Variable Refrigerant Flow Systems in the Field: The Good, the Bad & the Leaky

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ABSTRACT

Variable Refrigerant Flow (VRF) systems are increasingly positioned as a key building block of high-efficiency, electrified building design – offering improved occupant comfort through simultaneous heating and cooling and granular zone control. Yet real-world performance data reveal a persistent gap between optimal and actual performance. This paper examines three case studies: a commercial office building, a middle school, and a historic mill complex, spanning two states and two climate zones, to identify the operational, technical, and market factors driving that gap. Two cases, the office building and the middle school, draw on continuous sub-metered field monitoring and calibrated energy modeling; the third, the historic mill, is an implementation and design case study without continuous sub-metered energy data. Across the two monitored sites, VRF delivered measurable reductions in energy use and improved occupant comfort, confirming its efficiency potential when systems are properly installed and commissioned, while the mill case illustrates the ownership and market conditions that enable successful deployment. However, the case studies also expose recurring challenges: contractor unfamiliarity with installation, advanced controls and refrigerant charge management; incidence of refrigerant leaks; compressor failures linked to improper sizing or electrical misconfiguration; and limited fault detection capability. The paper synthesizes these findings into a set of actionable recommendations for utility program staff, consultants, and evaluators. Implementing these findings can mitigate early-life performance degradation and ensure VRF systems deliver durable savings and reliable comfort.

Introduction

The residential and commercial sectors together account for roughly 28% of U.S. end-use energy consumption, and approximately 31% of national greenhouse gas emissions when direct and indirect emissions are combined, placing the built environment at the center of any credible decarbonization strategy (EIA 2024a; EPA 2024c). Variable refrigerant flow (VRF) heat pump systems have attracted growing attention from building owners, designers, and energy efficiency program administrators as a key tool in that effort, with sales growing at roughly 15% per year compared to overall HVAC sales growing at approximately 2% (Slipstream 2023). VRF represents a meaningful step change from conventional heating, ventilation and air conditioning (HVAC) systems. VRF systems are capable of achieving seasonal heating efficiencies exceeding

200% and, in heat recovery configurations, of simultaneously heating some zones while cooling others. Its appeal extends beyond energy efficiency: granular zone-by-zone control, smaller mechanical footprints, the ability to route slim refrigerant lines through historic structures where large ductwork would be impossible, and quieter operation all contribute to its growing adoption.

The scale of the opportunity is substantial. Modeling by the National Laboratory of the Rockies (NLR) using the ComStock commercial building stock model found that VRF with heat recovery, paired with a dedicated outdoor air system (DOAS), is applicable to approximately 53% of the existing U.S. commercial building stock by floor area. It further has the potential to deliver 729 trillion BTUs in annual site energy savings, roughly equivalent to the annual energy use of 9 million U.S. homes, and avoid 41 to 56 million metric tons of greenhouse gas emissions annually, comparable to taking 9 to 12 million passenger vehicles off the road for a year (Kim, CaraDonna, and Parker 2023; EIA 2024b; EPA 2024b).

Yet the gap between modeled potential and real-world outcomes has proven persistent. Measured energy savings from VRF installations regularly fall short of pre-installation projections, and field studies have documented a pattern of early-life failures, including refrigerant leaks, compressor breakdowns, and control misconfiguration, which can negate much of the expected benefit. These reflect systemic gaps in contractor training, commissioning practice, and post-installation monitoring that the energy efficiency industry has not yet adequately addressed.

This paper examines VRF performance through three case studies spanning two states, two climate zones, and three building types. The primary data source is field monitoring conducted by Slipstream for Commonwealth Edison (ComEd), the primary electric utility serving northern Illinois, through its Energy Efficiency Research and Development (EE R&D) program. A third case study draws on documentation from the Massachusetts Clean Energy Center (MassCEC), a state agency that funds clean energy technology adoption across Massachusetts. Together, the case studies illuminate both what VRF achieves when properly deployed and the factors that constrain it. From there this paper provides actionable guidance for utility program staff, consultants, and evaluators seeking to close the gap between VRF's potential and its realized performance in the field.

VRF System Overview

VRF systems use refrigerant as the direct medium of heat transfer between indoor spaces and the outdoor environment. Variable-speed compressors modulate refrigerant flow continuously in response to real-time demand signals from individual indoor units, precisely matching output to actual load and achieving high efficiency across the part-load conditions that dominate a building's annual operating hours. For space heating, VRF systems can achieve heating COPs commonly exceeding 3.0, compared to a COP of roughly 1.0 for electric resistance heat. Gas-fired systems are rated on combustion efficiency (AFUE) rather than COP and are not directly comparable on that metric, though VRF still delivers a substantial source-energy advantage over typical gas-fired equipment.

Heat Pump versus Heat Recovery Configurations

VRF systems are available in two configurations. In a heat pump configuration, all indoor units connected to a given outdoor unit must operate in the same mode simultaneously. In a heat recovery configuration, a branch selector box allows different indoor units to heat and cool at the same time: the outdoor unit extracts heat from spaces calling for cooling and redirects it to spaces calling for heating. For commercial buildings with mixed exposures and diverse zone loads, such as is typically found in offices, schools, and mixed-use buildings, heat recovery is usually the appropriate choice and can deliver significant additional savings. This configuration decision is one of the most consequential in a VRF project and must be made early in the design process.

Role of the Dedicated Outdoor Air System

Because VRF indoor units recirculate room air without introducing outdoor air, meeting ASHRAE Standard 62.1 ventilation minimums requires a separate system. As such, VRF systems are almost always paired with a DOAS in commercial applications. The DOAS delivers conditioned outdoor air to each zone at flow rates calibrated to ventilation requirements, decoupling ventilation from sensible conditioning and enabling both systems to operate at peak efficiency. It is also the source of some of the most consequential performance problems documented in this study: oversized airflow rates and schedules that do not reflect actual occupancy can substantially inflate apparent HVAC energy consumption, creating a misleading picture of VRF performance that persists until DOAS operation is specifically investigated.

Cold-Climate Performance

Some cold-climate VRF products from major manufacturers are rated to operate in heating mode at outdoor temperatures as low as -22°F, enabling deployment across most of the continental United States. The ComEd field research validated cold-climate performance under real conditions: both ComEd-monitored buildings maintained occupied space temperatures above 70°F on the coldest monitored day, -9°F outdoor temperature (Slipstream 2023).

Market Applications and Suitability

VRF is best suited to mid-sized multi-zone commercial buildings in the 5,000 to 150,000 square foot range, such as multifamily residential, lodging, offices, schools, and historic structures requiring non-invasive retrofit. It is less well-suited to very large buildings where refrigerant pipe run length limits become prohibitive, high-exhaust applications such as restaurants and laboratories, and high-rise structures where refrigerant lift creates design complexity. An emerging but underutilized application is demand flexibility; the variable-speed compressors and building thermal mass that underpin VRF's efficiency also enable pre-cooling and pre-heating to shift load away from peak periods, an integration that is technically feasible today but not yet widely deployed.

Case Studies

The three case studies presented here span two states, two climate zones, and three building types. Two sites were part of a rigorous field research pilot conducted by Slipstream for ComEd's Energy Efficiency Research and Development (EE R&D) initiative, featuring continuous sub-metered energy monitoring, calibrated energy modeling, and operator interviews. The third, Wannalancit Mills, is drawn from the Massachusetts Clean Energy Center's VRF pilot program. Together they offer a varied but coherent picture of VRF performance across building types, installation contexts, and program environments. Table 1 summarizes the evidence base and Table 2 a performance summary of all three sites.

Table 1. Case Study Summary

Case Study	Data Source	Monitoring Period & Baseline	Evidence Type
Midwest Office Building	Slipstream field monitoring for ComEd EE R&D program	Continuous sub-metered monitoring; baselines are calibrated-model comparisons to water-source heat pump and PVAV + gas systems	Measured energy and comfort data; savings vs. calibrated modeled baselines
Midwest Middle School	Slipstream field monitoring for ComEd EE R&D program	Full calendar year of continuous sub-metered monitoring; baselines are calibrated-model comparisons to PTAC + hot water boiler and PVAV systems	Measured energy and comfort data; calibrated model used to isolate DOAS scheduling effect; savings vs. modeled baselines
Wannalancit Mills	MassCEC VRF Pilot Program case study documentation	No continuous sub-metered monitoring; design-basis sizing data only, no baseline comparison	Qualitative operator and installer reporting; no measured energy savings

Table 2. Case Study Performance Summary

Case Study	Building Type	Location	Size (SF)	Performance Summary	Key Lesson Learned
Midwest Office Building	Commercial office, new construction	Chicago, IL	101,988	Measured: 18–59% site energy savings vs. modeled water-source heat pump and PVAV+gas baselines	Installation failures (electrical) can be overcome; voltage regulation is critical
Midwest Middle School	K–12 education, new construction	Chicago suburbs, IL	158,000	Measured (calibrated-model adjusted): 36–62 kBtu/sf gas savings vs. modeled PTAC+boiler and PVAV baselines	DOAS scheduling decisions can dominate energy performance
Wannalancit Mills	Historic mill, multi-tenant office retrofit	Lowell, MA	143,000	No measured savings data; design-basis sizing only (system sized to	Owner familiarity and manufacturer commissioning are the key enabling conditions

Case Study	Building Type	Location	Size (SF)	Performance Summary	Key Lesson Learned
				164% of heating load and 248% of cooling load)	

A note on COP: This paper cites manufacturer-rated COP in the introduction as general context for VRF's efficiency advantage. The field monitoring underlying Table 2 did not measure field COP directly, and the performance summary data shown here are a proxy for VRF's efficiency advantage in these buildings.

Case Study 1: Midwest Office Building

Building and Project Overview

The Midwest Office Building is a midrise commercial office building located on the north side of Chicago, Illinois, encompassing 101,988 square feet across three floors. The building opened in 2018 as a newly constructed facility designed from the outset to be fossil-fuel-free, with air-source VRF selected specifically to electrify the heating function. The building operates 24 hours a day, seven days a week for field operations staff, though most office workers maintain standard business hours between 7 am and 4 pm. The building was comprehensively instrumented, with the entire building's VRF and DOAS system monitored throughout the study period (Slipstream 2023).

System Design and Configuration

Twelve VRF heat recovery condensing units are installed on the building's roof, ranging from 8 to 12 nominal tons each, all rated to operate in heating mode down to -13°F wet-bulb. The heat recovery configuration was deliberately chosen to capitalize on the building's mixed exposures: each VRF system has half its indoor units serving the east side of the building and half serving the west, maximizing opportunities for simultaneous heat recovery. Two DOAS units provide ventilation air to all VRF-served spaces, with enthalpy wheel ERVs and packaged DX cooling. Consistent with the building's all-electric design, DOAS preheat is provided by electric resistance rather than the gas-fired coils which can also be used for preheat in DOAS. The DOAS units operate as variable air volume systems with CO_2-based demand-controlled ventilation (Slipstream 2023).

Installation Experience

Despite the installation contractor being certified in VRF installation, the building's facilities staff spent the first two years of operation managing a cascade of failures: 20 motherboard replacements and 20 compressor replacements across the 12 VRF systems, with 10 compressor failures on a single unit alone. The root cause was ultimately traced to power surges and voltage irregularities. Once voltage regulators were installed on each system, the failures effectively stopped (Slipstream 2023).

Concurrent with the electrical failures, the building experienced significant refrigerant leaks from relief valves required by Chicago building code that cracked or broke off under compressor vibration. The exact amount of refrigerant lost was never quantified as the repairs fell under contractor warranty and were not independently tracked. Refrigerant undercharge may have contributed to compressor damage, creating a compounding failure mode that was difficult to diagnose. As of the study's conclusion, one of the twelve VRF systems continued to experience intermittent issues, and the facilities team was actively considering replacing it with equipment from a different manufacturer (Slipstream 2023).

The broader consequence of these early failures was reputational. Despite the system ultimately stabilizing and performing well, building operators rated the VRF system 3.5 out of 5 overall and stated they would not recommend it to other building owners, a sobering outcome for utility programs seeking to grow VRF adoption through peer referral.

Energy Performance

Once stabilized, the Midwest Office Building's measured energy use compared favorably against two modeled counterfactual baseline systems. Against a modeled water source heat pump baseline, measured VRF performance corresponds to electricity savings of 3.8 kBtu/sf annually while avoiding 18 kBtu/sf of natural gas consumption. Against a modeled packaged variable air volume (PVAV) baseline with gas heat, measured performance corresponds to 40 kBtu/sf of natural gas savings, yielding significant net site energy savings when fuel-switching credit is applied. Depending on which modeled baseline is used for comparison, overall site energy savings range from 18% to 59% (Slipstream 2023).

Comfort and Occupant Experience

The Midwest Office Building achieved robust thermal comfort. During winter occupied hours, the system maintained space temperatures within the ASHRAE Standard 55 comfort range 99.9% of the time. Summer comfort was similarly strong at 87.1% of occupied hours within range, with the remaining readings reflecting the building's tendency to run slightly warm rather than too cold. Building operators confirmed that occupant comfort complaints were typical of any office environment, an important finding given the two years of mechanical failures that preceded this period (Slipstream 2023).

Key Challenges and Lessons Learned

The Midwest Office Building demonstrates that voltage irregularities and power quality issues can trigger compressor and controls failures even when systems are installed by certified contractors. Electrical infrastructure review, including power quality assessment and voltage regulation, should be a standard element of pre-installation planning. It also demonstrates that early installation failures have lasting reputational consequences that constrain program growth; owners who experience difficult early-life performance are unlikely to become advocates for the technology even after problems are resolved.

Case Study 2: Midwest Middle School

Building and Project Overview

The Midwest Middle School is a 158,000 square foot, four-story new construction building opened in 2019 in the suburbs of Chicago. VRF systems serve classrooms, corridors, and offices, with the exception of the cafeteria/auditorium and gymnasium, which use single-zone rooftop units. The building was the only ComEd site to achieve a full calendar year of monitoring data (Slipstream 2023).

System Design and Configuration

Eighteen cold-climate VRF (ccVRF) heat recovery systems, each comprising two paired condensing units providing approximately 16 nominal tons, serve the VRF-conditioned spaces. All units are rated to -13°F wet-bulb. A total of 237 indoor fan coil units serve 101,764 square feet. Three constant-volume DOAS units with enthalpy wheel ERVs and natural gas preheat provide ventilation. The DOAS units were configured to operate 24 hours a day, 7 days a week, a scheduling decision that would prove central to the building's apparent energy performance (Slipstream 2023).

Installation Experience

The Middle School's installation was comparatively smooth. Facilities staff praised the centralized controls hub accessible via laptop and reported fewer occupant comfort complaints than at comparable schools with conventional boiler systems. Two challenges stood out, however; teacher difficulty navigating the VRF thermostat interface, pointing to a gap in occupant training that affects how systems are actually used, and the 24/7 DOAS operating schedule, which appears to have been set during the COVID-19 pandemic in response to early ASHRAE guidance recommending continuous ventilation. That guidance was subsequently revised, but the schedule was never corrected (Slipstream 2023).

Energy Performance

The school's raw measured HVAC energy use intensity of 58.4 kBtu/sf/year placed it in the top quartile of energy consumers among comparable education buildings in CBECS benchmark data, alarming for a new construction building with a modern VRF system. The explanation was the 24/7 DOAS schedule. When the calibrated energy model simulated standard school operating hours, the HVAC EUI dropped from 58.4 to 33.8 kBtu/sf/year, just below the peer median of 34.9 kBtu/sf/year. The VRF system was performing at benchmark; the DOAS scheduling was not (Slipstream 2023). Against modeled baselines, the school achieved natural gas savings of 36 kBtu/sf versus a PTAC + hot water boiler baseline and 62 kBtu/sf versus a PVAV baseline, strong results consistent with the broader ComEd findings.

Comfort and Occupant Experience

Where the Middle School's energy data told a complicated story, its comfort data told a simple one. The VRF system provided thermal comfort even during the coldest conditions of the monitoring period. On the coldest monitored day, -9°F, the system maintained a representative classroom at approximately 72.5°F, which is slightly below the 75°F setpoint but comfortably within ASHRAE Standard 55 criteria. Supply air temperature dropped from the typical 115–125°F range to approximately 105°F at this extreme, consistent with manufacturer capacity data. Across the full monitoring period, occupied spaces were within the ASHRAE 55 winter comfort range 91.8% of the time; the 8.2% of out-of-range readings were above the upper bound, meaning rooms were occasionally too warm rather than too cold (Slipstream 2023).

Key Challenges and Lessons Learned

The Middle School's central lesson is about interpreting measured performance data correctly. A pandemic-era scheduling choice, never revisited, generated an HVAC energy use profile that looked problematic in benchmark comparisons while masking a system performing at peer standards. For utility evaluators relying on measured data to assess VRF savings, apparent underperformance should trigger operational investigation before it triggers technology skepticism. The second lesson centers on occupant and operator training; thermostat usability problems and uncorrected DOAS schedules both reflect a training and commissioning gap that persists at many VRF deployments.

Case Study 3: Wannalancit Mills, Lowell, Massachusetts

Building and Project Overview

Wannalancit Mills is a restored 19th-century textile mill complex in Lowell, Massachusetts. The 650 Suffolk Street building is a four-story, 143,000 square foot structure serving over 50 commercial tenants, along with a conference center, café, fitness center, and University of Massachusetts Lowell research facility. The HVAC upgrade documented here was the second phase of a broader VRF deployment by the building's owner, Farley White Management Group, who had previously installed VRF in a separate building within the complex. Unlike the ComEd sites, this case study does not include continuous sub-metered energy monitoring (MassCEC 2021).

System Design and Configuration

The previous system was a gas-fired Modine heat exchanger serving direct exchange air handlers, which had exceeded its useful life with replacement parts no longer available. A key constraint was that the building's mechanical rooms are vertically stacked on the northwest side of each floor, accessible only through narrow doorways. Conventional packaged equipment would have required major structural modifications; VRF's modular architecture allowed custom air handler units to be brought into the mechanical rooms in segments and assembled in place (MassCEC 2021).

The retrofit installed twelve Daikin VRV rooftop heat pump units connected to custom air handler cabinets, re-using the existing ductwork distribution system. The system is sized at 241 tons total, designed to meet 164% of the heating load and 248% of the cooling load, providing intentional redundancy. The building is cooling-dominant despite its location in New England, owing to significant internal heat gains from over 50 commercial tenants and the research facility's computing equipment. VRF operates Monday through Friday, 6 am to 8 pm (MassCEC 2021).

Installation Experience

Wannalancit Mills presents a strikingly different narrative from the ComEd sites. The owner's prior VRF experience in the adjacent building translated into a smoother deployment. The installing firm, DXS Engineering, was familiar with both the building type and the Daikin system. The manufacturer's equipment representative performed start-up and commissioning, and Farley White's maintenance staff had received manufacturer training for ongoing maintenance and repairs in-house (MassCEC 2021). The most distinctive physical challenge was assembling the air handler units inside stacked mechanical rooms. Installers solved this by disassembling units, bringing components through narrow doorways, and reassembling in place. No structural modification to the historic building was required.

Energy Performance: Design Basis Only, No Measured Data

Unlike the two ComEd-monitored cases, Wannalancit Mills offers no measured performance data, and the evidence presented in this subsection should be weighted accordingly. The system design incorporates meaningful efficiency features, including variable-speed controls that engage the minimum energy stage needed to meet setpoints and the re-use of existing ductwork. The owner's stated objective of reducing energy costs and reduced maintenance burden appears to have been met based on qualitative operator reporting, though quantified savings await further monitoring (MassCEC 2021).

Comfort and Occupant Experience

Operator feedback at Wannalancit Mills was uniformly positive. The building's maintenance department, trained by the manufacturer, reported the system was easier to operate and maintain than what it replaced. The distributed nature of VRF was cited as a specific resilience advantage: if individual outdoor units fail, remaining units continue conditioning their zones, a meaningful contrast to a central plant failure. Pre-existing web thermostats were repurposed to give maintenance staff remote visibility into space temperatures building-wide, providing lightweight monitoring at no additional investment (MassCEC 2021).

Key Challenges and Lessons Learned

Wannalancit Mills' central lesson is about the enabling conditions for successful VRF deployment; owner experience, installer familiarity, manufacturer involvement in commissioning, and in-house maintenance capacity. These are the result of deliberate choices by a building owner who had already completed one VRF installation and understood what was required. VRF outcomes are primarily a market readiness story, not a technology story.

Phased installation also emerges as a risk management strategy. By deploying VRF in phases across buildings, the team was able to learn from each installation, apply lessons forward, and minimize occupant disruption across 50 active commercial tenants. Finally, the absence of sub-metered monitoring data is itself a finding. Without it, neither the program nor the owner can verify design-intent performance, identify developing faults, or contribute to the measured savings evidence base that the broader field needs.

Findings and Lessons Learned

The three case studies surface five findings that must be understood and addressed to enable VRF systems to consistently deliver their potential. These findings synthesize measured and calibrated-model performance from the two ComEd-monitored buildings with the qualitative implementation experience documented at Wannalancit Mills, together with the direct experience of building operators, contractors, and program administrators.

Finding 1: Installation Quality Is the Single Greatest Determinant of VRF Outcomes, and Contractor Unfamiliarity Remains Endemic

Two of the three case studies experienced installation challenges. The Midwest Office Building, despite being served by a certified VRF installer, experienced 20 compressor failures and 20 motherboard replacements in the first two years, ultimately traced to voltage irregularities not identified during commissioning. This pattern extends beyond the monitored sites. A GTI field study at Naval Station Great Lakes similarly documented installation and component failures (GTI/ESTCP 2019). As part of broader VRF market research, Slipstream interviewed five building owners with experience operating VRF systems, including two associated with the case studies in this paper, and found that all five had experienced early installation issues, three had replaced units within the first two years, one reported refrigerant leakage, and two said they would not recommend VRF to other owners (Slipstream 2023).

The contractor knowledge gap is structural not incidental. Manufacturer and sales representative interviews conducted as part of the ComEd market research found that all three major VRF manufacturers identified lack of contractor and installer education as the single greatest barrier to VRF adoption. One manufacturer noted the high stakes of this gap directly: a bad installation typically comes down to only one or two mistakes, but those mistakes cascade into the kind of early failures documented at the Midwest Office Building. When contractors are unfamiliar with a technology, they also price it higher to hedge their uncertainty about installation time and commissioning complexity. This creates a cost barrier on top of a quality barrier. Manufacturers projected double-digit year-over-year sales growth for the next five to ten years, meaning the trained workforce will be further outpaced by demand unless programs intervene deliberately (Slipstream 2023).

Finding 2: DOAS Configuration and Scheduling Decisions Can Dominate Building Energy Performance

The Midwest Middle School's measured HVAC energy use intensity of 58.4 kBtu/sf/year placed it in the top quartile of comparable education buildings in CBECS benchmark data. The cause was not the VRF equipment; it was the DOAS units running 24/7 on a COVID-era schedule that was never revised. When calibrated modeling simulated standard school hours, HVAC EUI dropped from 58.4 to 33.8 kBtu/sf/year, just below the peer median of 34.9 kBtu/sf/year (Slipstream 2023). The project team found that both ComEd-monitored buildings operated DOAS units at ventilation airflow rates two to three times higher than ASHRAE 62.1 code minimums, a pattern that substantially narrowed, and in some comparisons reversed, apparent VRF savings versus conventional baselines. For evaluators relying on measured data, apparent underperformance should trigger operational investigation before it triggers technology skepticism.

Finding 3: Refrigerant Leakage Has the Potential to Substantially Offset VRF's Greenhouse Gas Benefits, and Almost No One Is Monitoring It

VRF systems installed prior to 2026 use R-410A refrigerant, with a global warming potential of 2,088 times that of carbon dioxide. A 2022 ASHRAE Journal study of refrigerant service records across more than 1,800 cooling systems in a California school district identified a leakage rate of 0.7% (Pistochini et al. 2022); a Slipstream literature review citing a UK Department of Energy and Climate Change estimate put the high end at 3.8%. Applying these rates to the refrigerant charge of the ComEd-monitored buildings, Slipstream's analysis found that leakage at the low rate offsets roughly 10% of VRF's annual GHG savings, while leakage at the high rate offsets roughly 50% (Slipstream 2023). This is not hypothetical: the Midwest Office Building experienced significant refrigerant leaks from Chicago code-required relief valves.

None of the buildings included in these case studies actively tracked refrigerant levels between service visits. That gap is becoming more consequential under the AIM Act: EPA's HFC Leak Repair and Management Rule took effect January 1, 2026, requiring leak detection and repair for HFC-containing appliances with a charge of 15 pounds or more, and new VRF installation deadlines for lower-GWP refrigerants have been extended to 2027 or 2028 depending on permit timing (EPA 2024a). Even so, the existing R-410A installed base will remain in service for 15 to 20 years, and EPA regulations already prohibit venting refrigerant during servicing or decommissioning, requiring certified recovery and disposal (EPA 2024d). Contractor training is uneven on this front too: the same workforce gaps that drive installation failures create risk at end-of-life, and programs investing in contractor training should ensure recovery and disposal requirements are part of that curriculum.

Finding 4: Commissioning and Ongoing Performance Monitoring Are Consistently Incomplete, and the Consequences Can Be Large

At the Midwest Middle School, the 24/7 DOAS scheduling error persisted for multiple years after the guidance prompting it was revised. At Wannalancit Mills, no post-installation monitoring was conducted, but the MassCEC provides additional case studies that reinforce this picture. At the first example, Lolita Cocina, a bar and restaurant in Boston's Fort Point District, ongoing controls programming by the installing contractor through a maintenance agreement is what keeps the system functioning. At the second, Windsor Town Office, wind-driven reverse fan blade rotation on outdoor units was discovered and addressed only because the building was actively managed by an attentive operator (MassCEC 2021).

VRF systems are significantly more complex than the equipment they often replace. These examples reflect two related but distinct gaps: incomplete initial commissioning at startup, and the absence of ongoing monitoring and/or retro-commissioning to catch problems that develop over time.

Finding 5: When Properly Installed and Commissioned, VRF Delivers on Its Promises Across Climates and Building Types

The cautionary findings above are accurate and important, but they are not the complete picture. The Midwest Office Building, once stabilized, achieved winter thermal comfort within ASHRAE Standard 55 criteria 99.9% of occupied hours. The Midwest Middle School maintained a classroom at 72.5°F on a -9°F outdoor day. Wannalancit's operators describe a 'set it and forget it' experience that contrasts sharply with the failed equipment it replaced (Slipstream 2023; MassCEC 2021).

NLR's ComStock modeling estimates that VRF with heat recovery and DOAS, applied across the applicable U.S. commercial building stock, could deliver 729 TBtu in annual site energy savings and avoid 41 to 56 million metric tons of greenhouse gas emissions annually (Kim, CaraDonna, and Parker 2023). The case studies in this paper confirm those savings are achievable in real buildings. The gap between modeled potential and realized performance is not a technology gap, it is a market delivery gap.

Insights and Recommendations

The findings presented above point toward a clear set of practical interventions for utility program staff, consultants, and evaluators. The five recommendation areas below are organized by priority, with supporting rationale provided under each.

Recommendation 1: Treat Contractor Ecosystem Development as a First-Order Program Investment

Programs should establish minimum qualification requirements for VRF projects seeking incentives. All major VRF manufacturers offer training, and completion of manufacturer-sponsored training is the most credible qualification pathway and should be the primary requirement. Programs should maintain a registry of qualified installers shared with building owners during project development. The MassCEC's requirement of manufacturer-assisted startup as part of its quality assurance and quality control strategy is a directly applicable model (Slipstream 2023). Beyond minimum qualifications, programs can accelerate workforce development by co-sponsoring manufacturer training events, partnering with trade schools to integrate VRF content into HVAC apprenticeship curricula, and funding locally relevant installation guidance.

Pre-installation power quality assessment should become a standard element of VRF project development. Both ComEd-monitored buildings in this paper, the Midwest Office Building and the Midwest Middle School, required voltage regulation systems retrofitted after construction, a preventable failure.

Recommendation 2: Require Integrated VRF+DOAS Commissioning, and Fund It

For VRF projects serving 20,000 square feet or more, or involving 10 or more indoor units, programs should require that a commissioning authority independent of the installing contractor verify system performance before incentive payment is released. The commissioning scope should encompass both the VRF system and the DOAS. This would include verifying refrigerant charge, confirming each indoor unit achieves design airflow, checking that DOAS units are operating on schedules consistent with building occupancy, and verifying all control sequences are functioning as designed. The incremental cost is typically one to three percent of total HVAC system cost and is modest relative to the value of catching the errors that are routine in VRF installations.

Programs should require manufacturer-provided commissioning reports as project closeout deliverables, and conduct utility interval data review at 90 days to flag anomalies. Operator training should be a required commissioning deliverable for all project sizes, covering thermostat operation, DOAS scheduling verification, and recognition of abnormal system behavior.

Recommendation 3: Leverage Continuous Monitoring to Protect Savings and Build Evidence

Many major VRF manufacturers now offer cloud-connected monitoring platforms that can be activated on hardware already installed, in some cases requiring only a network connection. Where this capability is available, programs should require activation as a condition of incentive eligibility and seek read access to performance data for the duration of the warranty period; doing so can create ongoing verification at low incremental cost relative to dedicated sub-metering. Programs should confirm the specific monitoring capability, data access terms, and any subscription costs with each manufacturer, as these vary by product line. Programs should also require refrigerant charge documentation at commissioning and refrigerant log maintenance and should treat refrigerant leakage as a standard adjustment factor in greenhouse gas calculations for R-410A systems.

Recommendation 4: Develop Standardized VRF Program Offerings with Clear Baselines

The ComEd market research found VRF projects being handled through multiple program pathways with inconsistent baseline assumptions, creating uncertainty for building owners and inconsistency in savings claims. Prescriptive incentives tied to standardized baselines using ASHRAE Standard 90.1 Appendix G as the reference point are the most accessible format for building owners and most administratively efficient for programs; Northeast and Northwest programs provide directly adaptable models (Slipstream 2023). Incentive levels should reflect the fuel-switching nature of VRF in cold-climate applications, crediting gas savings rather than penalizing VRF for increased electricity consumption. Programs should also audit existing pathways, e.g., multifamily, new construction, affordable housing, to ensure consistent VRF eligibility and quality standards across all entry points.

Recommendation 5: Develop Targeted Outreach and Education Materials for Customers and Contractors

VRF's value proposition differs by building type; cold-climate reliability and quiet operation for schools, non-invasive retrofit for historic buildings, individual unit control and reduced maintenance for multifamily. Generic marketing materials are less effective than targeted collateral addressing each audience's actual decision context. Programs should also address the word-of-mouth problem proactively. Post-installation relationship maintenance, peer learning forums, and site tours connecting satisfied owners with prospective adopters can counter negative word-of-mouth. Equipping design engineers with VRF continuing education is a multiplicative investment: a single well-informed consultant specifying VRF correctly generates far more good projects than any single outreach campaign.

The Integrated Case for Action

The five recommendation areas above are mutually reinforcing. A program that invests in contractor training but does not require commissioning will still see DOAS scheduling errors go undetected. A program that requires commissioning but does not monitor post-installation performance will miss the refrigerant leaks and controls drift that develop afterward. A program that standardizes its incentive offering but does not develop the contractor ecosystem will find that market volume grows but installation quality does not keep pace. What is required is the integration of these elements into a coherent, purpose-built VRF program strategy, treating VRF not as a commodity HVAC upgrade but as a high-performance technology that rewards the full delivery chain investment it deserves.

Conclusions

VRF technology is mature, and regional and local decarbonization imperatives are creating durable policy and market tailwinds that can sustain adoption for decades. The evidence base presented here is still fairly limited, two monitored cases and one implementation case with qualitative data, but it suggests that the energy efficiency industry's task is shifting from proving the technology works toward building the market infrastructure, (i.e., the trained workforce, commissioning, monitoring systems, and program structures), that makes good outcomes routine rather than exceptional. Closing the gap between VRF's modeled potential and its realized performance looks achievable, though confirming that at scale will require a thorough review of an expanded set of case study data.

Three developments on the near horizon will shape what that infrastructure needs to look like. First, cold-climate VRF capability is advancing rapidly, with systems now rated to -22°F opening markets across the northern U.S. that were previously inaccessible. This is generating new demand for installers, evaluators, and program staff who understand cold-climate sizing, defrost cycling, and capacity management at temperature extremes. Programs investing in contractor ecosystem development today will be best positioned to serve this expanding market. Second, the EPA's phased transition to lower-GWP A2L refrigerants, with new VRF installation deadlines now extended to January 1, 2027 or January 1, 2028 depending on permit timing (EPA 2024a), will reduce the greenhouse gas risk from leakage in new systems, but will simultaneously require updated installer training and revised safety protocols that the workforce is only beginning to absorb. Third, growing integration of VRF controls with building automation and utility demand response platforms will unlock load flexibility potential that today's installations largely leave unrealized, but only for buildings whose operators have been trained and whose systems have been properly commissioned.

The buildings in this paper are early proof points of what a fully realized VRF market looks like. Reaching that market at scale requires utility programs, consultants, and evaluators to treat installation quality, commissioning, and performance monitoring not as implementation details but as the core of the work.

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