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Field performance of gas-engine driven heat pumps in a commercial building

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ABSTRACT

The aim of this study is to evaluate the field performance of gas engine driven heat pumps (GEHP) used in a commercial building. Four, 8 TR (cooling capacity) GEHP units were employed to provide air-conditioning to seven thermal zones in a commercial building. The performance of these GEHPs was assessed over a period of 10 months and compared with prior results reported in the literature. Additionally, this study provides a comparative economic analysis of GEHPs and conventional electrical heat pumps. During normal operation, the cooling capacity ranged between 12.3 kW and 19.3 kW. The average COP_{unit} of these systems varied from 0.15 to 0.85 during field operation. The gas engines were found to operate at significantly lower loads than their design capacity, and therefore, produced overall lower efficiencies. Oversized GEHP systems were deployed to meet the low cooling/heating demands attributed to the lower overall field performance. This study demonstrates the importance of sizing the GEHP/HVAC system similar to the load in buildings.

Performance sur le terrain de pompes à chaleur entrainées par un moteur à gaz dans un bâtiment commercial

Mots clés : Pompe à chaleur au gaz ; Étude de performance ; Essai sur le terrain ; Surdimensionnement de HVAC ; Bâtiment commercial ; Comparaison économique

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Nomenclature

BIM	building information modeling
COP	coefficient of performance
HP	heat pump
HSPF	heating seasonal performance factor
EHP	electric heat pump
EEV	electronic expansion valve
GEHP	gas-engine heat pump
LPG	liquid petroleum gas
IC	internal combustion
OHV	Overhead valve engine
RH	relative humidity
SEER	seasonal energy efficiency ratio
TR	ton of refrigeration
VRV	variable refrigerant volume
h	enthalpy [J kg^{-1}]
$\dot{m}$	mass flow rate [kg h^{-1}]

1. Introduction

Global research for more efficient cooling/heating has been increasing in recent years because of the demand for efficient, reliable and economical cooling/heating technologies. However, recent studies have focused primarily on the (i) improvements in equipment performance and efficiency; (ii) alternative energy sources to power the equipment; and (iii) hybrid applications to maximize the useful output by integrating with other technologies.

Space heating and cooling is one of the areas, which has room for improvement in terms of performance and efficiency. Heat pumps (HP) have been utilized for heating or cooling in domestic and commercial applications. There are many types of HPs depending on their energy source i.e. conventional electric heat pump (EHP), ground source HP, geothermal HP, solar assisted HP, chemical HP, hybrid power systems and gas heat pumps (Lauerhass and Rudd, 1981).

The gas engine-driven heat pump (GEHP) technology relies on gas engines to generate the mechanical energy required to operate the heat pump. Generating the desired mechanical power for the HP system on site avoids a two-stage penalty, i.e., first the generation losses at the power station and second, the transmission and distribution losses. This on-site generation might give a higher energy efficiency, especially for heating applications (Lian et al., 2005). The use of GEHP for heating and cooling was first introduced in the 1970s. GEHP became commercially available in 1985 (Ogura et al., 1987). Since then, the use of GEHP has spread across the globe for both space and water heating/cooling purposes.

A GEHP typically consists of a reversible vapor-compression HP, and a compressor mechanically coupled with an internal combustion (IC) engine. Since the cooling loads coincide with the peak demand for electricity in many areas, the use of GEHPs can overcome the peak energy demand and supply problem. The use of low-cost fuels like natural gas, propane or LPG, can be economically beneficial if the GEHP performs at rated efficiencies (Ficarella and Laforgia, 1999; Zhang et al., 2005). However, GEHPs have a problem, which is that their efficiency can be very low under part load conditions. A variable refrigerant volume (VRV) GEHP system can provide better performance for part loads by controlling the fuel supply to the engine and also provide ease of control (Zhang et al., 2005). The performance can further be improved by incorporating heat recovery or auxiliary power production to a GEHP system (Lian et al., 2005). Sanaye et al. in their theoretical analysis of the operation of GEHP over EHP reported that the cost of running GEHP was lower than EHP for four regions of Iran (Sanaye et al., 2010).

1.1. *Case for GEHPs performance testing*

The overall electricity supply efficiency in 2011 from generation input to end use was 33.42% in the US, which means that for every unit of energy for end-use, a total of 2.99 units of primary energy source were used (DOE/EIA, 2012). The average efficiency of natural gas-based combined-cycle power plants was 45% (2013) (EIA, 2013a), with further losses in transmission and distribution of electricity from the power plant to the point of use (Gopiya Naik et al., 2013). An electrical heat pump (EHP) utilizes this electricity to provide space conditioning by running a vapor compression cycle while a GEHP system utilizes natural gas to produce the required mechanical energy from an IC engine, which provides the desired power for running similar vapor compression cycles. The IC engines have their efficiency in the range of 30–40%. Although waste heat from IC engines can be recovered from the exhaust (Lazzarin and Noro, 2006; Sanaye et al., 2010), it is usually not implemented in small GEHP applications.

The potential users of GEHPs have a need to know their performance in real life systems. However, the manufacturers usually provide performance data based on standard testing in a controlled environment. There is a lack of information in the literature on the field performance of GEHP systems. The motivation for this study was to evaluate the field performance of existing natural gas-based GEHP systems in a commercial building and provide a comparative analysis with electric heat pumps. This study was done over a period of ten months to capture the seasonal variations.

1.2. *GEHP operation*

A GEHP is characterized by two main parts (1) an HP with a compressor, evaporator, condenser and an expansion valve and (2) a gas-fired IC engine (Zhang et al., 2005). The IC engine is mechanically coupled to a compressor through a drive or a gear assembly. The rest of the cycle operates like a conventional heat pump involving a reversing valve for cooling- and heating modes. Fig. 1 explains the operation of a GEHP unit.

2. Methodology

2.1. *Field setup*

Four sets of variable refrigerant volume (VRV) packages with a GEHP outdoor unit, and seven fan coil units were