor power is required because the duct diameter for ventilation air is smaller and friction rates are higher in DOAS systems. It's not a perfect cubic relationship, but there is a substantial benefit to DOAS.
	In a DOAS system in New York, energy or heat recovery ventilation (ERV or HRV) is typically used. This allows the building to pre-heat/cool the incoming fresh air using exhaust air leaving the building. This solution was stated by industry to be common practice.
	There are different philosophies on what temperature to condition DOAS air to before delivering it to the conditioned space. Some bring the air all the way down to the set point that the indoor recirculating air is at (i.e. 90 °F for heating, 55 °F for cooling). But more commonly, the air is brought to a "neutral" temperature of about 65-75 °F. The choice is up to the individual designer. The DOAS system typically has its own DX coil and furnace.
How NYSERDA can address	NYSERDA may want to consider additional incentives for ERV or HRV units in VRF projects. NYSERDA will also be encouraging the highest efficiency and performance of DOAS in projects, while also addressing their incremental cost.
NYC/Northeast-specific insights	ERV and HRV will operate differently based on climate zone. Features such as latent energy recovery may be more or less appropriate throughout the state. Defrost controls will vary depending on climate zone.

3.1.4 ASHRAE 15 & 34 Compliance (refrigerant safety)

Barrier Description	Like the ventilation requirements, ASHRAE standard 15 "Safety Standard for Refrigeration Systems" and ASHRAE standard 34 "Designation and Safety Classification of Refrigerants" are well known requirements among the VRF community. There is a logical reason for the existence of these standards because even though R-410A (the most common refrigerant used in VRF equipment) is not flammable or toxic, it can displace oxygen and render a room uninhabitable if too much refrigerant is released too quickly.
	The safety standards essentially put a limit on the mass of refrigerant that is allowed in a volume of space. For most space types, it requires 26 pounds or less of refrigerant per 1000 ft^3 (13 pounds or less per 1000 ft^3 for institutional occupancies such as hospitals, nursing homes, or asylums). There are exceptions and other requirements, but this is the data point that is typically designed around.
Possible solution or counteraction	This perceived barrier does not hinder VRF installations because engineering solutions have been developed safe design and installation practices to address refrigerant safety. Professional installations across the country over a period of the last two decades have proven out VRF systems are being designed and installed for refrigerant safety. The issue is unique from project to project and therefore the approach differs each time. Solutions usually take the form of increasing the size of the zone, re-routing refrigerant piping, or reducing the refrigerant charge by dividing the refrigerant circuit into multiple smaller zones if it is determined that there is too much refrigerant in a smaller zone. The measures used to comply with ASHRAE 15 and ASHRAE 34 are described in Daikin's white paper "ASHRAE Standards 15 and 34 – Considerations for VRV/VRF Systems"[4].

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

How NYSERDA can address	Intervention by NYSERDA is not necessary.
NYC/Northeast-specific insights	N/A

3.2 Major Technical Benefits/Opportunities

3.2.1 Lower fan energy consumption/less ductwork

Opportunity Description	In terms of outside air, as described in section 3.1.3, VRF systems are installed with only the code-minimum amount of ventilation rates required. That results in much lower fan energy consumed due to lower static pressure set points and less cfm of air. Also of critical importance is the reduction in duct leakage that lower cfm rates result in, which saves tremendous energy. The Florida Solar Energy Center (FSEC) studied the impact of reduced or eliminated ductwork in VRF systems compared to traditional air-distribution HVAC setups and found duct conduction loss savings in the range of 3-7% and duct leakage loss savings in the range of 6-12%[5]. The results vary significantly depending on building type, climate, and duct design. In addition to outside air requirements, VRF systems require some indoor fan energy to move air over the refrigerant coils. This is a small amount of energy due to the very low static pressure requirements when compared to a traditional extensive air distribution network.
How NYSERDA can address	NYSERDA should highlight the energy saving benefits of VRF in marketing materials.
NYC/Northeast-specific insights	N/A

3.2.2 Smaller VRF footprint on the roof & between floors

Opportunity Description	In medium size (100-500 ton) installations, air-cooled VRFs have a smaller footprint and are more flexible than the water cooled condensers (with one larger compressor and a large cooling tower). Water-source VRF condensers can be installed in numerous small mechanical rooms located throughout the building. Refrigerant lines are smaller in diameter than chilled water piping and free up space in that regard, and result in less auxiliary equipment. Furthermore, the DOAS systems that are typically installed in VRF systems contain much smaller ductwork than traditional air distributed HVAC systems.
How NYSERDA can address	NYSERDA should highlight the space saving benefits of VRF in marketing materials. VRFs allow for a greater percentage of the building volume to be utilized (through narrower plenums and greater ceiling heights or a greater floor density per vertical foot).
NYC/Northeast-specific insights	The premium on space is much greater in NYC than it is throughout the rest of the state. However, in any urban core (such as Buffalo, Rochester, and Albany), VRF will stand out due to its smaller footprint.

[5] http://fsec.ucf.edu/en/publications/pdf/FSEC-cr-1968-13.pdf

3.2.3 VRF's combination ratio between outdoor and indoor units

Opportunity Description	Because VRF is highly zoned and has multi/variable capacity compressors, the phenomenon of a "combination ratio" between the outdoor unit capacity and the indoor unit capacity arises. This means that the sum of an indoor unit's capacity typically exceeds that of an outdoor unit's capacity. This happens because the building zones may hit their peak at different times in the day (e.g., east facing zones will have a higher cooling load in the morning, while west facing zones will be higher in the afternoon), and building occupancy fluctuates (e.g.,. a conference room may be sized for 6 tons, even though most of the time the actual load is a small fraction). The effect of these factors is that the total indoor unit capacity can be much higher than what is required of the outdoor unit at any given time. This allows the outdoor unit to be smaller than may be the case with other HVAC technology types. This only applies to "point source" HVAC systems such as package unitary AC or PTACs. Central plants with chillers or water-source heat pumps can take advantage of zoning to right-size both the indoor and outdoor units.
How NYSERDA can address	Educate the market on the benefit of VRF's combination ratio to energy efficiency.
NYC/Northeast-specific insights	N/A

3.2.4 Variable speed compressors and fans

Opportunity Description	While the rest of the HVAC market is gradually migrating from single speed compressors to two, three, and eventually variable speed, VRF compressors can match the building load at any level. VRF compressors are three or more speed by definition, and many are continuous "inverter-duty" compressors. Inverter-duty compressors allow for a soft start to load ramp-ups and no sudden compressor cycling. The variable speed compressor also reduces unit cycling in part load conditions which helps with energy efficiency, set point management, and occupant comfort. Furthermore, compressor operation in part load allows for the combination ratio outlined in section 3.2.1 and allows designers to reduce condenser size (i.e. capacity). It should be noted that though heavily insulated, the long refrigerant line runs do result in some energy losses and offset some of the compressor efficiency gains. This is accounted for in energy models of VRF systems. Indoor fans can also vary in speed to match the flow rate of refrigerant entering the fan coil unit. This allows for further energy savings and comfort due to reduced air velocity in the zones.
How NYSERDA can address	NYSERDA can educate the market on the energy saving benefit of VRF's variable speed compressor.
NYC/Northeast-specific insights	N/A

3.2.5 Heat Recovery option

Opportunity Description	VRF technology, when installed with a heat recovery system, allows for transfer of heat between zones. This stands in contrast to traditional HVAC systems that must simultaneously expend energy to heat and cool various parts of the building. In heat recovery mode, the VRF compressor acts more like a pump,

	moving refrigerant throughout the network, and the branch selector boxes determine which zones receive either high or low-pressure refrigerant. Heat recovery VRF can significantly reduce energy consumption in certain situations. For example, in the winter, the perimeter zones could be in heating mode while the interior zones still require cooling. Also, depending on building shading and the time of day (at any time of year), zones facing east or west could have drastically different heating/cooling needs. Lastly, building occupancy could vary between offices and conference rooms. These are all factors that heat recovery VRF can efficiently address and reduce outdoor unit energy consumption. Conversely, when all zones are simultaneously in heating or cooling for most of the year, heat recovery equipment will not be the cost-effective option and the engineer should use heat pump VRF instead. Example 2 below shows a standard heat recovery VRF layout.
How NYSERDA can address	NYSERDA can highlight the energy saving benefit of proper applications of heat recovery in marketing materials.
NYC/Northeast-specific insights	N/A

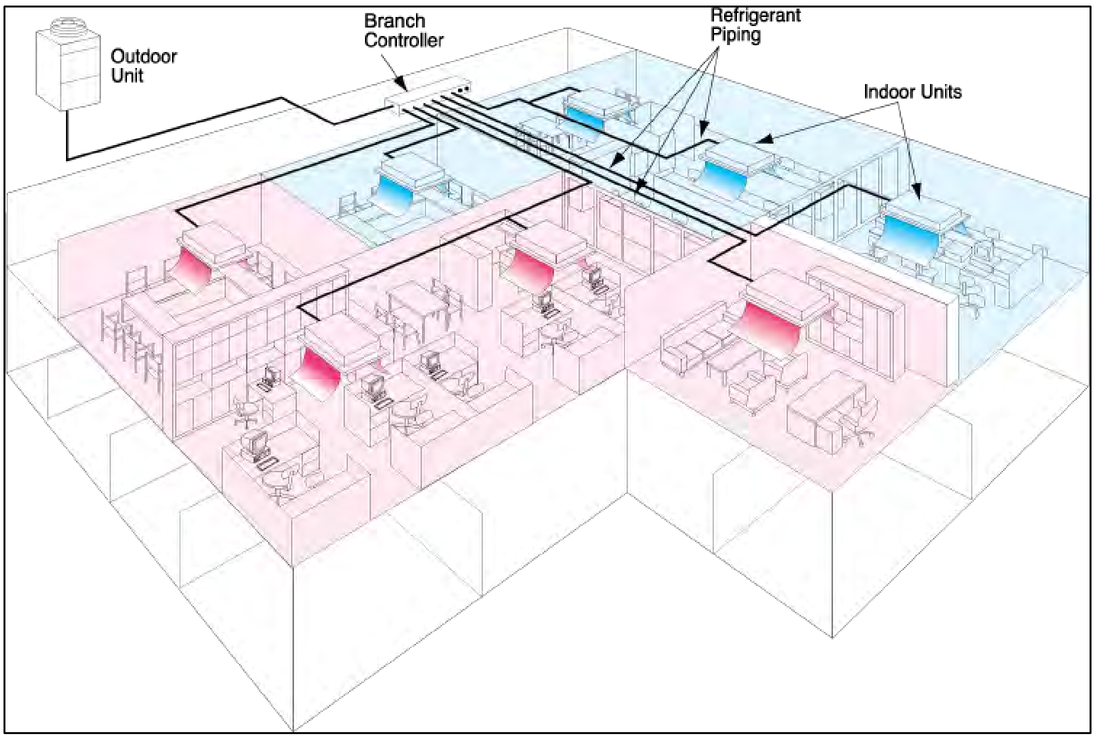

Figure 2: Example of Heat Recovery VRF Layout

3.2.6 Occupant comfort/Advanced controls

Opportunity Description	Because of reasons outlined in section 3.2.4, occupant comfort is a major benefit to VRF technology. The combination of the inherent variability of VRF with the factory-standard advanced controls that ship with the technology result in superior occupant comfort. VRFs tend to not overshoot the space temperature setpoint because of the continuous micro-adjustments that both the indoor and outdoor equipment make, and therefore also does not overcorrect. VRFs have superior humidity control with lower air flow. The result is greater occupant comfort.

How NYSERDA can address	NYSERDA can highlight the comfort benefits in marketing materials.
NYC/Northeast-specific insights	N/A

4 VRF Building Energy Modeling for New York City and Northeast

VEIC performed building energy modeling (BEM) analysis for five (5) building types across two (2) climate zones to study the effect of switching from more traditional, fuel-based HVAC systems to a DOAS/VRF system with heat recovery. A few key trends identified in that analysis are listed below. The terms "heating dominated" and "cooling dominated" are relative to the New York State climate regions.

- In general, cooling dominated buildings achieve higher energy and cost savings. This is characterized by large offices in the southernmost areas of NY, which tend to have high internal loads and large variable air volume (VAV) air distribution systems.
- In heating dominated buildings, large fuel savings are achievable but the cost savings are dependent on 1) whether overall electricity use can be reduced or kept steady; and 2) the ratio of fuel prices to electricity prices. This is characterized by older vintage apartment buildings that rely on unregulated fuels and ideally more southerly locations (although unregulated fuels are generally more prevalent to the north).
- In those heating dominated buildings that rely on unregulated fuels, the switch to DOAS/VRF offers significant improvements in energy cost stability by greatly reducing the dependence on fuels with historically volatile pricing.
- Cooling dominated buildings with existing large air systems can experience an overall reduction in electrical demand in all seasons. That reduction is more significant during the coincident summer peak period but fan savings in the VRF/DOAS system may contribute to year-round peak reductions. This is characterized by large offices in southern parts of the state with VAV air distribution systems.
- Heating dominated buildings may experience an increased annual electrical demand peak, although it shifts from summer peak to winter peak. The summer peak that is coincident with the overall NYISO peak does decrease but the winter peak increases tend to be higher than the summer peak decrease.
- To evaluate any one specific project, utility analysis should be performed to understand the existing breakdown of electrical loads by end use and the relationship of cooling loads to heating loads (to the extent possible). That will ensure building owners can make better informed choices about the potential benefits or drawbacks of the adoption of VRF technology.

4.1 Overview of VEIC's VRF Building Energy Model and Approach

VEIC's VRF building energy modeling (BEM) is conducted in OpenStudio, an open-source interface with EnergyPlus, an extremely flexible and powerful BEM platform developed by the U.S. Department of Energy (DOE) and the National Renewable Energy Lab (NREL). EnergyPlus is considered the replacement to the outdated DOE-2 platform, on which e-Quest (one of the most popular BEM tools) is built. In addition, NREL has developed open-source scripts that allow for quick generation of "prototype" building models. The DOE prototypes are populated with inputs based on national-level assessments of the Commercial Building Energy Consumption Survey (CBECS)[6] and national energy standard data. VEIC leveraged the DOE prototypes and applied appropriate alterations based on findings from the NYSERDA VRF market and technical analysis and regional and state specific building data.

Independently and in coordination with national collaboration initiatives like the Open Efficiency Initiative (OEI), VEIC has developed several OpenStudio "measures" (Ruby scripts) specific to evaluating the impact

[6] "Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey that collects information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures." https://www.eia.gov/consumption/commercial/

of changing building HVAC systems to VRF plus DOAS with exhaust air energy recovery. The VEIC VRF building energy modeling analysis uses these measures combined with Amazon Web Service (AWS) cloud servers to carry out large sets of BEM parametric analysis using OpenStudio and the DOE Prototype Buildings.

The VEIC analysis estimates 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. The scenarios include varying fuel prices, building age, internal electrical loads, and shell characteristics. Each scenario is applied to the building types and local climate conditions. For example, the medium multifamily and medium office building types are modeled with climate conditions in both New York City and Rochester. The high rise office and high rise multifamily are modeled in New York City exclusively. The small office building is modeled in Rochester exclusively.

Building types are drawn from the DOE's commercial reference buildings (formerly called "building benchmarks") that represent most commercial buildings of that type in each climate zone. Each collection of building type performance data includes details about the standard heating and cooling systems for that building type. These default systems represent the most common HVAC equipment types in each building type, with default performance levels (e.g. EER) reflecting the vintage of the chosen building.

VRF systems are more complicated than standard efficiency measures because they fundamentally alter how space conditioning services are delivered. VRF is often coupled with a dedicated outdoor air system and an energy recovery ventilation system. VRF technology is sensitive to outdoor conditions and to building load, which can vary significantly in newer buildings with advanced envelopes.

Energy modeling addresses these challenges through interactive, hourly internal load calculations that explicitly model technology performance characteristics given different variables and allow direct comparisons to baseline (existing) HVAC equipment.

Specifically, the VRF module used in the energy modeling software consists of custom code developed by VEIC to measure outcomes in buildings with and without VRF equipment. VRF performance is based on the California Energy Commission's Building Component Library entry for VRF, which in turn is based on a range of actual VRF performance levels.

Within the large parametric analysis framework, focus is directed towards specific output results. By building an appropriate analysis space and setting appropriate boundary conditions, the sensitivity of specific program or project objectives – notably energy, cost, and greenhouse gas (GHG) reductions - are better understood in relation to building, utility, or climate characteristics. For example, load shape as an output characteristic is an important indicator for application of a VRF program, so the large parametric analysis is directed to demonstrate responsiveness of a VRF program through the proposed input variations.

4.2 Building Stock Characteristics

4.2.1 Building Choice and Market Research

Seven building-location pairs were chosen to model:

- Medium-rise and high-rise office, and multifamily buildings in New York City (4 in total),
- And a low-rise office, a medium-rise office, and a medium-rise multifamily in Rochester (3 in total).

New York City and Rochester were used only as representative cities for climate averages in downstate and upstate regions, respectively. These seven prototypes are intended to reflect buildings in New York State that are both numerous and well suited for VRF systems. Given the need for a "high degree of individual zone control," NYSERDA's previous work on heat pump potential identified large office and multifamily buildings as among the best suited buildings for VRF systems.[7] Compared to other building types well suited for VRF equipment, office and multifamily buildings are more prevalent than hospitals,

[7] NYSERDA (2014), Heat Pumps Potential for Energy Savings in New York State, https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Current-Outlook/Presentations/Heat-Pumps-Potential.pdf.

nursing homes, and schools, or—as compared to strip malls—more likely to have shared HVAC equipment among multiple tenants. This corresponds with a study conducted for the State of Minnesota that notes VRF systems are less competitive than rooftop units in one story retail buildings.[8]

4.2.2 CBECS

Median and a range of percentile values were calculated based on the DOE's CBECS to characterize buildings' shape and size, age, HVAC and shell characteristics, and heating fuels. These characteristics serve to validate the reliability of building prototypes being modeled. The microdata from the 2012 survey (the most recent available) was limited to buildings that are primarily office space with five or more floors and located in the Northeast (New York, New Jersey, and Pennsylvania, plus the six New England states). While it is not possible to limit the data solely to New York City or State, the data provide a strong basis for the broader Northeast market. Characteristics of the selected buildings were weighted to ensure the sample set best reflects the actual building stock.

4.2.3 Other Data Sources

The New York City Office of Sustainability publishes energy benchmarking data for private and select municipal buildings, including multifamily buildings, of 50,000 square feet or larger. Although the benchmarking data provides annual energy consumption it does not disaggregate heating, cooling, or other shared loads, and does not provide details about space conditioning systems or building size.

4.3 Model Inputs

4.3.1 Prototype Building Models

The energy modeling software uses reference building prototypes drawn from widely used models. Recently constructed buildings are represented by two vintages based on ASHRAE 90.1 2007 and 2004 standards. Older buildings are represented by DOE commercial building reference models for the 1980-2004 era. These three vintages are named 2007 Code, 2004 Code, and Pre-2004, respectively. Prototype details cover building size, massing, fenestration, wall construction, HVAC systems, various electric loads, and occupancy characteristics (e.g. number of people and hourly schedules), resulting in robust and comprehensive building models to evaluate VRF equipment.

The BEM prototypes assume proper design and installation of HVAC systems and code compliant building envelopes, not necessarily representative of the majority of existing buildings in New York and the Northeast. Individual buildings may offer significant additional savings where systems and controls do not meet various code requirements or have not been maintained properly.

4.3.2 Existing Equipment

Building modeling assessed energy use with and without VRF equipment. The baseline heating and cooling systems varied depending on building type, age, and respective code compliant designs. The BEMs account for supplemental fan energy and pre-conditioning of makeup air.

Table 2: Existing building heating and cooling equipment

Building Type	Existing Heating System	Existing Cooling System
High-rise Multifamily	Single-zone PTACs with gas heat	Single-zone PTACs
Midrise Multifamily	Single-zone PTACs with gas heat	Single-zone PTACs
Large Office	VAV with hot water reheat and chilled water; standard efficiency boiler	VAV with hot water reheat and chilled water; centrifugal chiller; no economizer
Medium Office	Packaged VAV with gas heat and gas reheat	Packaged VAV with direct expansion cooling; no economizer

[8] Energy Management Systems (2015), Performance and Energy Savings of Variable Refrigerant Technology in Cold Climates, http://mn.gov/commerce-stat/pdfs/refrigerant-technology-cold-weather.pdf.

Small Office	Packaged single-zone air conditioner with gas heat	Packaged single-zone air conditioner

4.3.3 Location

Each prototype is customized to a specific region of the country and its operations are modeled over an average year for a specific location's climate. This analysis used two locations to represent New York's climate variation - New York City for Downstate and Rochester for Upstate. Weather characteristics are based on average hourly weather observed over a year for each city. Building characteristics reflect Zone 4A for Downstate and Zone 5A for Upstate. Together, these climate zones cover 90% of New York's population.

Table 3: Population representation based on climate zones in New York State

Zone	Population	% of NYS Population
4A	11,957,128	62%
5A	5,399,065	28%
6A	2,021,909	10%

Map: Pacific Northwest National Laboratory

4.3.4 Building Variations

Each building type/location/vintage set included a baseline condition and three changes to building systems to test the sensitivity of potential savings to building conditions.

- Air infiltration and wall/roof insulation were modeled at baseline (reflects CBECS for earlier than 2004, equal to code for 2004 and 2007 vintages) and at 50% reduction (representing building efficiency improvements).
- Interior building load was modeled at baseline and at a 50% reduction. This reduction reflects lower occupancy, as well as more efficient plug loads and the rapid adoption of LED lighting in office and multifamily buildings.

4.3.5 Fuel Price Variations

Building modeling estimated annual consumption of electricity and fossil fuel. These outputs were analyzed at baseline, high, and low prices.

Commercial electricity prices, blending both energy and demand charges, were customized to each modeled building based on local utility rates (ConEdison for New York City, and Rochester Gas for Rochester). Baseline prices consist of average bundled price for commercial customers for 2016 as reported to the US Energy Information Administration (US EIA);[9] high and low prices were 20% above and below each blended baseline price, respectively.

Fossil fuel prices were modeled for both natural gas and fuel oil, assuming only one fuel is used within a building. For natural gas, the baseline, high, and low prices consist of the mean, maximum, and minimum

[9] https://www.eia.gov/electricity/sales_revenue_price/pdf/table7.pdf

annual statewide prices (averaged over calendar years) for 2013-2017.[10] Similarly, for fuel oil, the baseline, high, and low prices consist of the mean, maximum, and minimum annual statewide prices (averaged over calendar years) for 2013-2017.[11] (Fuel oil prices reflect ultra-low sulfur fuel oil.)

Table 4: Fuel and electricity prices for upstate and downstate buildings

Fuel	Unit	High	Baseline	Low	Baseline ($/MMBTU)
Electricity – Downstate	¢ per kWh (blended)	23.16	19.30	15.44	$56.57
Electricity – Upstate	¢ per kWh (blended)	14.16	11.80	9.44	$34.58
Natural Gas	$ per thousand cubic feet	8.13	7.16	6.18	$6.90
Fuel Oil	$ per gallon	4.07	3.32	2.57	$23.97

4.4 VRF Energy Savings across Building Types and Vintages

4.4.1 Fuel Savings

Modeled VRF installations in office and multifamily buildings resulted in a 60-91% reduction in annual fossil fuel consumption and a range of 28% reduction to 25% increase in annual electricity consumption. Variations in fuel savings within building types based on year of construction reflects changes in energy code requirements for building shell air infiltration and insulation, mechanical ventilation levels, internal load levels, and heating and cooling equipment efficiencies.[12] For example, the electrical savings increases for the Midrise Apartment as it goes from pre-2004 to a 2004 vintage. This increase is largely related to more rigorous outside air ventilation requirements in that particular vintage shift associated with adoption ASHRAE energy standard 90.1-2004 and ventilation standard ASHRAE 62.2. In many of the other building types the electrical savings decreases as they go towards more recent vintages, which is generally due to lower internal loads (such as baseline efficiency improvements in interior lighting and equipment) resulting in less available savings. Note the results in Figure 3 below reflect the percentage reduction, whereas the magnitude of the energy savings is captured in the following sections.

[10] https://www.nyserda.ny.gov/Researchers-and-Policymakers/Energy-Prices/Natural-Gas/Monthly-Average-Price-of-Natural-Gas-Commercial
[11] https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Home-Heating-Oil/heating-oil-propane-kerosene-price.XLS
[12] Prototype building systems are drawn from DOE reference buildings for the pre-2004 era and from ASHRAE 90.1 for 2004 and 2007 eras. No data is available for pre-2004 code high-rise apartments due to the absence of a DOE reference prototype.

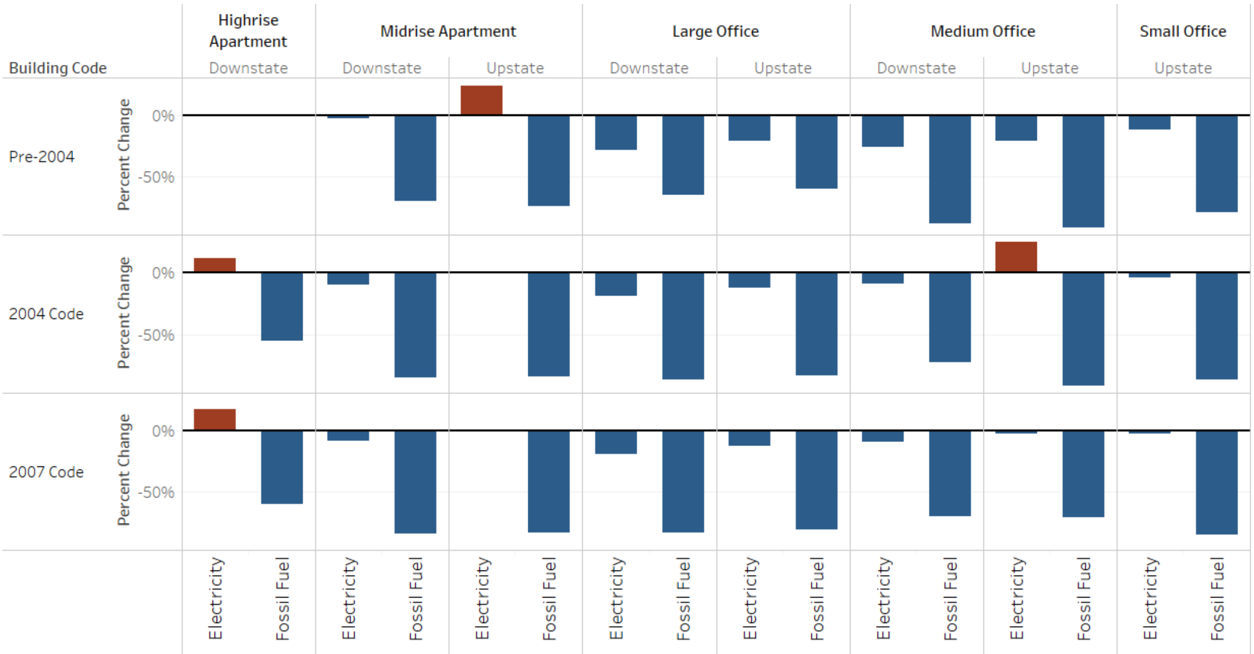

Figure 3: Percentage change in total building electric and fossil fuel consumption from VRF installations

4.4.2 Cost Savings

Electricity and fossil fuel prices are significant drivers of operational savings and cost effectiveness associated with VRF systems. The chart below illustrates the modeled change in annual energy costs for each building prototype in ASHRAE climate zones 4A and 5A in New York State based on fuel combinations of electricity and natural gas, and electricity and fuel oil. As noted in the Model Inputs section, fuel oil is significantly more expensive per MMBtu than natural gas in New York State.[13] This difference in fuel pricing results in greater reductions in annual fuel costs for VRF installations in buildings heated with fuel oil versus natural gas heating. Older (pre-2004) large office buildings with higher downstate cooling loads offer the highest cost savings opportunity of $1.11 per square foot of building floor area for oil and $1.04 per square foot for gas.

There are two significant trends in these figures. First, because the fuel savings are most significant the higher the fuel price, the more cost savings are available. That is significant in that where buildings rely on unregulated fuels with volatile prices, VRF may offer both savings and price stability by shifting loads to electricity that historically has more stable pricing. Second, because electricity is relatively expensive, the most cost savings are achieved in the scenarios where VRF can offer significant electrical savings. The large VAV systems (Large and Medium Offices) in downstate, where the cooling loads are more significant, appear to be prime targets because that system type generally has excessive cooling and large fan use that can be reduced with VRF systems.

[13] Model input baseline values are $23.97/MMBTU for fuel oil and $6.90/MMBTU for natural gas.

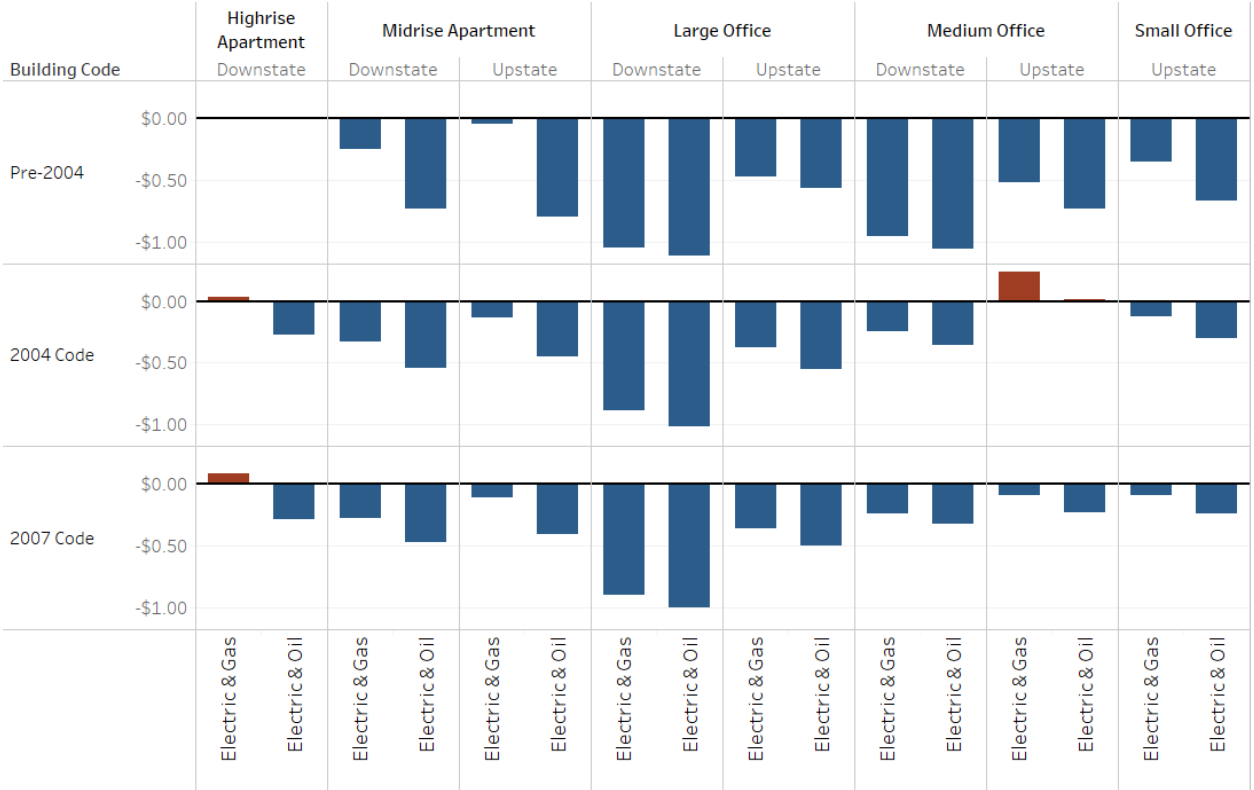

Figure 4: Change in total annual building energy costs ($/sq ft) for electric/gas and electric/oil combinations from VRF installations in multifamily and office buildings[14]

4.4.3 Peak Electricity Demand

Building electric energy peak demand is impacted by the installation of a VRF system through shifts of space heating loads from fossil fuel to electricity and the elimination or reduction in other electricity-intensive equipment, such as pre-heaters and central air handlers with large fans. Increases in building peak demand with VRFs typically occur on winter mornings when buildings are recovering from night or weekend space setback temperatures, whereas NYISO system-wide peaks during the winter are often found in the evening.[15] Beneficial peak demand impacts of VRFs are associated with the reduction of cooling energy loads and coincident with the NYISO system-wide summer peaks.

[14] No data is available for pre-2004 code high-rise apartments due to the absence of a DOE reference prototype. Upstate small office cases for the 2007 and 2004 code electric and oil results appear absent due to less than 2% change in cost per square foot.

[15] New York Independent System Operator, "Power Trends 2017." http://www.nyiso.com/public/webdocs/media_room/publications_presentations/Power_Trends/Power_Trends/2017_Power_Trends.pdf

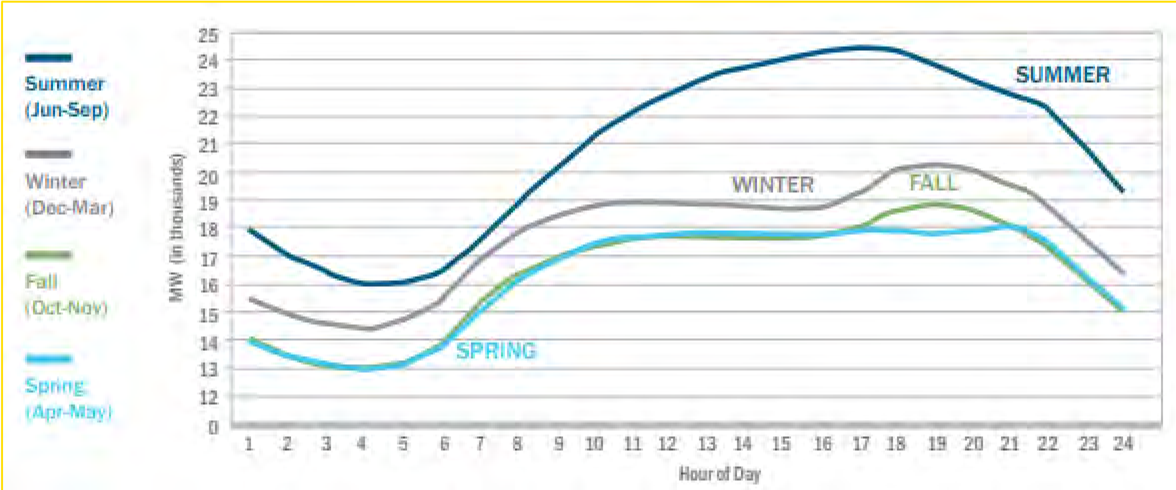

Figure 5: NYISO 2016 Seasonal Hourly Demand Patterns

The building energy modeling utilized a blended electric rate and tracked the peak *annual* electric demand, but did not report seasonal or hourly demand calculations. Tracking building seasonal and hourly demand data and incorporating utility demand charges would provide additional insights into the grid- and customer-level benefits of VRF technology adoption and is an opportunity for future NYSERDA research. However, modeled demand values are highly sensitive and more error prone than annual energy values. Therefore, a reliable study of grid demand requires more attention to detail to identify and eliminate erroneously high instantaneous loads that sometimes occur in energy models. That is generally accomplished by focusing in on a smaller set of scenarios where the modeling inputs are more controlled. Even though there is significant uncertainty in the precise value of the instantaneous peak, it provides order of magnitude trends between the different scenarios. The figure below looks at the change in annual peak between the baseline systems and the VRF case.

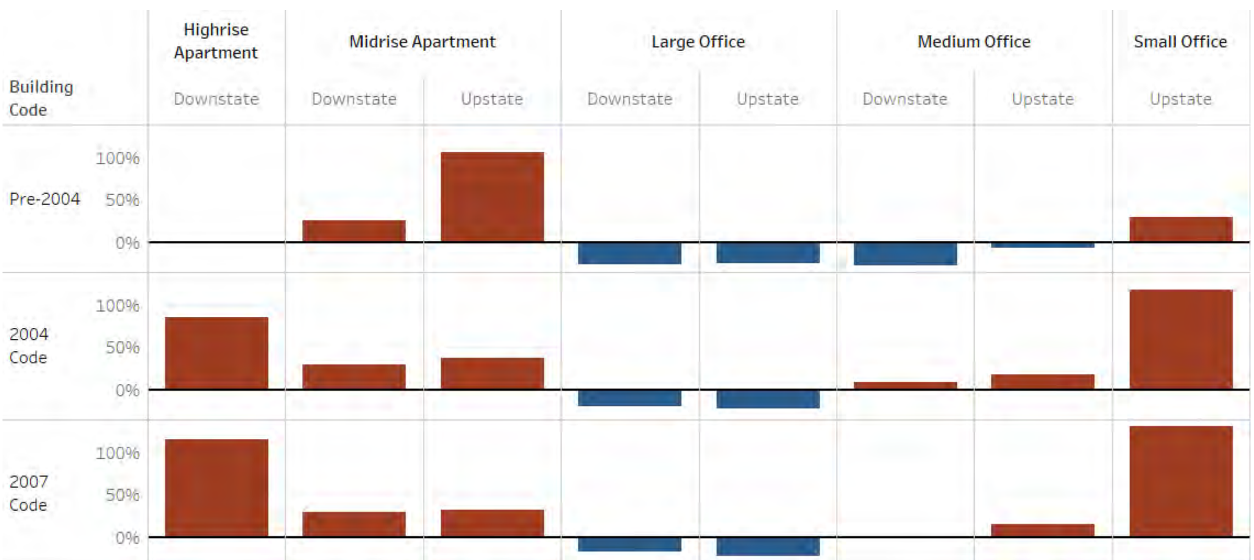

Figure 6: Change in peak building electricity demand in moving from reference HVAC system to VRF, as a percentage of existing conditions[16]

[16] No data is available for pre-2004 code high-rise apartments due to the absence of a DOE reference prototype. Downstate medium office and Upstate small office cases appear absent due to less than 1% change in peak demand.

The modeled building electric peak demand increases in many cases due to the shifting of heating load from natural gas or other fuels to a VRF electric load. In the cases where the *annual* peak has increased, that annual peak has also shifted from a summer peak to a winter peak. This occurs in the scenarios that have lower cooling loads relative to heating loads because of low internal gains (e.g., multifamily) and/or cooler climate (Zone 5a). It is likely that improved control strategies in the VRF scenarios (e.g., lesser setback for small offices) could reduce the magnitude of the winter peak increase.

For large offices and older medium offices, there is an annual peak reduction because they are more cooling dominated due to higher internal loads and higher energy associated with HVAC fans. In those cases the increase in winter heating peak is not significant enough to overcome the original summer cooling peak. Examples of the load profiles for Midrise Apartment and Medium Office are shown in Figures 7 and 8 below, where blue represents the hourly average electrical Wh (in 10 min time steps) of the VRF case for the given months, and Orange represents the average electrical Wh of the Baseline case for the given months.

Multifamily – Summer Peak is reduced, but the annual peak shifts to winter and is higher than the original peak.

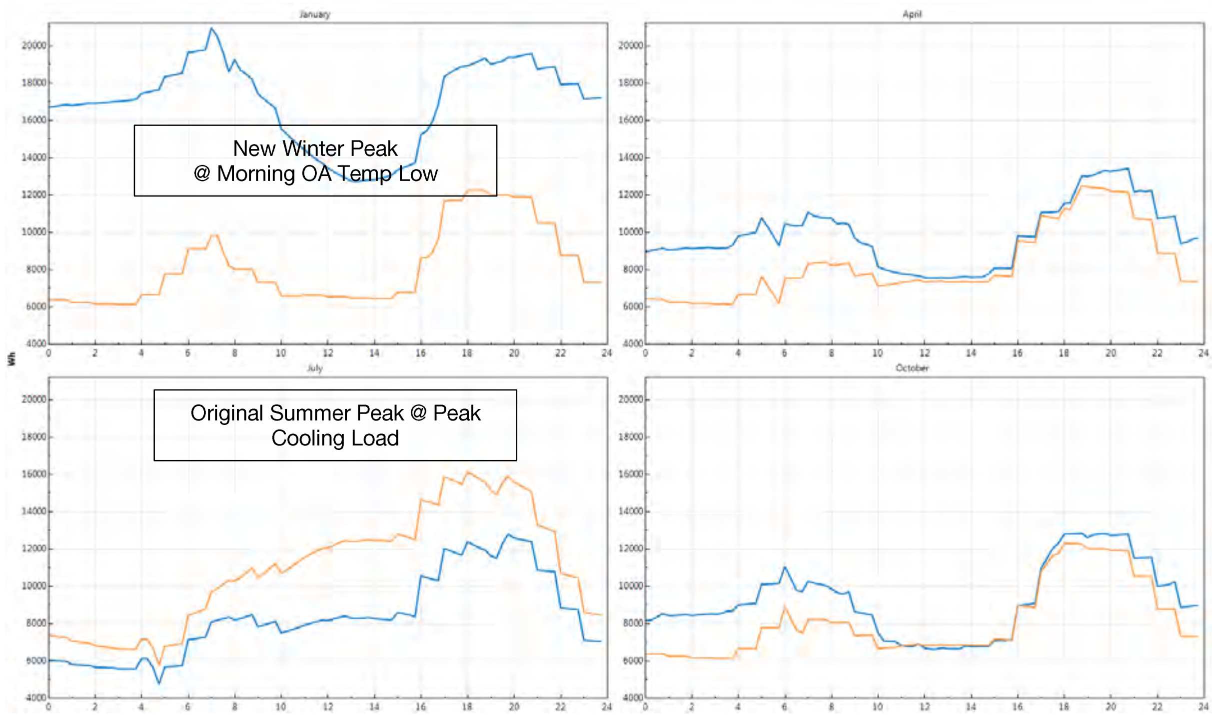

Figure 7: Reduction and shift of summer peaks to winter peaks with VRFs in multifamily buildings

Medium Office – Summer Peak and Winter Peak are reduced largely due to savings in fan energy and the peak heating load is much lower relative to peak cooling load due to high internal loads and fan reductions.

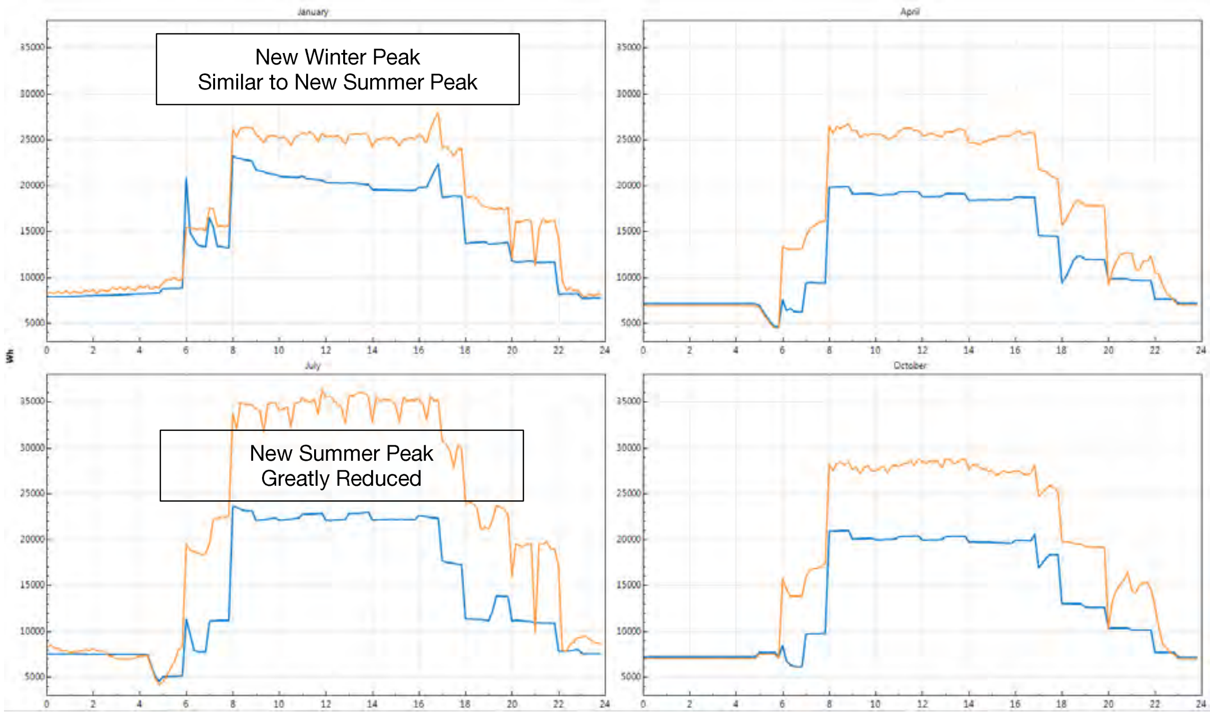

Figure 8: Reduction in summer and winter peaks with VRFs in large office buildings

4.5 VRF Savings in Office Buildings

VRF applications in large and medium office buildings result in significant cost savings in the Downstate climate zone. Large and medium offices have high internal loads due to greater densities of lighting, occupants, and equipment. In addition, the larger VAV air systems tend to have higher fan energy and excessive coincident heating and cooling, particularly in the older vintage where supply air temperature and economizer controls are less aggressive. These factors lead to significant cooling and fan energy savings that outweigh the added heating energy and allow for valuable electrical savings overall.

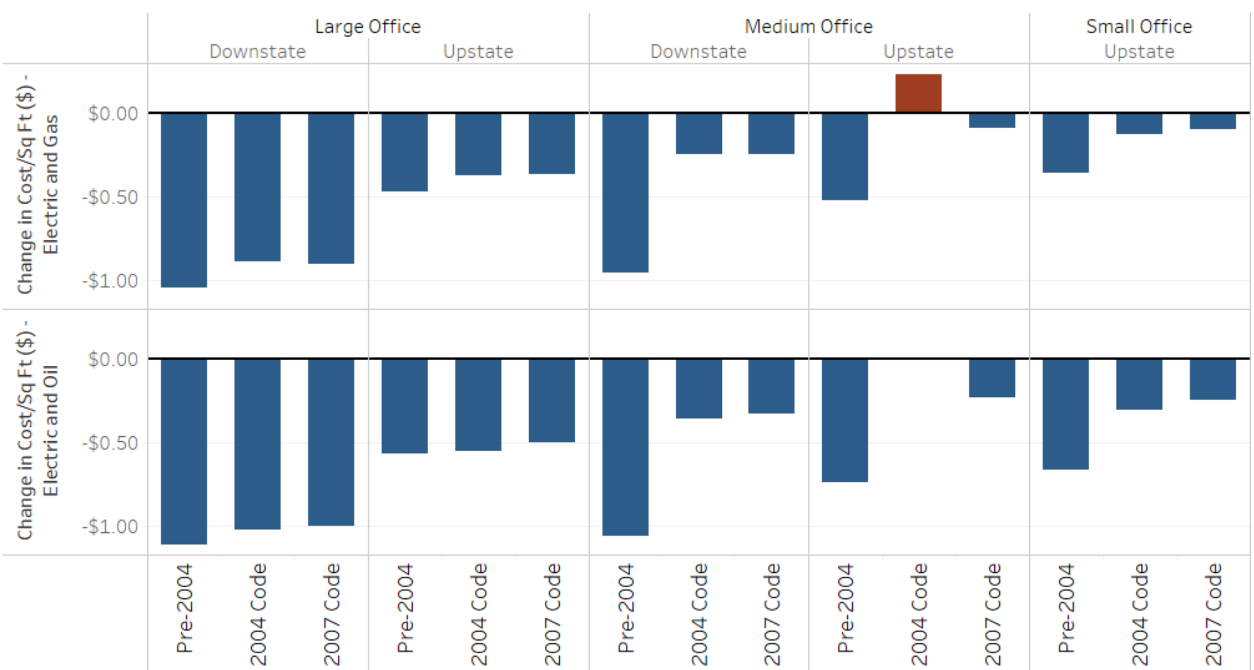

Figure 9: Net change in annual total energy costs per square foot by building type, location, and age

Modeled VRF installations in large and medium office buildings resulted in a 60-91% reduction in annual fossil fuel consumption and a range of 28% reduction to 25% increase in annual electricity consumption. A notable exception was older, small office buildings which had a significantly lower fossil fuel reduction. Variations in fuel savings within building types based on year of construction reflects improvements in energy code requirements for building shell air infiltration and insulation, mechanical ventilation and heating and cooling equipment efficiencies.[17] GHG reductions ranged from 41% less emissions to 10% more emissions and tracked with electricity due to the fact that they were an order of magnitude greater than fossil fuel reductions on an MMBTU basis.

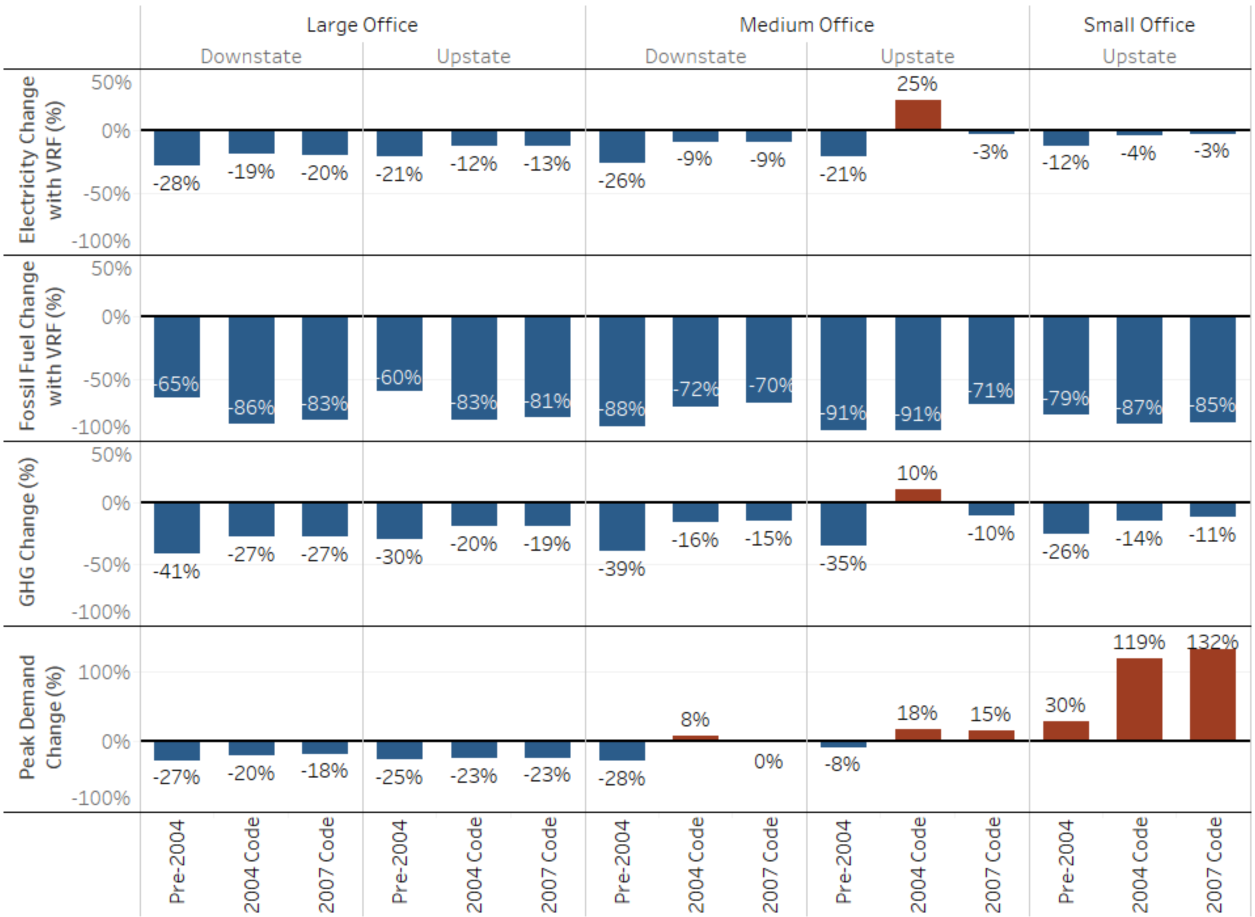

Figure 10: Change in annual electricity consumption, fossil fuel consumption, peak electricity demand, and greenhouse gas emissions, by building type and location. Changes in greenhouse gas emissions combine electricity and natural gas emissions.

4.5.1 Building Construction and Fuel Price Sensitivity: Large Office

VEIC conducted a sensitivity analysis on a code compliant (ASHRAE 90.1 2007), large downstate office building to assess the impact of differences in infiltration, insulation and building internal electric loads (e.g. lighting, occupancy, and plug loads) on the available savings from converting to a DOAS/VRF system. In addition, VEIC assessed the sensitivity of the savings to changes in the cost of electricity and fossil fuels (oil and natural gas). One variable in the sensitivity analysis was altered at a time in comparison to

[17] Prototype building systems are drawn from DOE reference buildings for the pre-2004 era and from ASHRAE 90.1 for 2004 and 2007 eras. No data is available for pre-2004 code high-rise apartments due to the absence of a DOE reference prototype.

the baseline case scenario, then DOAS/VRF is applied to the altered baseline to measure the energy impacts on a building that is better than code in some aspect.

VRF systems in large office buildings result in significant energy cost reductions primarily driven by electric cooling and fan energy reductions. Buildings with improved infiltration and insulation have minimal impact on the scale of savings for VRF systems. The building changes primarily impact heating, which does not drive the large office savings. However, the building model is highly sensitive to changes in internal electric loads (lighting and plug loads), which decrease the baseline scenario cooling and fan energy, resulting in a decrease of potential VRF savings. In this scenario, reducing the internal load by 50% reduces annual electricity cost by over $1 million and increases natural gas cost by only $12,000. The corresponding energy savings for converting to VRF are then reduced from $449,155 to $214,499 – resulting in a net energy savings reduction of $234,656.

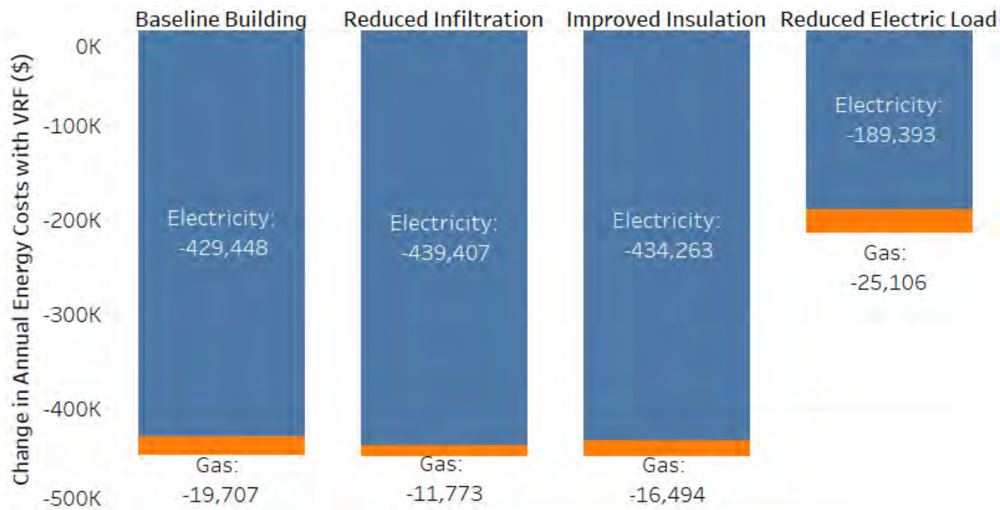

Figure 11: Change in annual energy expenditures for electricity (blue) and natural gas (orange) for the modeled Downstate large office building of 2007 vintage

The Downstate large office building natural gas fuel prices were modeled with the mean, maximum, and minimum annual statewide prices averages for 2013-2017. Downstate modeled electricity prices reflect average blended 2016 energy and demand rates from ConEdison as reported to the US EIA and a low and high range of 20% above and below the ConEdison rates.

Table 5: Downstate Modeled Electric and Natural Gas Prices

Fuel	Unit	High	Baseline	Low
Electricity	¢ per kWh (blended)	23.16	19.30	15.44
Natural Gas	$ per thousand cubic feet	8.13	7.16	6.18

As highlighted in Figure 12 below, large office building electricity costs are extremely sensitive to changes in electric rates both with and without VRF systems. However, the modeled VRF resulted in a reduction in the range of annual electric costs (delta between high and low) from $875,467 to $703,688 and a reduction of the baseline electric costs by $429,468 annually.

Impacts from variations in natural gas pricing have smaller impacts on large office building heating energy costs in comparison to the cooling dominated electric costs. The modeled VRF resulted in a reduction in the total range of annual natural gas costs from $6,471 to $1,104 and a reduction of the baseline heating costs by $19,707 annually. Although less common in downstate large office buildings, the impacts from variations in oil pricing have larger relative impacts on large office building heating energy costs compared to natural gas. The modeled VRF resulted in a reduction in the total range of annual oil costs from $37,271 to $6,359 and a reduction of the baseline heating costs by $68,419.

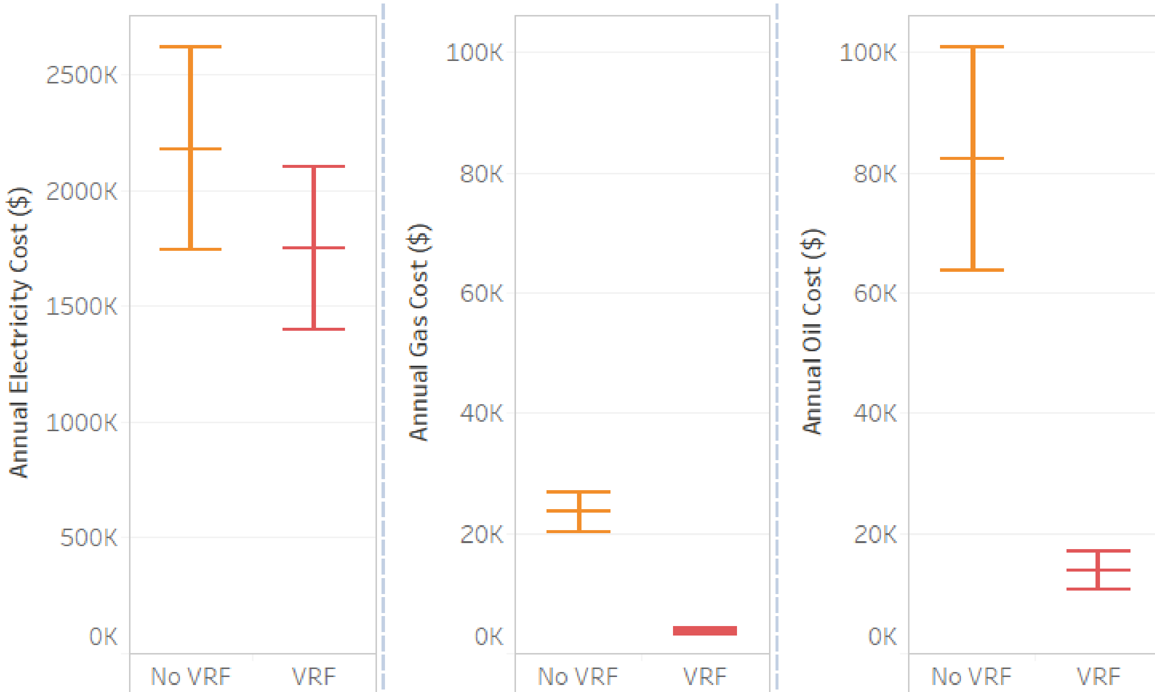

Figure 12: Sensitivity of annual energy costs to high, baseline, and low fuel price scenarios for a large office building in Downstate New York with (red) and without (orange) VRF equipment

4.6 VRF Savings in Multifamily Buildings

Apartment buildings have lower internal electric loads and corresponding cooling loads compared to office buildings, tending to shift energy burden towards heating fuel costs. This directly impacts the heating and cooling loads on the HVAC system and scale of savings from VRF technology. In addition, the baseline systems are small zonal systems, which avoids the coincident heating/cooling found in the office VAV systems and keeps the cooling energy lower.

Modeled VRF applications in midrise apartment buildings result in significant energy cost savings in both upstate and downstate climate zones ranging from $0.80 to $0.41 per square foot building area for oil heat scenarios. Similarly, all midrise apartment buildings with oil heating fuel resulted in approximately double the energy cost savings per square foot than those heated by natural gas. The changes in the baseline heating and cooling systems from PTACs in the midrise buildings to the combination water cooled heat pump boiler with electric backup and cooling tower in the high-rise building resulted in a substantial drop in total energy savings per square foot of building area from VRF technology.

As illustrated in Figure 13 below, greater savings are found in buildings constructed before 2007 code updates to ASHRAE 90.1. Also, electrical use in the residential buildings remains fairly neutral or even increases with the switch to VRF, which makes the available savings very sensitive to fuel pricing and therefore the scenarios that use oil pricing show better savings than those based on natural gas pricing.

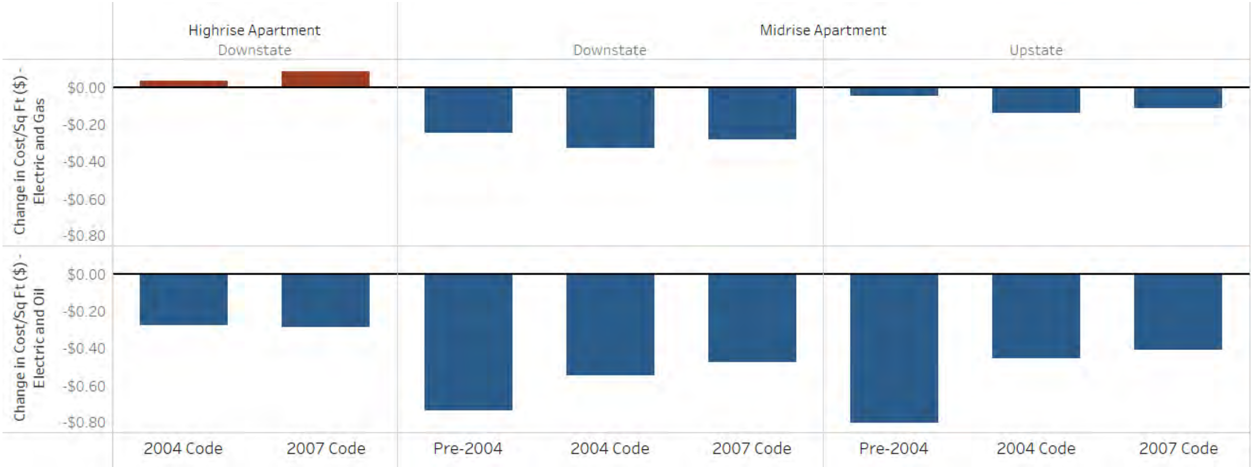

Figure 13: Net change in annual energy costs per square foot, combining electric and thermal fuels at baseline prices, by building type, location (Upstate or Downstate), and building vintage

As noted in Figure 14 below, apartment buildings modeled with VRF systems resulted in 55% to 85% reductions in energy associated with fossil fuel heating and a range of 10% reduction to 24% increase in electricity consumption.

VRF systems' ability to modulate, load match, and provide more efficient cooling than the single zone PTAC equipment modeled in the baseline midrise apartment building reduces cooling and fan energy usage. The shift of heating to electrical and the addition of the DOAS energy recovery ventilation typically increases overall energy use, or at minimum cuts into the savings gained on the cooling side. The impact is that, depending on the original cooling load, the net electrical use tends to be neutral or even increase. Therefore, the cost savings of specific projects is expected to be highly dependent on the fuel prices relative to electrical prices, the climate (downstate has more cooling than upstate), and whether a DOAS system can be implemented effectively (i.e., with minimal fan power).

Figure 14 indicates a significant increase in annual peak electricity demand. This reflects the displacement of the existing fossil fuel heating load with electric heat pump VRF. The modeled impact from increased peak demand is captured in the blended electric rate energy costs and is non-coincident with the NYISO seasonal and hourly peak demand. As noted previously, the magnitude of the peak has a high amount of uncertainty and might be exaggerated by the models, but the general trend of a reduced summer peak and shift of the annual peak to winter is likely.

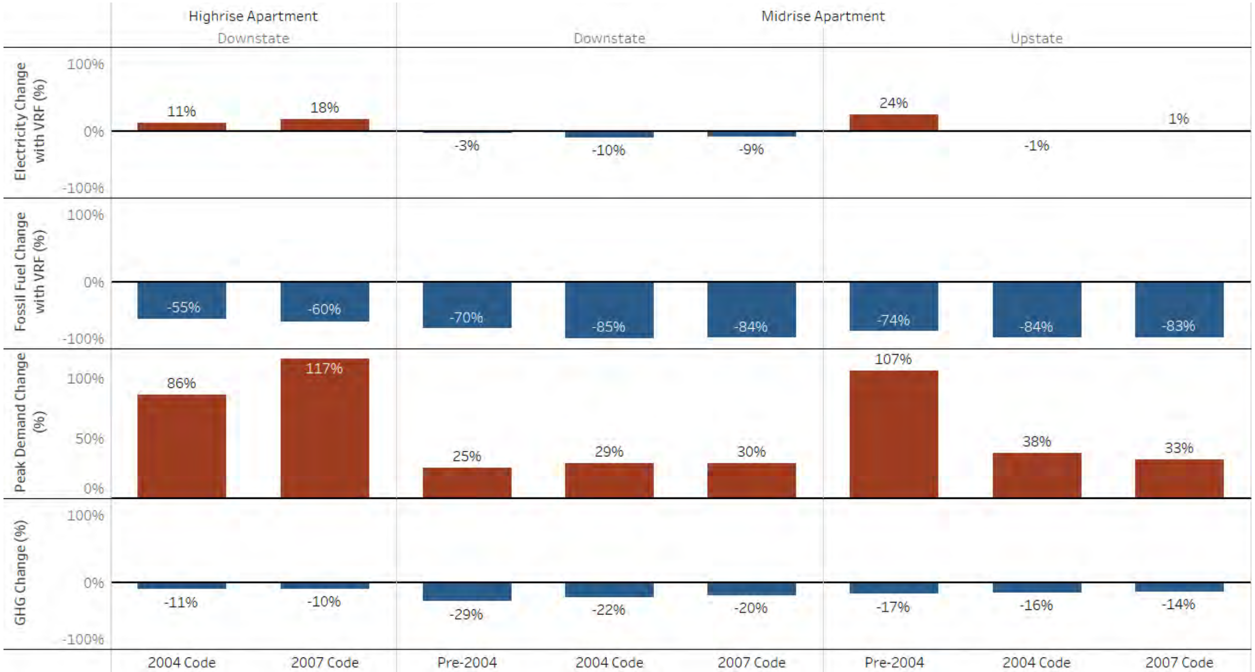

Figure 14: Change in annual electricity, fossil fuel, peak electricity demand, and greenhouse gas emissions by building type and location[18]

4.6.1 Building Construction and Fuel Price Sensitivity: Midrise Multifamily

VEIC conducted a scenario sensitivity analysis for older (pre-ASHRAE 90.1 2004), midrise Upstate apartment buildings to assess the impact of changes in infiltration, insulation, and building internal electric loads (e.g. lighting, occupancy, and plug loads) on the available savings of converting to a DOAS/VRF system. In addition, VEIC assessed the sensitivity of the savings to changes in the cost of electricity and fossil fuels (oil and natural gas). One variable in the sensitivity analysis was altered at a time in comparison to the baseline case scenario, then DOAS/VRF was applied to the altered baseline to measure the energy impacts on a building that is better than average in some aspect.

As noted earlier, VRF systems in large office buildings result in significant energy cost reductions primarily driven by electric cooling load reductions. Comparatively, midrise apartment buildings have lower internal electric loads and occupancy levels, and achieve energy cost savings primarily through the displacement of fossil fuel heating loads. For the same reason, improvements to infiltration and insulation offer significant additional energy cost savings for buildings (i.e., lower heating load from improved thermal shell), but in return thermal improvements reduce the magnitude of energy savings from VRFs. In the midrise apartment building model, the total VRF annual energy cost savings of $44,292 in the baseline scenario was reduced by $5,805 as a result of improved insulation and by $24,671 for reduced infiltration. Meanwhile, a reduction in internal electric loads, or “free heat”, results in a corresponding increase in oil heating load and increases the VRF savings by $7,500.

[18] Changes in greenhouse gas emissions combine electricity and natural gas emissions.

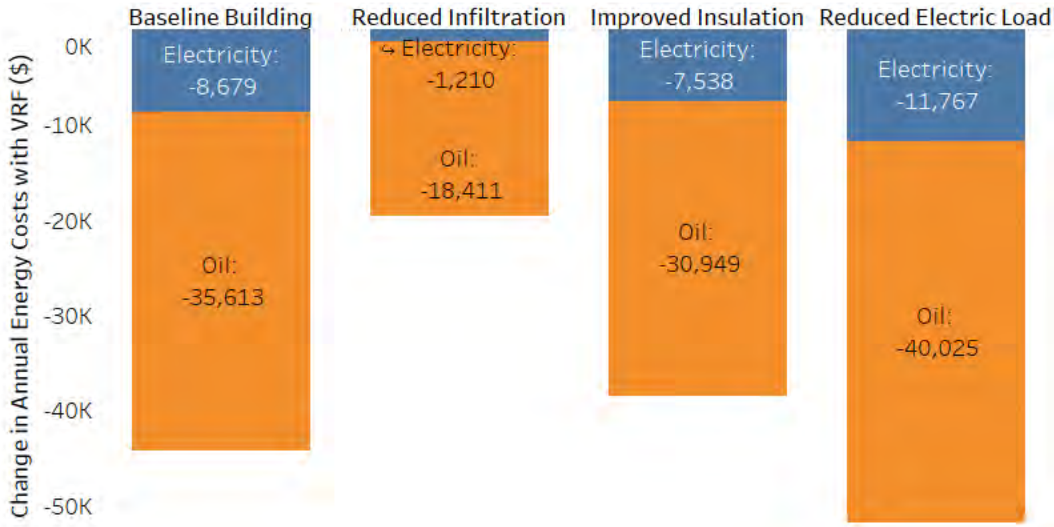

Figure 15: Change in annual energy expenditures for electricity (blue) and fuel oil (orange) for the modeled Upstate medium multifamily building of pre-2004 vintage

The conversion to VRF does not significantly increase the sensitivity to electricity prices in the midrise apartments. In Figure 16 below the VRF displacement of the electric heating load creates a marginal increase in the range of annual electric costs from $14,662 to $18,133, and a similar increase of the baseline electric costs by $8,679 annually.

Midrise apartment buildings served by natural gas in upstate New York are less sensitive to variations in fuel pricing. The modeled VRF resulted in a reduction in the total range of annual natural gas costs from $3,772 to $979 and a reduction of the baseline heating costs by $10,258 annually. Because the natural gas prices are low relative to electrical prices, the price sensitivity in both the baseline and VRF cases is relatively low.

Variations in oil pricing have significantly higher impacts on midrise apartment building heating energy costs in comparison to the cooling dominated office buildings. The modeled VRF resulted in a reduction in the total range of annual oil costs from $21,730 to $5,639, and a reduction of the baseline heating costs by $35,253 annually. Therefore, one factor to consider in regions with unregulated fuels is that electrification with VRF can produce significant increases in operational cost stability in addition to annual savings.

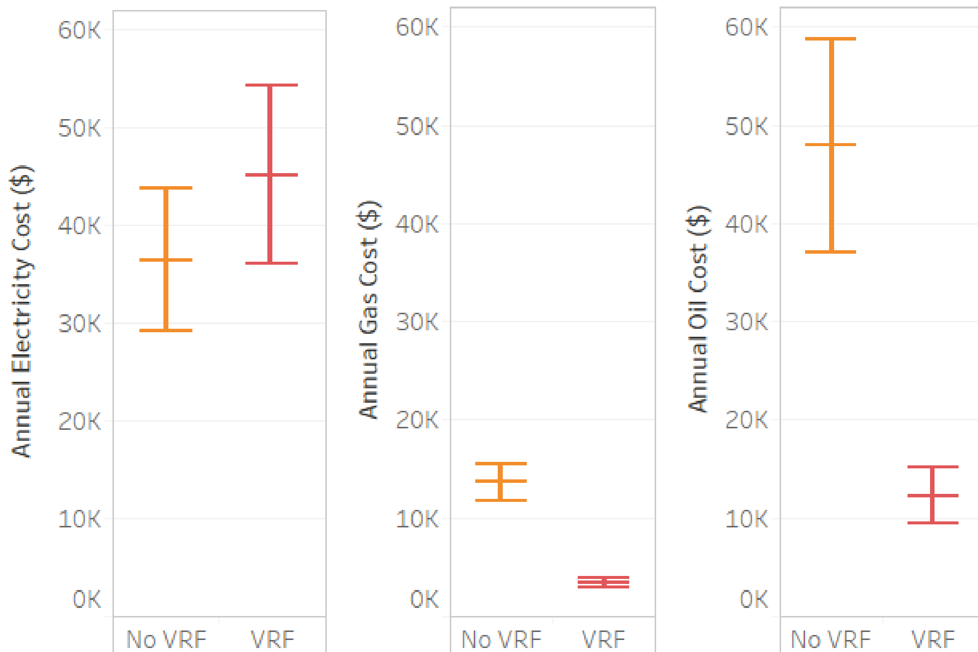

Figure 16: Sensitivity of annual energy costs to high, baseline, and low fuel price scenarios for a midrise multifamily building in Upstate New York with (red) and without (orange) VRF equipment

The sensitivity analysis of fuel prices illustrate the energy cost impacts when retrofitting to a VRF system. This parameter is a significant driver of cost effectiveness, screening, and change in annual operating costs.

5 VRF Equipment and Installation Costs

The VEIC team surveyed VRF distributors on equipment-only and fully installed incremental costs for VRF and typical HVAC systems. The Massachusetts Clean Energy Center (MassCEC)[19] graciously provided NYSERDA and the VEIC team early program participation data and reported VRF system installed costs for this analysis. Together, this information is an important input to identifying financial barriers to market adoption of VRF technology, and in developing appropriate financing or financial incentives to counteract the barrier.

Barrier Description	Developing representations and estimates of HVAC system costs is complicated and difficult to obtain with any level of accuracy. HVAC equipment costs are very sensitive to individual building design and use (e.g. office, residence, hospital, etc.). For this reason, equipment or full system costs are best analyzed on a project by project basis. Based on distributor feedback and VEIC team experience, VRF systems are more expensive on a per-ton basis than other system types like DX or PTACs. This is primarily due to the additional installation costs of refrigerant lines, condenser costs, and other advanced system components. However, there are "edge cases" where VRF can be less expensive. An example of this would be a building where asbestos, air ducts, and/or chilled water piping must be removed to accommodate traditional HVAC systems; whereas the building may

[19] http://www.masscec.com/air-source-heat-pumps-1

	be able to avoid these costs with the more limited space requirements of VRF refrigerant lines and wall/ceiling mounted cassettes.
Possible solution or counteraction	Incentives which are efficiently directed upstream to the distributor have been demonstrated as an effective way to address the price difference between VRF and other HVAC technologies. VRF systems are lower on the adoption curve as compared to traditional HVAC technologies and incentives help speed adoption and build economies of scale. Based on feedback from Efficiency Vermont program managers, an additional barrier to rate payer funded utility efficiency programs is programmatic constraints on fuel switching or the requirement of using an artificially high, code compliant VRF as a baseline. However, more recently states and utility efficiency programs are identifying VRF technology as an important part of broader strategic electrification planning.
How NYSERDA can address	Since VRF is frequently more expensive than other HVAC options, NYSERDA incentives would assist in making VRFs cost competitive and deliver significant energy savings.
NYC/Northeast-specific insights	No regional price differences were reported from distributors.

5.1 VRF Equipment Incremental Measure Costs (IMCs)

Distributors stressed that while the equipment-only costs are similar across different projects, the full installed system costs can vary widely. From a programmatic perspective, it is important to frame the reported costs as informational and not as a determinant of individual project cost-effectiveness for customers or ratepayer programs. The incremental cost data serves to allow comparisons between equipment and system costs, and to provide a comparison to reported MassCEC VRF project costs for fully installed systems.

Due to limitations in sharing proprietary distributor cost data, incremental costs and full system costs are not included in the public version of the report and used only for NYSERDA informational purposes only.

Reported project costs from MassCEC are relatively in line with the New York area distributor results though a more significant delta in installed costs was reported by distributors between systems with and without heat recovery.

Table 6: VRF Project Costs for Completed MassCEC Projects

VRF Project Costs			
Completed Projects Only; excludes LGDW project			
Metric	Completed Projects	VRF w/ Heat Recovery	VRF w/out Heat Recovery
$/ton	$4,580	$4,921	$3,498
$/"heating ton"	$5,929	$6,273	$4,760
$/BTUH (heating)	$0.49	$0.52	$0.40
$/sf	$14	$16	$9
# of Projects	5	3	2

The VEIC team utilized the MassCEC VRF program rebates to evaluate an example assessment of program costs. The MassCEC VRF program rebates are segmented based on property owner type (private, public/non-profit, and affordable housing) and incorporation of heat recovery. For privately owned buildings with heat recovery – buildings represented in the VEIC VRF building energy modeling – the MassCEC incentive is $1200 per heating ton.

Table 7: MassCEC VRF Grant Table (2018) [20]

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.*

The incremental measure costs (IMC) for complete systems, MassCEC grants, and energy savings for the modeled large office and midrise apartment buildings were evaluated by the VEIC team as an example of program and project cost-effectiveness. The summary table below captures the incremental installed costs, energy and GHG savings, simple payback, and example program grant funding based on two specific building scenarios (baseline and reduced internal loads) for Downstate large office and Upstate midrise multifamily buildings.

As detailed in Section 5, electric savings are the primary driver of cost savings for large office buildings and result in an eight year simple payback based on the estimated incremental costs reported by distributors.[21] However, a reduction in internal loads (50%) results in a longer simple payback of 13 years due to the reduced cooling load and capacity (tons), and increase in heating loads with the loss of the "free waste heat." Based on the 2018 MassCEC program guidelines, the large office buildings would receive the maximum grant of $180,000, but this incentive would represent only 5-7% of the total incremental cost. If the maximum grant cap was removed, based on the installed VRF heating capacity (644 tons for the baseline scenario), the $772,600 grant would represent 21% of the $3.76 million incremental installed cost and reduce the payback to seven years.

In the case of the Upstate midrise multifamily buildings, heating savings play a more significant role and based on the higher cost of fuel oil, results in a shorter simple payback of six years. In the scenario of reduced internal building loads, the heating load increases proportionally, further accentuating the cost savings from offsetting fuel oil use with VRFs and resulting in a shorter simple payback of five years. Midrise multifamily buildings would not be limited by the MassCEC maximum project grant limit resulting in a significantly higher percentage of the total incremental cost. Based on the installed VRF heating capacity (50 tons for the baseline scenario), the $60,000 grant would represent 37% of the $167,000 incremental installed cost and reduce the payback to four years.

[20] http://files.masscec.com/get-clean-energy/business/clean-heating-cooling/VRF_Fact_Sheet.pdf

[21] The incremental cost of the installed system ($4,792 per ton) for VRF with heat recovery used for this analysis is assumed to be conservative, as this approximately the same value reported by MassCEC for the total VRF installed cost.

Table 8: Summary Table of Large Office and Midrise Multifamily Program Metrics and Costs

Building	Scenario	Area (Sq Ft)	Cooling Capacity (Tons)	Heating Capacity (Tons)	IMC ($/ton)	Incremental Installed Cost ($)	Annual GHG Emissions Reduction (Metric Tons)	Annual Electric Savings (MWh)	Annual Natural Gas Savings (MMBTU)	Simple Payback w/o Incentive (years)	Simple Payback w/ Incentive (years)	MassCEC Grant No Max ($)	MassCEC Grant ($)
Large Office, Downstate, 2007 Code	Baseline Building	498,588	785	644	$4,792	$3,761,720	1,322	2,225,119	2854	8	7	$ 772,600	$180,000
												% of Incremental Cost	
												21%	5%

Building	Scenario	Area (Sq Ft)	Cooling Capacity (Tons)	Heating Capacity (Tons)	IMC ($/ton)	Incremental Installed Cost ($)	Annual GHG Emissions Reduction (Metric Tons)	Annual Electric Savings (MWh)	Annual Natural Gas Savings (MMBTU)	Simple Payback w/o Incentive (years)	Simple Payback w/ Incentive (years)	MassCEC Grant-No Max ($)	MassCEC Grant-Max ($)
Large Office, Downstate, 2007 Code	Reduced Load	498,588	570	637	$4,792	$2,731,440	709	981,310	3636	13	9	$ 764,300	$180,000
												% of Incremental Cost	
												28%	7%

Building	Scenario	Area (Sq Ft)	Cooling Capacity (Tons)	Heating Capacity (Tons)	IMC ($/ton)	Incremental Installed Cost ($)	Annual GHG Emissions Reduction (Metric Tons)	Annual Electric Savings (MWh)	Annual Oil Savings (MMBTU)	Simple Payback w/o Incentive (years)	Simple Payback w/ Incentive (years)	MassCEC Grant-No Max ($)	MassCEC Grant-Max ($)
Medium Multifamily, Upstate, Pre-2004 Code	Baseline Building	33,741	34	50	$4,792	$162,928	70	-73,551	1486	6	4	$ 59,900	$ 59,900
												% of Incremental Cost	
												37%	37%

Building	Scenario	Area (Sq Ft)	Cooling Capacity (Tons)	Heating Capacity (Tons)	IMC ($/ton)	Incremental Installed Cost ($)	Annual GHG Emissions Reduction (Metric Tons)	Annual Electric Savings (MWh)	Annual Oil Savings (MMBTU)	Simple Payback w/o Incentive (years)	Simple Payback w/ Incentive (years)	MassCEC Grant-No Max ($)	MassCEC Grant-Max ($)
Medium Multifamily, Upstate, Pre-2004 Code	Reduced Load	33,741	31	52	$4,792	$148,552	70	-99,721	1670	5	3	$ 62,600	$ 62,600
												% of Incremental Cost	
												42%	42%