The Natural Choice for Walk-in Refrigeration: Packaged Hydrocarbon Equipment

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ABSTRACT

Condensing units have long been the go-to technology for walk-in coolers and freezers, but an innovative new product being explored by Efficiency Vermont might change that. Packaged hydrocarbon refrigeration systems are future-proof, resilient, and highly scalable. Efficiency Vermont has collaborated with original equipment manufacturers (OEMs), contractors, and end users to pilot installations of this relatively new technology in a wide variety of commercial settings. Initial findings have shown that packaged hydrocarbon systems offer significant energy savings, installation benefits, and operation and maintenance improvements over conventional, remote condensing units. Packaged hydrocarbon units are also modular, making them ideal for smaller and underserved food retail applications.

This paper explores the benefits of packaged hydrocarbon units: (1) use of propane, with its ultra-low global warming potential, making it "future-proof" from forthcoming changes in refrigerant regulations; (2) flexibility in meeting space and capacity needs because of its modular design; (3) improved safety and simplified installation from multiple, contained refrigerant circuits requiring no field-based refrigerant connections; and (4) long equipment life, due to being installed fully indoors.

Efficiency Vermont has supported the installation of seven units and collected data on energy and utility cost savings, contractor experience, speed of installation, and cost-effectiveness. These installations also provide data on business owners, owner experiences, and greenhouse gas benefits related to State energy goals.

Introduction

Walk-in coolers and freezers, commonly referred to as "walk-ins," are spacious, insulated refrigerated areas equipped with large access doors that allow people to enter. Walk-ins serve two primary purposes: food storage and merchandising in the food/beverage sales sectors. Large walk-ins, typically found in cold storage warehouses, supermarkets, wholesalers, and grocery stores, are generally cooled by centralized multiplex "rack" systems while smaller walk-ins, which typically serve such applications as food service, are generally cooled using remote condensing units or packed equipment.

Walk-ins are ubiquitous, with over 1.7 million walk-ins identified in a 2014 Saturation Study (Table 1, below). As the need for refrigeration has only grown since 2014, this number of walk-ins represents a conservative estimate as we characterize the market size for this technology type and its application across various commercial building business types.

Table 1. Walk-ins and Condensing Units by Business Type

Business type	Total walk-ins
Convenience stores	46,847
Gasoline stations with convenience stores	247,350
Supermarkets and other grocery (except convenience) stores	440,524
Warehouse clubs and supercenters	45,522
Restaurant and eating places	921,610
Total units	1,701,853

Installed base for walk-ins and condensing units in the U.S. *Source:* Itron Saturation Survey, 2014.

The refrigeration equipment used to cool these spaces has substantial energy and environmental impact. At over 460 million square feet (ft^2) of cooled floor area (EIA, Itron) requiring approximately 300 kilowatt-hours (kWh) per square foot per year (U.S. Cooler 2012), the annual energy consumption associated with these coolers and freezers is estimated at 138 billion kWh per year. Estimating energy costs at eleven cents per kWh (U.S. Cooler 2012), this means that the total energy consumption of these coolers and freezers costs $15.2 billion per year. At 0.86 pounds of carbon dioxide (lbs. CO_2) per kilowatt-hour (EIA 2023), the greenhouse gas (GHG) impact associated with the energy consumption of the coolers alone is approximately 54 million metric tons of CO_2. Additionally, the GHG emissions attributed to refrigerant leakage from this refrigeration equipment is estimated at 4.4 million metric tons of carbon dioxide equivalent (CO_2e) per year[1]. A shift to more efficient, climate-friendly equipment can dramatically reduce the 58.4 million tons of GHG associated with this sector.

Many market forces drive purchase decisions in commercial refrigeration for walk-in coolers, but of greatest significance among these are:

- Cost
- Performance
- Contractor availability and familiarity with equipment
- Refrigerant regulations

Inflation-driven cost increases are creating new pressures across supply chains as customers are increasingly pinched and looking for ways to cut costs—not only in product and installation, but also in operational and maintenance. This adds a layer of complexity to finding the balance between capital costs and more efficient products that are less expensive to operate. Operating performance, particularly energy efficiency, creates a value proposition for installing better equipment, though this is often overshadowed by the dramatic rise in initial cost associated with this equipment and the lack of availability of higher-performance units on a tight timeline. A steady decline in skilled workforce in the trades is adding further pressure to this tension by decreasing contractor availability, which increases labor costs. On top of this, decarbonization efforts being driven by federal regulations are speeding up the transition to low-GWP

[1] Based on assumption of 20% annual leakage (a conservative estimate, from VEIC industry experience), an average refrigerant global warming potential (GWP) of 2788, 120 British thermal unit per hour (BTU/h) capacity per ft^2 of cooler floor area, and 4 lbs. of refrigerant charge per ton (12,000 BTU/h) of capacity (U.S. Cooler 2012).

refrigerants. As a result of all these pressures, refrigeration equipment is seeing rapid innovation to meet these changing market conditions.

Packaged Systems for Walk-in Refrigeration

Walk-ins are served by three distinct types of cooling equipment; 1) self-contained or "packaged," 2) remote condensing units (RCUs), and 3) centralized multiplex "racks." Each of these types is designed for particular business applications, though there is substantial crossover in equipment type usage for the same applications, especially for packaged and remote condensing systems. Table 2 shows the distribution of cooler types by business type.

Table 2. Distribution of refrigeration systems by business type in California

Business Type	Self-Contained Packaged Systems	Remote Condensing Units (RCUs)	Centralized Refrigeration (racks)
Food/Liquor (e.g., grocery and convenience)	4%	40%	56%
Health/Medical-Clinic	38%	62%	0%
Miscellaneous	14%	85%	0%
Office	42%	58%	0%
Restaurant	21%	79%	0%
Retail	1%	64%	35%
School	43%	57%	0%
Warehouse	0%	6%	94%
TOTAL AVERAGE	21%	56%	23%

The results presented above are weighted by site weight and walk-in floor area (ft^2). *Source*: California Commercial Saturation Survey 2014.

The above data is specific to the California market. Though it is not a specific representation of the US as whole, it provides an indication of how refrigeration system type differs by business sector across the US market. As shown in Table 2, most walk-in coolers use RCUs, representing 56% of the total inventory. Packaged equipment is somewhat common in health/medical (38%), offices (42%), and schools (43%), however RCUs still hold a larger market share in these business sectors. Although rack systems serve a large percentage of total walk-in floor area, these systems tend to be restricted to the largest applications; this paper focuses on opportunities where packaged equipment is a viable alternative to the conventional approach.

RCUs paired with evaporators comprise the main components of conventional refrigeration systems for walk-ins. RCUs are split systems consisting of a condensing unit, located outside the walk-in (either inside or outside the building envelope), paired with an evaporator unit, located inside the refrigerated space. Figure 1 shows an example of a conventional condensing unit and evaporator unit. When the condensing unit, which houses the compressor, is located outside, RCUs generate very little noise inside the building. Condensing units can get quite large, capable of meeting substantial cooling loads. Technicians can service the condensing unit without entering the walk-in, simplifying maintenance. Installation involves running refrigerant piping to connect the units and fitting valves into the lines, which adds to the complexity and cost. Field-installed refrigerant lines introduce energy losses and increased potential for refrigerant leaks, necessitating careful design and installation. Allocating external space for the condensing unit can involve permitting issues, equipment protection considerations, and extended piping runs that can be addressed, but at a cost and space disadvantage.

Figure 1. Example of a condensing unit (left) and evaporator (right) that might serve a walk-in. *Source:* t-rp.com/product-category/condensing-units.

Field experience by Efficiency Vermont technical staff indicates that the typical capacity of RCUs range from 0.5 to 10 horsepower (hp) (4,000–150,000 Btu/h). Larger units are available for specialty applications, but the majority market share for condensing units is under 10 hp. RCUs in this size range contain 2 to 50 pounds of refrigerant (the working fluid inside refrigeration systems), depending on the capacity of the equipment and length of the refrigerant piping needed to connect the condensing unit to the evaporator unit(s). The implications of this refrigerant charge are outlined in detail below.

Unlike RCU-cooled walk-ins, packaged walk-in units arrive as (or are retrofitted to be) self-contained entities, with integrated evaporators and condensers in a single box (see Figure 2). Installation is straightforward, as all components come pre-assembled. These coolers are typically placed wholly outside the walk-in, freeing up indoor space with no need for an evaporator inside the walk-in itself. These systems are generally a less expensive alternative compared to RCUs. Their cooling capacity is limited, however, so alternative solutions might be more suitable for larger spaces. Some packaged equipment can also be loud as a result of their compressors operating inside the building.

Figure 2. Example of wall- and top-mount self-contained walk-in coolers. *Source*: U.S. DOE, 2009.

There is an emerging class of packaged refrigeration systems, referred to as "packaged hydrocarbon systems", which addresses many of the shortcomings of incumbent packaged equipment and, in most small applications, provide a beneficial alternative to RCUs. In every business type listed in Table 2, RCUs currently have a larger market share. With the adoption of more of these packaged hydrocarbon units, the distribution could shift more business types to install packaged systems, creating a fundamental shift that would reduce environmental impact associated with walk-in cooling.

Refrigerants and Hydrofluorocarbon Phasedown

Regulatory Considerations

As we evaluate the refrigeration options for walk-ins, we need to consider refrigerants according to their impacts on emissions as well as their regulatory implications. Refrigerants are highly regulated substances with performance, safety, and environmental implications. Ideally, refrigerants will provide a balance of these three factors. The refrigeration market is shifting rapidly toward low–GWP refrigerants because of the outsized impact of refrigerants as greenhouse gases. Regulatory changes are in alignment with the international Kigali Amendment to the Montreal Protocol (United Nations 2016). In the US, hydrofluorocarbon (HFC) phasedown is being regulated by the Environmental Protection Agency (EPA) in accordance with the American Innovation and Manufacturing (AIM) Act. The EPA rules include a scheduled step-down of refrigerant GWP, causing a regular shift in industry standards around use of different refrigerants in commercial refrigeration (AIM Act 2020). Figure 3 shows the step-down schedule for refrigerant GWP through 2037. Significant near-term step-downs occur in 2024 and again in 2029.

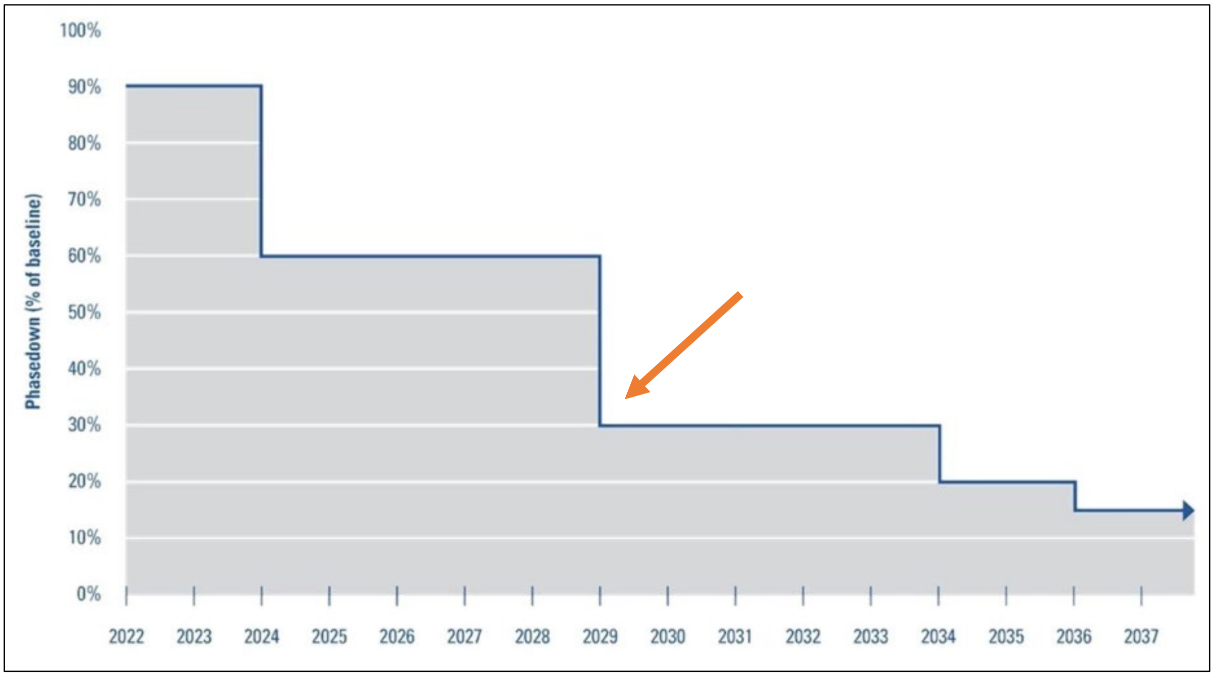

Figure 3. HFC phasedown schedule as a percentage of baseline. *Source*: EPA 2023.

The most common refrigerants used in conventional refrigeration systems are categorized as HFCs. This class of refrigerant is composed of various synthetic chemicals which were introduced to eliminate the ozone depletion characteristics of earlier refrigerants. Some of the most common HFCs used in commercial refrigeration are R-134a, R-404A, R-407C, and R-507. Some newer equipment has started to use a new class of refrigerants termed hydrofluoroolefins (HFOs) due to their low GWP values. HFO/HFC blends like R-448A and R-449A are also increasingly common. As shown in Table 3 below, the pure HFCs have GWP values between 1,300 and 3,985. Even the HFC/HFO blends, however, have moderate to high GWP values just under 1,300. According to the federal register 40 CFR Part 82, beginning January 1, 2021, the EPA banned R-404A, R-407C, and R-507A from use in new retail food refrigeration equipment. While R-134a, R-448A, and R-449A are currently still accepted refrigerant options, these will all be phased out of new equipment by 2026. In October 2023, the AIM Act published the Final Rule, which restricts the installation of new field-assembled products serving food retail—RCUs that have less than 200 pounds of refrigerant—to 300 GWP or less, effective January 1, 2026 (EPA Final Rule 2023).

Table 3. Common Refrigerant GWP Values (IPCC Fifth Assessment Report)

Refrigerant Classification No.	Refrigerant Type	GWP_{100}
R-134a	HFC	1,300
R-404a	HFC	3,943
R-407a	HFC	1,923
R-507	HFC	3,985
R-448a	HFC/HFO blend	1,273
R-449a	HFC/HFO blend	1,282

The regulatory environment, which is increasingly tightening restrictions, is applying pressure across the entire commercial refrigeration industry. New refrigerant requirements are having an outsized impact on split equipment such as RCUs. Not only does this equipment contain more refrigerant than packaged units, but it also has an increased likelihood of leaks. Due to the increase in flammability associated with many of the lower-GWP refrigerants, material handling and safety considerations for contractors who are working with this equipment in the field is also an issue. Packaged equipment has lower amounts of refrigerant and less chance of leaking the refrigerant it does contain. As the shift to lower GWP refrigerants becomes mandated, packaged cooling equipment is emerging as a clear winner in small retail food sectors with respect to regulatory considerations. It also opens the opportunity for a shift to *natural refrigerants*, which are future-proof from EPA phase-down regulations.

Natural Refrigerants

As refrigerant requirements change, the industry is making large capital investments in system redesigns to accommodate characteristics of new refrigerants. Redesigns are placing more emphasis on the concept of "future-proof" refrigerant selection. "Future-proof" implies that moving to ultra-low GWP refrigerants now will protect equipment design and selection from upcoming periodic regulatory changes.

Players in the refrigerant transition increasingly agree that the only truly future-proof refrigerants are natural refrigerants: ultra-low GWP options (<10) with no unintended emissions concerns. Although the chemical industry is touting HFOs as the low-GWP solution for the future, there are growing concerns related to the associated PFAS found with this class of refrigerants (ATMO 2022). Due to the favorable refrigerant characteristics of each natural refrigerant, ammonia is most commonly used in large industrial systems (>5,000 lb. charge), carbon dioxide in medium rack systems and large condensing unit applications (50 – 5,000 lb. charge), and propane is optimized in smaller condensing units and self-contained systems (0.5 – 50 lb. charge). Table 4 shows the primary natural refrigerants in use in commercial refrigeration, along with their GWP values and Safety Group Classifications. The Safety Group Classification matrix shown in Figure 4 helps inform some of the safety concerns relevant to natural refrigerants, which will be discussed in more detail later in this paper, and why certain equipment types are better suited to natural refrigerants as compared to others. "A" and "B" in the classification designate toxicity level, while numerals from 1 to 3 indicate flammability. Refrigerants with higher flammability or toxicity levels result in restricted use, often in the form of charge size limits and/or field-based refrigerant charging.

Table 4. Natural Refrigerants Used in Commercial Refrigeration

Natural Refrigerant Name	Refrigerant Classification No.	GWP_{100}	Safety Group Classification
Carbon Dioxide	R-744	1	A1
Ammonia	R-717	0	B2L
Propane (Hydrocarbon)	R-290	0.02	A3

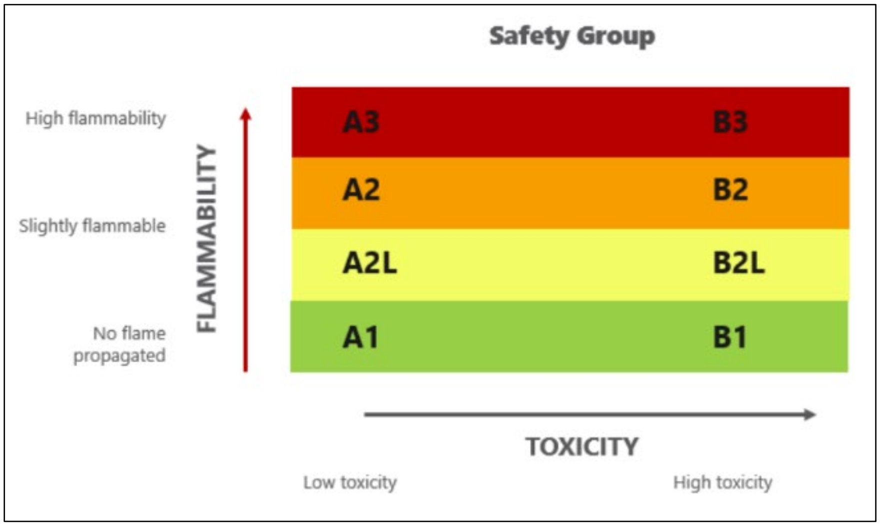

Figure 4. Safety Group Classification Matrix for Refrigerants

Natural Refrigerants and RCUs

Current refrigerant safety regulations effectively prohibit the use of hydrocarbons (a subset of natural refrigerants), due to their high flammability, and ammonia, due to its high toxicity, in RCUs. It is unlikely we will see these as options in near future. There is an alternative natural refrigerant, however, which several manufacturers use in RCUs: carbon dioxide (CO_2). CO_2 condensing units are available in a variety of capacities and provide a natural refrigerant solution for conventional RCUs, but they do have additional challenges compared to conventional RCUs.

CO_2 RCUs are substantially more expensive than conventional RCUs and operate at dramatically higher pressures as compared to HFC and HFC/HFO blends. As a result, these systems require different piping materials, system components, safety features, and installation techniques, which requires contractors to obtain new certifications, tools, and skillsets. Increased installation and product costs result in total installed costs as much as five or ten times those of conventional RCUs. As an emerging technology, CO_2 RCUs will need to come down significantly in cost (both product cost as well as contractor installation cost) to play a significant future role in walk-in refrigeration. In the immediate term, however, a shift to using hydrocarbons in packaged equipment presents the greatest opportunity to shift to natural refrigerants.

Hydrocarbon Packaged Refrigeration Systems

Hydrocarbon Refrigerants

Hydrocarbon refrigerants are extremely energy efficient. The inherent thermodynamic properties of hydrocarbons provide significant advantages over many synthetic refrigerants. Hydrocarbons have a high latent heat of evaporation, meaning that they can absorb a lot of heat during phase change from a liquid to a gas without a substantial increase in temperature. This high thermal capacity has significant efficiency benefits. The high refrigerant mass flow rate of hydrocarbons enables reduced refrigerant charges, which has efficiency, cost, and safety benefits. Lower operating pressures of hydrocarbon systems result in smaller compressors, which presents another opportunity for energy savings. Studies have shown energy savings up to 18.7% compared to R-134a (Fatouh 2018).

The advantages of hydrocarbons come with some safety risks. Classified as A3 refrigerants, hydrocarbons are non-toxic but highly flammable. Safe use of hydrocarbons usually involves small charge sizes, leak-tight systems, and leak detection/mitigation. Building codes limit the current charge size to 150 grams per circuit, which is less than 1/2 pound of refrigerant gas. RCUs are incapable of meeting these requirements, but packaged hydrocarbon coolers address all these concerns.

Packaged Systems

Hydrocarbon packaged systems are an emerging type of packaged refrigeration systems that provide an alternative to walk-in cooler and freezer applications that are commonly served by RCUs or conventional packaged units. Like conventional packaged coolers, hydrocarbon packaged systems combine the condensing unit and the evaporator unit into a single, compact system that is installed through the wall, ceiling, or door of the walk-in. Using natural, hydrocarbon refrigerants, however, makes these systems an efficient, low-GWP alternative for walk-in coolers and freezers.

Hydrocarbon packaged units are available in the US, ranging in size from 0.5 to 2.5 hp (1,300–15,000 Btu/h). The current capacity constraints are limited by the International Electrotechnical Commission (IEC) UL 60335-2-89 standard, which restricts the maximum charge size to 150 grams per circuit for A3 refrigerants, including R-290 (propane) and R-600a (isobutane) because of their flammability. These smaller capacities limit wider adoption and innovation of hydrocarbon equipment, narrowing its use either to smaller systems or multiple units. Updates to codes and standards, such as ASHRAE 15, EPA SNAP, and local Building Codes, are underway, which will help expand the reach of this opportunity. One manufacturer has entered the US market with this equipment and has met with a good deal of success.

The Rivacold "Best" Packaged Unit

A packaged cooler with integrated hydrocarbons is the Rivacold "Best" Packaged Unit for Cold Rooms. It employs a small-capacity system that can be modularly interconnected to meet nearly any load, while not surpassing the 150g per refrigerant circuit limit. These units are factory-sealed and tested to ensure leak-tight products, but they also contain a dedicated leak detection system for the rare occurrence of leaks. Products such as this are not only safe, but also meet all current refrigerant safety regulations in the US. US restrictions are substantially more limiting than in Europe, where adoption of hydrocarbons is far greater.

Efficiency Vermont partnered with Rivacold, an Italian-based manufacturer with a growing US presence, and a highly skilled local refrigeration contractor, Turner Piping and Refrigeration, to pilot the installation of the Rivacold Best. According to Efficiency Vermont's field testing, this walk-in equipment is flexible and easily installed, requiring very little training for refrigeration contractors. For smaller applications, the Best appears to be a highly cost-effective solution for walk-in cooler refrigeration, especially as a means of achieving a future-proof solution. Figure 5 shows images of the product and installation.

Figure 5. Image on the left shows the hole cut in the top of the walk-in from inside the cooler as the Rivacold unit is being set in place from above. Image on the right shows the fully installed unit on top of the walk-in.

A total of 7 units have been installed across 4 sites in Vermont. These units range in size from 1,300 Btu/h to 14,264 Btu/h, serving low and medium temperature walk-ins, at a café, an elementary school, a general store, and a pizzeria. Two of the sites have been new construction of walk-in coolers and freezers installed with the Best equipment, and the other two sites have been retrofits of existing walk-in coolers and freezers with the Best equipment replacing HFC equipment.

Installation

Installation simply involves cutting a hole in the ceiling of the cooler, dropping the unit into place, and wiring the controller to the unit. The Best units plug into a regular 120 volt or 240 volt outlet. This results in a very quick installation. Installation speed can be critical to limit downtime and minimize food spoilage. In contrast, RCU installation is substantially more involved, requiring mounting the condensing unit, running refrigerant piping, system evacuation, and charging—all avoided with a packaged unit installation. Faster installation of packaged units also means that time-constrained contractors can get more work done in a set period of time. With growing contractor constraints due to decreases in skilled contractors and an aging labor force, this provides significant value to the industry. The units are also modular, making them flexible in meeting various loads while simplifying the product line. Up to 8 units can be daisy-chained together and controlled by a single, primary controller.

Efficiency

There are a number of efficiency benefits found in this equipment. In addition to the efficiency gains from using hydrocarbons, Best has several other features which further improve its performance. It has a modulating, variable-speed compressor. It also has Modbus and Bluetooth connectivity for remote diagnostics and alarms. This enables service contractors to catch problems early and optimize settings for performance. It incorporates a smart defrost algorithm and, where beneficial, utilizes integrated floating head pressure controls. Initial performance data has indicated nearly 40% energy savings as compared to conventional RCU.

Field Testing Results

Contractor and Customer Feedback

The following is summarized customer and contractor feedback regarding various elements of the installation and operation of the Best equipment that was gathered during and after the projects were completed.

Contractor Feedback

- Easy and quick to install, sometimes negating need for subcontracted electrician
- Condensate management is critical to preventing moisture issues
- The units are very heavy (up to 420 lbs.) so using a lift and walk-in structural reinforcement can be needed
- We can use our less experienced staff for this installs
- They are easy to install but there are several important details you need to get right

Customer Feedback

- Like the short downtime for retrofits due to the quick installation
- Would consider using a contractor that doesn't specialized in refrigeration to save money
- Most contractors are not aware of this option, but when more catch on they will probably start installing
- Efficient units have lowered our electric bill

Energy Performance Data

Sub-metering equipment was installed on four Best units to collect energy and performance data. The sites are equipped with power meters to measure total power of the refrigeration system, along with temperature and humidity sensors to collect ambient conditions inside and outside of the refrigerated box. One month of data has been collected to date.

One of the sites being monitored has a single Best unit installed on a walk-in cooler that measures 6' x 8' x 8'. The estimated energy savings of the Best unit was compared to a conventional RCU installed indoors using R-134a refrigerant. The modeled savings were estimated to be 9,500 kWh per year and 7,150 lbs. of CO_2e of refrigerant GHG emissions[2]. The model uses manufacturer equipment data and application load shapes to estimate the savings. Preliminary metering results shows annualized energy savings of 18,500 kWh when compared to the conventional RCU, nearly doubling the modeled savings estimate. At an electric utility rate of $0.15 per kWh (characteristic of VT-specific commercial rates), this results in utility cost savings of $2,775 per year.

The meter data indicates that the unit operates at a reduced load 99.7% of the time, saving energy from the reduced compressor power draw. Figure 6 below shows the compressor modulating its speed to match the refrigeration load on the system. The maximum power draw on the system is 720 watts and the average power draw during the metering period is 260 watts. The average running power draw while the compressor is operating is 460 watts. Throughout the metering period, the temperature inside the refrigerated space maintained a consistent 36°F, and the temperature in the ambient space around the Best unit ranged from 72 – 93°F, with an average of 85°F.

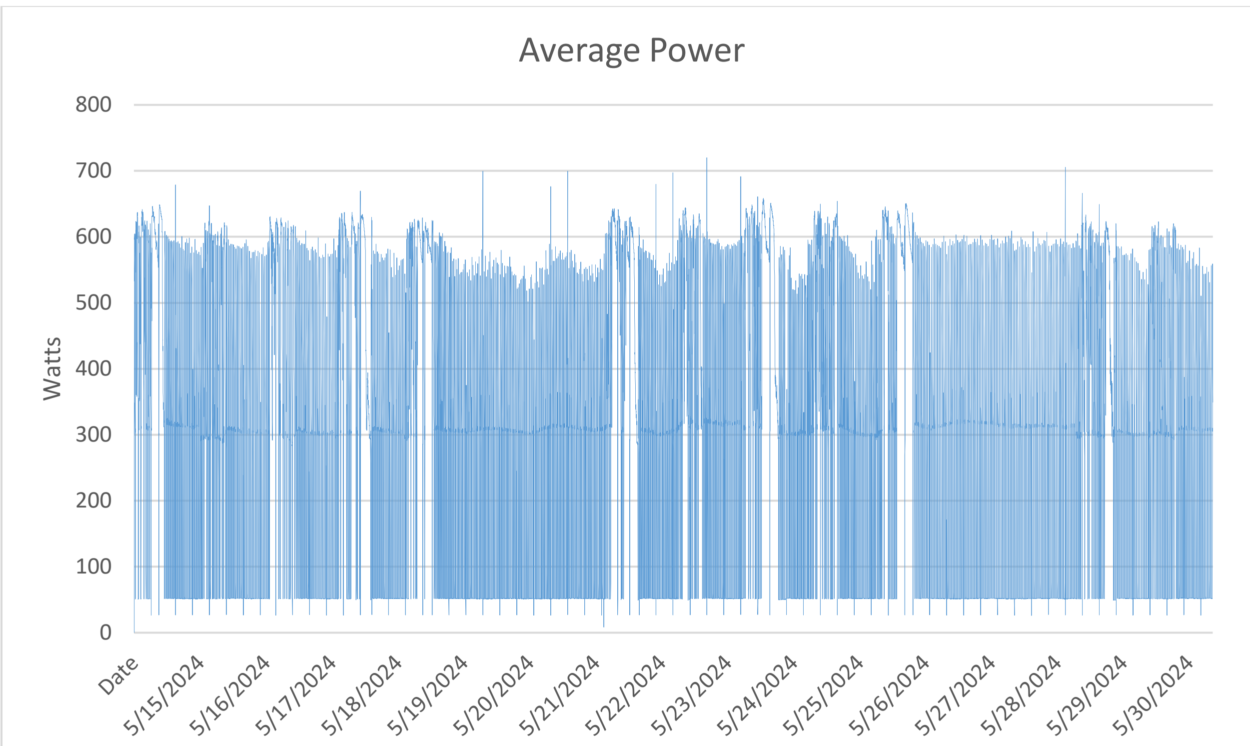

Figure 6 - Power consumption data for one medium temperature Best unit operating from 5/15/2024 – 5/30/2024

Table 5 below shows that the unit operates at less than 10% capacity for nearly half of the metering period, indicating a compressor duty cycle of 51%. Energy savings result from the Best unit operating at less than full load. The data shows that the unit operates at 50% or less capacity 66% of the time and above 50% capacity for 34% of the time.

[2] Assumes 25% annualized refrigerant leak rate which is characteristic of what Efficiency VT staff have seen in the field for condensing units.

Table 5. Operating capacity of Best unit over the metering period from 5/15/2024 – 5/30/2024

Percent Capacity	Watts Draw	Percent Time
10%	72	49%
20%	144	1%
30%	216	0%
40%	288	1%
50%	360	15%
60%	432	6%
70%	504	4%
80%	576	8%
90%	648	16%
100%	720	0%

Installation Cost Comparison

Cost data has been collected for all 4 of the pilot sites. Project costs for the Best systems were widely varied, with one of the sites incurring double the cost of another site. This is partially attributable to economies of scale, but not entirely. Shown in Table 6 below, the average cost per unit for the Best systems that have been installed is $8,574. The average cost per unit ranged from $5,541 to $11,151. The variation in these costs likely reflects the size of the project scope, physical location of the walk-in, age of existing equipment in this building, accessibility of electrical utilities, time of day to install, and other site specific details.

Table 6 – Project costs for Best units at pilot sites in Vermont

Site	Business Type	#Units Installed	Total Labor Cost	Total Materials Cost	Total Project Cost	Cost per Unit
A	Café	1	$2,905	$4,280	$7,185	$7,185
B	Elementary School	2	$4,200	$18,102	$22,302	$11,151
C	General Store	3	$4,375	$12,247	$16,622	$5,541
D	Pizzeria	1	$4,553	$5,868	$10,420	$10,420
					Average Cost	$8,574

Two of the sites received comparative quotes for conventional systems in addition to the quote for the Best systems that were installed. The conventional systems reflect a RCU being installed indoors in a split configuration using R-448A refrigerant. The average incremental cost of the Best system over the conventional R-448A system ranged from 34% - 98% increase. However, when you look at the one site (Site B) where we have a labor and materials breakout comparison, we can see a nearly 60% increase in materials costs for the Best units and a *20% reduction in labor costs*. It is important to point out that this project was a retrofit. As a retrofit, the refrigerant piping was already installed, significantly reducing both the materials and labor costs for the baseline system. New construction is therefore anticipated to be a much smaller cost premium (if at all) over a baseline RCU).

Table 7 – Project cost comparison between Best systems and R-448A RCU systems

Site	B	C
Business Type	Elementary School	General Store
#Units Installed	2	3
Best Labor Costs	$4,200	$4,375
Best Materials Cost	$18,102	$12,247
Best Project Cost	$22,302	$16,622
R-448A Labor Costs	$5,250	-
R-448A Material Cost	$11,360	-
R-448A Project Cost	$16,610	$8,381
Best Incremental Project Cost	$5,692	$8,241
% Increase over baseline	34%	98%

Conclusion

Walk-in coolers and freezers are responsible for substantial energy consumption and GHG emissions in the commercial building sector. Conventional refrigeration technology, often minimally efficient RCUs using HFC refrigerants, are responsible for the majority of small- to medium-sized walk-ins. Although CO_2 equipment represents an opportunity to shift RCUs to natural refrigerants, high product and labor costs associated with installation of CO_2 RCUs create a near-term barrier to adoption. There is an immediate opportunity to shift walk-in cooler refrigeration to natural refrigerants using ultra-efficiency, self-contained hydrocarbon packaged coolers, which could accelerate the US's transition to low-GWP refrigerants while saving electricity costs for customers.

Hydrocarbon packaged units use R-290, propane, which has a GWP of <1, making it a future-proof option. This equipment also employs a variety of high-efficiency components and control systems. Taken together, it is an incredibly efficient and ultra-low GWP refrigerant cooler option for walk-ins. The packaged form factor also makes them quick to install because there is no field-based plumbing or refrigerant connections, these products can be installed by non-specialized labor. This is a big time-saver for resource-constrained contractors, and customers are pleased with the reduced cooler downtime and reduced footprint of the product.

Hydrocarbon packaged systems are a valuable commercially available tool for decarbonizing walk-in coolers and freezers. What's more, they also offer modularity and ease of installation benefits. Given the size and GHG impact of this market, a shift toward this equipment type from conventional RCUs is a natural choice.

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