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Comparison of energy efficiency between variable refrigerant flow systems and ground source heat pump systems

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ABSTRACT

With the current movement towards net zero energy buildings, many technologies are promoted with emphasis on their superior energy efficiency. The variable refrigerant flow (VRF) and ground source heat pump (GSHP) systems are probably the most competitive technologies among these. However, there are few studies reporting the energy efficiency of VRF systems compared with GSHP systems. In this article, a preliminary comparison of energy efficiency between the air-source VRF and GSHP systems is presented. The computer simulation results show that GSHP system is more energy efficient than the air-source VRF system for conditioning a small office building in two selected US climates. In general, GSHP system is more energy efficient than the air-source VRV system, especially when the building has significant heating loads. For buildings with less heating loads, the GSHP system could still perform better than the air-source VRF system in terms of energy efficiency, but the resulting energy savings may be marginal.

1. Introduction

Decades after the first energy crisis in 1970s, building energy efficiency once again becomes a hot topic worldwide. Suffered from the soaring energy price in the past, people have been exploring ways to use energy more efficiently in their homes and workplaces. Improving building energy efficiency was emphasized in the new US Obama administration's plan for stimulating the economy and building a more sustainable society.

The movement towards net zero energy buildings brings tremendous challenges and opportunities to the Heating, Ventilation, Air-Conditioning, and Refrigeration (HVAC&R) industry. Many new, or relatively new, HVAC&R technologies are promoted with emphasis on their superior energy efficiency. Among these, the variable refrigerant flow and ground source heat pump systems are probably the most competitive technologies. They have similar advantages, including flexibility for installation, capability for individual climate control, and significant potential for energy savings. However, while GSHP systems have been used in the US for decades, VRF systems were just introduced into the US in recent years despite their popularity in Europe and Asia, and they are relatively new to many practitioners in the HVAC&R industry [1–3].

The VRF system is an outgrowth of the "multi-split" systems used in residential applications. The big difference between VRF systems and conventional HVAC systems is that they adjust cooling/heating output by modulating the refrigerant flow continuously with the variable speed compressor. VRF systems enable a single outdoor unit to be connected to multiple indoor units of varying capacity and configuration throughout a building. It typically comprises of one or more centralized outdoor unit(s), which contains one or multiple compressors, one of which is an inverter-driven variable speed compressor. The indoor units contain electronic expansion valve, direct expansion coil, and fan. The outdoor and indoor units are connected with relatively long refrigerant line and controlled by dedicated controllers. There are two types of VRF systems available: one is usually referred as "heat pump" (HP) type VRF, which provides either all heating or all cooling to multiple zones at a time. As a result, in shoulder season when the core zone needs cooling while the perimeter zones need heating, supplemental heating for perimeter zones may be needed to maintain the space temperature for thermal comfort. The other is referred as "heat recovery" (HR) type VRF, which provides heating and cooling simultaneously to multiple zones with various cooling or heating demand. The VRF system is further categorized into air-source VRF and water-source VRF depending on what heat sink/source is used for the outdoor unit.

VRF system incorporates several energy efficiency technologies, including variable speed compressor and fan, heat pumping from ambient air to conditioned spaces, and heat recovery between

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warm and cold refrigerants, but it has some unique characteristics that may result in additional energy consumptions. First, same as other types of air source heat pumps, VRF systems need defrost the air-refrigerant heat exchanger in the outdoor unit when they run in heating mode. Second, the long refrigerant line may result in significant heat/cool loss and increased compressor power consumption. Third, some VRF systems require special "oil return" operation to get the lubricant oil back to the compressor, which consumes extra energy compared with conventional packaged air source heat pumps.

Typical GSHP system usually comprises of multiple water-to-air heat pump units, which are connected with the ground loop heat exchanger through a common two-pipe water loop. Since each of the water-to-air heat pump units can run in either cooling or heating mode independently, the GSHP system can provide simultaneous cooling and heating for different zones of the building.

VRF systems are more efficient than conventional packaged direct-expansion variable air volume (VAV) systems and central built-up VAV systems with chillers and boilers. A simulation comparison of air-source VRF systems with chilled water based systems for a moderate Brazilian climate showed VRF systems saved about 30% energy in summer and 60% in winter [1]. Another simulation study on a prototypical ten-story office building in Shanghai China showed air-source VRF systems saved 22.2% and 11.7% energy compared with central VAV systems and fan coil systems, respectively [4]. For an existing office building in Maryland, USA, VRF systems showed energy savings from 27.1 to 57.9% compared with central VAV systems depending on system configurations and design conditions [5]. Water-source VRF systems saved about 20% energy compared with fan coil systems for a three-story office building in shanghai China [6].

Currently, there is few, if any, published literature reporting how the energy efficiency of VRF systems compares with GSHP systems. In the US, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is in the process of developing rating standard AHRI 1230 for VRF systems at present time. Furthermore, energy performance of VRF systems cannot be modeled with non-proprietary building energy simulation programs like EnergyPlus [7] or DOE-2 [8], which are widely used by researcher/engineer/designer to evaluate energy performance of various types of HVAC systems. However, there are a few proprietary tools available for simulating VRF systems, such as EnergyPro and Trace 700. In addition, a customized version of EnergyPlus was developed and used for a few simulation studies on VRF systems [4–6,9]. This special version of EnergyPlus is not available to the public, and the VRF module developed for EnergyPlus was not verified or adopted by the EnergyPlus development team led by USDOE.

The most accurate and reliable way to compare the energy efficiency of VRF and GSHP systems may be to monitor two identical buildings at the same location but using VRF and GSHP systems, respectively. However, these kind of monitored data are not currently available yet to the best knowledge of the authors. Computer simulation with credible software programs is a proven feasible way to get quantitative comparison of the energy efficiency between the two types of systems. In this article, a recent effort of such simulation-based investigation is reported.

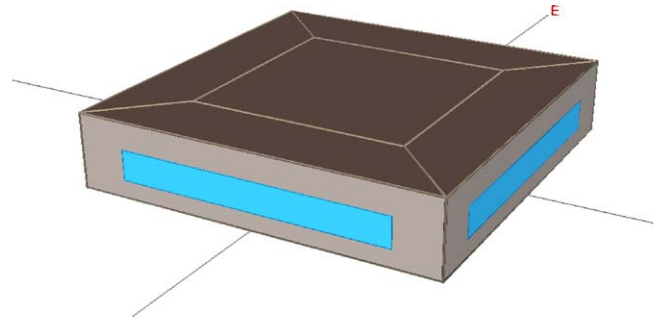

Fig. 1. 3D image of the simulated small office building.

2. Simulation approach

The comparative result of energy efficiency between VRF and GSHP systems depends not only on the difference of the two technologies, but also on many other factors, of which the building thermal characteristics and the climate are the most dominant. In this investigation, a small office building with a conditioned floor area of 360 m^2 was selected. As shown in Fig. 1, this square-shape one story office building has four perimeter zones (with 4 m depth and one at each orientation) and one core zone. Table 1 summarizes characteristics of the building.

The four perimeter zones occupy 64% of the total building floor area. The building thus has potential needs for simultaneous heating and cooling to meet the demand of all five zones year round. Two cities were selected to represent the hot and cold climates of the US: Miami and Chicago.

The building was chosen to represent typical existing buildings in terms of energy efficiency levels; it is not intended to be as energy efficient as required by current energy standard such as ASHRAE 90.1-2007.

Since both HR type VRF and GSHP system can provide simultaneous heating and cooling for various spaces within a building, the energy consumption of these two systems are comparable.

For each of the two locations, a HR type air-source VRF system and a GSHP system that uses single-stage scroll compressors and vertical ground loop heat exchanger (VGLHE) are designed for the

Table 1
Characteristics of the small office building.

Component	Description	Performance
Exterior wall construction	Metal framing with R-13	U-factor = 0.58 W/(m^2 °C)
Roof construction	Built-up roofing with insulation	U-factor = 0.31 W/(m^2 °C)
Floor construction	Slab-on-grade with R-30 insulation	U-factor = 0.14 W/(m^2 °C)
Windows	Double pane with low-e, 30% window–wall-ratio	U-factor = 2.77 W/(m^2 °C) SHGC = 0.43
Lighting power density	Electrical lighting	15.0 W/m^2
Equipment power density	Plug loads	8.0 W/m^2
Occupant density		18.6 m^2/person
Outside air	Ventilation rate	0.007 m^3/s/person
Cooling setpoint	Cooling thermostat	24 °C
Heating setpoint	Heating thermostat	21 °C
Operating schedule	On 6 am to 10 pm weekdays and 6 am to 6 pm Saturday, off Sundays and holidays	
Air economizer	No air economizer	