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GEOTHERMAL ENERGY UTILIZATION FOR BUILDINGS SERVICES

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ABSTRACT:

The Earth's large amount of thermal energy is virtually an inexhaustible resource often placed too deep in the ground. Making use of this kind of energy is possible in limited areas. In this paper we analysed a GSHP system, in Galati city (Romania), for which we monitored the available thermal energy. For the analysis we used operational reliability theory, the concept of degradation, which in this case means a reduction of the ground's thermal capacity as a result of continuous exploitation, meaning low temperature of the thermal agent used for transporting the heat from the ground to the primary exchanger of the heat pump. The decrease of thermal energy supply in the ground means that the heat pump wills no longer function properly in order to provide the energy for heating the building. The term time to failure refers to the time when the ground can no longer provide the minimum required energy for the heat pump operation, in terms of energy efficiency. What we want with this approach is to offer a solution in order to control and manage the heat pump operation.

1. INTRODUCTION

Ground source heat pump systems are used in many applications for heating or cooling residential buildings. Ground source heat pump coupled with energy efficient building all controlled by a building automation system represents a solution to reduce the energy consumption in buildings according with requirements (Hong W. et al., 2018). The green intelligent building is the result of 4C technology development: computer technology, control technology, communication technology, cathode ray tube graphics display technology (Song J. F., 2009).The building automation system is a multi-protocol architecture for a variety of applications and it is necessary to solve various problems about integration between the equipment and its subsystems (Jing P., 2016), (Wang L., 2015). In that sense application of renewable energy is the basis for European integration but also application of energy indicators represents the basis for environment protection (Malenovic-Nikolic J. et. al., 2018).

Design of GSHP systems is a multi-disciplinary process with interactions between different components of the system. The design inputs include local climate, building layout and use to establish the duration and frequency of the thermal loads applied to the ground. The design of the components of the system must also consider the interaction between heat pumps, fluid circulation pumps, absorber fluid, absorber piping and other connections (ASHRAE, 2007), (Johnston I. W. et. al., 2011). A ground source heat pump uses the ground as a heat exchanger in heating or cooling systems in buildings.

For our system, a ground heat exchanger is used to exploit the geothermal energy with the heat extraction from the deep ground using vertical boreholes as U tubes. The vertical U tubes are mainly used because it needs small land areas and higher thermal efficiency than those for horizontal heat exchangers. In vertical tubes the working fluid is water – antifreeze which circulates through the tubes that are inserted into a borehole which is drilled underground at 100 m, with a diameter of 100 mm. The advantage of ground source heat pumps systems, including the efficiency performance, may be lost if the sizing of ground heat exchanger is not properly designed (Hu P.F. et. al., 2013). A problem that occurs in sizing the ground heat exchanger is the asymmetrical boundary condition in the analysis of heat transfer between the working fluid and the surrounding soil (Hu P.F. et. al., 2013).

In practical conditions, the fluid temperature differs along the U tubes and the heat transfer from the two legs of the U tubes is influenced by each of them (Hu P.F. et. al., 2013). The temperature difference between the inlet and outlet of the U tube near the ground surface represents the heat exchangeability of the ground heat exchanger. The temperature of the working fluid in the ground heat exchanger should vary depending on the ground's thermal diffusion state with the running time of the heat pump (Hu P.F. et. al., 2013).

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As a building energy conservation technique, ground source heat pumps have increased substantially due mainly to ever increasing high prices of energy and to environmental concerns owing to excessive energy consumption. Bhutta M.M.A. et.al. (2012), analyse CFD techniques and came to the conclusion that for the simulation of heat exchanger design they would be precious means. The geothermal heat exchangers represent the base for the normal operation of heat pump systems, and the rock-soil type and the longitudinal temperature distribution are vital for the thermal characteristics. Moreover, the surrounding rock-soil is nothing but a hindrance in heat transfer which is a complicated stable process. Significant research has been carried out into the phenomenon of heat transfer, especially on geothermal heat exchangers and the research was aimed at experimentation, numerical simulation and theoretical analysis models (Hu P.F. et. al., 2013), (Bouhacina B. et.al., 2015), (Katsura T. et.al., 2008), (Nam Y. et.al., 2008), (Shang Y. et.al., 2011). Their contribution consists of a method meant to calculate the temperature of rock-soil in conditions of pipe-group heat extraction with the help of a temperature superposition starting from the linear heat source theory[8] anticipated the existence of the rock-soil temperature variation between the functioning and recreation period of ground source heat pumps by setting up a 3D model of a single-well, single-U heat exchanger in combination with multi-aperture theory. The outcome showed that the soil characteristics bear a bigger impact on the soil temperature than the environmental factors do. Choi et.al. administered a CFD numerical simulation method in order to evaluate the influential aspects that include shank spacing, borehole depth, flow velocity and differential temperature of the inlet/outlet on the heat transfer rate of the ground source heat pump.

In the paper presented below we analysed a ground source heat pump (GSHP) system, in Galati-Romania, for which we monitored the available thermal energy. For the analysis procedure we used operational reliability theory, the concept of degradation, which in this case means a decrease of ground's thermal capacity as a result of continuous exploitation meaning low temperature of thermal agent used to transport the heat from the ground to the primary exchanger of the heat pump. The term *time to failure* refers to the time when the ground can no longer provide the minimum required energy for the heat pump operation, in terms of energy efficiency. We want with this approach to offer a solution to control and manage the heat pump's operation.

1. EXPERIMENTAL

For our study to measure the thermal energy extracted from the ground we designed a heat pump system coupled to ground. The measurements of temperature outlet/ inlet to thermal energy extracted from the ground were made using sensors, one for the outlet pipe from the ground, S1 and other inlet to the ground S2, the registration of data were made with a data logger. The heat pump functional scheme is presented below in Figure 1. The external network is represented by the ground heat exchanger and the primary exchanger of the heat pump. The thermal agent is transported by the circulating pump P1. The interior network is represented by the condenser of the heat pump to the storage tank.

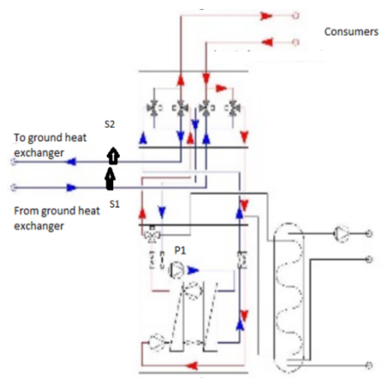

Figure 1.The functional schema of Heat pump NIBE use for research

The place where the drilling and the mounting of the soil heat exchanger took place is presented in Figure 2 below. The perimeter where the drilling took place and a detail relative to the tube that was used are presented in Figure 2.

Figure 2.Location of heat exchangers with soil/ The tube protection. The position of drillings (three) is marked with red. The scale is 1:500

The soil heat exchanger is made up of three vertical U-tubes, each having a depth of 100m. The diameters of the drilling and pipework used are: D - drilling diameter -110mm, d - external diameter of pipes-35mm, internal diameter of pipes 32mm, b - distances between pipes 50mm.

2.1. Power law theory

Degradation (Mcpherson, 2010) is described as one of the consequences of the Second Law of Thermodynamics - *entropy*. The evidence for degradation is apparently everywhere in nature. All devices /equipment are fabricated from materials that will tend to degrade in time. The materials' degradation will continue until some critical device parameter can no longer meet there required specification for proper device functionality. Equipment failure, either electrical or mechanical, can usually be attributed to the degradation of a given material under stress. The term stress is very general and not restricted just to the more common meaning: mechanical stress. Stress refers to any external agent which is capable of causing a degradation to occur in the material properties so that the device/ equipment can no longer function properly in its intended application.

S represents a critically important parameter and let us assume that *S* changes monotonically and relative lowly over the lifetime of the material/device/ equipment. A Taylor expansion about *t*=0, produces the Maclaurin Series (MCPHERSON, 2010):

$$S(t) = S_{t=0} + (\frac{\partial S}{\partial t})_{t=0} + \frac{1}{2}(\frac{\partial^2 S}{\partial t^2})_{t=0} t^2 + \cdots .. \quad (1)$$

The expansion can be approximated by simply introducing a power-law exponent *m* and writing the above expansion (MCPHERSON, 2010):

$$S = S_0[1 \pm A_0(t)^m] \quad (2)$$

Where A_0 is a material/device-dependent coefficient and *m* is the power-law exponent. A_0 and m are adjustable parameters that can be extracted from observed parameter-degradation data. For $+A_0$, the observed parameter *S* increases monotonically with time, where for $-A_0$ it decreases.
When S parameter decreases with time

$$S = S_0[1 - A_0(t)^m] \quad (3)$$

Taking the logarithm of both sides of Eq. (3):

$$\ln(S^*) = m\ln(t) + \ln(A_0) \quad (4)$$

The critical parameter in our case S is Q_{soil} = the energy extracted from ground is:

$$Q_{soil,(t)} = Q_{soil,t=0} + \left(\frac{\partial Q_{soil}}{\partial t}\right)_{t=0} + \frac{1}{2}\left(\frac{\partial^2 Q_{soil}}{\partial t^2}\right)_{t=0} t^2 + ... \quad (5)$$

$$Q_{soil} = Q_{soil,0}\left[1 \pm A_0(t)^m\right] \quad (6)$$

$$\ln(Q^*_{soil}) = m\ln(t) + \ln(A_0) \quad (7)$$

$$Q^*_{soil} = \frac{Q_{soil}}{Q_{soil0}} - 1 \quad (8)$$

Where thermal energy extracted from ground Q_{soil} [W]; thermal energy extracted from ground the lowest value $Q_{soil,0}$ =483[W].

The thermal energy measure provided by the ground is presented in Figure 3:

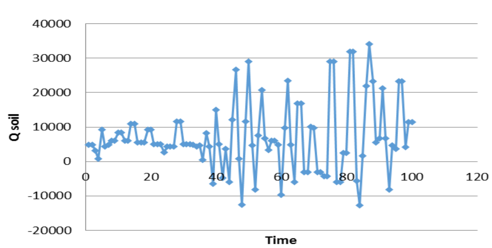

Figure 3.Variation of Q_{soil} with time

2.2. Results and discussion

Using the data above and Eqs7,8, we get the results presented below:

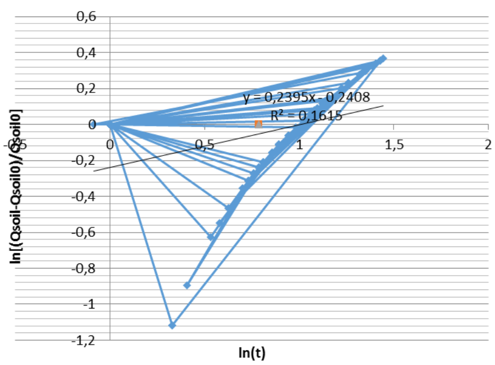

Figure 4. Graphical representation of (Eq. 7)

From the graph above results the values for m =0.239 and A_0 =exp (-0.240).The equation given by (Eq 3) is:

$$Q_{soil} = 483[1-0.786(t)^{0.239}] \quad (9)$$

Analyzing Figure 4 for $m\langle 1$ the degradation rate of the ground thermal energy is:

$$R = \frac{dQ_{soil}^*}{dt} = m(t)^{m-1} \quad (10)$$

$$R = 0{,}239(t)^{0{,}239-1} \quad (11)$$

2. CONCLUSION

With this theory we can evaluate any type of grounds with different structures, the heat capacity in different intervals of time. So, we can appreciate the moment when we must act to regenerate the thermal capacity of the ground. A continuous exploitation of the soil to supply energy can lead to the severe degradation of it. The (Eq9) offers the possibility to evaluate the thermal energy extracted from the ground in time, after a number of hours of operation of the heat pump. It is well know that the thermal energy from the ground depends on the climate variation. So, a continuous operation mode of the heat pump is not recommended. Equation 9 is a possible solution to evaluate the value of heat energy from the ground and it could offer theoretical information about the quantity of thermal heat at different moments of time.

Originality of the paper:

1. The formulation of Q_{soil} variation power law (with time), law which can be adapted for different geographical areas, with different clime depending on the soil structure, according to some measurements.

2. The heat pump operation using a program depending on the heat capacity of the ground.
3. It could be a procedure to establish the time when we must act to regenerate the soil using artificial methods.

References:

ASHRAE (2007). *Chapter 32-Geothermal energy*, In 2007 ASHRAE Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers.

B. BOUHACINA, R. SAIM, H.F. OZTOP (2015).. Numerical investigation of novel tube design for the geothermal borehole heat exchanger, *Appl Thermal Eng*, **79**,153–162.

M.M.A. BHUTTA, N. HAYAT, M.H BASHIR, A.R. KHAN, K.N. AHMAD, S. KHAN (2012). CFD applications in various heat exchangers design: a review, *Appl Thermal Eng*, **32**, 1–12.

J.C. CHOI, S.R. LEE, D.S. LEE (2011), Numerical and analytical analysis of vertical ground heat exchangers: intermittent operation in unsaturated soil conditions, *Computers and Geotechnics*, **38**, 949–958.

P.F HU, Z.Y. YU, Z. NA, L. FEI, X.D. YUAN (2013). Performance study of a ground heat exchanger based on the multipole theory heat transfer model, *Energy and Buildings*, **65**,231–241.

WANG HONG, ZHU XIANGQIAN, LI DANDAN, ZHENG YUANPAN (2018). Research on integration and key technologies of green intelligent building automation system. *J. of Environmental Protection and Ecology* 19 (3) 1155-1165.

T. KATSURA, K. NAGANO, S. TAKEDA(2008), Method calculation of the ground temperature for multiple ground heat exchangers, *Appl Thermal Eng*, **28**, 1995-2004.

J. MALENOVIC-NIKOLIC, D. VASOVIC*, G. JANACKOVIC, L. MILOSEVIC, I. ILIC KRSTIC (2018). Realisation of the goals of sustainable development based on application of energy indicators in environmental engineering. *J. of Environmental Protection and Ecology* 19 (1),916

J.W. MCPHERSON. (2010), *Reliability Physics and Engineering*. Springer. New York Dordrecht Heidelberg London.

Y. NAM, R. OOKA, S. HWANG,(2008). Development of a numerical model to predict heat exchanger for ground source heat pump system, *Energy and Buildings*, **40**, 2133–2140.

Y.SHANG, S.F. LI, H.J. LI, (2011). Analysis of geo-temperature recovery under intermittent operation of ground-source heat pump. *Energy and Buildings*, 43, 935–943.

J. F. SONG: Intelligent Building. China Architecture & Building Press, Beijing, 2009.

P. JING: Building Automation. China Building Material Industry Publishing, Beijing, 2016.

I. W. JOHNSTON, G. A. NARSILIO, S. COLLS. Emerging Geothermal Energy Technologies, KSCE Journal of Civil Engineering (2011) 15(4):643-653,DOI 10.1007/s12205-011-0005-7

L. WANG, J. LV, J. LIU: Intelligent Building System Integration under Industry 4.0. Building Electricity, 24 (5), 55 (2015).