Water-source VRF

Variable refrigerant flow (VRF) technology is a high performing HVAC system newer to the United States, though common in Europe and Asia. Recent improvements in refrigerants and interest in energy performance have increased its use in the United States. VRF systems use refrigerant as a distribution fluid to move heat between a variable-speed compressor unit and one of many indoor fan coil units to heat or cool an individual zone in a building. Energy is saved due to the variable speed of the compressor, the distribution of energy-dense refrigerant as opposed to air, zone-level heating and cooling (reheat never needed), and heat recovery from one zone to another.

In the cold climate of the upper Midwest, air-source VRF systems have difficulty meeting heating loads when the outdoor temperatures drop below -5°F. Because of this difficulty during common cold spells, they are either oversized (adding to system cost) or supplemental heat is added (adding to operating cost). Cold temperatures can also cause frost issues around outdoor units, as well as compressor failure. A VRF system served by a water loop—in place of air—does not have these issues, making the technology more practical and effective in cold climates such as the upper Midwest. A water-source VRF system can be connected to a boiler and cooling tower or, for even higher performance, a ground heat exchanger.

VRF AT 749 UNIVERSITY ROW

The building at 749 University Row is a highly energy efficient, multi-tenant office building constructed in Madison, Wisconsin in 2013. The building's developer, contractor, and design team chose a ground-source VRF system as the best solution to achieve a high level of energy performance while meeting the comfort needs of the tenants and the operating needs of the developer.

The design team used energy modeling to identify the most energy efficient system for the building at 749 University Row. The modeling showed ground-source systems to be the most efficient (see gray bars in Figure 1 for modeled energy savings versus a common VAV system). VRF was only slightly less efficient than a more typical ground-source

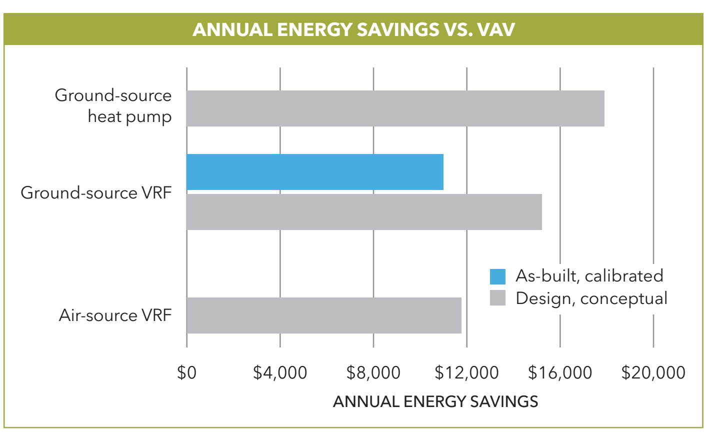

Figure 1: Annual energy savings of system options versus a typical VAV system, as modeled in design (gray) and after monitoring performance (blue).

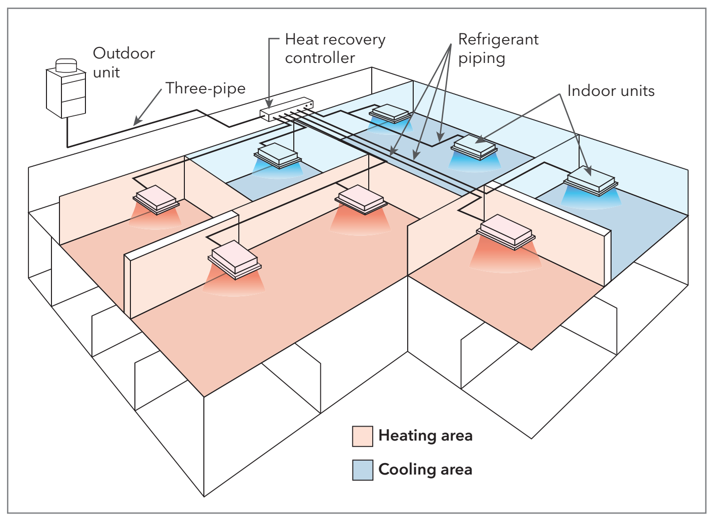

Figure 2: Variable refrigerant flow systems can deliver cooling to some zones and heating to others, with no reheat needed (an air-source system is shown here).

heat pump (GSHP) system. While the first cost of a GSHP system was also somewhat lower, the design team ultimately chose the ground-source VRF system because it had fewer maintenance requirements, provided greater flexibility for tenants, and required less space. The VRF system could fit in one mechanical room on each floor, as opposed to heat pumps being located around the floor in each tenant space. This increased the amount of rentable area in the building, increased zoning flexibility in tenant's space, and led to fewer overall compressors to maintain. Based on the owner's experience, the VRF system was also somewhat quieter for tenants than a heat pump system.

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Figure 3. In a water-source VRF system, the condensing units *(left)* exchange heat with a fluid loop (white pipes); they distribute this energy to/from heat recovery controller *(top right)* which in turn distribute the energy to/from individual fan coil units at each zone *(bottom right)*.

Krupp specifically chose not to consider an air-source VRF system because of the problems with air-source systems in cold climates—they had first-hand experience with older-generation air-source VRFs that had not performed well in this climate. Having decided to use a water-source VRF, the design team then had to determine whether to use a boiler and cooling tower to maintain water temperature or a geothermal borefield. The borefield was significantly more expensive (first cost of $250,000) but was preferable because:

- it would eliminate the boiler and cooling tower energy consumption (though it would require some pumping power);
- it would allow the VRF system to operate even more efficiently in the summer, partly due to the region's excellent ground properties;
- it would eliminate outdoor evaporative rooftop cooling equipment, reducing maintenance and improving the aesthetics of the building.

Because water-source VRF systems don't use air to move heat, a separate outside air system (generally called a dedicated outside air system, or DOAS) is required to ventilate the space. The design team for 749 University Row chose to install a rooftop ground source heat pump (with an energy recovery wheel). It did not make sense to add VRF to the rooftop unit since there is no potential for heat recovery, it is not a multizone system, and there is little need to conserve space on the roof.

Madison Gas and Electric, the building's energy utility, provided support to monitor the ground-source VRF system as it was the first of its kind in the region. Heating system efficiency was slightly better than the manufacturer's rating while cooling system performance was slightly worse.

MANUFACTURER VS. MEASURED PERFORMANCE FOR GROUP SOURCE VRF SYSTEM

	Heating COP	Cooling EER
Manufacturer (AHRI) Rating	3.1	13.0
Measured Performance	3.3	11.9

However the primary energy efficiency benefit of VRF systems is not in their peak performance, but rather in their overall seasonal performance (measured by their Integrated Energy Efficiency Ratio or IEER). VRF systems excel in low or partial load periods (i.e. spring and fall, when heating loads are low) because of the variable speed nature of the system.

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To investigate seasonal performance after the building was in operation, the energy engineers used a calibrated energy modeling approach that incorporated monitored energy performance from 749 University Row. The blue bar in Figure 1 shows the results. The ground-source VRF system saved less energy than anticipated for two reasons. About half of the decrease is due to the heating and cooling loads simply being lower in the actual building than the design models. But the other half of the decrease is because the seasonal performance, or IEER, of the VRF system did not perform to manufacturer specifications.

For this project, the cost of the ground-source VRF system at 749 University Row was $29.9/ft^2$. In comparison, the cost of a GSHP system would have been about $28.4, and an air-source VRF system would have been $25.3/ft^2$.

The payback for the system at 749 University Row is very long (31 years) because of its less-than-optimal seasonal performance, coupled with a very high performance building with low loads. The payback would decrease to 22 years with a VRF system that performs according to specifications.

PAYBACK PERIOD OF GROUND SOURCE VRF (COMPARED TO VAV)

Cost Premium for GS-VRF	Federal Tax Credit	Focus on Energy Incentive	Annual Energy Savings	Simple Payback
$399,000	$25,000	$34,900	$11,000	31

Energy performance is not the only reason for choosing a ground source VRF system. The non-energy benefits (space, maintenance, acoustics, etc.) outlined above are compelling criteria as well, and in this case were enough to lead the owner to choose this system. Also note that costs for VRF systems have been steadily decreasing since the system at 749 University Row was designed in 2012.

MAKING WATER-SOURCE VRF WORK

- If the contractor does not have extensive experience with VRF, have an engineer complete a full design first (as opposed to a design-build approach), especially one with experience.

- Consider the non-energy benefits of VRF systems. Because of their small footprint, first costs for some construction projects can be substantially reduced by decreasing the floor-to-floor heights. Using VRFs can also increase a buildings usable square footage, as it did at 749 University Row.

- In cold climates, strongly consider the use of water-source VRF systems. The operator of 749 University Row has stated that the water-source system has not had nearly the maintenance issues associated with air-source VRFs at other projects.

- Keep refrigerant piping runs as short as possible to prevent losses in capacity. Manufacturers will provide specific limits to the length and rise of refrigerant piping. Install condensing units in multiple locations (such as one per floor as was done at 749 University Row) to help meet these constraints.

- Employ a contractor with significant refrigerant piping experience; VRF systems have a lot of piping, and complex connections.

- Have commissioning personnel investigate any potential for simultaneous heating and cooling between adjacent zones, or oscillation between heating and cooling within zones. This may require additional time at the site for observation and tuning of thermostat control loops.

- Follow ANSI/ASHRAE Standard 15: Safety Standard for Refrigeration Systems to maintain a safe building in light of the large volume of refrigerant present in these systems. Contractors should also avoid using flared fittings and should thoroughly pressure test all piping.

OTHER RESOURCES

Proven Energy-Saving Technologies for Commercial Properties, Chapter 7: Variable Refrigerant Flow, **https://buildingdata.energy.gov/cbrd/download/1912, NREL 2014**.
Seventhwave New and Market Ready Technologies, *Variable Refrigerant Flow*, **www.seventhwave.org/new-technologies/variable-refrigerant-flow-vrf**

Sustainable Design of Water Source V RF, ASHRAE Journal, October 2013.