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Review paper of Modeling of an Air Conditioning System with Geothermal Heat Pump for a Residential Building

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Abstract: ***The need to address climate change caused by greenhouse gas emissions attaches great importance to research aimed at using renewable energy. Geothermal energy is an interesting alternative concerning the production of energy for air conditioning of buildings (heating and cooling), through the use of geothermal heat pumps. In this work a model has been developed in order to simulate an air conditioning system with geothermal heat pump. A ground source heat pump (GSHP) uses the shallow ground as a source of heat, thus taking advantage of its seasonally moderate temperatures. GSHP must be coupled with geothermal exchangers. The model leads to design optimization of geothermal heat exchangers and to verify the operation of the geothermal plant.***

Keywords: Geothermal Heat Pump, Residential Building.

INTRODUCTION

The increasing energy demands the fact that fossil fuels are finite resources and the problem of pollutant emissions has allowed renewable energy sources (RES) to be considered and developed, including geothermal [1].

Geothermal energy is used in order to generate electricity or for direct uses, especially for heating [2]. Direct use of geothermal energy is the oldest and the most common utilization of this energy source.

There are many possibilities for these uses: geothermal heat pumps or ground source heat pumps (GSHPs), space heating, greenhouse and covered ground heating, aqua cultureture pond and raceway heating, agricultural crops drying, industrial process heat, snow melting and space cooling, bathing, and swimming [3].

The GSHP systems for heating and cooling are considered one of the most energy-efficient and cost-effective renewable energy technology [4]. Moreover these systems allow to reduce the greenhouse gases (GHGs) emissions [5].

Geothermal heat pumps systems use the subsoil (the interior of the earth) as a source and extract heat at low deep [6].

Heat pumps are devices that allow to transfer heat from a lower temperature system to a higher temperature system.

Geothermal heat pump or ground source heat pump (GSHP) is a heating and/or cooling system that pumps heat to or from the ground. The GSHP uses earth as a heat source (during winter time) or a heat sink (during summer time). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems [7]. The major advantage of GSHPs derives from their better performance if compared with traditional system because they takes advantage of a more stable temperature of the heat source during the whole year, thus the coefficient of performance (COP) is increased, and the operational costs of heating and cooling are reduced [8].

The GSHPs systems can be classified as follows:

(i) Open systems: if groundwater is used as heat transfer fluid,

(ii) Closed systems: if there are some heat exchangers in the underground, and the groundwater is not the heat transfer fluid [9].

Among the closer systems there are many different configurations: horizontal, spiral, and vertical loop [10].

An air conditioning system with geothermal heat pumps consists of three parts [11]:

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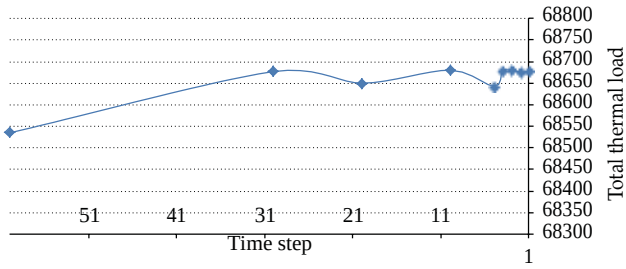


Figure 1: Thermal load as a function of time step

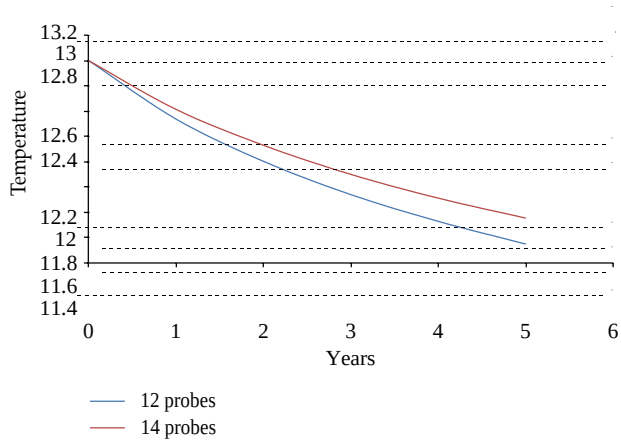


Figure 2: Ground temperature variations with exchanger numbers

(i) Geothermal heat exchangers,

(ii) heat pump,

(iii) Heat distribution system (radiant floors are particularly suitable because they have the great advantage of working with lower temperature gradients if com- pared to conventional systems [12]).

The operating mechanism for heating is as follows:

(i) The fluid (antifreeze added water), flowing in geothermal heat exchangers, exchanges heat with the ground and comes back heated to surface;

(ii) Fluid transmits its heat to the heat pump and back in the heat exchangers with lower temperature;

(iii) Heat pump transmits its heat to the fluid flowing in radiant floors;

(iv) Radiant floors heat the building.

GSHP must have a heat exchanger in contact with the ground or groundwater in order to extract or dissipate heat. Several major design options are available for these, which are classified according to layout and fluid: direct exchange systems circulate refrigerant underground, closed loop systems use a mixture of antifreeze and water, and open loop systems use natural groundwater. Direct exchange geothermal heat pump is the oldest type of geothermal heat pump technology.

In this work a GSHP system with vertical heat exchangers has been studied.

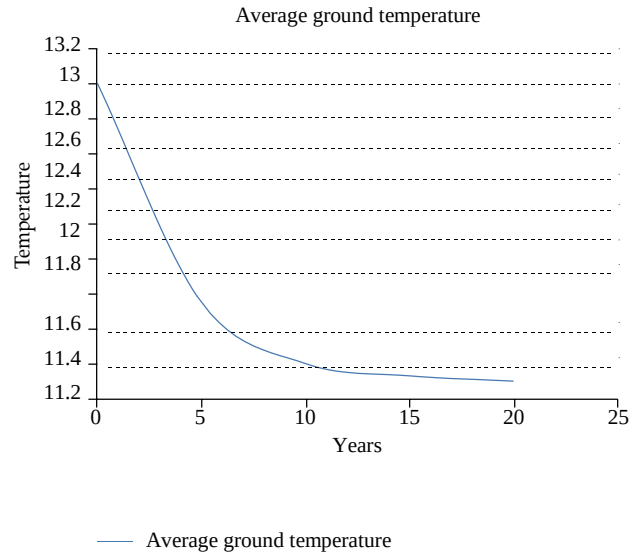


Figure 3: Average ground temperature for 14 exchangers in 20 years.

The growth of GSHPs technology was slower than other RES or conventional technologies due to many factors: nonstandardized system designs, significant capital costs if compared with other systems, and limited individuals knowledgeable in the installation of GSHP systems. Nevertheless these problems have been resolved on an ongoing basis, and the acceptance of the GSHP technology is increasing [1].

GSHP systems COP is higher than COP of other heat pump systems: it usually varies from 3 to 6, depending on the earth connection setups, system sized earth characteristics, installation depths, and climate of the area. Instead, for example, for an air source heat pump system the COP range is from 2,3 to 3,5 [1].

GSHP systems have higher initial costs than conventional ones because of the costs of the heat pump unit and the connection with the ground, specially drilling, but the operating costs are lower than conventional systems because of their high efficiency. Therefore the economic feasibility of GSHP systems depends on location, due to the price of electricity, natural gas, and other heating fuel. If these are not expensive, GSHP system may not be the cheapest option. On the contrary when there are low electricity costs, the GSHP systems are economically advantageous [1].

In particular, for example, if electricity is produced by a photovoltaic system the operating costs and the GHG emissions become remarkably low.

Therefore in order to increase the efficiency of the GSHP system and to reduce the costs, the optimal sizing of the plant is needful. The TRNSYS 17 software can be used for the system simulation in order to refine the sizing.

1. METHODS

Presizing. The studied building is part of a building complex and consists of 14 apartments located over 4 floors. The building was planned to include a central heating system, for heating and domestic hot water, that uses one heat pump and vertical geothermal heat exchangers. During

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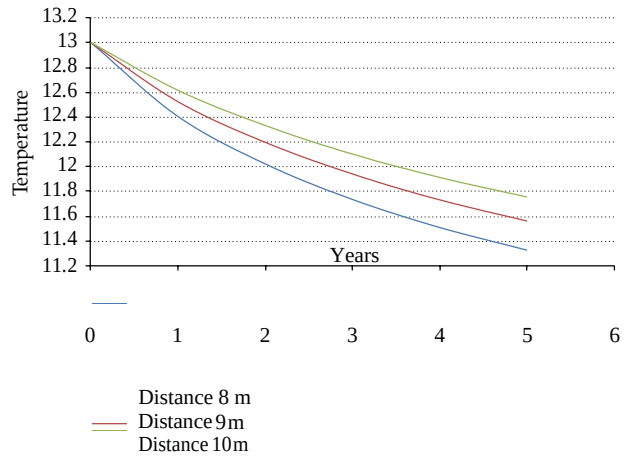


Figure 4: Average ground temperature varying number of exchangers.

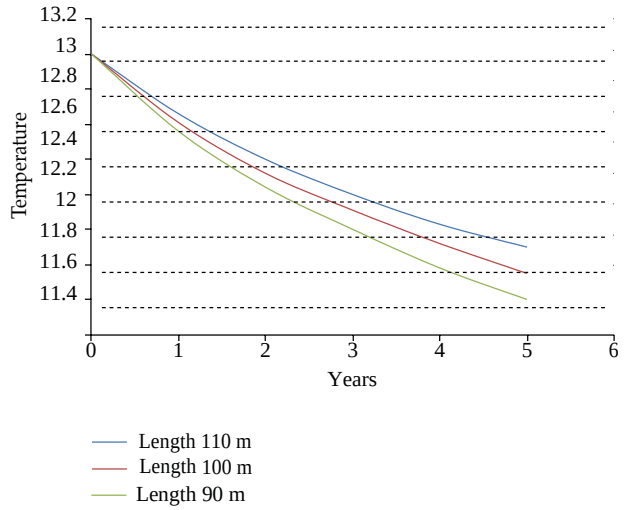
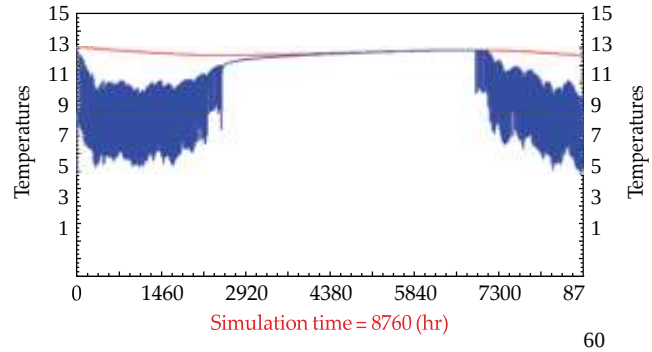


Figure 5: Average ground temperature varying exchangers length.

Table 1: Data for calculation of thermal load.

Building Data		
Thermal zone		D
Number of heating days		167
Daily hours of heating		12
Heated surface (gross)	m^2	3510,61
Outer surface that bounds the volume	m^2	2101,73
Usable area	m^2	930
Climatic Data Project	°C	20
Value of internal project temperature		

Summer time, the system works in natural cooling operative mode. The thermal load of the building is 43,2 kW for heating



6: Fluid temperature in output from exchangers dur

Figure ing the first year.

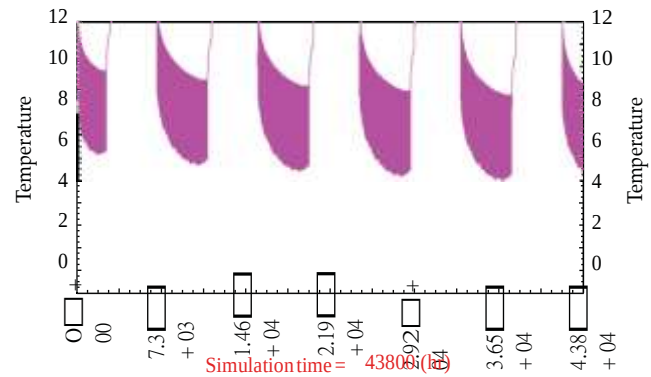


Figure 7: Fluid temperature in output from exchangers during 5 years.

Table 2: Features of vertical heat exchangers.

Features of vertical exchangers	
Number	12
Length	100 m
Distance	8 m
Type	single U
External diameter U	32 mm
Internal diameter U	29 mm
Bore diameter	12 cm
Distance by centers of U	5 cm

Geothermal heat exchangers have been presized accord- ing to the procedure described in VDI4640 German law [9]. The procedure of VDI4640 is strictly applied for small 30 kW), but sized systems (< we used this procedure for an

Approximate sizing only. Then the final size has been obtained by the approximate one, by simulation with software TRNSYS

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We choose one geothermal heat pump with a power of 47,2kW, whose fluid consists of water and ethylene glycol

(1) Calculation of heating load P_t(= 43, 2kW); (25%), with freezing temperature of −13 C. (2) Definition of temperature of radiant floor (= 35 C);

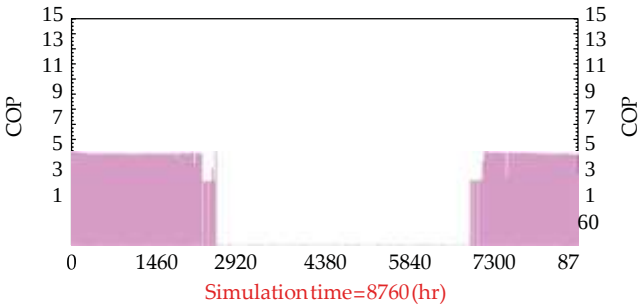


Figure 8: COP of heat pump in the first year (during winter time).

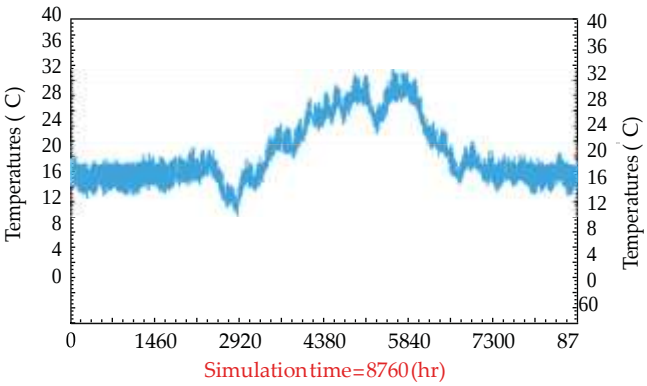


Figure 9: Air temperature in the apartment.

(3) choice of heat pump and definition of the COP (coefficient of performance) with the operating condition B0/W35, COP=4,33;

(4) calculation of the power exchanged with the ground P_{ev} [= (COP − 1)/COP = 35, 22 kW];

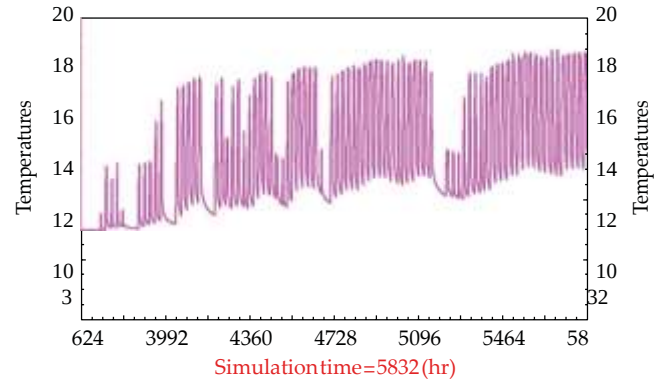
(5) extraction from VDI4640 of the specific power extraction (= 50 W/m);

(6) Calculation of total length of vertical geothermal Ex (= / = 1107 m ; m;

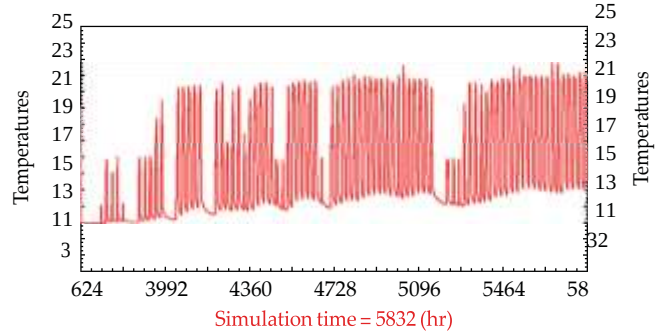
(7) oversized (15%) = 1273 hangers

(8) Assumption of 12 vertical heat exchangers (each one 100 m long) (Table 2).

Simulation. The software TRNSYS 17 has been used in order to simulate the operations system.
TRNSYS is a complete and extensible simulation envi- ronment for the transient simulation of systems, including multizone



10: Fluid temperature in input in radiant floor in summer (Natural cooling).



Figur e 11: Fluid temperature in output from radiant floor in summer (natural cooling).

Setting the global simulation parameters. When you run a simulation, the Studio also creates a TRNSYS input file (a text file, that contains all simulation information but no graphical Information).

by which you control which variables are integrated, printed,

The Simulation Studio also includes an output manager,

The system has been represented in TRNSYS Simulation

and/or plotted, and a log/error manager that allows you to study in detail what happened during the simulation [15].

Studio and the Building has been created in TRNBuild.

buildings.

TRNSYS consists of a suite of programs: the TRNSYS Simulation Studio, the Simulation Engine (TRNDll.dll) with its executable (TRNExe.exe), the Building input data visual interface (TRNBuild.exe), and the Editor used to create stand-alone redistributable programs, known as TRNSED applications (TRNEdit.exe) [14].

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The main visual interface is the TRNSYS Simulation Studio. Here, we can create projects by drag-and-dropping components

to the workspace, connecting them together and The Building has been modeled in TRNBuild by dividing it into 16 thermal zones (14 apartments, 1 zone of stairs, and 1 garage) [16].

The simulation with TRNSYS 17 allows the calculation and displays one or more variables on interval of time. Most of variables are studied within annual simulation, but average ground temperature is studied in five-year simulation.

We studied the following variables:

(1) thermal loads;

(2) air temperature in thermal zones;

(3) fluid temperature in input and output from radiant floors;

(4) fluid temperature in input and output from geothermal heat exchanger; average ground temperature

(5) COP of heat pump;

(6) Optimal time step for simulations.

Optimal time step has been studied observing building thermal loads varying with time steps.

2. RESULTS

The results of the simulation are represented in Table 3 and Figure 1.

The optimal time step for simulation is 1 minute.

The study of average ground temperature is very important because this variable must not change more than 2 C over long period.

We have chosen the following as target for the average ground temperature:

(1) Ensure no overexploitation of the ground;

(2) Achieve a new balance for the ground average temperature.

Changes in ground temperature varying with number of exchangers are shown in Figure 2.

The average ground temperature change after 20 years is shown in Figure 3, and it is equal to 1,7 C, below the threshold of 2 C, necessary not to have an overexploitation.

Changes in average ground temperature as a function of distance between exchanger are shown in Figure 4.

Changes in average ground temperature varying with exchangers length are shown in Figure 5.

We obtained that the configuration which gives the best performance has the following characteristics: 14 vertical exchangers in series with distance of 10 m and length of 100 m (Table 4).

The temperature of fluid in output from exchangers is represented in Figure 6.

It can be seen in Figure 6 that during the first year the minimum temperature of the fluid in output from the exchangers is 6 C. In Figure 7 we can see that the same temperature at five years is 5 C.

Performance is good because COP is always more than 4.

Moreover, it resulted that the minimum temperature of the fluid in output from the heat pump is 1,5 C. The heating due to the ground is 4,5 C.

Air temperature in the apartments (represented in Figure 9) ensure comfort conditions.

The fluid temperature in input in the radiant floors resulted 19 C at the end of the summer, while fluid temperature in output at the end of the summer was 22 C as shown in Figures 10 and 11.

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Table 3: Thermal load varying time step simulation.

Time-step	Total thermal load [kWh]
1 hour	68535,845218584532
30 minutes	68677,478548530451
20 minutes	68469,790308356302
10 minutes	65833,167347961783
5 minutes	68533,186713158425
4 minutes	68678,316559261531
3 minutes	68680,138881754820
2 minutes	68676,275556369017
1 minute	68677,942675267512

Table 4: Configuration of Exchangers that Gives the Best Performance.

Number of vertical exchangers	14
Distance	10 m
Length	100 m
Configuration	14 exchangers in series

4. CONCLUSION

In order to refine the sizing of the system, the TRNSYS 17 software is used.

The simulation of the system over a period of 5 years shows the best configuration for the exchangers: 14 vertical heat exchangers in series with distance of 10 m and length of 100 m.

The results show that the system works properly, because

(1) The temperature in the apartments ensures comfort conditions;

(2) The ground is not subject to overexploiting;

(3) High heat pump efficiency.

Simulation with software TRNSYS allows to refine the sizing of the system and accordingly to reduce the initial costs for the ground connection—in particular for drilling and probes that are about the 35% of the total costs—and the operating costs.

CONFLICT OF INTERESTS

The authors certify that there is no conflict of interests with any financial organization regarding the material discussed in the paper.

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