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Comparison between design and actual energy performance of a HVAC-ground coupled heat pump system in cooling and heating operation

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ABSTRACT

This work compares the experimental results obtained for the energy performance study of a ground coupled heat pump system with the design values predicted by means of standard methodology. The system energy performance of a monitored ground coupled heat pump system is calculated using the instantaneous measurements of temperature, flow and power consumption and these values are compared with the numerical predictions. These predictions are performed with the TRNSYS software tool following standard procedures taking the experimental thermal loads as input values. The main result of this work is that simulation results solely based on nominal heat pump capacities and performances overestimate the measured overall energy performance by a percentage between 15% and 20%. A sensitivity analysis of the simulation results to changes in percentage of its input parameters showed that the heat pump nominal coefficient of performance is the parameter that mostly affects the energy performance predictions. This analysis supports the idea that the discrepancies between experimental results and simulation outputs for this ground coupled system are mainly due to heat pump performance degradation for being used at partial load. An estimation of the impact of this effect in energy performance predictions reduces the discrepancies to values around 5%.

1. Introduction

Ground coupled heat pumps are recognized by the U.S. Environmental Protection Agency [1] as being among the most efficient and comfortable heating and cooling systems available today. These pumps represent a good alternative system for heating and cooling buildings [2–10]. By comparison with standard technologies, these heat pumps offer competitive levels of comfort, reduced noise levels, lower greenhouse gas emissions and reasonable environmental safety. Their electrical consumption and maintenance requirements are lower than those required by conventional systems and, therefore, have lower annual operating cost [11–13].

The design of a ground coupled heat pump HVAC system is based on predictions coming from simulation tools. First step in a standard design procedure is the estimation of the thermal loads that the air-conditioned area is going to demand. Its value determines the capacity of the ground source air-conditioning system. From this value and a proper estimation of the ground thermal properties, the characteristics of the water to water heat pump and the required length and layout of the borehole heat exchangers are estimated.

The purpose of this work is to compare a standard design procedure based on a TRNSYS [14] simulation with the experimental results obtained on a monitored geothermal plant. The experimental validation of design models for thermal facilities is the subject of a considerable amount of research works [15–19]. In Ref. [15], an air-cooled reciprocating chiller is modeled and analyzed. In Ref. [16], for instance, a variable-refrigerant-volume air-conditioning system is simulated using EnergyPlus and experimentally validated. In Ref. [17], a numerical model for heat storage with phase change materials is presented and experimentally checked. In Ref. [18], the cooling capacity of earth–air–pipe systems is modeled and evaluated. And in Ref. [19], the design and performance of solar powered absorption cooling systems is studied. Many other references can be included here, being the ones presented before just a representative sample of the strong activity in the area.

Some of the models describing the behaviour of thermal facilities have been implemented as modules for the TRNSYS software tool. Its experimental validation is also a field of strong research activity [20–23]. In Ref. [20], a comparison between measured and predicted long term performance of a grid connected photovoltaic system using TRNSYS is performed. In Ref. [21], thermal testing and numerical simulation with the TRNSYS software of a prototype cell

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Nomenclature

CDF	coefficient of performance degradation factor
COP	coefficient of performance
C_p	specific heat at constant pressure
CP	circulation pump
DPF	daily performance factor
f	circulation pump variable control function
$\dot{h}$	enthalpy flow
$\dot{m}$	mass flow
PF	performance factor
PLR	partial load ratio
Q	thermal loads
$\dot{Q}$	instantaneous thermal loads
SPF	seasonal performance factor
T	temperature
W	energy consumption
$\dot{W}$	power consumption

Greek letter

α	coefficient of performance degradation parameter

Subscripts

in	input
max	maximum
out	output
ww	water to water heat pump

using light wallboards coupling vacuum isolation panels and phase change materials is presented. In Ref. [22], experimental measurements and numerical modeling with TRNSYS of a green roof are compared. And in Ref. [23], the validation of a TRNSYS computer model for solar assisted district heating systems with seasonal hot water heat store is studied. More references can be added being the presented ones just a representative sample of the almost standard use of TRNSYS software as simulation tool of the dynamic behaviour of thermal facilities.

In the subject of the present work, the experimental validation of models for ground coupled heat pumps working in heating and cooling mode, the amount of research works is more limited. In Europe, research focused in this area has been performed in Turkey, with the objective of experimentally characterizing the system performance, and also in the development of models to predict this performance. In Hepbasli [24,25] and Inalli and Esen [26,27] the experimental characterization of ground coupled heat pump system performance working in both heating and cooling modes was tempted. There are also studies of ground coupled heat pump system performance when combined with thermal solar energy [28–31]. In Esen et al. [32,33] models to predict ground coupled heat pump system performance are presented. These authors have also developed research in the subject of the present work. In Ref. [34] experimental measures of the energy performances of a horizontal ground coupled heat pump system are shown, which are used to validate a numerical model describing ground heat transfer. In Ref. [35] a study on modeling and performance assessment of a heat pump system for utilizing low temperature geothermal resources in buildings is presented. Finally, in Ref. [36–40], the recent research developed in China on the subject of ground coupled heat pumps working in refrigeration mode is described.

The main objective of this work is to compare long term energy performance experimental measurements of a monitored ground coupled heat pump system, with the predictions from a standard design procedure based in the TRNSYS simulation tool. One of the difficulties that appear when doing this comparison comes from the fact that the actual thermal loads differ significantly from the estimated ones. These estimations are based in predictions of building occupancies, weather data. . .being in many cases substantially different than the actual operation conditions. To avoid this difficulty, in this work the measured thermal loads are used as input value of the simulation design tool to evaluate the goodness of the models describing the ground coupled heat pump HVAC system.

In this study a comparison between the energy performance measured in GeoCool geothermal experimental plant and the energy performance predictions from a standard design procedure is performed. This procedure uses as input values the thermal loads measured along a whole year of measurements, nominal heat pump capacities and performances, and ground thermal properties. Numerical predictions and experimental results are compared, performing then an exhaustive analysis of the origin of the discrepancies between both.

This article is structured as follows. In Section 2, the experimental setup of GeoCool installation is described. Section 3 presents the procedure to calculate the system energy efficiency. Afterwards, in Section 4, the simulated system, its structure, inputs and outputs are explained. In Section 5, the results are presented and discussed. Finally, in Section 6, the conclusions obtained from the presented results are summarized.

2. Geothermal experimental plant

Geothermal experimental system was the result of a EU project (GeoCool) and air-conditions a set of spaces in the Department of Applied Thermodynamics at the Polytechnic University of Valencia, Spain, with a total surface of approximately 250 m^2. This area includes nine offices, a computer classroom, an auxiliary room and a corridor. All rooms, except the corridor, are equipped with fan coils supplied by the experimental system: an air to water heat pump and a ground coupled (geothermal) heat pump working alternately (Fig. 1). The geothermal system consists of a reversible water to water heat pump (15.9 kW of nominal cooling capacity and 19.3 kW of nominal heating capacity), a vertical borehole heat exchanger and a hydraulic group. The water to water heat pump is a commercial unit (IZE-70 model manufactured by CIATESA) optimized using propane as refrigerant. As reported in GeoCool final publishable report [41], the coefficient of performance of the improved heat pump is 34% higher in cooling and 15% higher in heating operation. The vertical heat exchanger is made up of 6 boreholes of 50 m. depth in a rectangular configuration, with two boreholes in the short side of the rectangle and three in the large side, being 3 m the shorter inter-borehole distance. All boreholes are filled with sand and finished with a bentonite layer at the top to avoid intrusion of pollutants in the aquifers.

The GeoCool plant was designed to allow a fair comparison between a ground source (geothermal) heat pump system and an air source heat pump system [2,3], therefore a network of sensors was set up to allow monitoring the most relevant parameters of these systems (Fig. 1). These sensors measure temperature, mass flow and power consumption. The temperature sensors are four wire PT100 with accuracy ±0.1 °C. The mass flow meters are Danfoss Coriolli meters, model massflo MASS 6000 with signal converter Compact IP 67 and accuracy <0.1%. The power meters are multifunctional power meters from Gossen Metrawatt, model A2000 with accuracy ±0.5% of the nominal value. Data from this sensor network is collected by a data acquisition unit Agilent HP34970A with plug-in modules HP34901A.

The geothermal system is characterized by the heat that the ground can absorb or transfer. To record this value inlet and outlet fluid temperature of the water to water heat pump and circulating mass flow are measured. In addition inlet and outlet temperature