Large VRFs Versus Small Mini/multi Split Heat Pumps: A Comparison

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Electrifying buildings is viewed as a major pathway to reducing carbon emissions and eliminating the use of fossil fuels. Because heating is typically the highest single energy end use in multifamily buildings in New York State, and the highest user of fossil fuels, the use of heat pumps is a primary electrification strategy. The most efficient heat pumps are ground source heat pumps, but these are generally limited to suburban and rural areas, due to the need for land for wells. So, air source heat pumps are expected to be a main way to electrify multifamily buildings. This is already occurring in new multifamily buildings, with rapid growth in the use of air source heat pumps across the state, and this transition has also started in the conversion of existing buildings from fossil fuels.

Multifamily buildings use two broad types of air source heat pumps: Larger commercial systems and smaller residential systems. These heat pumps are almost exclusively split systems, in other words, systems with an outdoor unit and one or more indoor units. The nomenclature is a little confusing. Some people use "VRF" to refer to both types, because both typically use variable speed compressors, but few manufacturers refer to the smaller systems as "VRF". Some people refer to the small systems as "multi-split ductless", but the large systems are also multi-split systems and can be ductless. We will use an abbreviated version of the Air Conditioning, Heating, and Refrigeration's (AHRI) nomenclature: AHRI refers to the larger systems as "Commercial Variable Refrigerant Flow (VRF) Air-Conditioners and Heat Pumps"; we will refer to these as "large VRFs". AHRI refers to the smaller systems as "Residential Variable-Speed Mini-Split and Multi-Split Heat Pumps,"; we will refer to these as "small mini/multi-splits".

The decision whether to use large VRFs or small mini/multi-splits in multifamily buildings, either in new building or in existing buildings, is an important one. The early trend a few years ago was to use large VRFs, whereas more recently both types of systems are commonly installed. Energy and design professionals should choose the system that best suits their specific building. However, as discussed below, large VRFs cost measurably more to install, use measurably more energy, use measurably more refrigerant, and in many cases take up more space. We therefore pose the question: Should small mini/multi-splits not be given first preference in multifamily buildings?

This document is limited to split system air source heat pumps that deliver air to the indoor space ("air-to-air" heat pumps), rather than air-to-water, water-to-air, or water-to-water heat pumps. Split system air-to-air heat pumps currently comprise most of the heat pumps being used in the U.S. and overseas, and they are expected to dominate electrification efforts, at least in the near term and possibly long-term as well. Our focus on split system air-to-air heat pumps is not intended to detract or de-emphasize other heat pumps types (ground source heat pumps, packaged rooftop heat pumps, etc.), each of which has an important place in the electrification effort. We also do not include packaged terminal heat pumps (PTHP's, also informally referred to as "PTAC heat pumps") in our analysis, because none of the units currently available on the market are able to provide efficient operation in the New York climate[1] and so should not be considered for multifamily carbon reduction work until such time that a cold-climate version is developed.

Energy Use

Large VRFs use more energy than small mini/multi-splits, for the same building load. We know this for several reasons:

- A comparison of heating energy use found it to be higher for large VRFs than for small mini/multi-splits, in new multifamily buildings, in a study that is a couple years old. We examined more recent buildings and confirmed this finding.
- Federal energy efficiency requirements are lower for larger equipment.
- Average actual product efficiencies are lower for large VRFs.
- Prior studies that have found low efficiencies for large VRFs.

Separately, better-than-minimum energy programs (e.g. ENERGY STAR, CEE, NEEP, state and utility programs, etc.) primarily cover small mini/multi-splits. Fewer such programs exist for large VRFs.

A 2018 study of eight large VRFs in new multifamily buildings found the average heating usage to be 13.5 kbtu/SF/year, compared to one building with a small mini/multi-split that had a heating energy use of 5 kbtu/SF/year, lower than that of any of the large VRFs[2] . Because this study only used a single small mini/multi-split, we looked at additional buildings and expanded the study to nine large VRFs and six small mini/multi-splits, including the buildings from the earlier study. We found the average heating usage for large VRFs to be 13.3 kbtu/SF/year, compared to a 7.5 kbtu/SF/year average for small mini/multi-splits, representing a 77% higher average heating energy use for the large VRFs. The spread of the energy use of the 15 buildings is shown in Figure 1.

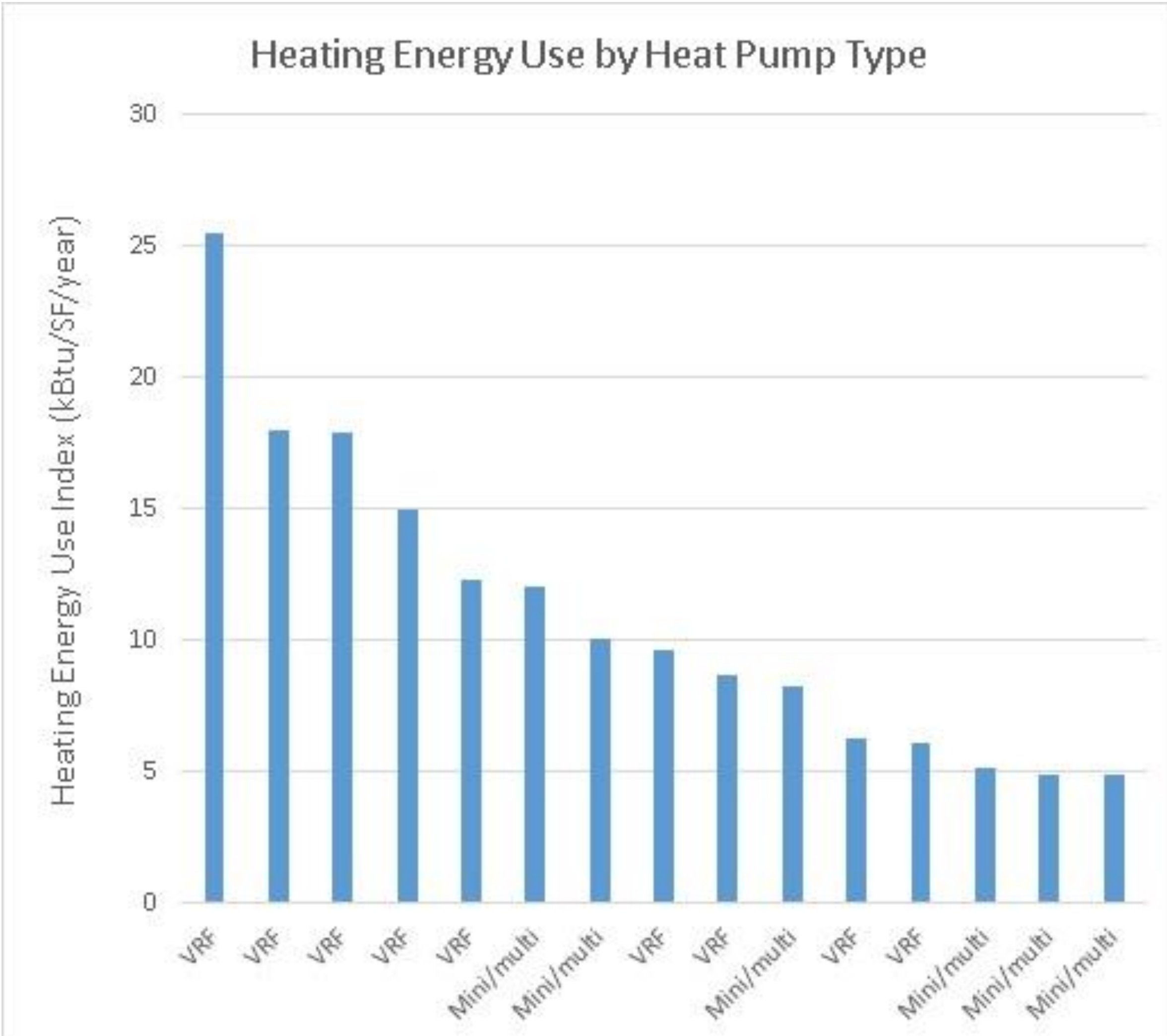


Figure 1: Heating Energy Use in New Multifamily Buildings

The building stock for each of the two samples are similar, in terms of average number of stories (5 story average for both types of buildings), building size (65000 SF average for large VRFs, 95000 SF average for small mini/multis), and number of apartments (155 average for large VRFs, 130 average for small mini/multis). All buildings are relatively new buildings (built in the last 10 years), and so building envelope differences are presumed to contribute minimally to the difference in energy use. All buildings are in New York State, with a mix of both large VRFs and small mini/multis both in New York City and Upstate: Six of the VRF's are in NY City, and three are upstate. Five of the small mini/multis are upstate, and one is in NY City.

A literature survey of the actual annual-average heating efficiency of small mini/multis concluded that the typical operating COP in the New York State climate is about 2.5.[3] If small mini/multis indeed are 76% higher in efficiency, as found in our EUI comparison, this means that large VRFs have a typical COP of 1.4. Low COPs for large VRFs have been seen in two prior studies, both of which were done in warmer climates of the Southeast U.S., and so should be conservative (high COP) relative to efficiencies in the Northeast. One study reported COPs of 1.2-2.0.[4] The second study reported monthly heating COPs through winter in the 1.4-1.75 range.[5]

Reasons for Lower Efficiency of Large VRFs

Lower Efficiency Ratings

Large VRF's are lower in rated efficiency than small mini/multis, but it takes a little work to find this.

It is somewhat difficult to directly compare federal efficiency requirements (as well as ASHRAE Standard 90 requirements) for the two system types, because different metrics are used: Large VRFs are rated in steady-state COP at 47°F outdoor air temperature, whereas small mini/multi-splits are rated in HSPF, which account for both steady-state efficiency and efficiency when equipment cycles on and off. However, we do know that there is a trend for federal efficiency requirements to get lower as equipment gets larger. For example, heating and cooling efficiency requirements are 3%-9% lower for large VRFs over 135,000 Btu/hr capacity, relative to large VRFs in the 65,000-135,000Btu/hr range. DOE's regulations have always allowed lower equipment efficiencies for larger equipment.

We examined the Northeast Energy Efficiency Partnership (NEEP) cold climate heat pump listings for small mini/multi-splits, which DO include the steady-state heating efficiencies (COPs at 47°F) that are used for large VRFs, which are not included in the AHRI ratings. First, to make sure we are comparing apples-to-apples, we compared the average NEEP HSPF to the average AHRI HSPF, and found them to be similar, and in fact the average NEEP HSPF is 3% LOWER than the average AHRI HSPF. Then we compared the average NEEP small mini/multi COP at 47 F (3.97 COP) to the average large VRF AHRI COP at 47°F (3.57 COP). The small mini/multi COP is 11% higher than the average COP for large VRFs. The difference in efficiency at the 17°F rating condition is even larger, with the average NEEP rating 2.92 COP, which is 26% higher than the average large VRF efficiency at 17 F of 2.33 COP.

The NEEP ratings are relevant to actual installed efficiencies in New York State, because they have been required by NYSERDA to qualify for small mini/multi-split incentives, and most investor-owned utilities in New York State also require compliance with the NEEP standard in order to qualify for utility small mini/multi incentives.

Difference in Part Load Performance

Another possible reason that large VRFs use more energy than small mini/multi-splits is a difference in part load performance, including how low the capacity to which the outdoor unit can reduce, when fewer and fewer indoor units are calling for heating or cooling. We examine this through the turndown ratio (ratio of smallest capacity to rated capacity). But of specific interest is not the turndown ratio itself, but how small the actual capacity can go. At very low capacities, when the required capacity of indoor units is smaller than the outdoor unit capacity, one of several things occur, any of which will increase energy use: 1. The outdoor unit cycles on and off. 2. The outdoor unit stays on but operates inefficiently. 3. The outdoor unit uses an inefficient unloading control, such as hot gas bypass, indicated in literature of various VRF manufacturers.

Some large VRFs can reduce their capacity substantially, reporting minimum heating capacities in the 5,000-10,000 Btu/hr range. But more manufacturers report higher minimum capacities, in the 12,000-24,000 Btu/hr range, based on published turndown ratios (typically 10%-20%) and depending on the capacity of the outdoor unit. Even though large VRFs are available in smaller capacities, such as 6-8 tons, it is unusual for these to be used in multifamily buildings because they can only serve 1-3 apartments. It is more common for large VRFs in the 10-14 ton range to be used for multifamily buildings, serving 5-10 apartments each. A turndown of 10% applied to 10-14 tons is 1.0-1.4 tons. A turndown of 20% applied to 10-14 tons is 2.0-2.8 tons. We conclude that some manufacturers of large VRFs turn down to sub-12,000 Btu/hr heating capacities, but that the majority turn down to the 12,000-24,000 Btu/hr range.

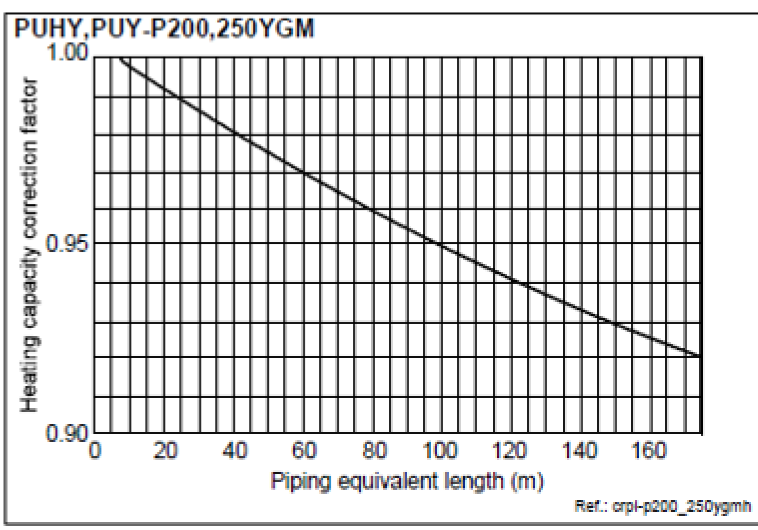
For small mini/multi-splits, the minimum turndown ratios are reported to be in the 12%-13% range. However, testing at NREL put these turndown ratios in doubt, as they found an actual turndown of 21% for a system which claimed to have a 13% turndown.[6] We examined a few product catalogs and found turndown ratios reported in the 13-50% range. All manufacturers of small mini/multi-splits have products that have minimum capacities below 9,000 Btu/hr.

In the absence of harder data, we conclude that large VRFs in the typical 10-14 ton range can turn down to the 12,000-24,000 Btu/hr range (10%-20%), with possible exceptional products dipping below 12,000 Btu/hr. We similarly conclude that small mini/multi-splits in the typical 1.5-3.0 ton range can turn down to the 7,000-18,000 Btu/hr range. Therefore, small mini/multi-splits for multifamily buildings will likely deliver better part-load performance than large VRFs, and so use less energy for much of the heating season. The mention of hot gas bypass multiple manufacturers of large VRFs is of concern and could substantially increase energy use, but short-cycling or inefficient rebalancing could well also substantially penalize energy use of large VRFs at part load.

Other Causes

Beyond the known higher efficiency of small mini/multi-splits, and the likely better part-load performance, what other reasons could possibly explain a substantial difference in energy use, as high as 76% more for large VRFs? Answers are many. The two equipment types are simply very different. Possible explanations could include:

1. Efficiency loss due to long refrigerant piping. We know that long piping results in higher refrigerant flow pressure drop, and that pressure drop increases energy use. An example of capacity loss due to long pipes is shown in the figure below.[7] We believe that whereas increased pressure drop in long pipes causes capacity to drop (due to lower saturated condensing



temperature), power consumption remains the same (because the compressor has to pump refrigerant over the same pressure head for the lower saturated condensing temperature and higher saturated evaporator temperature), and so efficiency decreases with longer pipe length, and energy use increases.

2. Pressure drop at fittings. Small mini/multi-splits typically use a single length of soft copper piping between the outdoor unit and indoor unit, without fittings and with large-radius pipe turns, whereas large VRFs use more fittings such as elbows, tees, VRF-specific takeoff fittings, and connections at intervening control boxes, in installations where such control boxes are used. Increased pressure drop causes increased energy use as described above.
3. Energy use due to oil return cycle on large VRFs. Large VRFs periodically go into an oil return cycle, typically increasing compressor speed and opening control valves to force oil in the system back to the compressor. One manufacturer reports a 4-minute oil return cycle for every 8 hours in heating and a 6-minute cycle for every 3 hours in cooling.
4. "Snow falling protection" cycle. Because large VRFs have an upward-discharge airflow pattern, they are subject to the risk of snow accumulating on their fans when not operating. For example, one manufacturer reports that the outdoor fan operates at maximum speed for one minute when the heat pump is not operating and the outdoor temperature is below 5°C. Small mini/multi-split outdoor units typically have horizontal airflow and so are not subject to this snow accumulation risk.
5. Control differences. For example, one manufacturer of large VRFs reports a "low-noise" mode, where the indoor fan is forced to low speed. A low indoor fan speed will typically result in lower energy efficiency. There are many other such control differences. Without more information on these control differences, attributing energy penalties only to large VRFs is speculative. In some cases, control differences could increase energy use of small mini/multi-splits. But heat pumps are complex pieces of equipment, and reasons for variations in energy use are many. For example, Energy use could vary depending on the energy use of crankcase heaters, basepan heaters, defrost algorithms, outdoor fan control, use of backup electric resistance heat, and much more.

We conclude this energy discussion with two takeaways:

a. Large VRFs use measurably more energy than small mini/multi-splits.
b. There are multiple known reasons for this difference in energy use, and other possible explanations that have not been quantified.

Footprint and Location of Outdoor Units

A common statement in favor of large VRFs is that they are indeed larger in capacity, so there are fewer outdoor units, so they will take up less space. This is incorrect in many cases. The large VRF outdoors units have upward airflow, and so cannot be stacked, whereas at least two manufacturers allow stacking, two-high, of the smaller mini/multi-splits. For example, a row of 6-ton VRF outdoor units, with service clearance, takes up 324 square inches of footprint per ton (including service/clearance area around the units), whereas a row of 3-ton units, stacked two high to deliver the same 6 tons, per stacked pair, takes up only 212 square inches per ton. If the number of apartments increases, the 3-ton units can be stacked not only two high, but they can be set in two rows, spaced 20-24 inches apart, requiring only 263 square inches per ton (including clearances), still a lower footprint than the larger 6 ton VRF units.

Even for small mini/multi-splits from manufacturers that cannot stack two-high, the footprint of two 3-ton heat pumps, with service clearance, is not much more than a single 6-ton large VRF. The smaller depth dimension of the small mini/multi-splits work to their advantage, to offset some of the advantage of the single large VRF.

The required footprint for the VRF units can be reduced in some cases by using larger systems, for example 12-ton or 14-ton units. In most cases, the difference in footprint between large VRFs and small mini/multi-splits is likely to be small. The only exception might be in cases where there are many apartments and the smaller heat pumps need to be placed in more than two rows. In this case, the spacing between the second and third rows needs to be larger, to avoid air recirculation. So, if the number of apartments is very large, and if the outdoor units are all concentrated in one location rather than at the top of a column of apartments, the large VRFs might fit more capacity for a given footprint. For buildings with a smaller number of apartments, or where outdoor units are generally at the top of apartment stacks, the footprint of small systems will in many cases be smaller. In general, the difference in footprint is not expected to be significant between large VRFs and small mini/multi-splits.

The outdoor units of small mini/multi-splits can be more easily wall-mounted than large VRFs. For example, most large VRF outdoor units weigh well over 500 pounds, however typical wall-mount racks are only rated to 500 pounds. Large VRFs will also protrude farther out from the wall. Although wall-mounting of large VRFs has been done, it is rare, and requires specialty racking.

Installed Cost

Large VRFs cost more to install than mini/multi-splits.

A prior study reported large VRFs cost $15-20/SF, compared to small mini/multi-splits that cost $10-18/SF. Midpoints of these ranges would imply that large VRFs cost 25% more to install than small mini/multi-splits.[8]

A survey of several more recent quotes found that large VRFs cost $15-34/SF, with an average of $22/SF, for a sample of 13 quotes. Small mini/multi-splits cost $8-23/SF, with an average of $15/SF, for a sample of eight quotes. The average large VRF cost is 50% higher than the average small mini/multi-split cost.

Of interest in our sample is one project for which the same contractor quoted both large VRF and small mini/multi-splits, for the same building. The large VRF installed cost was 24% higher.

There are several plausible reasons for the difference in cost. Large VRFs are produced in far smaller production quantities and have more features, such as advanced controls, heat recovery, and other large-commercial heating/cooling capabilities. Fewer contractors install large VRFs, so there is less competition for installing this type of equipment. In upstate New York, the lower number of large VRF installers means more travel time to job sites, further adding to construction cost.

Refrigerant Quantity and Leak Risk

Virtually all air source heat pumps in the U.S., both large VRF and small mini/multi-splits, use refrigerant 410a, which has a relatively high global warming potential if leaked/released. With increasing concern about this impact, issues of refrigerant quantity and risk of leaks are important.

Refrigerant quantity (also referred to as refrigerant *charge*) appears to be measurably higher for large VRFs, per unit of system capacity, than for small multi-splits. This appears to be true even for similar-pipe-length systems, for example if outdoor units are located on the roof in a direct comparison. The difference grows even larger if small multi-split outdoor units are located close to their indoor units, for example on a balcony or wall-mounted close by.

One study indicates that large VRFs use 3.7-10 pounds of refrigerant per nominal ton of capacity[9]. Another study indicates 3-6 pounds per ton .[10] We examined refrigerant charge for a sample of large VRFs and found refrigerant charge in the 3-5 pounds per ton range, allowing for added charge for typical line lengths. Although we found that the base charge for large VRFs averages only 2.2 pounds per ton, large VRFs have a significant additional charge that must be added, which depends on a variety of factors, including system size and line length. This additional charge starts even for line lengths of zero, unlike small mini/multis for which line length corrections only start after a minimum line length (see below). We conclude that 3-6 pounds per ton is representative of large VRFs.

For small mini/multi-splits, we examined refrigerant charge for a small sample of units and found refrigerant charge in the 2.0-4.2 pound per ton range, averaging 2.6 pounds per ton, as a base charge before corrections for line length. This is confirmed by one of the above studies, that reports 2.6 pounds per ton for small systems. Small mini/multi-splits typically allow a minimum line length for which no added charge is required. We sampled a few products from different manufacturers and found that this minimum line length varied from 25-82 feet, averaging 43 feet. Almost all manufacturers required 0.21 ounces of added refrigerant per foot of pipe over this minimum. This represents only 0.2 pounds per ton of added charge, for a system with maximum line lengths, because indoor units close to the outdoor unit do not require any added charge, even though indoor units farther from the outdoor unit require more charge.

If we take 4.5 pounds per ton as a midpoint representative of large VRFs (including both base charge and added charge), and 2.8 pounds per ton as representative of small multi-splits (2.6 pounds/ton plus 0.2 pounds/ton added charge for maximum line length), we conclude that large VRFs use 60% more refrigerant charge, typically, than small multi-splits.

Large VRFs not only have more refrigerant, but typically have joints that are less accessible, for leak detection and repair. Small mini/multi-splits typically only have joints at the outdoor units and at the indoor units, using continuous small soft-copper piping between the outdoor units and indoor units, without joints. However, large VRFs have a variety of joints between the outdoor and indoor units, which are typically located in chases and other less accessible locations. The risk of leaks being more difficult to locate and to repair is likely higher with large VRFs. The risk of larger refrigerant loss is also higher with large VRFs, due to their having more refrigerant. It has been shown that most refrigerant is lost in large, catastrophic leaks.[11]

There are also issues relating to refrigerant quantity limitations relating to requirements in ASHRAE Standard 15, that limits the pounds of refrigerant of a system, per cubic foot of the smallest space served by the system, that limits some applications of large VRFs, or requires work-arounds such as using ducted systems to serve multiple small spaces.

Cooling

In New York's cold climate, we direct our attention mostly to heating season performance. However, large VRFs also use more energy in cooling than small mini/multi-splits. As previously mentioned, rated efficiencies of large VRFs are lower. Furthermore, the impact of long refrigerant lines is even greater in cooling, due to higher refrigerant flows and so higher refrigerant flow pressure drops.

Contractors, Service, and Maintenance

There are fewer contractors available to install and service large VRFs than there are for small mini/multi-splits. In New York City, this might be less of an issue, due to the size of the city and availability of contractors. However, in upstate New York, this is more of an issue. For example, a specific medium-size upstate city was surveyed, and found to have multiple local contractors in town that can install or service multiple brands of small mini/multi-splits, whereas the closest contractors available to service any of the VRF brands are on average over 50 miles away.

As mentioned previously, finding and repairing refrigerant leaks in large VRFs is more difficult than in small mini/multi-splits, due to more joints per system and some joints being less accessible.

In the case of a major repair issue at the outdoor unit, buildings with large VRFs lose heating/cooling to more apartments, during such downtime, because they service multiple apartments, than do small mini/multi-splits, which typically serve one apartment per system. For example, a failed compressor in a 14-ton large VRF with a single compressor might result in loss of heat to 5-10 apartments in midwinter, for a period of several hours to several days. Because these apartments are typically adjacent (for example, in a single vertical stack), this situation risks substantial loss of interior temperature during the service downtown. With a single small mini/multi heat pump, loss of a compressor means loss of heat to one apartment, which can still gain heat from adjacent heated apartments, and so will lose less heat and so its interior temperature will drop less than during downtime of a large VRF heat pump.

Features

Although large VRFs use more energy and cost more to install, they come with added features that may be of interest. These include:

- Ability to heat/cool makeup air. Makeup air can be separate zones on a large VRF system.
- Submetering capability. VRF systems can allocate energy use to different zones. This is typically an indirect estimate based on control valve position and the duration for which they are open, rather than a direct measurement of energy flows. However, it can still be useful for allocating energy costs and for troubleshooting energy use and energy losses.
- Heat recovery – the ability to simultaneously heat and cool different zones on one system, and to productively use the rejected heat from cooling zones in reducing the energy use for zones in heating.
- Controls capabilities.
- More types of indoor fan coils, including recessed cassette type units, which are not typical in apartments, but could be of interest for office spaces and common areas.

Conversely, small mini/multi-splits have some advantages, in addition to using less energy and having lower installed cost. These include:

- Ability to be included on the tenant/occupant meter.
- Residential electricity rates, without demand charges.

Conclusions

Large VRFs use as much as 90% more energy than small mini/multi-splits, and cost approximately 25%-50% more to install. Large VRFs require approximately 80% more refrigerant per nominal ton of capacity. Service and maintenance are likely easier and less costly for small mini/multi-splits. In many cases, small mini/multi-split outdoor units take up less space than large VRFs. For these reasons, small mini/multi-splits deserve priority as a split system air source heat pump option for multifamily buildings, over large VRFs.

Large VRFs do have some advanced features, such as ability to heat/cool makeup air, and heat recovery, that might offer benefits in some cases for common area heating/cooling loads. Where long pipe lengths are required, such as for high-rise buildings, large VRFs offer greater lengths, but at even greater energy use.

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