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Energy modeling of ground source heat pump vs. variable refrigerant flow systems in representative US climate zones

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ABSTRACT

The ground source heat pump (GSHP) and variable refrigerant flow (VRF) systems are the most competitive HVAC technologies in the current market. However, there are very few studies reporting the comparison of the annual energy consumptions and Electric Peak demand reductions between GSHP and VRF systems because of the limitation of the whole building energy simulation software. Current version of EnergyPlus can model both GSHP and air-source VRF. Therefore, three representative US climate zones including Chicago, Baltimore and Atlanta are selected for conducting this comparison study. The EnergyPlus simulation results show that the GSHP system not only saves more energy than the air-source VRF system but also significantly reduces the Electric Peak demand regardless the climate conditions. This makes the GSHP system a more desirable energy efficient HVAC technology for the utility companies and their clients.

1. Introduction

Goetzler et al. [1] addressed that residential and commercial buildings consume about 40% of US primary energy including 74% of electricity consumption, 56% of natural gas consumption, and significant oil consumption in the Northeastern. Over the long term, buildings are expected to continue to be a significant component of increasing energy demand and a major source of carbon emissions, driven in large part by the continuing trends of urbanization, population and GDP growth, as well as the longevity of building stocks. The increasing importance of building energy efficiency generally, as well as EERE's programmatic focus on net zero energy homes (NZEH) and net zero energy commercial buildings (NZEBs) brings tremendous challenges and opportunities to the Heating, Ventilation, Air-Conditioning, and Refrigeration (HVAC&R) industry. Many new, or relatively new, HVAC&R technologies [2] are promoted with emphasis on their superior energy efficiency. Among these, the ground source heat pump (GSHP) and variable refrigerant flow (VRF) systems are the most competitive HVAC technologies in the current market.

As shown in Fig. 1, the GSHP system rejects the heat to the ground (in the cooling mode) or extracts the heat from the ground (in the heating mode). It takes the advantages of the moderate ground temperatures to increase the efficiency and reduce the operating cost of the HVAC system. It usually comprises of multiple water-to-air heat pump indoor 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. As of 2004, Lund et al. [3] reported that over a million GSHP units were installed worldwide to provide 12 GW of thermal capacity, with an annual growth rate of 10%.

The VRF system was first introduced in Japan in 1982 [4] as ductless multi-split air conditioning technology. The key is the refrigerant flow control. Fig. 2 shows that the multiple indoor units are connected a single outdoor condensing unit. Without the ductwork, the refrigerant is circulated to the indoor units and directly transfers the heat from or to the conditioned spaces. In addition, it can continually control the amount of refrigerant flowing to each of the evaporators, enabling the use of many evaporators of differing capacities and configurations. The system modulates the compressor speed of the outdoor unit to meet the total heating and cooling demands in the building. Therefore, the advantages of the VRF system include individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another.

Because VRF system is still relatively new to the US market and most of HVAC practitioners including building energy modelers in the HVAC industry, there is few published literature comparing the annual energy consumption between GSHP and VRF systems. Liu's study [5] shows the GSHP system saves 9.4% and 24.1% of HVAC energy in Miami and Chicago compared with the "heat recovery" type VRF system. Currently, most of energy modeling programs has

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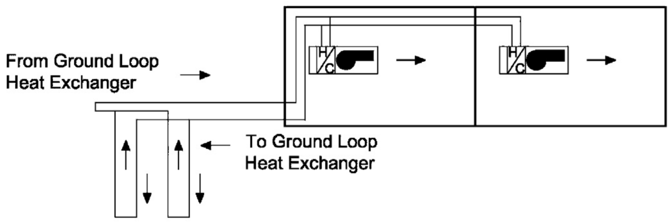

Fig. 1. Schematic of GSHP system.

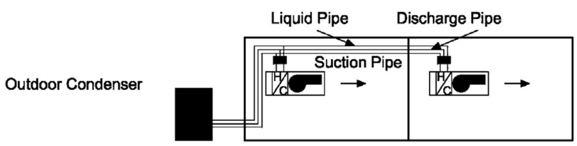

Fig. 2. Schematic of VRF system.

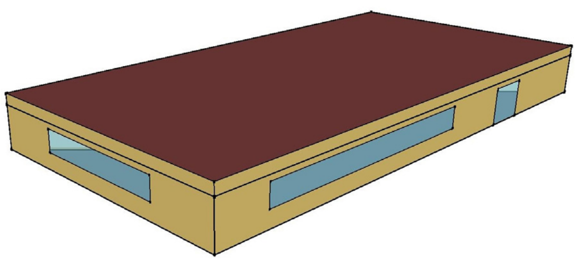

Fig. 3. 3D view of the simulated small office building.

certain limitations on their simulation capabilities, and can only model either GSHP system or VRF system. As a key part of DOE's building energy-efficiency strategy, the whole building energy simulation program, EnergyPlus has this remarkable energy analysis capability, and then was chosen for this comparison study. EnergyPlus 7.2 [6] has also expanded its modeling capability to allow simultaneous heating and cooling (heat recovery) for the VRF system.

2. Description of simulated building

As shown in Fig. 3, a small office was selected for this comparison study. The office has a rectangular footprint and total conditioned space of 465 m^2, which has four thermal zones in the perimeter and one core zone in the interior, as illustrated in Fig. 4. The floor to floor height is 3.66 m with 0.61 m high return plenum. The building is oriented 30° east of north.

The same office was assumed to be located in three representative US climate zones as described in the ASHRAE standard 90.1-2010. The three climate zones include Mixed-Humid (Zone 4A), Cool-Humid (Zone 5A) and Warm-Humid (Zone 3A). Baltimore,

Fig. 4. Floor plan of the simulated small office building.

Table 1
Construction of the small office building.

Building envelope	Construction detail
Exterior wall	Wood shingle over plywood with R-11
Roof	Built-up roof with R-3 mineral board insulation and plywood sheathing
Floor	Slab-on-grade with R-30 insulation
Windows	1) Double pane clear, 3 mm glass, 13 mm air gap 2) Double pane clear, 3 mm glass, 13 mm argon gap 3) Double pane clear, 6 mm glass, 6 mm air gap 4) Double pane lowE, 6 mm lowE glass outside, 6 mm air gap, 6 mm clear glass
Door	Single pane grey, 3 mm glass

Table 2
Internal loads of the small office building.

Internal load	Unit
Light power density	16.1 W/m^2
Equipment load	10.8 W/m^2
Occupant density	11 people/100 m^2

Chicago and Atlanta were selected to represent these climate zones, respectively. Table 1 lists the construction details of the small office building. The corresponding internal loads are shown in Table 2 including lighting power density, equipment load and occupant density.

The office operated from 6 am to 7 pm during the course of the year. In the cooling mode, the thermostat setpoints were 24 °C during occupied hours and 30 °C during unoccupied hours. In the heating mode, 20 °C was selected as occupied room temperature and 15 °C was used in the unoccupied hours. In order to conduct a fair comparison study, the indoor fan was assumed to run continuously with the constant air flow rate during the occupied hours, which was autosized by EnergyPlus. The fan efficiency and motor

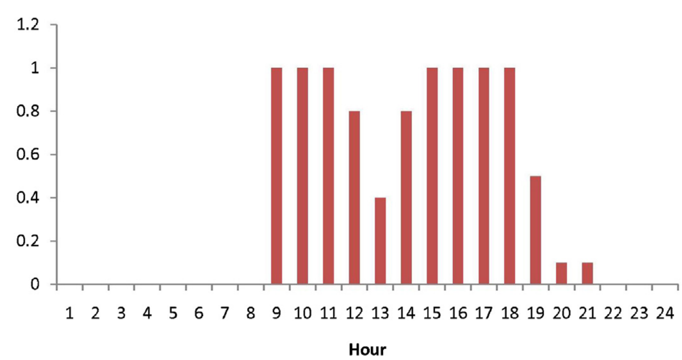

Fig. 5. Building occupancy schedule.

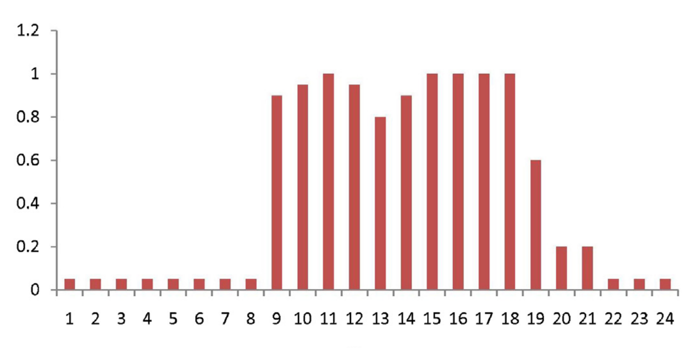

Fig. 6. Building lighting schedule.