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In situ optimization methodology for ground source heat pump systems: Upgrade to ensure user comfort

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ABSTRACT

Ground source heat pump systems have been proved to be one of the most efficient systems for heating and cooling in buildings. However, an optimal energy performance depends on a good control of the auxiliaries, which stand for an important part of the total energy consumption. The authors previously developed an experimental in situ optimization methodology for the water circulation pumps frequency of ground source heat pump systems when single stage and multi-stage ON/OFF regulation is employed. However, the user comfort was not completely met under extreme weather conditions during summer. This paper presents the upgrading of this energy optimization strategy combining circulation pumps frequency variation and building supply temperature compensation in order to ensure the user comfort while keeping high energy savings. Experimental results show that the user comfort is met by means of this new methodology and the energy savings (33%) are even higher than those obtained with the previous methodology.

1. Introduction

Ground source heat pump (GSHP) systems can lead to a 40% savings in annual electricity consumption, in comparison to air to water conventional heat pumps [1]. In order to achieve an optimal performance of these systems, a proper operation of all the components of the system as a whole should be carried out.

Over the last years, research has focused on capacity control, mainly by means of variable speed compressors. For instance, Fahlén and Karlsson compared control for ON/OFF compressor with variable speed control for a brine-to-water heat pump [2,3]. In addition to this, the importance of the auxiliaries in space heating and cooling systems was highlighted by several studies [4–6]. This becomes especially important in GSHP systems, where two circulation pumps are required.

In [7] a control strategy was developed to predict optimal ground source heat pump water flow rates under part load operation, and it was evaluated through a simulation model for single speed and tandem speed heat pumps. In [8] the results of a simulation model were compared with experimental data in a GSHP installation with variable speed compressor, variable speed water circulation pumps and variable speed fans in the coils.

The authors previously developed an experimental in situ optimization methodology for the water circulation pumps frequency of ground source heat pump systems when single stage [9] and multi-stage [10] ON/OFF regulation is employed. The results from this methodology were combined in an energy optimization algorithm together with an outdoor temperature reset (or temperature compensation) strategy in order to keep both the setpoint of the heat pump and the flow rates of the water circulation pumps at an optimal combination [11]. The key point to find this optimal combination was to consider the pump circulation rates optimizing the total power consumption of the system and not only the heat pump power consumption. This optimized control was compared to a standard control, and energy savings around 30% were obtained depending on the period analyzed [10,11].

However, although an important enhancement of the energy performance of the system was observed when applying the optimized control, the use along several seasons led to some complaints from the users. After analyzing carefully the operation of the system and all the working conditions, it was detected that the user comfort was not met in extreme weather conditions during summer mainly during July, as the indoor temperature and relative humidity observed in several rooms during these extreme days in summer took values around 27 °C and 70% respectively. No complaints were received about the heating season comfort.

This paper describes the reason why the former algorithm did not meet the user comfort and proposes a new integrated optimization strategy in order to make the system operate at its optimal

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Nomenclature

Symbol

c_p	specific heat at constant pressure
f	frequency
$\dot{m}$	flow rate
n	operation state of the heat pump unit
$\dot{Q}$	heat capacity
RH	relative humidity
T	temperature
UA_0	overall heat transfer conductance of the room
$\dot{W}$	electrical power

Subscripts

a	air
amb	outdoor ambient
avg	average value
comp	compressor
ECP	external circulation pump
ICP	internal circulation pump
FC	fan coil
max	maximum value
min	minimum value
nom	nominal value
room	room
R1	room 1
R2	room 2
SB	building supply
sys	system
Tank	outlet of the tank
w	water

Greek symbols

α	partial load ratio of the system
ε	effectiveness

Acronyms

GSHP	ground source heat pump
GSHX	ground source heat exchanger
PF	performance factor
DPF	daily performance factor
SPF	seasonal performance factor

point from the point of view of energy performance while being able to meet the user comfort at any time. The experimental measurements presented in this paper have been analyzed for cooling mode. Future analysis will be done during the next heating season.

2. Background

2.1. Geothermal experimental plant

The geothermal installation studied in this paper was built in year 2005 in the framework a European project called GEOCOOL (Geothermal Heat Pump for Cooling and Heating along European Areas, contract number NNE5-2001-00847). Since then, the installation has been completely monitored. In the Framework of another European project, GROUND-MED (Advanced ground source heat pump systems for heating and cooling in Mediterranean climate, contract number TREN/FP7EN/218895), different energy optimization studies were carried out during years 2009–2013. The research work presented in this paper has been developed in this framework.

The experimental plant air-conditions a set of spaces in the Department of Applied Thermodynamics at the *Universitat Politècnica de València*, Spain, covering a total floor area of approximately 250 m^2, and includes a corridor, nine offices (located on the east façade of the building), a computer room and a service room with office equipment and other internal loads. Each office, along with the service room, is equipped with one fan coil, except for the computer room which has two installed fan coils. The corridor is not air conditioned. Each fan coil can be individually regulated by means of a thermostat; and comfort temperature and fan speed can be manually selected by the user. The control for each fan coil is governed by a three ways valve that allows the heating/cooling water to be modulated through the fan coil. The valve is controlled by the thermostat of the room.

Each room has a fan coil unit supplied by the GSHP system. The GSHP system mainly consists of a reversible water-to-water GSHP, a ground source heat exchanger and two hydraulic loops (one for the internal loop coupled to the building, and another one for the external loop coupled to the ground) as shown in the diagram of the installation in Fig. 1. The GSHP currently installed, is a prototype unit developed and manufactured in the framework of the GROUND-MED. It consists of a water-to-water reversible GSHP, which uses R410A as refrigerant. The heat pump is reversible both on the refrigerant and on the secondary fluid circuits thanks to the use of water reversing valves, in such a way that it always works in counter current conditions resulting in a higher efficiency. The nominal heating and cooling capacities are 18 kW (35 °C return/17 °C return) and 15.4 kW (14 °C return/25 °C return) respectively. In order to better adapt the GSHP capacity to the building thermal load, the GSHP has two scroll compressors of the same capacity working in tandem. The evaporator and condenser are two brazed plate heat exchangers of the same geometry with 42 plates each. The ground source heat exchanger (GSHX) consists of a vertical borehole heat exchanger (grid of 2 × 3 boreholes, 50 m deep, 3 m separated from each other; each borehole contains a single polyethylene Utube of 25.4 mm internal diameter, with a 70 mm separation between the upward and downward tubes.

As shown in Fig. 1, the system is divided into two hydraulic circuits. The internal one consists of 12 parallel-connected fan coils units, an internal hydraulic loop and a water storage tank. The external one consists of the ground source heat exchanger which is coupled to the heat pump by an external hydraulic loop. The system operates from 7 a.m. to 8 p.m. during 5 days per week.

Both circuits have circulation pumps in order to pump the water to the fan coil units (ICP; nominal values at 50 Hz: 3180 kg/h, 0.63 kW) and the GSHX (ECP; nominal values at 50 Hz: 2650 kg/h, 0.36 kW). The internal pump operates continuously along the day, whereas the external pump only works when at least one of the compressors of the heat pump is running. The water flow rate in both circuits can be varied by means of two frequency inverters.

A network of sensors was set up so that the installation is completely monitored: water temperatures (four-wire PT100 with accuracy ±0.1 °C.), mass flow rates (Danfoss flow meter model massflo MASS 6000 with accuracy <0.1%) and power consumptions (Gossen Metrawatt power meter model A2000 with accuracy ±0.5%). Further details on system description can be found in previous publications [10–12].

2.2. In situ optimization methodology for the water circulation pumps frequency

The authors previously developed an experimental in situ optimization methodology for the water circulation pumps frequency [10]. Its main advantage is that it is based on experimental measurements and it can be carried out in situ at any installation. Therefore, it is able to take into account the real characteristics of the installation as well as real operating conditions. A summary