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FEASIBILITY STUDY OF NEW GEOTHERMAL SYSTEM FOR HEATING PREMISES AND THERMAL COMPLEXES: EXPERIMENTAL INVESTIGATION OF WATER-AIR HEAT EXCHANGER IN THE EAST OF ALGERIA

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Abstract

This paper constitutes a new technological solution for the exploitation of one of the most important geothermal deposits located in the locality of Biskra (South-east Algeria). This is the Albian aquifer whose hot waters from boreholes, hot springs and spas are poorly exploited while ambient temperatures during winter periods reach very low levels, especially at night. The principle of this geothermal system is to immerse a PVC tubular water-air exchanger in a pool permanently supplied with hot water from a low-energy geothermal borehole with a high flow rate. The choice of PVC material is attributed to the fact that hot geothermal waters are generally of an aggressive composition to steels and metals in general. The geothermal air heater allows the heating of the ambient cold air which is introduced into the exchanger and then extracted hot using an extraction fan. The hot air is then diffused into premises for heating during the winter season. The improvement in the performance of this type of exchanger is highlighted, in particular by acting on the number of pipes of the exchanger and the air flow rate using geothermal energy (low energy) as a source of renewable and clean energy. The experimental results obtained showed that the energy gain is a function of the length of the exchanger and the air flow rate. This gain can be up to 20°C between the inlet and outlet of the miniature exchanger model, which means that the proposed solution could be technically feasible.

1. Introduction

The great electric power part in Algeria is mostly used for cooling and heating the domestic commercial buildings. Thus, air conditioning technologies become the issue of a great interest and the high quality of energy efficiency for higher comfort standards is mostly demanded [1], [2].

Although air conditioning costs too much in both cold and hot climate, it is extremely important. So, the reduction in heating loads through the use of geothermal energy would certainly be justified.

It is necessary that the geography of using these technologies should be well defined, and that a list of the performance of these systems be presented, especially the best ones in different climatic and geographical locations in Algeria.

Algeria's buildings are responsible for about 40% of the country's overall electric energy consumption (Fig. 1). In homes, energy use for fans and air conditioning systems is more than 50%. As a result of their efficiency and low impact on the environment, air-ground/air-water heat exchanger systems have gained traction as a viable option for dealing with this issue.

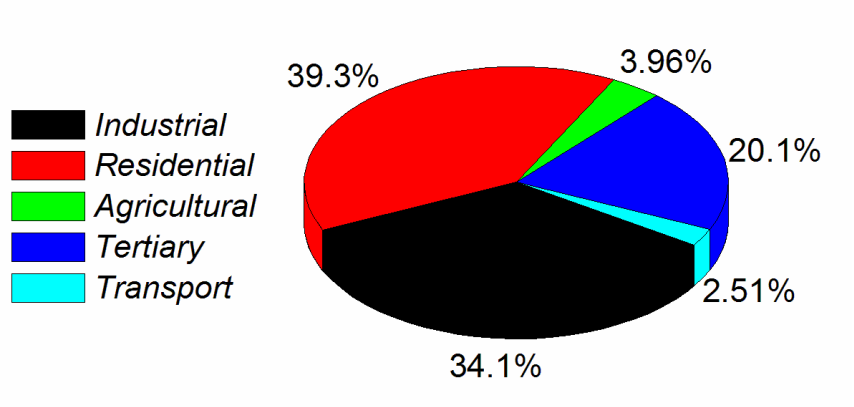


Figure 1. Electricity consumption by sector in Algeria 2021 (APRUE 2022)

Many researchers over the word developed and investigated the performances of ground buried, and air-water heat exchanger [4-8]. We cite as an example the work of Urcheguia et al. [09], who presented an experimental comparison between the thermal performance of an air to water heat pump system and a ground coupled water to water heat pump system for cooling and heating. The obtained results show that, the air-water system is preferable than water-water heat exchanger for a whole climatic season, in terms of primary energy consumption; in both cooling and heating modes.

Hassan et al. [10] studied the influence of size and shape on the hydraulic and thermal efficiency of microchannel heat exchangers (MCHE) with various geometries and channel cross-sections. They noticed that, the increase in the number of channels increases the efficiency and pressure drop. Thus, the circular channel gives the highest performance (thermal and hydraulic).

N. Moummi [11] was awarded in 2010, the prize for the best experimental work by the center of development of renewable energies (CDER) for his studies on the buried exchanger

that he realized and installed at the University of Biskra. This subject also interested the researchers of south Algerian universities; The study of Rouag et al [12] investigated the feasibility of solar adsorption air refreshment technologies in the region of Biskra (Algeria), they interest to the possibility of substitute the dry cooling tower (DCT) with a new additive water cooling system with the use of an earth-water heat exchanger (EWHE). This additive EWHE operates only when the ambient temperature exceeds the operating restrictions of the DCT. They noticed that, the geothermal solution can be a good alternative to replace the DCT and reduces cost compared with other solutions. Furthermore, the same research team developed new transient semi-analytical model by means of the Bessel function method, to predict the thermal performance of EAHE and their deterioration as a function of the duration operation caused by soil thermal saturation [13]. The investigation of continuous operation of the EAHE was made for the soil of the region of Biskra (Southern Algeria) (34°47′N - 005°43′E) by considering extreme ambient temperature (57 °C). They noticed that the deterioration of EAHE performance is recorded for longer duration in hot and dry climate. The soil radius reach 0.55 m from the pipe surface after 6 h of continuous operation. Thus, the authors published the second part of this study by Mehdid et al. [14] to predict thermal performance of Earth-to-Air Heat Exchanger (EAHE) operating under transient conditions for cooling mode. They proposed a new semi-analytical model, called Generalized RBM model (GRBM model). Therefore, they validated the developed model by an experimental investigation which was carried out in the region of Biskra (Algeria).

Belloufi et al [15] predicted the EAHE's thermal performances during extreme summer conditions. The transient numerical model permits to calculate the influence of soil properties, air velocity and continuous functioning. They noticed that, the thermal performance of EAHE is depending on soil thermal conductivity of soil and air velocity. The derating factor in the studied cases was ranged from 0% to 35% that can mislead the design of the EAHE if neglected. In did, the first 33 m from the pipe opening can provide 91% of the whole reduction in air temperature.

The paper of Hadjaj et al. [16] investigates experimentally the thermal performances of water–air helical PVC piping heat exchanger in El-Oued city (Algeria). This technology can be used for cooling buildings or greenhouses in the southeastern Algeria. The influence of air velocity in the performances of the exchanger with 30 m of length and 0.06 m of diameter was highlighted; the exchanger was immersed into water well at 5 m depth. The results show that the maximum heat exchange reached about 418 W at 10 m/s of air velocity and the maximum temperature difference between outlet and the inlet air was 14.1 °C.

Lebbihiat et al. [17] presented a review on the available literature and the main practices of geothermal resources in Algeria, they studied the development roadmap. Furthermore, the use of geothermal energy and newer technologies around the world are summarized. They analyzed the obstacles that prevent the development and use of geothermal energy in Algeria, the utilization opportunities and solutions to promote the development in the country are proposed.

The area of Biskra located in the southeast of Algeria contains the most important boreholes, hot springs, and spas of the Albian aquifer. It is also one of the most important geothermal deposits there, despite its misuse.

In this paper, we propose a new solution base on heat exchanger immersed in a pool and the surrounding air blown through this exchanger to heat it. The main objective of this study is the Evaluation of heat exchange and performance of a new geothermal heat exchanger for domestic heating for the revalorization of poorly exploited hot water from geothermal deposits. This new technical solution provides the advantage of available, sustainable, clean and cheap energy.

2. Geothermal considerations

Geothermal energy is a soft energy that depletes its resources from the depths of the earth, it is not dependent on climatic conditions or time, it manifests itself in the form of volcanoes, geysers, fumaroles, hot springs and boiling mud pools. There are indeed two types of geothermal energy: high enthalpy used for the production of electricity and low enthalpy which includes two kinds of geothermal energy. Very low energy geothermal energy with temperatures below 30°C and low energy geothermal energy based on heat ranging from 30°C to 100°C.For the case of Algeria's geothermal energy potential, studies reveal the existence of more than 200 hot springs located mainly in the northeast and northwest regions of the country, with 37 hyperthermal springs (T>45° C), the hottest of which being that of Hammam Meskhoutine (98°C) [18]. The Albian sandstone reservoir in the Sahara region extends over most of the northeastern Algerian desert and a large part of its west, and thermal springs are rare in this region. The Albian aquifer is exploited by wells for mainly domestic and agricultural uses. The water temperature ranges from 30°C to 80°C respectively from west to east [19].

Although springs with high temperatures have been found in the area around Biskra, more than two hundred (200) springs have been counted in the northern part of the country with lower temperatures. They are mainly used for the purpose of balneological, although there is a small amount of greenhouse heating [20].

It should be noted that there are also other high temperature sources that can reach 118°C in Biskra [21]. In this region of Biskra, concerned by our study, the intercalary continental aquifer is in the form of an artesian aquifer, and it constitutes the largest groundwater reserve in the Algerian Sahara (Fig.2). This free aquifer is surmounted by the thermal complex [22].

Regarding energy production, the geothermal energy has been expected, by the CDER, to grant a potential of 700MW (plus the flow from the exploitation of the Albian platform with the total flow of the hot water sources hot). Thus, these hot springs are abandoned and not used either in the agricultural field or industrial purposes [23].

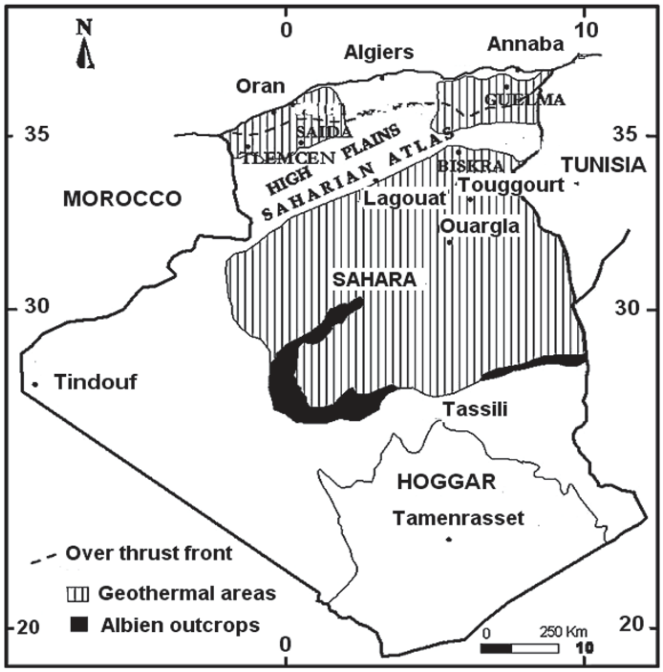


Figure 2. Main geothermal zones in Algeria [24]

The hot water of the boreholes, hot springs and spas of the Albian aquifer are among the most important geothermal deposits do exist in the region of Biskra (South-east of Algeria), are poorly exploited. Indeed, the use of a heat exchanger immersed in a tank and blowing ambient air through this exchanger in a habitat to heat it considered as a new technological solution to benefit from available, sustainable, clean and cheap energy.

Among the problems which can prevent the proper use of hot geothermal waters is the is sediment corrosive effect of the different components of these waters on metal installations, such as (calcium sulfate or calcium carbonates) precipitate and form deposits in adherence to the pipes walls. This constitutes major handicap for the use of geothermal water in Saharien regions [25].

The main uses of geothermal water in Algeria are domestic heating, spas and agriculture. Several projects have been launched for direct geothermal applications for domestic heating and in the agricultural field (greenhouse heating and aquaculture). A geothermal power plant pilot project is planned to be implemented in the eastern geothermal zone in Hammam Debagh, Guelma province. A successful fish production project in the geothermal area of the Sahara (Ouargla and Touggourt) is a good example of the use of geothermal water with hot water at a temperature of 60°C. Eighteen greenhouses covering a total area of 7200 m2 are heated by geothermal waters from the Sahara at 57°C. The temperature of the source combined with a flow rate of 1 L/s is used to ensure a minimum temperature of 12°C inside each greenhouse. Significant geothermal potential has been found in the geothermal area of the Sahara; sufficient to heat 9000 greenhouses and the total energy consumption for geothermal is about 1778.65 TJ/year [26]. Recently, the fish farms in Algerian Sahara use Albian geothermal water to produce more than 1500 tons/year of tilapia fish.

Another small project has also been initiated in Hammam Sidi Issa geothermal water (46 °C) by exploiting a reversible heat pump, used for heating and cooling twelve 12 classrooms, library and primary school canteen [20].

3. Experimental

3. 1. Experimental setup

Biskra is an Algerian Saharan city located at 34°48 North (latitude) and 05°44 East (longitude). Characterized by a very hot and dry summer climate and very cold winter with minimum temperature of 4°C, average maximum relative humidity of 89%.
The characteristic parameters, defined in all models are given in table 1.

The proposed experimental model in this paper (Fig.3), is a tubular geothermal water-air heat exchanger with four (04), six (06) and eight (08) pipes immersed in a pool, continuously supplied with hot water from a borehole, located in the municipality of Ourllal two kilometers from the border of the municipality of Bouchagroune, west of Biskra city. Chiselled at more than 3400 meters deep and whose temperature at the exit of the borehole is estimated at 67°C.

Table 1. Characteristic parameters for the three heat exchangers

Material	Thermal conductivity	Pipe wall thickness	Pipe length	Distance between two consecutive pipes	Pipe inner diameter
PVC	λ_{pvc} = 0.16	e= 01 mm	L=1 m	l=78 mm	di=32mm

This model can be schematized as follows:

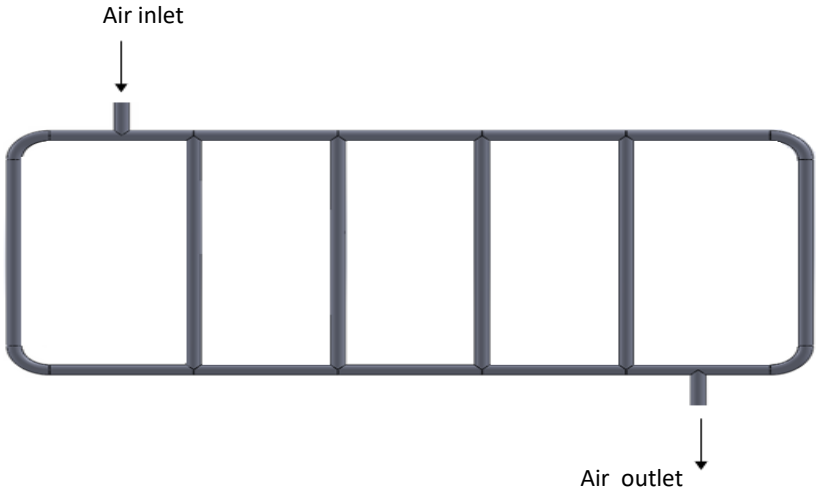


Figure 3. Geothermal water-air tubular heat exchanger

This technological solution makes it possible to reduce the consumption of electrical energy intended for the heating of habitats, buildings and especially those of thermal spas (Fig. 4).

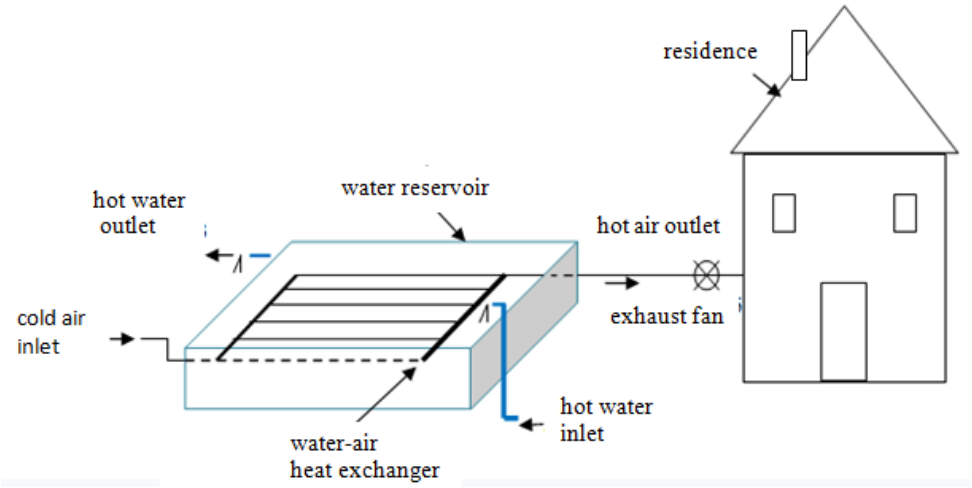


Figure 4. Geothermal water-air heat exchanger used for domestic heating

3. 2. Experimental measurements, calculation and uncertaintity analysis

These experiments are realized by using three (03) thermocouples for the mean temperature measurement; Ambient, outlet and inlet temperatures, water temperature is measured by a mercury thermometer. Thus, solar radiation intensity, temperatures and air flow rate are, respectively, are measured with Kipp and Zonen pyranometer CM 11 with 1% accuracy, k-type thermocouples with an accuracy of 0.01◦C, a Kimo-type anemometer with hot

wire (VT300) with ±3% of reading and ±10 m^3 for the flow rate measurement and ±3% of reading and ±0.1 m⁄s accuracy.

The efficiency of the exchanger is calculated by considering:

• The water-air heat exchanger operates during cold seasons for space heating

• The water around the submerged pipe is homogeneous

• The thermo-physical properties of the air flowing inside the exchanger are considered constant in the temperature interval concerned by the study.

• The temperature of the water in the pool is homogeneous and constant

• The flow is steady state

The one formula used for the calculation of the performance of the exchanger in this paper is the one used for the calculation of the efficiency by Hadjaj et al. [16]:

$$\eta = \frac{Tout - Tin}{Tw - Tin} \tag{1}$$

The uncertainties in the recorded values of the experimental tests are based on the errors analysis in measurements. The calculation of the result R of set of measurements is given as a function of dependent variables $X_1, X_2, \ldots, X_n$ [27, 28].

$$R = R(X_1, X_2, X_3, \ldots, Xn), \tag{2}$$

$X_1, X_2, X_3 \ldots$ are the measured variables.

The uncertainty δR is calculated from the independent variables $\delta X_1, \delta X_2, \ldots, \delta Xn$ [29, 30]:

$$\delta R = \left[\left(\frac{\partial R}{\partial X1}\delta X1\right)^2 + \left(\frac{\partial R}{\partial X2}\delta X2\right)^2 + \cdots + \left(\frac{\partial R}{\partial Xn}\delta Xn\right)^2\right]^{1/2} \tag{3}$$

In these experiments, the independent measured parameters are: exchanger inlet temperature Tin, exchanger outlet temperature T_{out}, ambient temperature T_{amb}, solar irradiation and air flow rate.

Equation (1) can be written as:

$$\eta = f(T_{out}, T_{in}, , T_w)$$

The uncertainty equation for heat exchanger efficiency, η, is written as:

$$\delta\eta = \left[\left(\frac{\partial\eta}{\partial Tin}\delta Tin\right)^2 + \left(\frac{\partial\eta}{\partial Tout}\delta Tout\right)^2 + \left(\frac{\partial\eta}{\partial Tw}\delta Tw\right)^2\right]^{1/2} \quad (4)$$

The total uncertainty in calculating efficiency, η, is almost in the order of 0.5%.

4. Results and discussion

In this paper, an experimental study was carried out which relates to the dimensioning and the evaluation of the performances of three heat exchangers, differentiated by the number of pipes (length) during the four could day (winter period) from the Biskra region. Thus, a series of experiments was carried out by varying the length (the number of pipes and the air flow at the inlet of the exchanger (Fig. 05), with the aim of verifying the feasibility of this technological solution. For this, we seek to measure the temperature of the air at the inlet and outlet of the exchanger. The test method is to operate the heat exchanger in the test procedure under nearly steady conditions, measure T_{amb}, T_{in} and T_{out} are required for the analysis method and *I*G to control the outdoor conditions.

Environmental outdoor conditions are illustrated in form of graph describing the global hourly insulation and the ambient temperature and of testing day, which we have determined by. The recorded values of these two important parameters are presented in Figure 6.

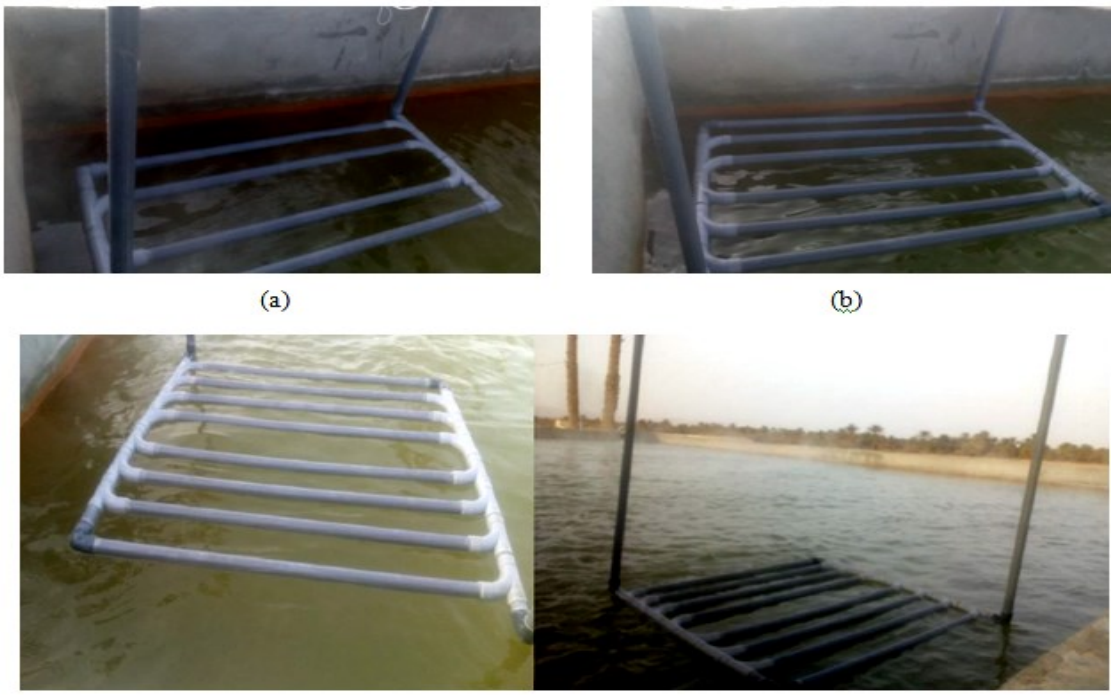


Figure 5. Tested Heat exchangers: (a): 4-pipe (b): 6-pipe (c): 8-pipe

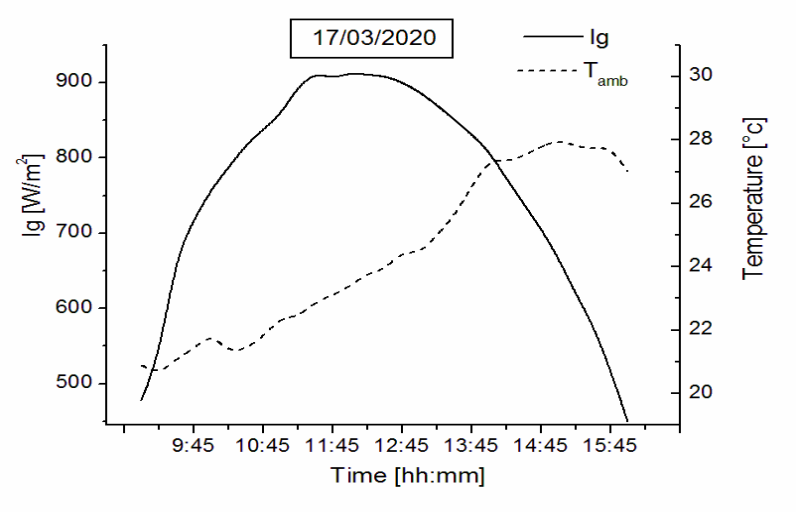


Figure 6. Environmental condition of the characteristic day

4. 1. Influence of the air flow rate and the exchanger length on the outlet temperature

As mentioned in the previous sections, the tests were carried out at the end of the cold season under similar conditions and in more or less steady climate.

Figure 07 shows the performance variation of the three exchangers; four, six and eight pipes as a function of the air flow rate. These performances are expressed in terms of temperature differences between the air inlet and outlet. The length immersed in hot water is 5m, 7.5m and 10 m. On the other hand, the temperature difference varies from 17 to 15.7 °c, from 19 to 18.4 °c and from 22.8 to 21.4 °c for the three exchangers 4, 6 and 8 pipes respectively, and for air flow rate values varying from 80 to 160 m^3/h.

The results shown below lead to the conclusion that there is an inversely proportional relationship between the air flow rate and the air temperature difference between the inlet and the outlet of the exchanger and that there is a clear improvement in heat gain provided by the addition of new pipes. This can be explained by the fact that the longer the holding time in the exchanger, the higher the heat exchange between the hot water of the borehole and the air.

Figure 8 shows the influence of the exchanger length on the temperature difference of the heated air; the interpretation of the curve illustrated in this figure leads to the conclusion that there is a proportional relationship between these two parameters. Indeed, the more the length of the exchanger increases (increase in the number of pipes), the greater the temperature difference. This result shows that the heat transfer is better with a longer length.

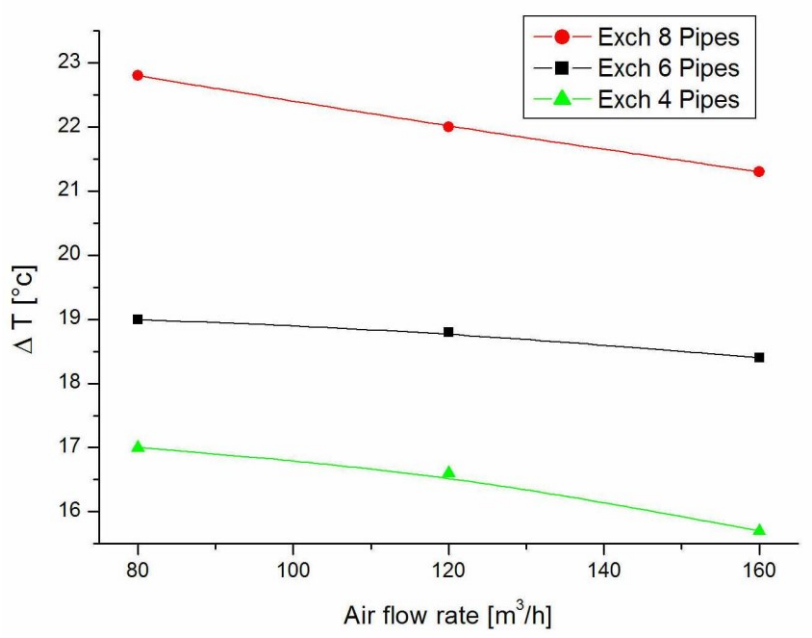


Figure 7. Variation of the temperature difference Vs air flow rate for the three exchangers

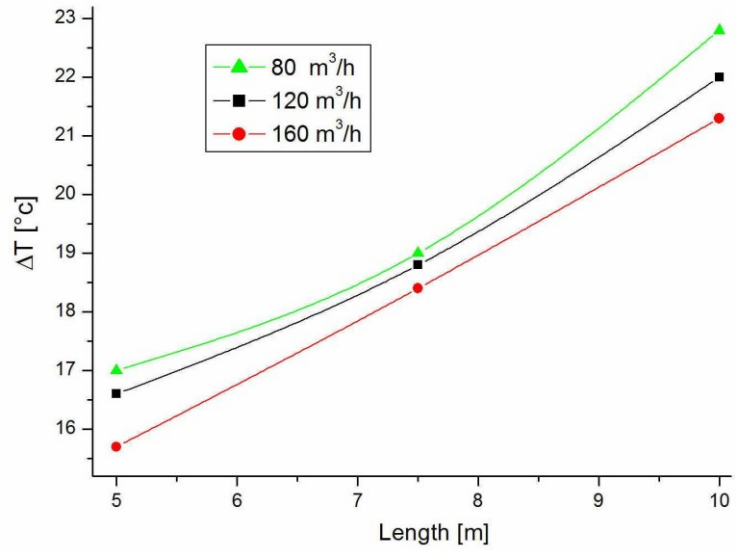


Figure 8. Variation of temperature differences as function of the Exchanger length for different air flow rates

4. 2. Influence of the air flow rate and the exchanger length on the exchanger efficiency

System efficiency changes based on tow parameters; air velocity and temperature. Figure 09 illustrates the variation of the heat exchanger efficiency according to the flow rate for the three exchangers. The interpretation of the curves illustrated in Fig. 10 shows that the efficiency and the air flow rate are proportional and that there is a clear improvement brought to the efficiency by increasing the number of pipes. The efficiency values reached are of the order of

47.9 to 49.3% for a 4 pipes heat exchanger, from 53.52 to 58.41% for a 6 pipes heat exchanger and of the order of 65.14 to 68.94% for the 8 pipes exchanger.

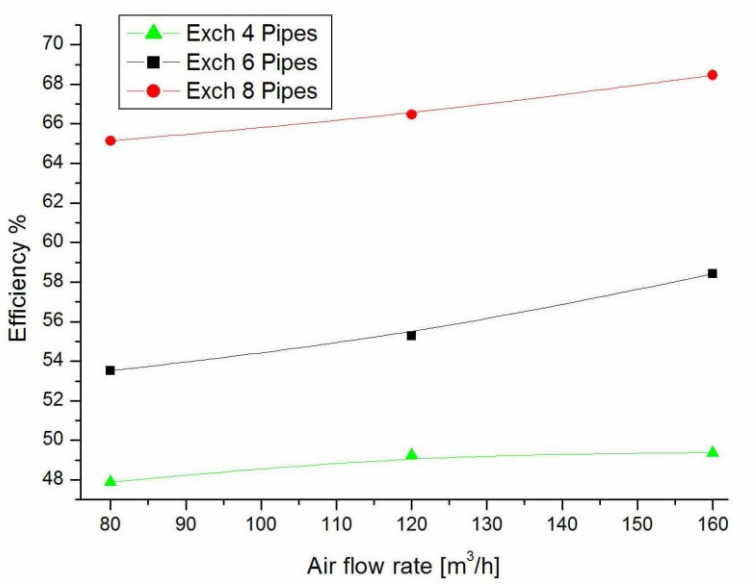


Figure 9. Variation of the efficiencies Vs the air flow rate for the three exchangers

Figure 10 illustrates the variation of the efficiencies Vs the air flow rate for the three exchangers, it is clear that increasing the length by adding pipes increases the efficiency of the exchanger. As for the increase in the air flow rate also increases the efficiency of the exchanger, this is perhaps due to the increase in the inlet temperature related to the heating of the air fan with increasing air flow, which increases the difference between the values of the temperature of the hot water and that of the air at the inlet of the exchanger.

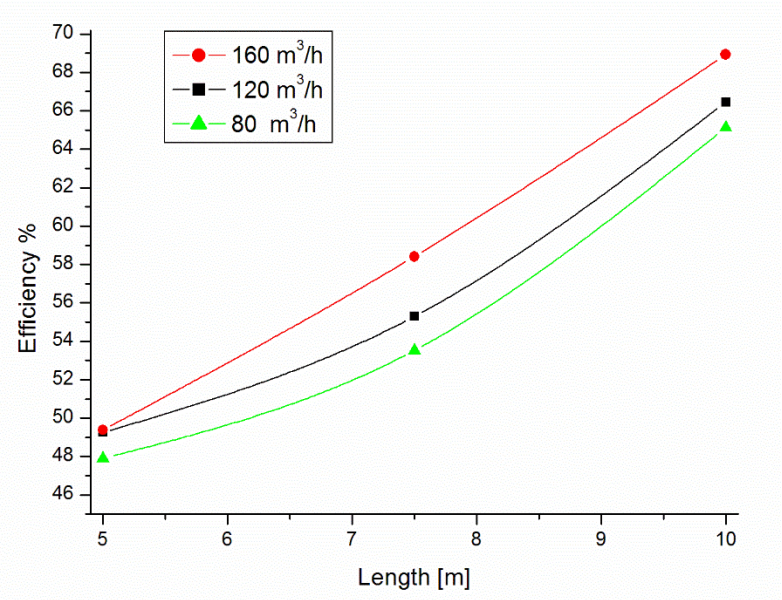


Figure 10. Variation of the efficiency according to the length for different air flow rates

5. Conclusion

This paper presents a new technological solution for the heating of premises and thermal complexes through the use of a geothermal source that is widely found in Algeria, especially in eastern Algeria, it is drilling hot water sources. These sources are not or badly exploited whereas they can present a durable and sustainable solution for the heating of the habitats in the east of Algeria.

This solution consists of immersing a tubular water-air exchanger in a pool permanently supplied with hot geothermal water from a low-energy geothermal borehole with a high flow rate. The geothermal air heater allows the heating of the ambient cold air which is introduced into the exchanger and then extracted hot using an extraction fan. The hot air is then diffused into premises for heating during the winter season.

From the experimental results obtained in this study, it was concluded that the technological solution proposed in this paper is technically feasible. It allowed gaining more than twenty degrees Celsius (20 °c) with a miniature heat exchanger model. In addition, increasing the number of pipes (the length) significantly improves the performance of the exchanger. Although, the increase in flow rate leads to a decrease in the temperature difference between the inlet and the outlet of the exchanger, it improves its efficiency.

The exchanger used in this experimental study is made of PVC. The problem that can be encountered is the immersion of the exchanger given its low density with the air in front of the water. The use of other materials such as galvanized steel or stainless steel will be more efficient from a thermal efficiency point of view, since the thermal conductivity of these materials is higher than that of PVC; however, a study of the resistance against corrosion is essential since hot geothermal water constitute an aggressive environment for metals.

Nomenclature

d_i	Pipe inner diameter	m
L	Exchanger length	m
l	Distance between two consecutive pipes	m
e	Pipe wall thickness	m
T	air temperature	°C
T_{in}	Inlet air temperature	°C
T_{out}	Outlet air temperature	°C
T_w	Water temperature	°C
ΔT	Air difference temperature $(T_{out}-T_{in})$	°C
$\delta\eta$	Uncertainty of the exchanger efficiency	%
η	Thermal efficiency	%
λ_{pvc}	Pipe thermal conductivity	(W/mK)

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