

Energy Efficiency FACTSHEET

Ground-Source Variable Refrigerant Flow Heat Pumps:

A Solution for Affordable Housing, Assisted Living, Hotels and Dorms

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In recent years, the decreasing costs and increasing quality of variable refrigerant flow (VRF) equipment have led to efficiencies comparable to – and even exceeding – the efficiency of standard ground-source heat pump (GSHP) systems. Because of this, the cost-effectiveness of installing ground-source heating, ventilating, and air conditioning (HVAC) systems has been called into question.

The advantages of GSHPs (sometimes called geothermal heat pumps) are that they tap a large reservoir of nearly constant-temperature heat (the ground) and they use water as the heat-exchange fluid, which is more efficient than using air. However, VRF technology, even with air-to-air heat exchangers, can meet or exceed the efficiencies of GSHPs by using multi-speed fans and variable speed compressors. In addition, VRF technology enables recovery of heat or cooling from one zone

to use in other zones (in buildings where some zones are in heating mode while others are in cooling mode).

A ground-source VRF heat pump system combines the advantages of both technologies into one system, making it one of the most efficient HVAC systems available for many applications. By using ground water loops, multi-speed fans and variable speed compressors, ground-source VRF heat pump systems achieve savings over either GSHP or VRF on their own.

What is a Ground-Source Heat Pump?

A typical heat pump heating and cooling system is called an air-to-air heat pump because it exchanges heat with outside air in order to provide heating or cooling. These heat pumps are rated based on American Heating and Refrigeration Institute (AHRI)

standards. AHRI tests equipment under identical laboratory conditions to determine its rating. This rating allows for apples-to-apples comparisons of efficiency among different manufacturers. It turns out, however, that the performance of air-to-air systems in real world conditions, where the equipment is exposed to very hot and very cold conditions, is often inferior to performance in lab conditions. To compensate for decreased performance in extreme conditions, equipment is often specified to be over-sized. If ambient conditions were more moderate and more predictable, this over-sizing would not be necessary.

One way to achieve relatively constant ambient conditions is to bury pipes underground, where the temperature is relatively constant year round. Because heat is exchanged with the ground rather than the outside air, GSHPs remain

a very efficient source of heating and cooling all year.

The GSHPs typically use the refrigerants R-22 or R410A, which are well-suited to efficiently draw heat from or reject heat to water in this temperature range. Because water transfers heat much more

efficiently than air, the system gains additional efficiency by using water as the heat exchange fluid.

The piping system can be installed in one of four common configurations:

- Closed loop systems, which consist of three

configurations: slinky or straight horizontal trenches (Figure 1), vertical wells (Figure 2) and pond/lake source (Figure 3).

- Open loop system, which requires an underground well (Figure 4).

Figure 1. *Horizontal trenches*

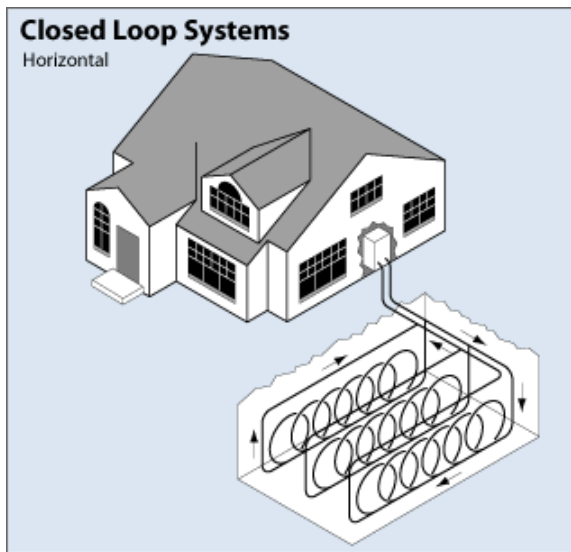


Figure 2. *Vertical wells*

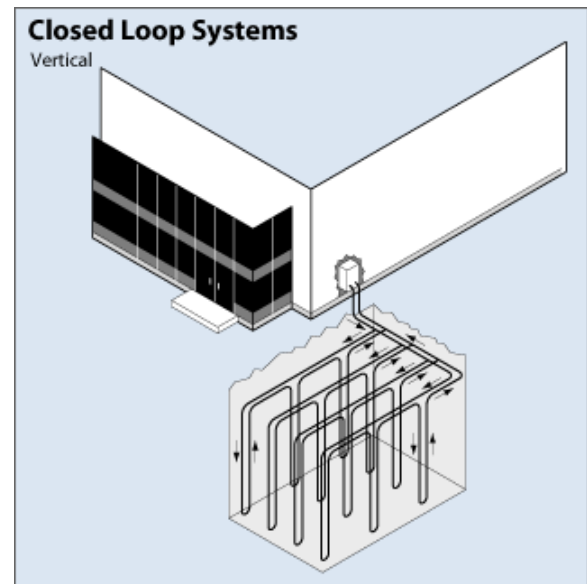


Figure 3. *Pond source*

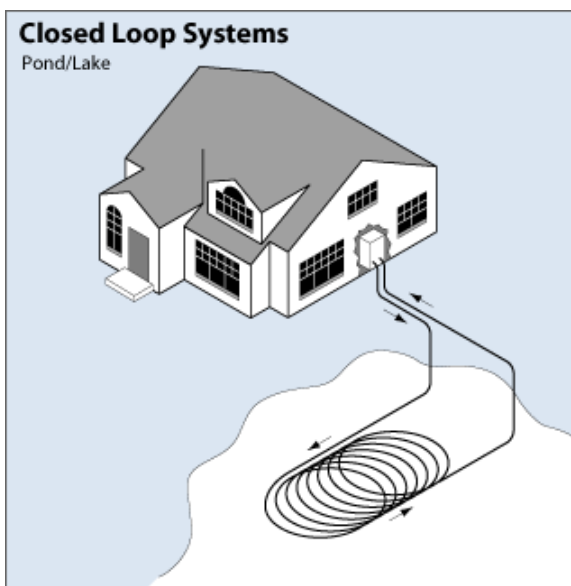
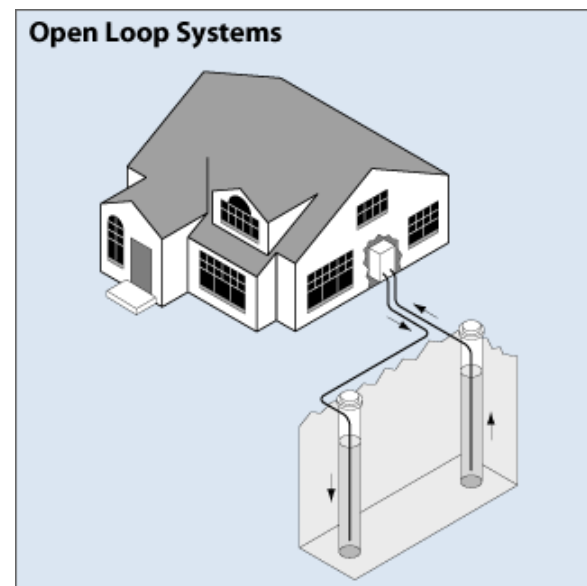


Figure 4. *Open well*



Things to consider:

1. Pipe length depends on a number of factors, but for estimating purposes a rule of thumb is about 400 lineal feet per 400 square feet of building. The slinky design shown in Figure 1 requires an area for trenches that is about twice the area of the building.
2. "Construction hygiene" is critical. The piping must be protected from dirt, critters and other sources of contamination.
3. The horizontal piping should be 5-10 feet deep, depending on frost level. The deeper the pipe, the more stable the temperature; the more stable the temperature, the more efficient the system.
4. Heat pump systems can provide pre-heating for potable hot water with a desuperheater when the heat pump is in cooling mode.

- Minimal losses from ducts since most or all of the ductwork is eliminated. Eliminating ducts may also allow buildings to be designed with lower floor-to-floor heights, reducing construction costs.

These features, as shown in Figure 5, make VRF more efficient than most other HVAC and water heating technologies in many applications. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and AHRI have developed a new efficiency test standard – Standard 1230 – to capture these features. The new standard is the Integrated Energy Efficiency Ratio (IEER), which was developed to more accurately reflect the efficiency of VRF systems. As shown on slide 4 in this ICF International presentation on *EER and IEER Ratings in HVAC Program Implementation* (http://www.cce1.org/cce/mtg/06-10mtg/files/ComHVAC_ICF_Odell.pdf), the energy efficiency ratio

(EER) is described as "not so good at indicating energy (kWh) savings potential." As noted on slide 5, IEER "may be a better indicator of energy usage."

VRF systems have heat exchanger units located outdoors that are connected to one or more indoor units. In some conditions, one or more units may be in heating mode at the same time that others are in cooling mode. This feature allows heat rejected from rooms that are in cooling mode to be used by other rooms that are in heating mode.

VRF Benefits

Some of the benefits of VRF systems are:

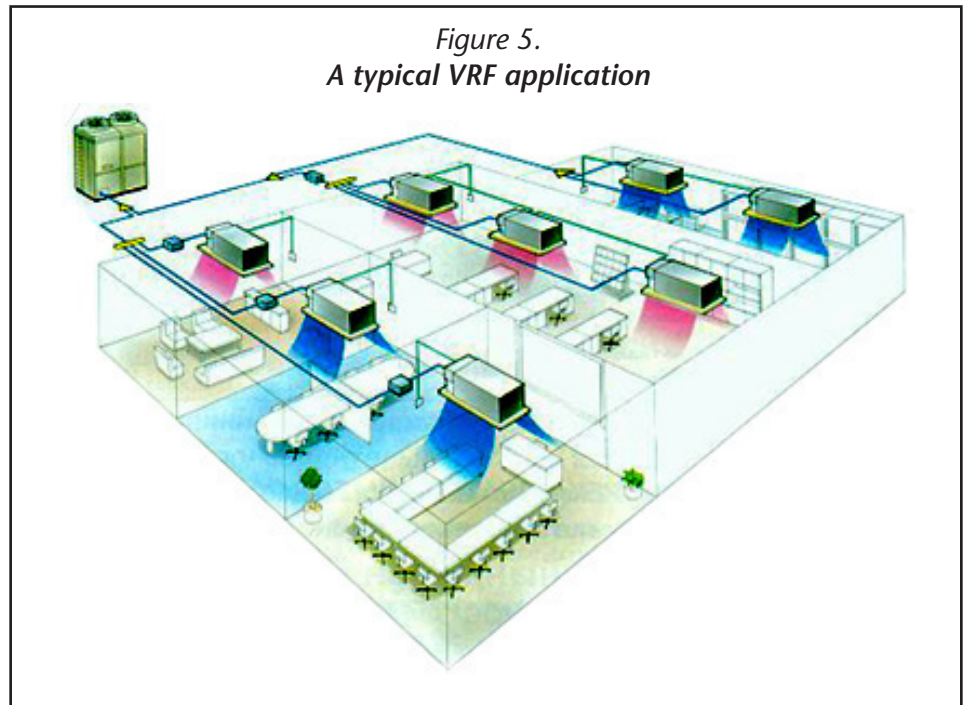
- Energy savings due to better part-load efficiencies and reducing or eliminating duct losses, when compared to standard air-to-air heat pumps.
- Smaller mechanical space requirements, both interior

What is Variable Refrigerant Flow?

VRF equipment has the following features that make it a very efficient HVAC system:

- Multi-speed fans on the indoor and outdoor units rather than single-speed fans.
- Linear expansion valve rather than open/close.
- Variable speed compressor.
- Internal/external heat recovery between zones. Heat rejected from one zone can be used in another part of the building rather than being rejected to the outside.

Figure 5.
A typical VRF application



- and exterior.
- Design flexibility with the variety of indoor air handler options.
- Easier retrofits where running ductwork is an issue, such as an older building that lacks ductwork or where the current ductwork is undersized.
- In retrofit applications, existing ductwork can be used for ventilation air.
- Greater rentable space due to smaller mechanical rooms.
- Lower construction costs due to less space required between floors for ductwork.
- Relatively lighter weight, minimizing structural requirements.

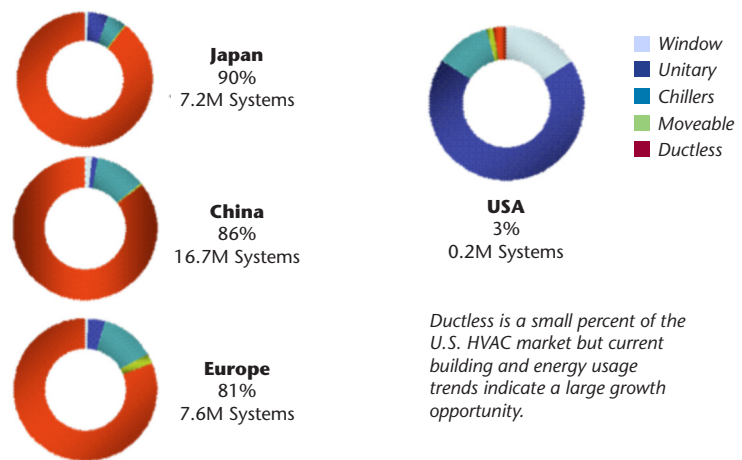
The VRF technology is not new; in fact, it is the technology of choice in Japan, China and Europe, as depicted in Figure 6.

The term “ductless” in this chart is synonymous with VRF. However, VRF now includes many styles of equipment, including wall-mounted ductless, above ceiling ducted, cassettes, floor mount and more.

What Are Potential Energy Savings of a Ground-Source VRF Heat Pump System?

To compare the energy use of various HVAC systems, a 25,000 square foot single-story assisted living building was modeled for 10 cities using *Energy Pro* building modeling software. The energy used per system type and per city is noted in Figure 7 and Table 1 (see next page).

Figure 6.
VRF market share in various markets



The modeling software algorithms have resulted in conservative energy savings. Using Energy Star's Portfolio Manager (http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager), many VRF buildings have come in with energy use index (EUI) better than the model results.

Applying Ground-Source VRF Heat Pumps in the Real World

The Little Deschutes Lodge (<http://www.discoveryparklodge.com/littledeschuteslodge>), an affordable housing project for seniors in La Pine, Oregon, has a ground-source VRF heat pump system and the facility is nearly

Figure 7.
Percent theoretical savings over air-source heat pump

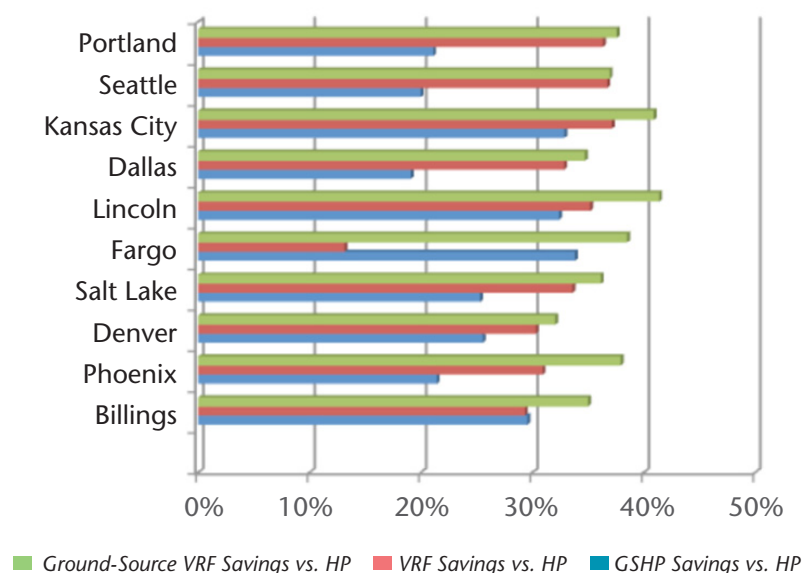


Table 1.
Annual energy use (kBtu/sf/yr) and percent savings compared to air-source heat pump

City	Air-Source Heat Pump (HP) ¹	Ground-Source HP ²		VRF (air-source)		Ground-Source VRF HP	
		kBtu	% Savings	kBtu	% Savings	kBtu	% Savings
Billings	65.3	46.0	30%	46.2	29%	42.5	35%
Phoenix	65.9	51.8	21%	45.5	31%	40.9	38%
Denver	59.5	44.3	26%	41.5	30%	40.4	32%
Salt Lake	60.7	45.4	25%	40.3	34%	38.8	36%
Fargo	72.8	48.2	34%	63.2	13%	44.7	39%
Lincoln	72.9	49.3	32%	47.2	35%	42.7	41%
Dallas	65.2	52.8	19%	43.8	33%	42.6	35%
Kansas City	73.5	49.3	33%	46.2	37%	43.5	41%
Seattle	54.9	43.9	20%	34.7	37%	34.6	37%
Portland	56.5	44.6	21%	36.0	36%	35.3	38%
Median Energy Use & Savings	65.3	47.1	28%	44.6	32%	41.7	36%

¹ EER = 10.0, Seasonal Energy Efficiency Ratio (SEER) = 13.0, Heating Season Performance Factor (HSPF) = 5.0.

Air-source heat pumps are commonly used in assisted living facilities, hotels, etc.

² EER = 15.7, Coefficient of Performance (COP) = 3.3

net-zero energy. Little Deschutes Lodge is a 26-unit complex with on-site laundry, a community room, a reading room, and two computer centers. Even with these amenities and features, the total gas and electric bills for the facility, divided by the number of apartments and by 12 months per year, came to only about \$37 per month per apartment! Little Deschutes Lodge's site EUI is only 29 kBtu/square foot/year, compared to about 70 kBtu/square foot/year for an average dorm unit as calculated using Energy Star's *Portfolio Manager*. This project has a *Portfolio Manager* score of 95, modeled as a dorm, which means that it is more efficient than 95 percent of other similar units.

The Little Deschutes Lodge design from SOLARC Architecture and



Engineering, Inc. in Portland, Oregon (<http://www.solarc-ae.net/>), includes the following components:

- 28 horizontal trenches, each approximately 150 feet long.
- Header piping at 6 foot depth, trench piping at 9 foot maximum depth.
- 600 feet of 1-inch pipe per trench, with four pipes spaced evenly in a 3-foot-wide trench.

- Trenches spaced 12 feet on center.
- Overall area of the piping field is approximately 50,000 square feet.
- Four heat pumps (Mitsubishi City-Multi PQRV P96TGMU, 8 tons each) serve the apartments, office, reading and fitness rooms.
- One Florida Heat Pump (ES-070, 5.5 tons) serves the community room and kitchen.

- One 300 cfm energy recovery ventilator serves the community room and kitchen, and one 800 cfm unit serves the rest of the building.
- Ducted units in apartments, ductless in common spaces.
- A desuperheater is used for preheating hot water.
- The solar thermal system is thermally connected to the ground loop to take advantage of solar energy when advantageous.

Maximizing Efficiency and Minimizing Maintenance

For affordable housing to be viable, operating and maintenance costs need to be as low as possible so property owners can hedge against rising utility costs and rising operating and maintenance costs. In addition, since the majority of affordable housing is sponsored and/or developed by non-profits, the owners need to be able to cover all of their operating expenses, including debt coverage, so they do not lose money. Having a very energy efficient HVAC system can go a long way to help achieve these goals. This is especially important in light of the fact that property owners can only raise rents to the extent that the area median income (AMI) of the county increases on a percentage basis.

The U.S. Department of Housing and Urban Development (<http://portal.hud.gov/hudportal/HUD?src=/about/mission>) was created to help advance affordable housing. And, as stated in this article, *Moving Toward Zero Energy Homes* (<http://www.nrel.gov/docs/fy04osti/35317.pdf>), produced for the U.S. Department of Energy by the National Renewable Energy Laboratory, the goal for residential housing should be net-zero energy.

At www.energystar.gov, some studies show that utility costs represent the single largest controllable cost in an apartment community – typically accounting for 25 to 35 percent. Reducing energy use by 15 percent in a typical 250-unit master-metered community will increase net operating income, and can enhance asset value by over \$1 million (using a 6 percent capitalization rate). In a similarly sized individually metered community, this same savings may increase asset value by over \$200,000 annually.

Conclusions

Based on modeling of the multi-unit assisted living building using *Energy Pro* software, we can draw the following conclusions:

- Ground-source VRF heat pump systems can reduce energy consumption for heating and cooling by as much as 32-40 percent over the current energy code minimum efficiency in many locations and applications.

- The value of ground-source systems is more evident in extreme climates.
- Ground-source systems are invariably more expensive than air-source systems, so in each case the engineer will need to do a cost-effectiveness analysis to determine if the extra cost of the ground-source system can be justified.
- Air-source VRF projects bid by experienced VRF installers are coming in at about \$14-18/square foot. Ground-source systems can cost approximately \$30/square foot. Systems combining ground-source with VRF will be slightly more. For sites requiring a lot of earth work anyway, like a school with playing fields, large parking lots, etc., the added cost of trenching for the ground-source piping may be less, making a ground-source system more attractive.
- The cost premium for a ground-source VRF heat pump system will have to be weighed against the advantages, but if you are striving for maximum efficiency, consider installing a ground-source VRF heat pump system.

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<http://www.energy.wsu.edu/Documents/EEFactsheet-GSHP-Feb2011.pdf>

About the Author

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Marcia Karr, P.E., an Energy Engineer at the Washington State University Extension Energy Program, is a licensed mechanical engineer with over 30 years of experience in commercial building design, construction and maintenance. She performs energy audits for commercial buildings, and provides technical assistance to commercial building owners, operators and builders in exploring energy saving opportunities. Karr's previous positions include code plan reviewer, union trades manager, design/build engineer, field construction engineer/project coordinator, and HVAC/plumbing designer (commercial, institutional and residential).

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