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Short communication

Optimization of hybrid – ground coupled and air source – heat pump systems in combination with thermal storage

N. Pardo [a,*], Á. Montero [a], J. Martos [b], J.F. Urchueguía [a]

[a] Departamento de Física Aplicada (DFA), Universidad Politécnica de Valencia, Camino de Vera S/N, 46022 Valencia, Spain
[b] Departamento de Ingeniería Electrónica (DIE), Universidad de Valencia, Av. Vicent Andrés Estellés S/N, 46100 Burjassot-Valencia, Spain

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ABSTRACT

Ground coupled heat pumps are attractive solutions for cooling and heating commercial buildings due to their high efficiency and their reduced environmental impact. Two possible ideas to improve the efficiency of these systems are decoupling energy generation from energy distribution and combining different HVAC systems. Based on these two ideas, we present several HVAC configurations which combine the following equipments: a ground coupled heat pump, an air to water heat pump and a thermal storage device. These HVAC configurations are linked to an office building in a cooling dominated area in order to evaluate in these conditions the total electrical consumption of each configuration to obtain which one satisfy the thermal demand more efficiently. The results of our simulations show that the electrical energy consumption obtained when the system employs a suitable configuration is of around the 60% compared with an HVAC system driven by an air to water heat pump and around the 82% compared with an HVAC system driven by a ground coupled heat pump.

1. Introduction

Nowadays, the increase of energy consumption in developed societies is producing serious changes in the natural environment such as the global warming. Around 40% of all greenhouse gas emissions in developed countries have their origin in building equipments, where approximately 60% are produced by cooling and heating systems [1,2]. In this context, new HVAC configurations which implement new management strategies are required to improve their energy efficiency and to reduce their environmental impact. Two possible ideas to achieve these objectives consist in combining different HVAC systems and decoupling energy generation from energy distribution.

Ground coupled heat pumps (GCHP) are an attractive solution for cooling and heating commercial buildings due to their higher efficiency compared with conventional air to water heat pumps (AWHP) [3–6]. The Environmental Protection Agency (EPA) recognizes GCHP systems among the most efficient and comfortable heating and cooling alternatives available today [7]. A possible way to improve the efficiency of GCHPs can be achieved by combining them with other HVAC system, such as an air to water heat pump. A proper management of the combined system could potentially produce a system performance better than the performance achieved by each one working independently. Research works in this line has been presented in Refs. [8,9].

A thermal storage device incorporated in an air conditioning system allows decoupling energy generation from energy distribution. This possibility produces two important advantages, it allows a size reduction of the heat pump, and diminishes the effects of the thermal load peaks generating thermal energy when the environmental conditions are more favourable. As reported in [10–13], the incorporation of a thermal storage device could produce high energy savings in an air conditioning system and, in particular, in the systems driven for an electrical heat pump in a cooling dominated area.

Following these research lines the purpose of this work is to evaluate the electrical energy consumption and the energy efficiency of several air conditioning layouts in a cooling dominated building, implementing both ideas together. The procedure to evaluate the energy efficiency of the designed HVAC system is as follows. First step in the procedure is the evaluation of the electrical energy consumptions of the air conditioning system when is driven by a pure AWHP system or by a pure GCHP system. These values are used as a reference for comparison with the consumptions of the implemented layouts. Then, we present an air conditioning configuration composed by a GCHP combined with an AWHP to study the behaviour of both systems working together. Afterwards, we combine a stratified water tank as thermal storage device with a GCHP or with an AWHP to study the behaviour when energy generation and distribution is decoupled. Finally, we

* Corresponding author. Tel.: +34 963877007/79895; fax: +34 963877179.
E-mail address: nipargar@doctor.upv.es (N. Pardo).

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present a hybrid configuration which combines both heat pumps and a stratified water tank and we evaluate the efficiency improvement of this combined alternative.

This work is structured as follows. In Section 2, *simulated system*, we describe the simulated office building, including the estimation of its thermal loads, a description of the air conditioning configurations linked to it, the air conditioning design parameters employed in the simulation and the models describing the different components. In Section 3, *simulation results and discussion*, we present and discuss the results of our simulation. The electrical energy consumptions for each device are calculated for each configuration and an evaluation of its energy efficiency is presented. We also analyze the advantages and disadvantages of each configuration from the energy efficiency point of view and also from the point of view of costs. Finally, in Section 4, *conclusions*, we summarize the main obtained results.

2. Simulated system

An office building, located in the Mediterranean coast area, is modelled to obtain a thermal load in order to evaluate in these conditions the energy performance of the described air conditioning configurations. The thermal comfort criteria employed to obtain an estimation of the thermal loads demanded by the office building is the Predicted Mean Vote (PMV) index [14]. In Section 2.1 we present the evaluation of these thermal loads following this criteria as well as a description of the building parameters. Section 2.2 describes the adopted layouts for each air conditioning configuration and in Section 2.3 its design parameters are presented. Finally, in Section 2.4 the energy model of the employed components is formulated. The simulation of these systems is performed by means of TRNSYS software package [15].

2.1. Thermal loads

We focus this study in the cooling dominated area of the Mediterranean coast. To estimate the thermal loads demanded by the office building we consider that the heating season comprises the period from January to March and from November to December, and the cooling season the period from April to October. Daily load in heating or in cooling has to satisfy neutral thermal comfort conditions. The weather database employed describes an average season representing the Mediterranean coast weather for the city of Valencia (Spain).

We choose the Predicted Mean Vote (PMV) index to evaluate the comfort state in our simulation. This index is the criteria to estimate the comfort state proposed by the ISO7730-1994 standard. The value of the PMV index is calculated, in our simulation, at each time step for the air conditioning space, following ISO7730-1994 recommendations and considering that the activity is 1.2 met for moderated office activity, the thermal resistance of clothing is 1.0 clo (when the considered working clothes are shirts, trousers, jackets, and shoes) and, finally, the value for the mean air velocity is estimated at 0.1 m/s.

The model of the office building adopted for this study is chosen to be representative of this kind of buildings in our area. It features three floors with a length of 30 m, a width of 20 m and a height of 3 m with eight thermal zones per floor. External walls are defined as ventilated façades composed by four elements: perforated brick, 5 cm of insulation, air chamber and a Naturex plate cover; its global conductivity is 0.51 W/m^2 K. The window fraction is approximately 22% in each façade; the windows are composed by a glass, with solar radiation transmissivity equal to 0.837 and conductivity equal to 5.74 W/m^2 K, dedicating a 15% of this area to the frame surface with conductivity equal to 0.588 W/m^2 K. The internal and external shadow factor for these windows is estimated at 0.7. Gains due to occupancy and lights are as follows. Peak building occupancy is 11 m^2/person. Each office worker contributes 132 W of internal gain, where 54% are assumed to be sensible and 46% latent. The working schedule starts at 7:00 and at 9:30 the occupancy arrives to its peak. The lunch time is from 13:00 to 15:00 in this period the occupancy decrease until a 50%. Finally, people start to leave the office at 18:00 and the office is empty at 20:00. The light system is switched on at 7:00 in the morning and increases progressively until its peak at 8:00. The value of the peak lighting density is 20 W/m^2. This value is constant until 19:00; in this moment starts to decrease and all the lights are switched off at 20:00.

Taking into account all these considerations, the daily loads in heating season and in cooling season are calculated. The obtained values show that the thermal demand is substantially shifted towards cooling compared to heating. This asymmetric demand is a characteristic of office buildings in Mediterranean areas, where the climate is characterized by hot summers and warm winters. Due to this fact, all the HVAC layouts studied try to improve the system energy efficiency when operating in cooling mode.

2.2. Air conditioning configurations

The air conditioning configurations coupled to the above described office building are described in the following paragraphs.

2.2.1. Air to water heat pump configuration (‘Air’)

Air to water heat pump configuration (‘Air’), composed by an AWHP, an internal water pump and an air fan. Thermal energy is generated and supplied by the air to water heat pump when it is demanded by the building.

2.2.2. Ground coupled heat pump configuration (‘GCHP’)

Ground coupled heat pump configuration (‘GCHP’), composed by a water to water heat pump (WWHP), a ground heat exchanger and an internal and an external water pump. Thermal energy is generated and supplied by the ground coupled heat pump when it is demanded by the building.

2.2.3. Ground coupled heat pump and air to water heat pump configuration (‘GCHP + Air’)

This configuration combines a GCHP and an AWHP. Thermal energy is generated and supplied to the thermal load by the GCHP and, if this element has not enough capacity to supply the demanded thermal energy, the AWHP is switched on and supplies thermal energy up to satisfy the thermal demand. The GCHP system is switched on first because its coefficient of performance is the higher of both.

2.2.4. Air to water heat pump with thermal storage device configuration (‘Air + S’)

This configuration combines an AWHP system with a thermal storage device. A period in the night is dedicated to store thermal energy. This energy is generated by the AWHP system. The procedure to supply thermal energy to the load in cooling mode is as follows. The thermal demand is first satisfied by the thermal energy previously stored during the night. If the thermal storage device has not enough capacity, this element is supported by the AWHP until the thermal demand is covered. Finally, the thermal storage device is by-passed when its water outlet temperature is higher than its water inlet temperature. At these conditions only the AWHP supplies thermal energy to the load.