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An innovative solution to increase the performances of an Air-Cooled Heat Pump by Horizontal Air-Ground Heat-Exchangers

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Abstract

This work presents the performances of an Air-Cooled Heat Pump combined with Horizontal Air Ground Heat Exchanger. The Horizontal Air Ground Heat Exchanger has been used not for the direct ventilation of the room, but for the treatment of the outside air flux of an Air-Cooled Heat Pump; consequently, the heat pump works with colder and warmer air than outside one in summer and winter, respectively. The results are exposed in terms of the Coefficient of Performance and Energy Efficiency Ratio of the Air-Cooled Heat Pump.

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Keywords: HAGHE; Heat Pump; COP; EER; ZEB; Ground; geotherm.

1. Introduction

The combustion of fuel energy sources involves a degrading effect to the atmosphere, leading to an increasingly rapid rise in the concentration of greenhouse gases and altering the thermal balance of the Earth, with an abnormal increase in atmospheric temperature.

Several action programs and international policies aim to cut the primary energy consumption and carbon dioxide emissions, considered the main causes of the greenhouse effect and the temperature rise [1, 2]. The construction sector is the protagonist in environmental issues due to the disproportionate use of non-renewable sources which shows, along with the transport sector, the biggest potential of energy efficiency in all countries [3]. The

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disproportionate use of non-renewable sources of the building sector makes it the biggest potential of energy efficiency in all countries.

This study presents the performances of an air-cooled heat pump coupled with a Horizontal Air-Ground Heat Exchanger. Horizontal systems are typically placed at least a depth between 1.5 and 2.0 m, spaced at least 1.5 m, to avoid the thermal influence between each other. The outdoor conditions highly affect the behavior of the horizontal systems [4]. The study presented in [5], through numerical simulations, points out the optimized designs of horizontal ground heat exchangers considering several layouts and pipe materials. The optimum design of horizontal ground heat pump systems for spiral-coil-loop heat exchangers is suggested by the study presented in [6]. The horizontal heat exchangers provide long pipes positioned at a 1 and 2 m soil depth through heat transfer fluid flows and changes heat to or from the ground [7]. The innovative strategy introduced in this project provides the use of the HAGHE not for the ventilation air, but for treatment of the air flux before it meets the exchanger of an air-cooled heat pump, in order to work with colder and warmer air than outdoor air, in summer and winter, respectively. The analysis has been carried out for different climatic zones. In particular, it has been carried out an analysis for a cold climate in zone E, the city of Torino in Italy and, for warm climate in zone C, the city of Brindisi. The dynamics simulations have been performed using TRNSYS 17 (Transient System Simulation) tool, through the setting of several data for the model, such as the flow rates, the burial depths and the diameter of the probe, for each climatic area.

Nomenclature

COP	Coefficient of Performance
EER	Energy Efficiency Ratio
HAGHE	Horizontal Air-Ground Heat Exchanger
ACHP	air-cooled heat pump
$L_{n,e}$	Absorbed electrical power of the heat pump [W]
Qs	amount (in module) of heat flux transferred to a well at a higher temperature Ts [W]
Qi	amount (in module) of heat flux extracted from a well at a lower temperature Ts [W]
T	temperature of the external air at a specific time of the year [K]
R^2	regression coefficient
t	treated air
nt	not treated air

2. The Air-Cooled Heat Pump

The performances of the Air-Cooled Heat Pump are monitored by the Coefficient of Performance (COP) and Energy Efficiency Ratio (EER) expressed by the following equations:

$$COP=Q_s/L_{n,e} \quad (1)$$

$$EER=Q_i/L_{n,e} \quad (2)$$

The COP is the parameter that represents, in the heating mode, the ratio of the useful heat supplied by the heat pump and the energy used to extract this heat from the cold source. For an air-to water heat pump, using COP it is possible to compare the amount (in module) of heat Qs, transferred to the water at a higher temperature than the external air, and the work $L_{n,e}$ provided to the heat pump. In accordance to the Carnot's theory, the COP value increases if the difference between the external air temperature and the water temperature became lower. The EER parameter represents the efficiency of the heat pump in the cooling mode. In the air-to water heat pump EER is the ratio between the amount (in module) of heat Qi extracted to cool the water flow rate and the work $L_{n,e}$ provided to the heat pump. Even in the cooling mode the value of efficiency increases when the difference between the external air temperature and the water temperature is lower. The trend lines of the COP (Table 1) and EER (Table 2) have been obtained from the COP and EER values at the maximum frequency, in function of the external air temperature and water temperature (data declared in accordance with the UNI EN 14511-2: 2011) of a commercial heat pump with a thermal power of 100 kW. The temperature range considered for the COP evaluation are 0 - 20°C for Brindisi and -8°C - 20°C for Torino.

Table 1. COP trend lines in function of T air.

	COP trend lines	R^2
35°C BR	y=0,0000003924*(T^6)-0,0000268942*(T^5)+0,0007211356*(T^4)-0,0092622391*(T^3)+0,0501520086*(T^2)+0,0499598547*T+2,49993028	0,9995
35°C TO	Y=-0,0000001366*(T^6)+0,0000062328*(T^5)-0,0000595543*(T^4)-0,0007920620*(T^3)+0,0095376004*(T^2)+0,1108459433*T+2,5188261998	0,9986
45°C BR	y=0,0000003935*(T^6)-0,0000265387*(T^5)+0,0007020815*(T^4)-0,0089750790*(T^3)+0,0499265392*(T^2)+0,0225011933*T+1,998999559	0,9994
45°C TO	Y=-0,0000001190*(T^6)+0,0000056479*(T^5)-0,0000598872*(T^4)-0,0006436253*(T^3)+0,0093448317*(T^2)+0,0864112624*T+2,0130321708	0,9985

Table 2. EER trend lines in function of T air.

	EER trend lines	R^2
7°C	Y= 0,000002*(T^4) -0,000287*(T^3)+0,017150*(T^2)-0,56883*T+10,9500	0,9998
12°C	Y=-0,0000010*(T^4) +0,0000893*(T^3)-0,0009028*(T^2)-0,1668466*T+7,0735317	1

The regression coefficient R^2 ranges between 0 and 1; the model does not explain the data for a value of R^2 equal to 0. The model perfectly describes the data when the regression coefficient is equal to 1. The study provides the comparison between the performances of the air-cooled heat pump considering the external air and the air treated by the horizontal air ground heat exchanger, in order to point out the good results using the storage capacity of the ground.

3. The Trnsys settings

The analysis of the HAGHE system has been conducted in a Trnsys 17 environment. TRNSYS (Transient System Simulation) tool allows solving algebraic and differential equations and performing a modular approach through the division of a complex problem into a sum of simpler problems. The first type used is Type15 that involves the weather data for several cities supplied by Meteonorm. Through the Type 15 it has been possible to calculate several parameters that are primary for a correct use of the Type 501. The Type 501 uses the Kusuda and Achenbach equation in order to obtain a physical model for vertical distribution of the ground temperature. Through the Type 501, Trnsys processes in input the "amplitude of surface temperature", the "time shift" and the "mean surface temperatures" obtainable through the climatic data output from Type 15. The first parameter is the difference between the maximum temperature and the average one, the second parameter is the time between the first day of the year and the one in which the lowest temperature have been recorded. The last parameter is the yearly average temperature of the air. Independently of climatic parameters, the use of Type 501 needs to set the thermal conductivity of the ground, the ground density, the depth of the probe and the specific heat of the ground.

In type 31 have been set the parameters about the HAGHE probes. The analysis has been conducted by varying, in type 31, the diameter of the probe and the air flow rate within, at fixed values of length and installation depth of the probes. The input of air data in type 31 are the output of Type 15 and type 501. The simulation results are the hourly temperatures of the air outgoing from the 30 meters' probe, at 3 meters of depth for each city analyzed.

In Type 501, the following parameters have been set:

- Ground density = 2723 kg/m^3;
- Ground specific heat = 840 J/kgK;
- thermal conductivity of the ground = 2 W/mK;
- the depth of probe installation = 3 m.

The parameters used for type 31 have been set starting from the technical data of the heat pump, chosen for the study. The machine needs of 13.200 m^3/h of air to the air heat exchanger. In order to move the air in the geothermal heat exchanger, commercial polypropylene pipes have been chosen. Starting from each value of the air flow rate, the ducts considered for the study are the following:

- N°2 ducts with a diameter of 630 mm and 6600 m^3/h of mass flow rate, air velocity 5,88 m/s;
- N°3 ducts with a diameter of 500 mm and 4400 m^3/h of mass flow rate, air velocity 6,22 m/s;
- N°6 ducts with a diameter of 400 mm and 2200 m^3/h of mass flow rate, air velocity 4,86 m/s;
- N°10 ducts with a diameter of 315 mm and 1320 m^3/h of mass flow rate, air velocity 4,70 m/s;

The analysis has been carried out from October 15 to April 15 for the winter period, June 1 to August 31 for the summer season, representing the most critical periods of the year. The daily working period is considered from 8.00 to 18.00, as required by the office use.

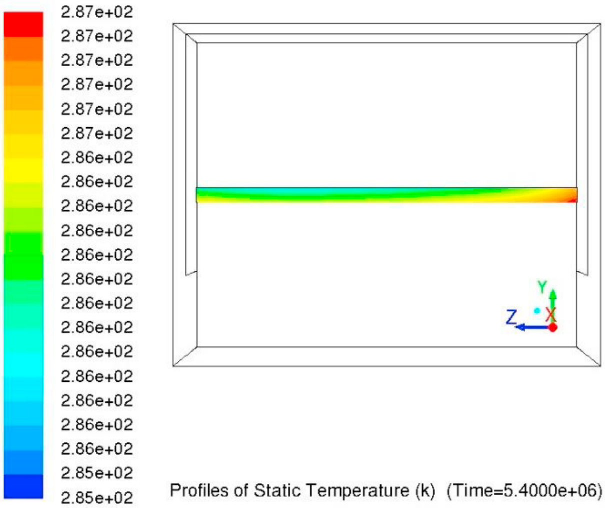

Fig.1 Temperature distribution around the pipe.

In fig. 1, the temperature distribution around the pipe is reported for a previews work [8], where it is possible to note the lower influence of the air flow rate on the ground with a higher heat capacity.

4. Results

The aim of the present work is to describe the behavior of combined system compared with the conventional operation of a traditional Air-Cooled Heat Pump. The convenience in the use of HAGHE is conditioned by several parameters, such as thermal conductivity of the ground, diameters of probe and air flow rate. To simplify and facilitate the analysis, the results have been represented for the summer and winter seasons and described through the COP and EER trends.

The results of the daily average COP, with (COP_t) and without the HAGHE (COP_{nt}), are showed in fig. 2.

The efficiency of the pre-treatment system increases with the decrease of the air flow rate conveyed in the HAGHE. For lower value of air flow rate, at the same temperature of hot water produced, the distance between the two curves become higher. Reducing the diameter of the probe and the air flow rate within, it has been obtained a damping effect on the oscillating behavior of COP trend. Indeed, if the air flow rate in the HAGHE is high, the COPt and COPnt lines have the same trends, despite it may be noted that the first one is upper than the second one, for almost all winter time. The pre-treatment in the first part of heating season it may get a good convenience. Approaching to the end of winter time, it has been observed a reversal trend between the two lines. In this period, the external air may be used directly. The efficiency of the system may increase using a bypass in order to send the air, at the highest temperature, directly to the heat exchanger of the heat pump. In this way, the heat pump always works in the best conditions, with the lower absorption of electric power.

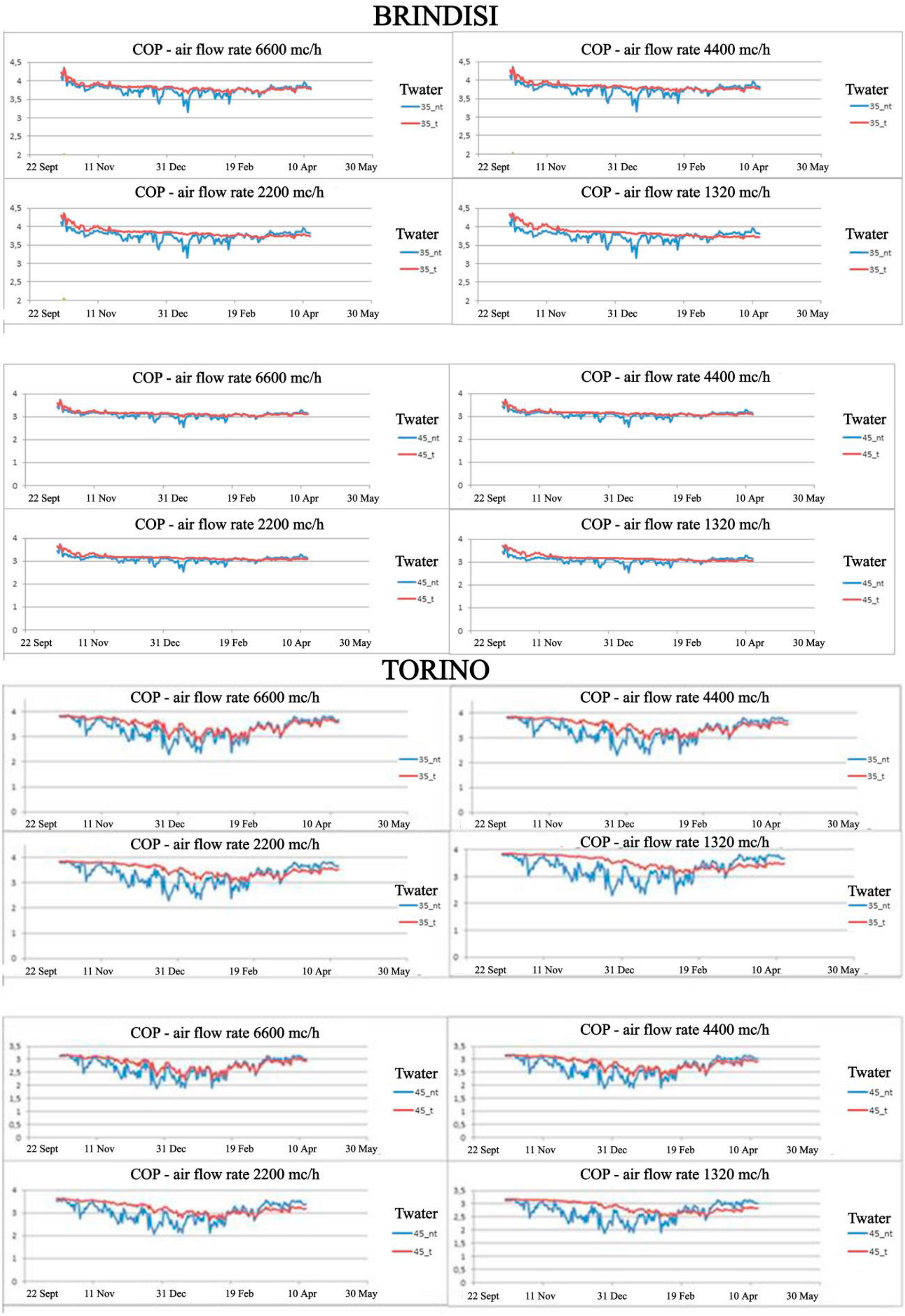

Fig. 2. COP at Brindisi and Torino with ground thermal conductivity of 2 W/mK.

The pre-treatment, in the summer time, leads the heat pump to work at appreciable efficiency values during all the cooling season. The air from the HAGHE, colder than external one, increase the EER value. The trend lines of daily average values of EER_t and EER_{nt} are shown in the figs 3 and 4, where the blue lines correspond to the traditional operation of the machine and the red lines correspond to the pre-treatment one.

The use of pre-treatment technology during the cooling season is convenient in any cases. The average EER_t values obtained, for fixed cold water temperature, increase with the decrease of air flow rate and diameter of the probe. Lower value of air flow rate leads to have an EER_t distributions more stable. The use of HAGHE reduces the fluctuations of EER values during the cooling season.

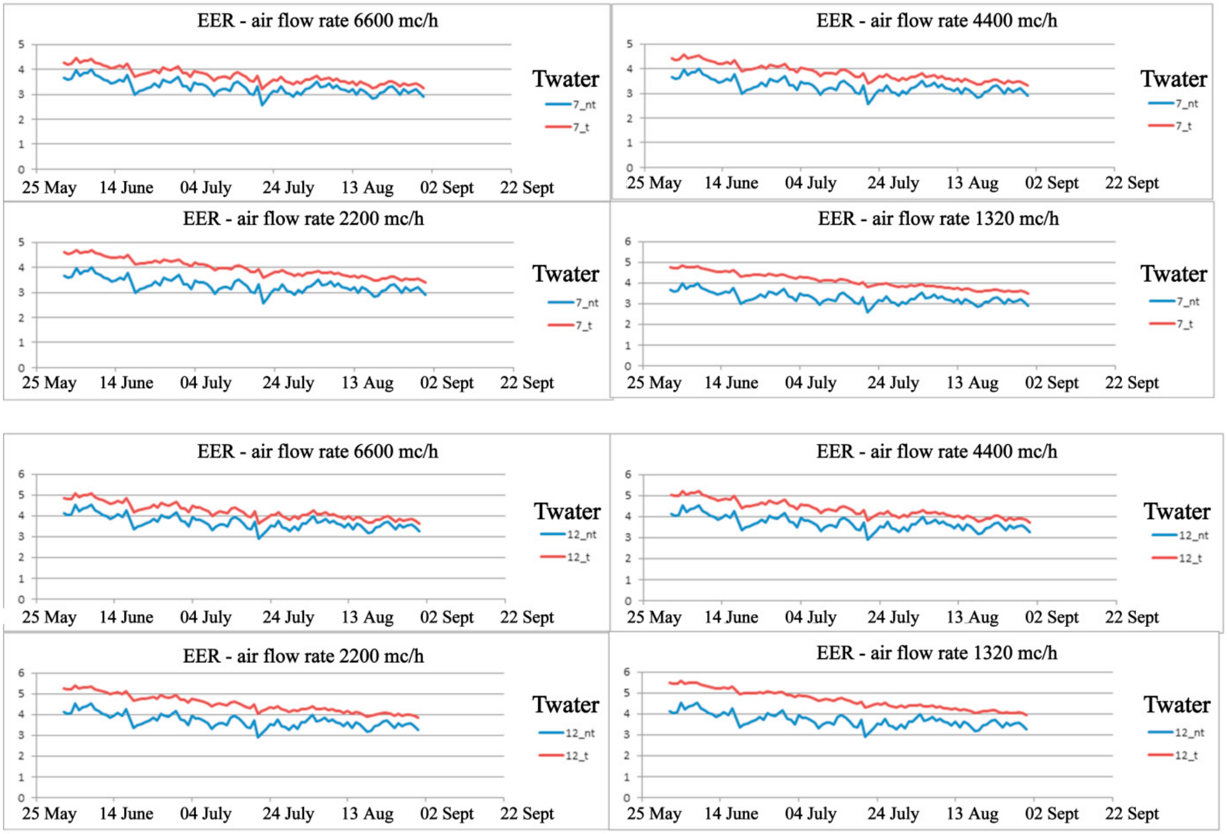

Fig. 3. EER at Brindisi with ground thermal conductivity of 2 W/mK.

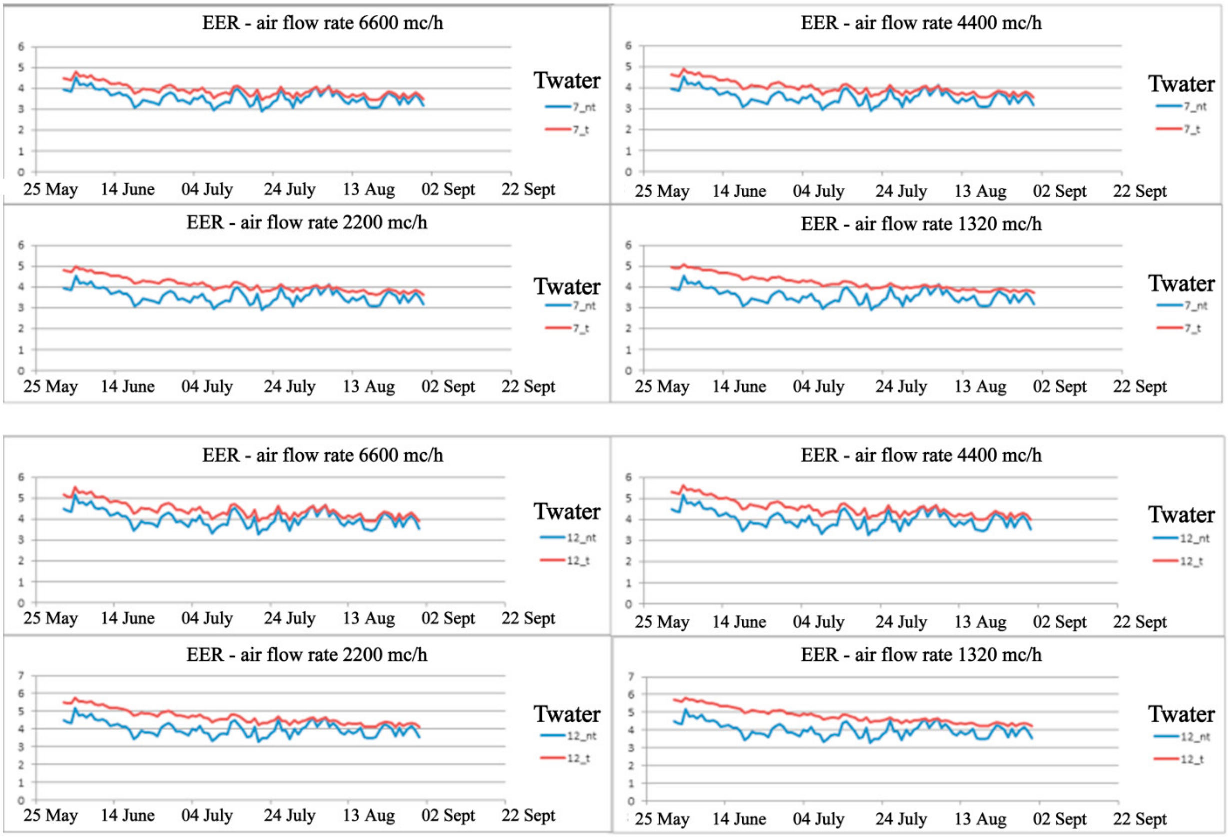

Fig. 4. EER at Torino with ground thermal conductivity of 2 W/mK.

5. Conclusions

This work proves the possible improvement of ACHP operation resulting using a HAGHE, in order to pre-cooling or pre-heating the air exchanged by heat pump in summer and winter operation mode. The analysis has been carried out considering different operating conditions and for two different climatic areas. An interesting result is the chance to use heat pumps in winter mode in regions where, typically, the low temperatures do not permit to use such technology. As well as for the warm areas, where the high temperatures adversely affect the efficiency of the heat pump in the production of cold water for cooling applications.

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