Efficiency Assessment of an Earth-Air Heat Exchanger System for Passive Cooling in Three Different Regions - the Algerian Case

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The energy consumption in buildings for heating and cooling continues to increase from year to year, in order to meet people's increased demand for thermal comfort. A key energy issue for the buildings sector, the largest consumer of energy, requires the rational use of traditional resources and the application of non-polluting, inexhaustible renewable energy technologies that allow sustainable development. The public authorities are currently showing a clear desire to reduce energy consumption in the buildings sector through various legislated thermal regulations. In Algeria, law 99-09 and executive decree 2000-09, followed by other regulations, have as objectives the control of energy and the introduction of energy efficiency in buildings. In this paper, we focused on the effectiveness of the earth-to-air heat exchanger system for cooling buildings in three different climate regions in Algeria. The Earth to air heat exchanger device is a promising technology for reducing or avoiding the use of air conditioning systems. The Earth to air heat exchanger system which exploits the thermal inertia of the soil puts two different temperature sources in thermal contact, the air which circulates in the tubes, and the ground placed in contact with the tubes. This model was validated to show a good agreement between simulated results and other experimental data published. The simulation results confirmed that A maximum energy gain of 2221.15 kWh, 523.56 kWh and 300.27 kWh over a cooling season can be reached for Timimoun, Djelfa, and Jijel.

Keywords: *Earth-air heat exchanger, EAHE, soil, passive cooling, different climates, geothermal energy.*

1. INTRODUCTION

The earth–air heat exchanger (EAHE) is a system that consumes less energy to operate. It exploits the thermal inertia of the soil. Like any heat exchanger, the air-ground exchanger puts two different temperature sources in thermal contact [1]. During the hot season, the hot source is the air that circulates in the tubes and the cold source is soil. This is reversed during the cold season [2]. The air temperature at the exchanger inlet corresponds to the outside air temperature [3,4]. In the literature review, many theoretical and experimental works have been reported on the various types of EAHE. Thermal properties, cooling, and heating performance of EAHE systems have been studied. Tzaferis et al. [5] studied eight different models predicting the performance of EAHE systems. The outlet air temperature is calculated by knowing the inlet air temperature, air velocity, length, radius, and depth of the pipe. The root means square (rms) error was found to be 3.5% for all cases. The eight models give

approximately the same results. Mihalakakou et al. [6] presented a transient implicit numerical model coupling heat and mass transfer into the soil and the pipe. An axisymmetric system in polar coordinates was studied. Gauss-Seidel iterative method was used to solve the equations. An excellent agreement between the theo–retical and the experimental temperature of circulation air and soil temperature was shown. Mihalakakou [7,8] studied two models in his paper. A dynamic and deterministic model was studied to calculate the outlet air temperature for the heating season by implanting a single buried pipe from real Athens climatic ambient air and soil data. Bojic et al. [9] utilized an EAHE which has two pipes buried in the soil, one made of PVC and the other of steel. To calculate its performance for different seasons, they employed finite volumes and time marching to develop a numerical model to solve a steady-state energy equation. He evaluated the technical and economic performance of an EAHE for heating and cooling of a building. The model used was based on 1dimensional steady-state energy equations. They have developed a building simulation program by using the time marching methodology. The results found that the EAHE system utilized covered a portion of the daily building needs and it is more energy-efficient in summer than in winter. Gauthier et al. [10] developed a transient fully 3-dimensional heat transfers numerical model for

predicting the thermal behavior of soil heat exchanger storage system(SHESS). This model was validated with an experimental SHESS installed in a greenhouse. As a result, the SHESS is very attractive for reducing the energy consumption with an optimal blowing velocity of 4m/s compromised between the cost and its performance. Pierre Hollmuller [11] developed an analytical solution for a cylindrical air/soil heat exchanger submitted to constant airflow with harmonic temperature input and adiabatic or isothermal boundary conditions. The results showed good agreement against a finite difference in numerical and an experimental setup. G.N Tiwari et al. [12] presented a thermal model developed and validated by round the year experimental work at New Delhi India to study the annual thermal performance. The thermal model based on quasi-steady-state conditions of an EAHE consists of a PVC pipe of 39 m length and 6 cm diameter integrated into a greenhouse located in New Delhi India. A fair agreement was found between predicted and experimental data. The temperature of the greenhouse increases by 8°C in summer and 4°C in winter when EAHE operational for a typical day in June and January, respectively. The maximum value of heating potential 11.55MJ and cooling 18.87 MJ has been found during off sunshine (8 pm-8 am) hours and peak sunshine hours (8 am-8 pm). The results showed that the coefficient of the performance increased by 138% and 110% in October and March respectively when the working hours of an EAHE are optimized. Kumar et al. [13] developed a numerical model of the EAHE system consisting of a transient axisymmetric system and based on finite difference method for predicting energy conservation potential of EAHE. The model was validated against experimental data from similar tunnel installing in Mathura India and a satisfactory agreement was found. The daily cooling and heating potential was averaged to 456 and 296 kWh, respectively. De Paepe and A Janssens [14] used a one-dimensional analytical method to analyze the influence of the design parameters to determine to reach the optimal thermal effectiveness with acceptable pressure loss. It was found that thermal performance and pressure drop varied proportionally to the length but inversely proportional to the diameter. More tubes in parallel both rise thermal performance and lower pressure drop. Al Ajmi et al. [15] developed a theoretical model within TRNSYS-IISIBAT of an EAHE for calculating the outlet air temperature and cooling potential in a hot and arid climate of Kuwait. The presented model was validated against other published experimental works studies and shown a good agreement. It was found that a pipe with a 60m in length and a 0.25m in diameter and with a 100kg/h of air mass flow rate gave a reduction of 2.8°C indoors in a domestic building at the peak hour of mid-July. 30% of season cooling demand may be reached. Badescu et al. [16] investigated heating and cooling potential during the year by an analytical pneumatic and thermal design procedure for EAHE. The air circulated into two different paths (the z and Π paths). The model was validated against experimental data and a good agreement was observed. The results were checked by a computing fluid dynamics (CFD) analysis and also a good agreement was observed between CFD outputs and experimental values. The EAHE energy obtained depends

significantly on its geochemical configuration. The Z path is always preferable to the Π path system. Misra et al. [17] used experimental data and CFD modeling to study the thermal performance of an earth air tunnel heat exchanger (EATHE) under transient operating conditions in a hot and dry climate of Ajmer in India. Passing through EATHE having 0.1 m diameter and 60m length at 5m/s flow velocity air dropped of 18.8°C after 24 hours of continuous work, the cooling of air reduces from 18.7°C to 16.6 °C. Maerefat and Haghighi [18] studied an integrated earth-to-air heat exchanger and solar chimney techniques for cooling in the hot season. It was found that a length more than 20m and an 0.5m optimum diameter for cooling pipes showed to provide the thermal comfort condition. They deduced that in case of the poor solar intensity of 100W/m² and high ambient air temperature of 50°C providing thermal comfort for cooling is difficult. Thiers et al. [19] developed a specific model integrated into the dynamic simulation software COMFIE. The model incorporated most of the thermal phenomena in the exchange between air and soil except for water infiltration to the ground which makes the model suitable for any kind of real situation. The model was validated against experimental data on two real cases. The results showed a fairly small error in the air outlet temperature. Tittelin et al. [20] developed a new numerical model to simulate an EAHE used response factor method with finite elements program to solve 2-dimensional conduction problems. The results calculation time is reduced compared to other similarly accurate methods. It was precise for any solicitation period (1 day to 1year), every kind of soil characteristic was considered. Fabrizio et al. [21] evaluated cooling and heating performance realizable using EAHE different Italian climates with a reference to three localities Naples, Rome, and Milan. They found that the best heating and cooling performance have been obtained for the coldest climates (Milan). The optimum parameters for good cooperation are 50 m length, 3m of depth, and 8m/s of airflow velocity speed. The influence of tube material is negligible. Benhammou et al. [22] developed a transient one-dimensional model to study the cooling thermal performance in the Algerian Sahara climate. They studied the influence of geothermic and dynamic parameters on the thermal efficiency of EAHE. The model was validated against other theoretical and experimental works data. They concluded that a greater drop in air temperature results in higher air inlet temperature. The outlet air temperature decreases with the increase of pipe length but there was not a significant reduction of temperature over a pipe length of 50m. It is observed that a rise from 10 to 30 cm of the pipe diameter changes the inlet temperature from 22.3 to 23°C. The outlet temperature increased as a result of the pipe diameter. It was found that the air outlet temperature increased with the increase of air velocity. For an ambient air of 44°C, the rise of outlet temperature was 5.59°C when the air velocity changes from 1m/s to 3m/s. Benhammou et al. [23] presented another paper of an EAHE assisted by a wind tower as a new design of passive cooling system used for cooling in hot and arid regions of Algeria. They developed a transient analytical model which was validated against other experimental values. It was concluded that a tower with 5.1m can

generate 592.61m³/h of airflow rate. The daily cooling potential can reach a maximum of 30.7 kWh corresponding to a pipe of 70m in length. Belatrache et al. [24] modeled and simulated an EAHE employed as an air conditioning system for buildings in the southwest Algerian climate. They validated the model against other experimental works in literature. The relative error of outlet air temperature was lower than 1%, so the model can properly predict the thermal performance of an EAHE device. The results showed that a simple EAHE can provide 246.815 kWh in a cooling season.

In this paper, we have chosen three different regions in Algeria. The EAHE system was carried by numerical simulation for three different climates in Algeria: - climate of the city of Jijel (humid Mediterranean type); - climate of the city of Djelfa (semi-arid climate); - climate of the city of Timimoun (hyper-arid and dry Saharan type). This study shows the energy contribution of the soils types regarding the performance of the EAHE system. For this purpose, we compare three different soils types in different climates. The main objective of this study is to assess the influence of three different soils and climates on the overall performance of the EAHE system.

2. MODELING THE EAHE SYSTEM

The modeling of the EAHE involves the use of two dis–tinct models, a thermal soil model for predicting the temperature of the soil at different depths and a thermal model of EAHE for predicting the temperature of circulating air in the pipe.

2.1 Modeling the soil temperature

The ambient air temperature, T_a , can be expressed as a periodically signal according to the relationship:

$$Ta(t) = \overline{Ta} + Aa \times \cos\left(\frac{2\pi(t - t0, a)}{365}\right) \qquad (1)$$

With:

$$\overline{Ta} = \frac{1}{1year}\int_{1}^{1year} Ta(t)dt \qquad (2)$$

Either from hourly data:

$$\overline{Ta} = \frac{1}{8760}\sum_{i=1}^{8760} Ta,i(measured) \qquad (3)$$

or from monthly data:

$$\overline{Ta} = \frac{1}{12}\sum_{i=1}^{12} Ta,i(measured) \qquad (4)$$

The amplitude of the temperature oscillations Aa is given by:

$$Aa = \frac{Ta\max + Ta\min}{2} \qquad (5)$$

The ambient air temperature is easily measurable or accessible from weather databases. On the other hand,

the soil temperature cannot be known without the use of a thermal probe placed at the depth of the soil. In the absence of a database capable of providing this temperature, modeling is necessary [1]. The resolution of The equation of heat transfers:

$$\frac{\partial T(z,t)}{\partial t} = as \times \frac{\partial^2 T(z,t)}{\partial z^2} \qquad (6)$$

Applied to the semi-infinite soil with the boundary conditions:

$$T(0,t) = \overline{Ts} + As \times \cos\left(\frac{2\pi(t - t0, s)}{365}\right) \qquad (7)$$

T (∞, t) is finite for the infinite depth soil.

For $z = \infty$: $T(\infty, t) = Ts$

Have the following form of solution for calculating the temperature T (z, t) of the soil, at time t and depth z:

$$T(z,t) = \overline{Ts} + As \times e^{-\frac{z}{d}} \times \cos\left(\frac{2\pi(t - t0, s)}{365} - \frac{z}{d}\right) \qquad (8)$$

where:

$$d = \sqrt{\frac{as \times \tau}{\pi}} \qquad (9)$$

$$as = \frac{\lambda s}{(\rho s \times Cs)} \qquad (10)$$

$t_{0,s}$: phase constant, time of maximum surface tem–perature since the start of the year (days).
τ: the annual time period of temperature wave(s).

2.2 Modeling the air temperature along the EAHE

The model can be simplified by the following thermal assumptions:

- The analysis is one-dimensional and the airflow inside is identical (assumption of 'piston' flow).

- The dimensions and physical properties are identical.

- The surrounding soil has homogeneous and identical thermal properties.

- The heat exchange inside the tube where the heat transfer air circulates is dominated by forced convection.

The EAHE is represented by a straight tube with a length L, in Figure 01. The thermal balance for a segment of the exchanger is:

$$\dot{m} \times Ca \times dt(x) = \frac{dx}{Rth} \times (T(z,t) - T(x)) \qquad (11)$$

$$Rth = Rcv + Rp + Rs \qquad (12)$$

R_{th}: Represents the overall thermal resistance descri–bing the heat exchange between the air flowing through the exchanger tube and the surrounding soil as shown in Figure 1. It can be determined using three thermal resistance values:
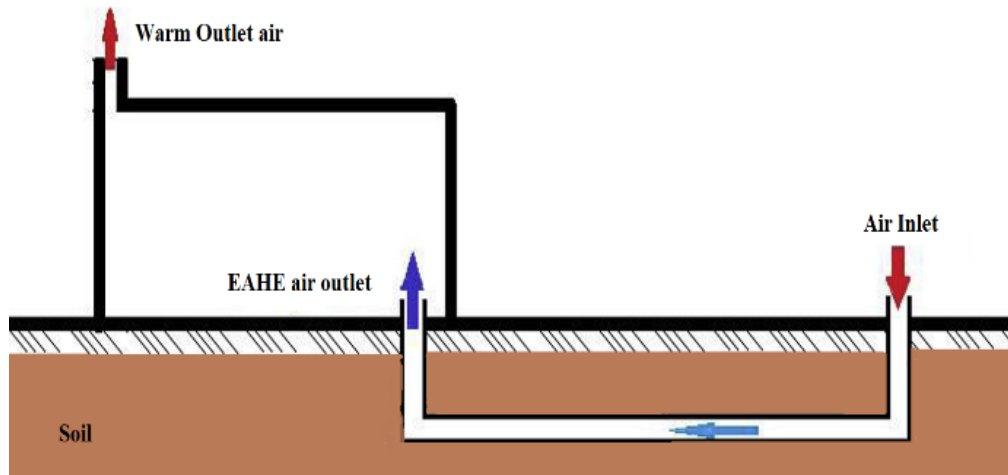
Figure 1. circulation of the air in the exchanger.

$$Rcv = \frac{1}{2 \times \pi \times r1 \times hcv} \qquad (13)$$

$$Rp = \frac{1}{2 \times \pi \times L \times \lambda p} \times \ln\left(\frac{r2}{r1}\right) \qquad (14)$$

$$Rs = \frac{1}{2 \times \pi \times L \times \lambda s} \times \ln\left(\frac{r3}{r2}\right) \qquad (15)$$

r_1: inner pipe radius(m)
r_2: outer pipe radius (m)
r_3: radius of cylinder denoting thickness of disturbed soil surrounding pipe (m)

The distance between the pipe outer surface and the undisturbed soil is assumed to be equal to the radius of the pipe.

We use the following boundary conditions to solve equation:

$$T(x) = Ta \; ; \qquad \text{for } x = 0 .$$

$$T(x) = T(z,t) \; ; \quad \text{when } x \text{ tends to infinity.}$$

We get:

$$T(x) = \begin{cases} \left(Ta(t) - T(z,t)\right) \times \exp\left(\dfrac{-z}{\dot{m} \times Ca \times Rth}\right) \\ + T(z,t) \end{cases} \qquad (16)$$

This expression reflects the evolution of the air temperature, along the exchanger as a function of the temperature of the air entering the exchanger and the temperature of the ground taking into account the thermos-physical characteristics of the soil; The geometry, and the nature of the tube and the airflow. The Reynolds number, *Re*, characterizes the flow regime (laminar, turbulent, or mixed). It is defined as the relationship between inertial forces and viscous forces:

$$\text{Re} = \frac{\rho a \times va \times D}{\mu a} \qquad (17)$$

The Prandtl number, *Pr*, characterizes the thermal behavior of the fluid. It is defined as the ratio of the kinematic viscosity of the fluid to its thermal diffusivity:

$$\text{Pr} = \frac{\mu a \times Ca}{\lambda a} \qquad (18)$$

The Nusselt number, *Nu*, for flow inside the tube is given by:

$$Nu = \frac{hcv \times D}{\lambda a} \qquad (19)$$

A transient one-dimensional model was developed for studying the thermal performance of earth-to-air heat exchangers (EAHE) for summer cooling under the Algerian Sahara. The effect of extremities was also taken into account. The model validation against both theoretical and experimental data of other researchers showed a good agreement. In addition, a detailed sensitive study was carried out to investigate the influence of geometrical and dynamical parameters on the thermal performance of EAHE. Results showed that the air outlet temperature decreases with the increase of the pipe length but it increases with the increase of pipe cross-section and air velocity. However, the daily mean efficiency increases when the length of pipe increases but it decreases when the cross-section area of pipe or air velocity increases. It is also observed that the coefficient of performance drops quickly with the increase of the air velocity. Considering as reference the thermal performance of EAHE under steady-state conditions, the investigation of Derating Factor (DF) reveals that the thermal performance of EAHE in transient conditions is more influenced by the variation of operating duration, pipe diameter, and air velocity. In this case, the airflow circulates in forced convection by a fan, the diameter of the pipe is small compared to its length and the flow is most often turbulent. The simplified formula adopted is that proposed by Hollmuller (2001) [26]:

$$Nu = 0.023 \times \text{Re}^{0.8} \times \text{Pr}^{0.4} \qquad (20)$$

The convective exchange coefficient is therefore equal to:

$$hcv = \frac{Nu \times \lambda a}{D} \qquad (21)$$

The masse flow rate is given by:

$$\dot{m} = \frac{\rho a \times \pi \times D^2 \times va}{4} \qquad (22)$$

The heat flux rate $\dot{Q}$ provided by EAHE transfer–red from the air when flowing along the buried pipe to the surrounding soil is defined by:

$$\dot{Q} = \dot{m} \times Ca \times (Tin - Tout) \qquad (23)$$

The cooling potential obtained from EAHE is exp–ressed by:

$$Qc = \sum \dot{m} \times Ca \times (Tin - Tout) \times \Delta t \qquad (24)$$

The coefficient of performance measuring the effi–ciency of the EAHE system can be determined by the following relation:[3]

$$COP = \frac{Qc}{Win} \qquad (25)$$

$$COP = \frac{\dot{m} \times Ca \times Cd \times (Tin - Tout)}{Win} \qquad (26)$$

where
Cd: coefficient of discharge of the pipe=0.6.
Win: theoretical blower input power =125W.

2.3 Geographical and climate description

Algeria is a vast country situated in the north of Africa with three main types of climates; a Mediterranean climate in the north, an arid desert climate in the south, between these two major types of climate there is a semi-arid transition climate. This paper studies the utilization of the EAHE system in three of its localities: Timimoun, Djelfa, and Jijel as shown in Figure 2. The city of Adrar is located in the southwest of Algeria. Its site is characterized by an altitude of 264 m above the sea, a longitude of 0.17 ° W, a latitude of 27.53 ° N, Djelfa is located in the middle of Algeria. Its site is characterized by an altitude of 1180 m above the sea, a longitude of 3.38 ° E, a latitude of 34.33 ° N and Jijel is located in the northeast of Algeria. Its site is characterized by an altitude of 264 m above the sea, a longitude of 0.17 ° W, a latitude of 27.53 ° N. The monthly averages ambient temperature data for the three localities Timimoun, Djelfa, and Jijel are done by Table 1. [28–30]: It can be noticed that in summer months especially in July and August since they are the hottest months in Algeria, conversely, winter months of December and January are the coldest.

Table 1. The monthly averages ambient temperature

Mean monthly ambient air temperature(°C)			
	Timimoun	Djelfa	Jijel
January	9.9	7.2	10.9
February	17.4	5.7	13.8
March	21	9.2	14.9
April	25.4	16.2	16.4
May	33.2	18.3	20.5
June	35.2	23.1	24.9
July	37.3	28.1	27.1
August	36.9	28.2	28.1
September	32.4	24.5	23.7
October	23.9	16.6	19.7
November	17.5	10.1	15
December	11.7	6.3	12

Emberger defines a rainfall quotient which makes it possible to classify the different types of Mediterranean countries' climates. the Emberger rainfall quotient is determined according to the following Stewart (1969) formula for Algeria:

$$Q3 = 3.43 \times \frac{P}{(M - m)} \qquad (27)$$

Table 2. Emberger rainfall quotient in three regions.

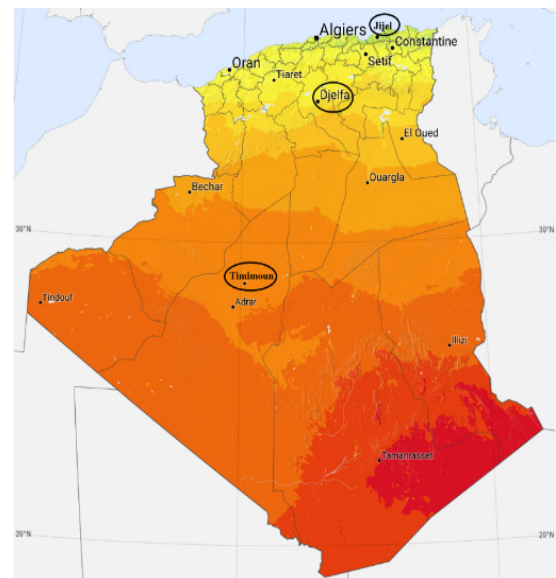|	Timimoun	Djelfa	Jijel
P(mm)	17.86	264.67	1062.4
M(°C)	45.31	34.44	31.16
M(°C)	5.27	1.28	8.65
Q3 (/)	1.53	27.38	142.90

Figure 2. Variation of solar irradiation in different locations in Algeria.

Table 3. Soil characteristics in three different regions.

Location	Type of soil	Density (kg/m³)	Specific Heat capacity (kJ/kgK)
Timimoun	Sandy Clay	1800	1.3400
Djelfa	Silt loam	1415	0.8040
Jijel	Sandy loam	2100	1.0476
		Thermal conductivity W/(m.K)	Thermal diffusivité (m²/s)
Timimoun	Sandy Clay	1.5	6.22×10^{-7}
Djelfa	Silt loam	0.6	10.4×10^{-7}
Jijel	Sandy loam	2.2	10×10^{-7}

Table 2 shows different parameters *P*, *M*, *m*, and Q3 for the three localities. Timimoun is located in the Saharan bioclimatic floor in mild winter. Djelfa is located in a semi-arid climate with a cool winter. Jijel is located in a humid climate with a warm winter. See Figure 2.

Table 3, shows different parameters soil type; den–sity, specific heat capacity, thermal conductivity and thermal diffusivity for the three region soils.

3. RESULTS AND DISCUSSION

3.1 Model validation:

The verification of the accuracy of the models was done using experimental data reported in the literature. As shown in Table 4, there is a good agreement between the theoretical(simulated) data and the experimental data of al-Ajmi et al. [15]. The mean relative error is 4.57%, the soil at different depths can be estimated for a location.

Table 4. Verification of the soil temperature against experimental data of al-Ajmi et al. [15].

Month	Experimental [9]	Simulation	Error %
January	29	24,8	14,4
February	24	23,1	3,75
March	24	22,3	7,08
April	24	22,4	6,67
May	25	23,6	5,6
June	26	25,4	2,31
July	28	27,5	1,79
August	30	29,3	2,33
September	31	30,2	2,58
October	30	30	0
November	29	28,8	0,71
December	25	26,9	7,6

The outlet air temperature is validated against the experimental data of Bansal et al. As can be seen in the Table 5, the results show a good agreement, the maxi–mum relative error of 1.2%, and that's mean a relative error estimated to 0.75%. The evolution of the air temperature circulating in the buried pipe is validated by experimental data for volume rate $\dot{V}$=155.5 m³/h re–corded by Hatraf et al. [28] at the University of Biskra situated in the south of Algeria.

Table 5. The outlet air temperature of EAHE Validation.

HATRAF et al. parameters for validation						
Soil : λ_s =2.01 w/(m.K), C_s =1380 J/(kg.K), ρ_s =2300						
kg/m³, a_s =6.33 x 10⁻⁷, PVC : λ_p =1.17 w/(m.K), Cp =900						
J/(kg.K),L= 45.7 m, D=0.11 m, z = 3 m.						
X (m)	0	0.5	10.7	17	23.3	34	45.7
T_{Exp}°C	36.5	35.5	30.5	28	27	26	25
T_{sim} °C	36.5	36.2	31.2	29.2	27.8	26.2	25.2
Error %	/	1.4	2.3	4.3	3	0.8	0.8

Table 6. Validation of air temperature in the buried pipe against Hatraf et al. [28].

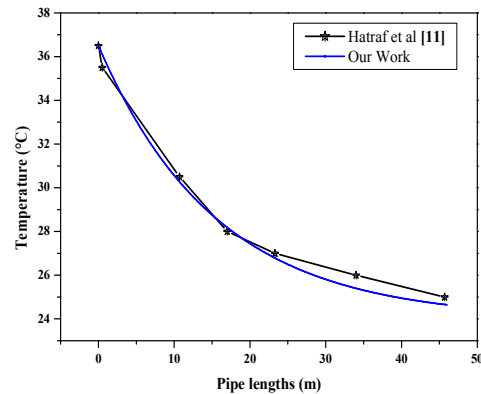| L =23.42 m; D= 0.15 m, Tsoil = 26.7 °C , (pipe in PVC), Bansal et al. Parameters [27]				
V_a (m/s)	T_{in} (°C)	T_{out} Bansal et al. [3] (°C)	T_{out} Our work	Error (%)
2	43.4	33.1	32.7	1.2
3	42.4	33.1	33.0	0.3
4	42.3	33.5	33.4	0.3
5	42.2	34.2	33.8	1.2

Figure 3. Validation of air temperature in the buried pipe against Hatraf et al. [28].

The detailed input parameters for the comparisons are described in Table 6. As seen in Figure 3, and Table 6, there is an excellent agreement between the theoretical and the experimental data. The mean relative error=2.1%. the thermal model of the EAHE can be used for estimating the air temperature circulating through and in the outlet of the pipe.

3.2 Soil temperature

Figure 4, shows the variation of the soil temperature as a function of the days of the year for different depths in the three regions. The temperature of the soil at a de–termined depth follows a periodic variation. From Figure 4, we notice that the amplitude of the oscill–a–tions decreases rapidly as one moves away from the ground surface. The amplitude of the temperature var–iation decreases exponentially with depth. The phase shift increases with depth. The average temperature in depth represents the average value of the ground surface temperature for one year. The period remains unchanged in depth. The soil can be used as a heat source for cooling in the summer season or heating in the winter season.

Table 7. The average of soil temperature at different depths during a year.

| Depth		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Timimou	1m	18.6	18	19.5	22.5	26.4	30.1	32.6	33.2	31.7	28.6	24.7	21.1
	2m	22.1	20.7	20.7	21.9	24.2	26.8	29	30.5	30.5	29.3	27	24.1
	3m	24.4	22.9	22.3	22.4	23.5	25	26.8	28.3	29	25.8	27.7	26.2
	5m	26.3	25.4	24.8	24.2	24.1	24.4	25	25.8	26.5	27	27.1	26.9
Djelfa	1m	4.2	3.7	6.1	10.9	16.8	22.1	25.5	26	23.5	18.7	12.8	7.5
	2m	8.5	6.9	7.3	9.7	13.5	17.7	21.1	22.9	22.4	20	16.1	12
	3m	11.8	9.8	9.1	9.9	12.1	15	17.9	20	20.6	19.8	17.6	14.7
	5m	15.2	13.7	12.6	12	12.2	13	14.5	16	17.2	17.8	17.6	16.7
Jijel	1m	6.9	6.1	9	13.6	19.1	24.1	27.2	27.6	25.1	20.5	14.9	10
	2m	10.8	9.3	9.9	12.4	16.1	20.1	23.3	24.9	24.3	21.8	18	14
	3m	13.8	11.9	11.5	12.4	14.7	17.6	20.3	22.3	22.8	21.8	19.5	16.6
	5m	17.1	15.6	14.6	14.1	14.5	15.5	17.1	18.6	19.7	20.2	19.7	18.7
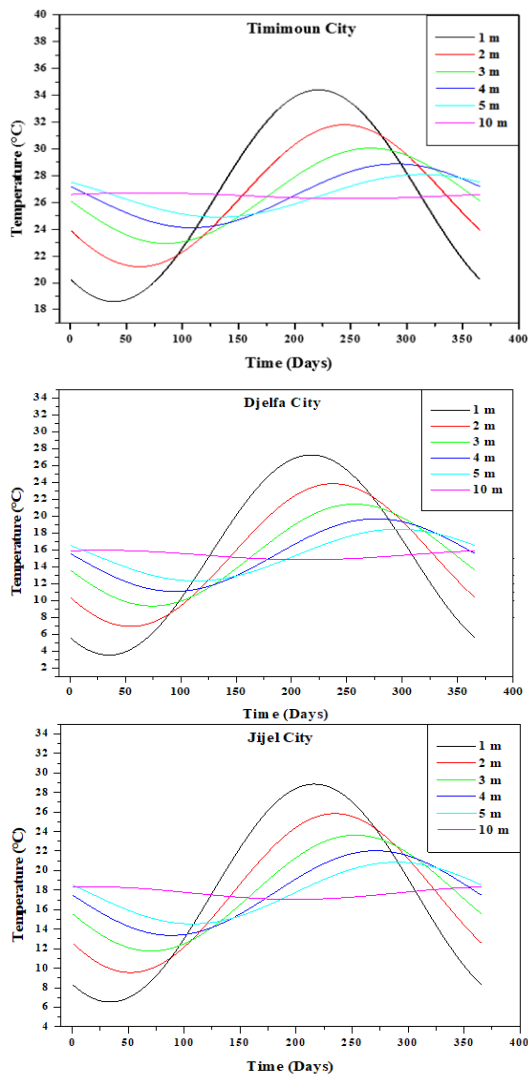
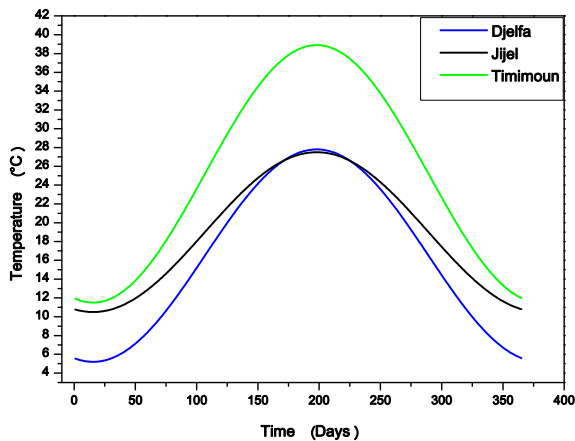**Figure 4. Annual variation of soil temperature in three different Regions.**

Figure 5. Annual variation of ambient temperature in three different Regions.

The soil thermal model can be considered to be appropriate for the simulation of the thermal behavior of the soil temperature. Table 7, shows the mean soil temperature at different depths in different months. From Table 7, it's noted that the minimal soil temperature used for cooling in the summer period is recorded in June with the value of 13, 15.5, and 22.1°C in Djelfa, Jijel, and Timimoun, respectively, at 5m of depths. It is noted

that the minimum soil temperature used for cooling in the summer period is recorded in June with the value of 13, 15.5 in Djelfa and Jijel respectively. However, the value in May was 22.1°C in Timimoun at depths of 5m. Also, the maximum soil temperature used for the heating in the winter period is recorded in November with the value of 27.7 °C in Timimoun at depth of 3m, and 20°C for Djelfa at depths of in October, while in Jijel the best heating temperature is 19.9 °C recorded in November at depths of 4m.

Figure 5 illustrates adequately the daily mean air ambient temperature changes as a function time by cosine functions including the climatic data of Timi–moun, Djelfa and Jijel. The choice of the burial depth of the tube takes into account a soil temperature lower than 26 °C during the cooling period and also the thermal potential, defined by $\Delta T = \left(T\left(z,t\right) - Ta\left(t\right)\right)$.

We notice that the cooling period for Timimoun is the longest. It began from May 1 to September 30 but for Djelfa and Jijel, the cooling period lasts from June,.1 to August 30. The depths of 5m,2m,2m and pipe lengths of 45m, 30m,30m can be used for cooling in Timimoun, Djelfa and Jijel. A PVC pipe is used for its advantages; the performance of the EAHE system is not affected by the material of the buried pipe. PVC pipe can be used as a cheaper material pipe. The pressure of PVC tubes is considerably reduced compared to the tubes of traditional materials thanks to their internal surfaces close to the ideal smooth state. The hourly variation of temperature for ambient air, outlet air when operating with EAHE for hot days presented in Figure 5. The cooling potential for each day is estimated to 26.21 KWh, 13.83 KWh and 7.66 KWh for Timimoun, Djelfa and Jijel successively.
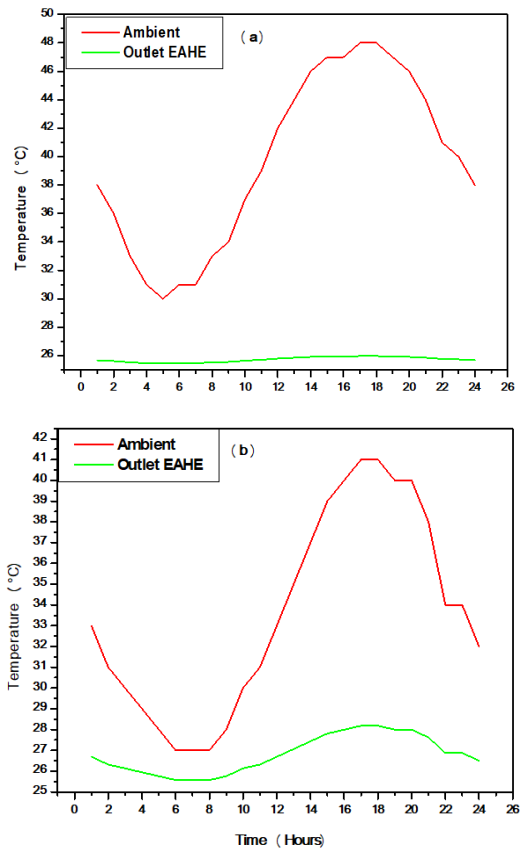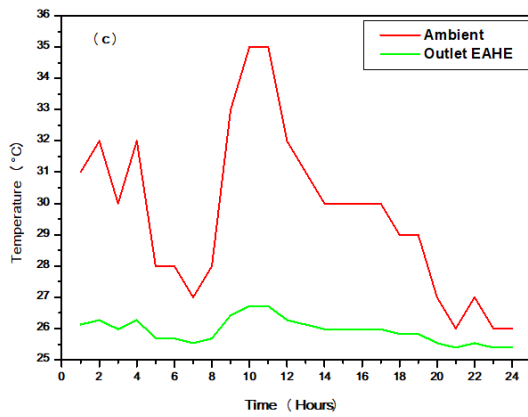
Figure 6. Hourly variation of temperature for ambient air, outlet air of EAHE for the hottest day in (a) Timimoun; (b) Djelfa; (c) Jijel.

3.3 Influence of the different parameters on the thermal cooling potential

A study of the effect of the air volume rate, diameter, thickness, thermal conductivity of pipe and thermal diffusivity of soil to determine different coo–ling capacities is done. The basic operating parameters of the EAHE systems installed at the three different locations are pipe installation depth 5/2/2m and pipe length 45/30/30m for Timimoun, Djelfa and Jijel. The other parameters are: air volume rate $\dot{V}$ =250 m³/h, diameter and thickness are consecutively D =0.15m, δ =2mm, of a PVC pipe material.

• The influence of air volume rate

Figure 7, show the predicted monthly cooling of EAHE system for three localities: Timimoun, Djelfa and Jijel for different volume rate of air 150,200 and 250m³/h which corresponds to estimated air velocities at 2.7, 3.6 and 4.5m/s. The cooling energy gain can be estimated to 628,03 kWh, 271,89 kWh, and 154,04 kWh in the hottest month of July. Quantities of 2221.15 KWh, 523.56 kWh, and 300.27 kWh over a cooling season can be reached for Timimoun, Djelfa, and Jijel successively for a 250m³/h volume rate of air.
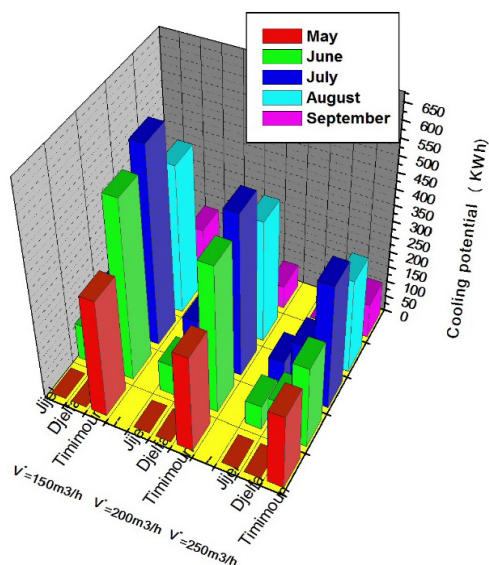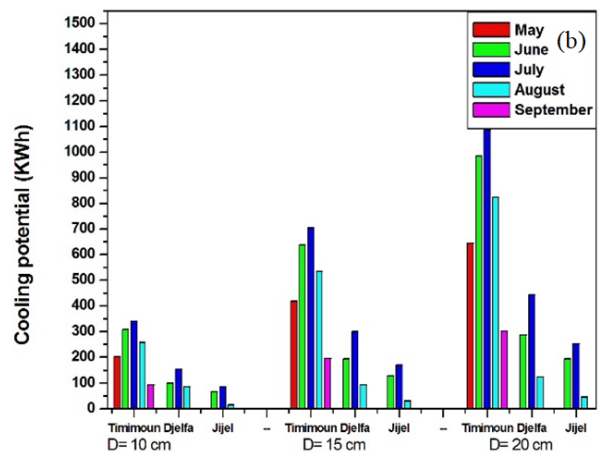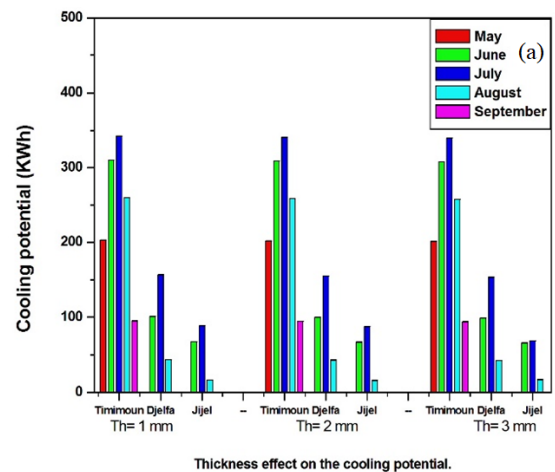

Figure 7. The monthly cooling energy provided by the EAHE for different air flow.

The results presented in Figure 7 show that cooling potential varies proportionally with the airflow volume. On the other hand, a high flow rate can generate a turbulent regime which increases the pressure drops, while a low flow rate may be insufficient for the room to be cooled. A difference of 929.85 kWh, 186.42, 107.62 can be gained in Timimoun, Djelfa, Jijel successively between an airflow of 250m³/h and another of 150m³/h.

• The influence of dimensions and characteristics of pipe

Figure 8, presenting the diameter, thickness and pipe material effect on the cooling. To judge the influence of the thickness on the cooling potential, we present, the evolution of the cooling potential of the temperature for different thicknesses 1mm,2mm and 3mm of the tubes in Figure 8 (a). It can be seen that increasing the thickness of the tube increases the potential for air cooling by an insignificant value; a few kWh between a thickness of 1mm and another of 3mm estimated to 10.42 kWh,6.84 kWh, 20.82 kWh in Timimoun, Djelfa and Jijel successively over a cooling period can be obtained. To judge the influence of diameter on the cooling potential, we present the monthly evolution of this potential in Figure 8 (b). Note that the air cooling potential increases as the diameter increases and that for the same flow rate $\dot{V}$=250 m³/h, it reaches a value of 2636.9 kWh, 555.71kWh, and 23.38 kWh in Timimoun, Djelfa and Jijel successively over a cooling season between a diameter of 0.10m and another of 0.20m.

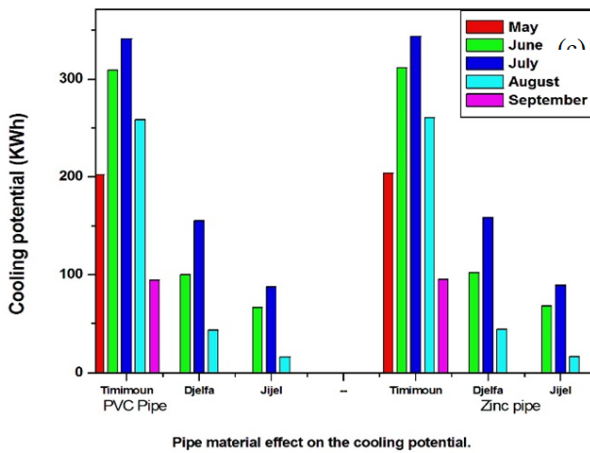Thickness effect on the cooling potential.

Figure 8. The monthly cooling energy provided by the EAHE for different dimensions: (a) Thickness effect, (b) Diameter effect, (c) pipe material effect.

The increase in the diameter of the tube which increases the contact surface of the exchanger with the ground allows a greater heat exchange and subsequently increases the cooling potential, on the other hand, the large diameter of the tube, decreases its resistance to the pressure of the ground. Figure 8(c), presented the pipe material effect on the cooling. It can be seen that the influence of this parameter is no longer significant on the cooling potential of the air leaving the air-ground exchanger as shown in Figure 9 (a). Between a PVC tube (λ_p =0.16 W m^{-1} K^{-1}) and a zinc tube (λ_p =116 W m^{-1} K^{-1}) a gain in cooling potential of 9.48kWh,6.65 kWh,3.68 kWh in Timimoun, Djelfa, and Jijel successively is recorded. Therefore, less expensive PVC tubing is preferable.

• **The influence of soil thermal properties**

To better study the influence of the thermal diffusivity a_s of soil, a comparison is done. Three systems EAHE supposed to be installed in soils of thermal diffusivity similar to the three locations mentioned in this study at the same depth z=3m and which have the same lengths L=40m.Figure 9 illustrates the variation of the cooling potential during a summer period that extends from May to September. We notice that as the diffusivity increases, the temperature of the soil increases, and therefore the cooling potential decreases. It's also noted that the sandy clay soil of Timimoun ensures thermal performance which allows better heat dissipation, and subsequently is the most favourable for cooling it in hot and arid regions, unlike Djelfa silt loam which is less evacuator. In the hot month of July, a cooling potential of 270.99 kWh, 176.67kWh was gained by the sandy clay soil and the sandy loam soil successively relative to the silty loam soil during a cooling season.

3.4 The efficiency of the EAHE

To determine the efficiency of the EAHE system, the Figure illustrates the coefficient of performance COP for a typical case in each location. The common typical parameters are a PVC pipe of 250 m^3/h volume rate, a

diameter of 0.15m, a pipe thickness of 2 mm, a length of 30m for Djelfa and Jijel,45m for Timimoun, on the other hand, the ground depths are 2m,3m,5m for Djelfa, Jijel, and Timimoun successively. Values COP of 4.2,1.8 and 1.1 in Timimoun, Djelfa, and Jijel are obtained in July which is the hottest month. Jijel's COP for August is around 0.4. We deduce that the ambient temperature is close to that of the ground (monthly average of 24.9 ° C), it is that of summer thermal comfort (26 ° C), the system can be put out of service on the last days of the month. The proportion of free energy provided by the system, that is to say, what have been gained considering the electrical energy consumed by the fan$(1-1/COP)$ is 76.19% - 44.44% - 9.09% in Timimoun, Djelfa, and Jijel consecutively in the hot month which is July.
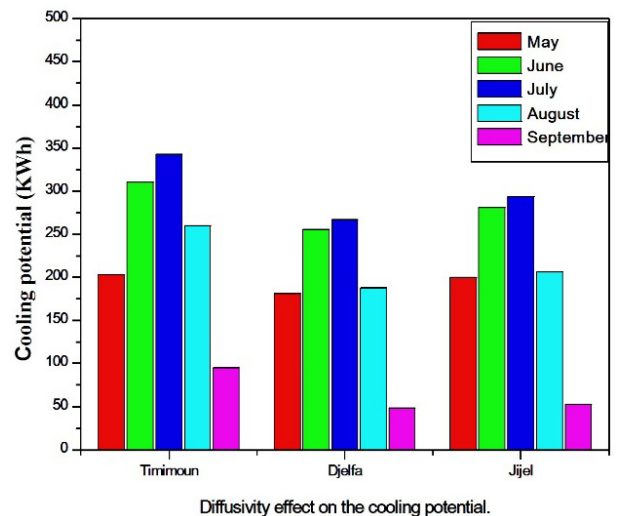

Figure 9. The monthly cooling energy provided by the EAHE for different thermal diffusivity.
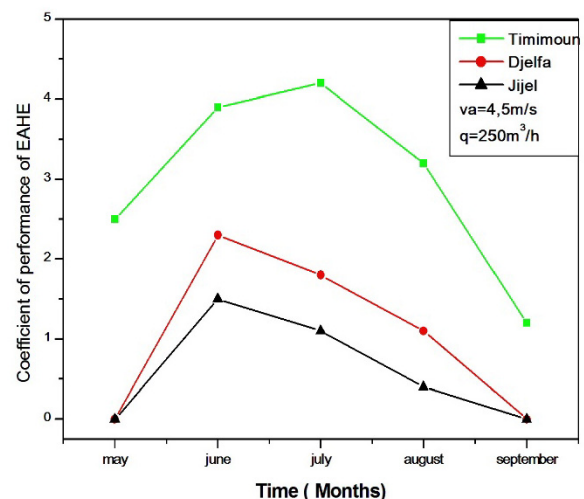

Figure 10. The monthly cooling energy provided by the EAHE for different regions.

4. CONCLUSION

According to the study presented in this paper, the following conclusions can be drawn:

The present model of the soil temperature, which gives good agreement with experimental data of literature, can be used to estimate and predict the soil

temperature profile at the various depths in different localities of Algeria for an eventual utilization of low geothermal energy as an alternative source of energy. The depth of z=5m can be used for cooling in Timimoun. The depth of z=2m can be used for cooling in Djelfa and Jijel. The model presented was validated against other studies and it shows good agreement. It can be considered to be appropriate for simulation of the thermal behavior of an EAHE and calculating the energy gain. Based on the three localities, each city represents a different climate in Algeria. This study shows that an EAHE system can be an interesting system for cooling in different climates of Algeria. The EAHE can be used to reduce energy demand in the domestic building in different climates of Algeria especially in the arid climates (south) of Algeria. The cooling potential for a typical hottest day is estimated to 26.21 kWh, 13.83 kWh, and 7.66 kWh for Timimoun, Djelfa, and Jijel successively. A maximum energy gain of 2221.15 kWh, 523.56 kWh, and 300.27 kWh can be reached with a 0.15m pipe diameter and a 250m^3/h air volume rate used. It means that a sum of money of 8884.60 DA, 2094.24 DA, 1201.08 DA considering an average electricity consumption of 4 DA/kWh can be saved for Timimoun, Djelfa, and Jijel respectively over a cooling season.

ACKNOWLEDGEMENTS

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NOMENCLATURE

T_a	Ambient air temperature (°C)
$\dot{m}$	Mass flow rate of the air (kg/s)
$\dot{V}$	Heat flow rate(m³/h)
a_s	Thermal diffusivity of the soil(m²/s)
C_a	Thermal capacity of air (J/kgK)
C_s	Thermal capacity of the soil(kJ/kgK)
D	Pipe diameter(m)
DA	Algerian Dinar
L	Pipe length(m)
Q_c	Cooling potential(kWh)
r_1	Inner pipe radius(m)
r_2	Outer pipe radius(m)
r_3	Radius of cylinder denoting thickness of disturb soil surrounding pipe(m)
R_{cv}	thermal resistance between air and pipe inner surface (K/W)
R_p	thermal resistance of the buried pipe(K/W)
R_s	thermal resistance of the soil (K/W)
t	Time passed from the begin of the year(days)
T_{in}	Inlet air temperature(°C)
T_{out}	Outlet air temperature(°C)
z	Depth in the soil(m)

Greek symbols

δ	Pipe thickness(m)
λ_a	Thermal conductivity of the air(w/m K)
λ_p	Thermal conductivity of buried pipe (W/m K)
λ_s	Thermal conductivity of the soil(W/m.K)
μ_a	Dynamic viscosity of air (Pa s)
ρ_a	Density of air(kg/m³)
ρ_s	Density of the soil(kg/m³)

Subscripts

a	Air
p	Pipe
s	Soil

ПРОЦЕНА ИСКОРИШЋЕЊА ИЗМЕЊИВАЧА ТОПЛОТЕ ВАЗДУХ-ЗЕМЉА ЗА ПАСИВНО ХЛАЂЕЊЕ У ТРИ РЕГИОНА АЛЖИРА – СТУДИЈА СЛУЧАЈА

К. Хасини, А. Бенатиалах, А. Харуз, Ђ. Белатраче

Потрошња енергије за загревање и хлађење зграда је у порасту из године у годину како би се задо–вољила потреба људи за комфорним становањем. Кључни проблем у сектору стамбених зграда, нај–већем потрошачу енергије, је рационално кориш–ћење класичних ресурса као и примена чистих технологија и обновљивих извора енергије како би се обезбедио одрживи развој. Власт жели да смањи потрошњу енергије у зградама увођењем прописа о грејању и расхлађивању. Циљ закона 99-09 и декрета 2000-09 јесте контрола и коришћење енергије у зградама. Овај рад се бави ефикасношћу система измењивача топлоте ваздух-земља за расхлађивање зграда у три климатски различита региона Алжира. Измењивач топлоте ваздух-земља је перспективна технологија којом може да се редукује или избегне коришћење система за климатизацију. Измењивач топлоте ваздух-земља који користи термичку инерцију земљишта доводи у термички контакт два различита извора тем–

пературе, ваздух који циркулише у цевима и земљу која је у контакту са цевима. Евалуација модела је показала слагање између резултата добијених симулацијом и резултата објављених у литератури.

Симулацијом је потврђено да се максимални добитак енергије од 2221,15; 523,56 и 300,27 kWh у току сезоне хлађења може остварити у регионима Тимимун, Ђелфа и Ђиђел.