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Generalised water flow rate control strategy for optimal part load operation of ground source heat pump systems

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HIGHLIGHTS

- Control strategy developed for predicting optimal GSHP water flow rate.
- Strategy operates under part load conditions to improve seasonal performance.
- Control strategy requires minimal on-line inputs and design data.
- Evaluation of strategy against nominal flow using GSHP simulation models.
- Potential improvement in seasonal performance of between 20% and 40% observed.

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ABSTRACT

A control strategy was developed to predict optimal ground source heat pump water flow rates under part load operation. Using this strategy, optimal flow rates are calculated from available design data and minimal on-line measurements. The optimal control strategy was evaluated with validated single speed and tandem speed ground source heat pump simulation models in both heating and cooling mode. A range of building load profiles were implemented when analysing heat pump system performance. The optimal strategy was shown to result in an improvement in system performance when compared to nominal flow rate operation, particularly for low load conditions. Due to the prevalence of low load operation over a heating or cooling season, the seasonal system performance (SPF_3) was shown to increase by between 20% and 40% when using the optimal strategy.

1. Introduction

In line with an increased focus on reducing carbon dioxide emissions, a 2009 EU directive specifies that 20% of European energy consumption should be attributed to renewable sources by 2020 [1], with a more recent 2014 directive advising a 27% share by 2030 [2]. In the US and Europe 40% of primary energy use is attributable to the building sector [3], while space heating, cooling and hot water production account for half of that value [4]. Ground source heat pumps (GSHPs) are an effective renewable energy option for the building sector and are widely implemented in northern European countries for space heating [5]. The majority of GSHP systems operate with single speed compressors [6] supplying heating/cooling capacities of between 10 and 20 kW [7,8].

Over the course of a heating or cooling season, heat pump systems predominantly operate under unsteady, part load conditions [9]. When operating at part load, the system performance can be significantly degraded [10] due to the power consumed by auxiliary components [11]. A number of ongoing research and demonstration projects are tasked with monitoring the seasonal performance factor (SPF) of GSHPs at various sites [12,13]. Other research has explored methods of improving performance through the use of control strategies, by implementing variable speed compressors and water circulation pumps [14,15]. An optimum water flow rate has been shown to exist for maximising the system coefficient of performance (COP_3) [16]. With regards to part load operation, the observed degradation in performance can be curtailed through a further reduction in circulation pump speed [17,18]. A number of studies have researched methods of

Abbreviations: COP, coefficient of performance; GSHP, ground source heat pump; SPF, seasonal performance factor.

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Nomenclature

k_{EF}	Carnot efficiency change per degree kelvin (K^{-1})	d	design
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)	E	external pump
n_p	pump power exponent (–)	e	evaporator
n_t	pump mean temperature exponent (–)	HP	heat pump
P	power (kW)	I	internal pump
Q	capacity (kW)	max	maximum
T	temperature (K)	o	optimal
α	part load (–)	s	steady state
η	Carnot efficiency (–)	$T1$	one compressor operation
θ	mean temperature difference (K)	$T2$	two compressor operation
		tot	total
Subscripts		w	water
c	condenser		

improving COP_3 through water flow rate control, primarily for variable speed heat pumps. The most commonly referred to control method involves modulating circulation pump speed to maintain a constant water temperature difference across the heat pump heat exchanger [10,19–21]. While this method does not result in an optimal flow rate, which varies non-linearly with capacity [9], strategies developed for optimal control often require a significant amount of on-line measurements [22–25]. This may not be practical from an economic perspective for small and medium sized installations. Research into practical control techniques for optimal part load operation has been predominantly directed at variable speed heat pumps [26]. For fixed and tandem speed heat pumps some studies have developed analytical models for optimising steady state performance through control of secondary circuit flow rate [27–29]. However, optimal water flow control has received little attention for fixed speed heat pump systems under part load conditions. This issue is addressed in the current study, through the development of an optimal part load strategy for controlling internal and external circuit water flow rates. The strategy incorporates a simplified analytical control model requiring only design data, available from heat pump and circulation pump data sheets, and minimal on-line inputs. This strategy is generalised and can be applied to a range tandem and fixed speed heat pump systems with variable speed secondary circuit pump control. The control strategy is evaluated over the course of a heating and cooling season using a validated simulation model of an installed system.

2. System evaluation

A simulation model was developed based on a GSHP system installed in an occupied building at the campus of Universitat Politecnica d'Valencia (UPV), Valencia, Spain, as part of the GROUNDMED project [13]. A schematic of the GSHP system is shown in Fig. 1. This system contains a tandem speed heat pump operating with one ('mode 1') or two ('mode 2') compressors, which replaces a previously installed single speed heat pump. Heating and cooling capacities for the tandem and single speed heat pumps are shown in Table 1. Variable speed circulation pumps are installed on the internal and external circuits and 12 multi-speed fan coils with bypass lines are implemented to heat or cool the 11 zones.

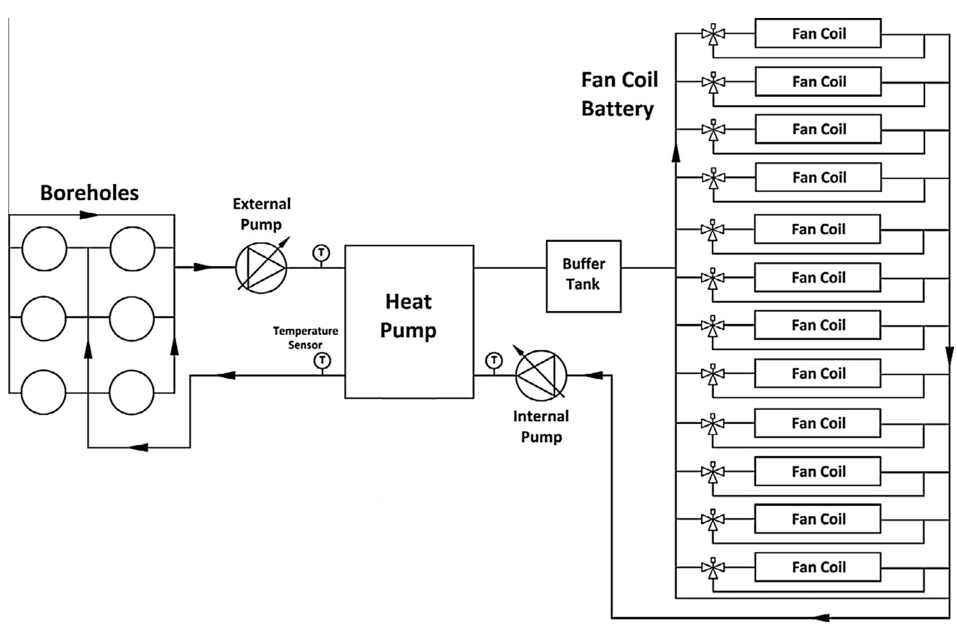

Fig. 1. System schematic.