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Capacity-controlled ground source heat pumps in hydronic heating systems

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Abstract

The objective of this study was to investigate the energy-saving potential of using variable-speed capacity control instead of the conventional intermittent operation mode for domestic ground source heat pumps. Variable-speed capacity control is commonly used in air-to-air heat pumps, but not in ground source heat pumps for hydronic heating systems, even though the energy-saving potential may be greater for this application. A theoretical analysis indicates how the energy efficiency is influenced by variable-speed capacity control of the compressor. The analysis shows that, to take full advantage of the capacity control, care should be taken to achieve the correct relationship between refrigerant flow and heat transfer media flows. Intermittent control and variable-speed capacity control were compared by laboratory tests on two capacity-controlled heat pumps and one standard heat pump with a single-speed compressor. Test data were then used for seasonal performance factor (SPF) calculations. The SPF calculations show that despite improved performance at part load the variable-speed controlled heat pump did not improve the annual efficiency compared to the intermittently operated heat pump. This is mainly due to inverter and compressor motor efficiencies and the need for improved efficiency and control of pumps used in the heating and ground collector systems.

Keywords: Heat pump; Ground source; Heating; Survey; Control; Variable speed

Pompes à chaleur sol-eau à puissance régulée utilisées dans les systèmes de chauffage hydrauliques

Mots clés : Pompe à chaleur ; Sol-eau ; Chauffage ; Enquête ; Régulation ; Vitesse variable

1. Introduction

Heat pumps for domestic use are connected to loads which vary continuously, and so it must be possible to adjust their capacity. Conventionally, this is done by intermittently switching the heat pump on and off. However, there are other methods of capacity control, with continuously variable-speed control being the most efficient [1–4]. Variable-speed control of heat pumps has previously been investigated and compared to conventional intermittent control by Miller [5], Tassou and Qureshi [6], Halozan [7] and Poulsen [8] among others. Improved energy efficiency, in the range of 10–25%

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Nomenclature

A	area (m^2)
$\dot{C}$	heat capacity flow rate ($W K^{-1}$)
COP	coefficient of performance (−)
DOT	dimensioning outdoor temperature (°C)
Full load	the thermal load of the building or process at design conditions
Part load	the thermal load of the building or process which is lower than the full load
h	specific enthalpy ($J kg^{-1}$)
$\dot{m}$	mass flow ($kg s^{-1}$)
n	rotational speed (rpm)
NTU	number of transfer units (−)
Δp	pressure difference (Pa)
$\dot{Q}$	heating capacity (W)
R	ratio (−)
SPF	seasonal performance factor; heating system (including supplementary heater, pumps and heat pump) $SPF = (Q_{hps} + \eta_{heater} W_{heater})/(W_{hps} + W_{heater})$ (−)
T	temperature (K)
U	thermal transmittance ($W m^{-2} K^{-1}$), uncertainty of measurement
V	volume (m^3)
$\dot{V}$	volume flow rate (m^3/s)
vsd	variable-speed drive
W	electric energy input (J or kWh)
$\dot{W}$	electric power input (W)

Greek letters

ε	heat exchanger effectiveness (−)
η	efficiency (−)
φ	evaporating efficiency (−), i.e. the ratio between the mass flow of refrigerant vapour and the total refrigerant mass flow at the compressor inlet
ν	specific volume ($m^3 kg^{-1}$)
τ	time (s)

Subscripts

1	condensation
2	evaporation
3	after compressor
4	after evaporator
b	brine
c	condenser
comp	compressor
e	evaporator, electric
heater	supplementary heater
hs	heating system (including heat pump, pumps, radiator pump and supplementary heater)
hps	heat pump system (heat pump and pumps)
hp	heat pump (excluding pumps)
i	inlet to the heat pump
is	isentropic
m	mean
mc	mechanical
m, el	motor, electric
mt	mechanical transmission
o	outlet from the heat pump
p	pump
R	refrigerant
sw	swept
v	volume, volumetric
w	water

compared to intermittent operation, is reported [5,6,9–12]. These savings are due to better performance at part load through heat exchanger unloading and lower supply temperature, higher compressor efficiencies, fewer on/off cycles, reduced need for supplementary heating and reduced need for defrosting [5,13]. However, the majority of these investigations, except for Poulsen [8], have been concerned only with air source heat pumps, mostly air-to-air units. Ground source heat pump systems are used in buildings with a relatively large annual heat demand, and hence such systems have a greater potential for energy savings. In addition, they are usually sized to cover a large part of the total annual energy demand, and therefore operate at part load for most of the time. However, these systems do not benefit from the reduced need for defrosting, and the effect of unloading of heat exchangers will normally not be as great as for air source units, due to the use of highly efficient plate heat exchangers.

Consequently, the objective of this study was to investigate the energy-saving potential of applying variable-speed capacity control to brine-to-water heat pump systems. The work was carried out both by theoretical analysis and by laboratory tests, to create input data for calculating the seasonal performance factor.

2. Background

The heating demand of a building depends on the outdoor climate and the building design. How efficiently the required heat can be supplied to the building is dependent on the design, efficiency and control strategy of the heating system and, of course, on the efficiency of the heating equipment, in this case the heat pump. Today, heat pumps for hydronic heating systems usually operate in an intermittent on/off mode in order to adjust the capacity to the load. By using variable-speed capacity control instead, the efficiency can be increased as previously described in Section 1.

If the heat pump operates intermittently, it must supply heat at a higher temperature than necessary when in the on