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Experimental Study of the Annual Operation of an Air-soil Heat Exchanger in Ouagadougou

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Abstract: The use of air-soil heat exchangers for cooling habitats has developed considerably in recent years. An air-soil heat exchanger (ASHE) is a geothermal system that uses the thermal inertia of the soil to heat or cool part of the air to renew a habitat. It is sometimes called a Canadian well or a Provencal well. In this present work, we have presented the experimental prototype implemented in Ouagadougou. It is an air-soil heat exchanger consisting of a U-shaped PVC pipe of horizontal length 15 m, diameter 16 cm and placed at a depth of 1.5m (slope of about 2%) in floor. The experimental work consists in measuring, on the one hand, the temperature of the air from the inlet of the tube to the outlet in steps of 2 m in length and, on the other hand, the temperatures of the ambient air, air in the habitat and soil at 1 m and 1.5 m depth. This study has allowed analyzing the evolution of air temperatures in the system. The thermals performances of air-soil heat exchanger have been also evaluated and his influence on air temperature in the habitat. The results show that the experimental setup is of good quality. In practice, the thermal efficiency is between 20% and 70%.

Keywords: Air-soil Heat Exchanger, Cooling, Experimental Prototype, Thermals Performances

1. Introduction

Increasing population and economic growth combined with global and local climate change conditions have encouraged the increasing demand for building cooling energy [1].

An air-soil heat exchanger (ASHE) is a geothermal system that uses the thermal inertia of the ground to heat or cool part of the air to renew a habitat. It is sometimes called a Canadian well or a Provencal well. The principle of the system is to inject into a habitat, air flow from outside that is forced beforehand to flow in a pipe buried at a certain depth in the soil [2, 3]. As a technology for renewable energy utilization, the ASHE presents various advantages such as economical and efficient energy utilization, no pollution, low operation cost, unrestricted by geological

conditions. It is considered as a green energy technology of tremendous potential for building energy supply [4, 5]. As the main equipment in the system for heat transfer, the soil heat exchanger transfers heat between fluids in the tube and surrounding soils [6, 7].

In this paper, the implementation of the experimental device called a Canadian well or Provencal well or air soil heat exchanger (ASHE) will be discuss. This device will be used to cool the air intended for a habitat. This experiment is carried out on the physics platform at University Joseph KI-ZERBO in Burkina Faso. The results obtained from this work will allow us to evaluate the thermal performance of the ASHE and its influence on the air temperature in the habitat.

2. Scheme and Description of Experimental Device

2.1. Scheme of Experimental Device

The experimental air-soil exchanger (or Canadian well) that we experience on the platform is shown schematically in Figure 1.

2.2. Description of Experimental Device

Our device consists of two parts: the exchanger and the house.

It is an air-soil heat exchanger consisting of a U-shaped PVC pipe of horizontal length 15m, diameter 16cm and placed at a depth of 1.5m (slope of about 2%) in floor. Some parts of the device are described in Figure 2.
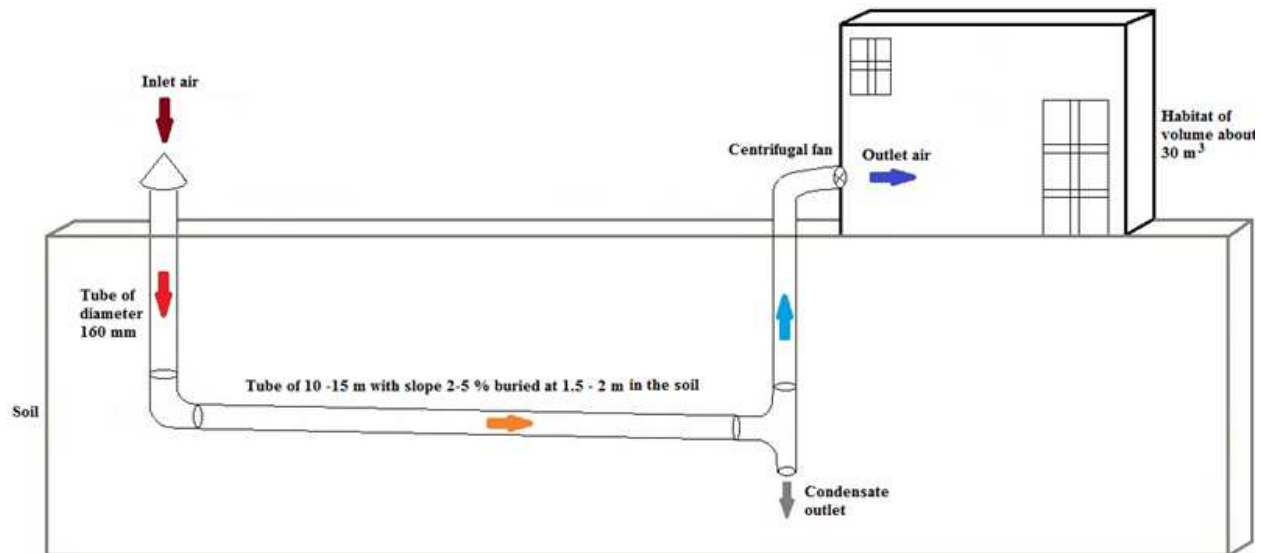

Figure 1. *Scheme of experimental device.*

Figure 2. *Description of some parts of experimental device.*

The inlet of the exchanger is covered by a filter and a hat to protect against dust and insects. At the outlet of the exchanger, the tube is insulated with glass wool in order to limit heat losses. We opted for the PVC tube taking into account several considerations that are cost, tightness, rigidity and durability. Bojic et al. [8] and Bansal et al. [9] have shown that the nature of the tube has very little influence on the thermal performance of an air-to-ground heat exchanger. The outlet of the tube is connected to a vacuum cleaner that has a speed of 4.5 ± 0.1 m.s^{-1}, a flow rate of 258 m^3.h^{-1}. Its role is to force the flow of air from the inlet to the outlet of the tube.
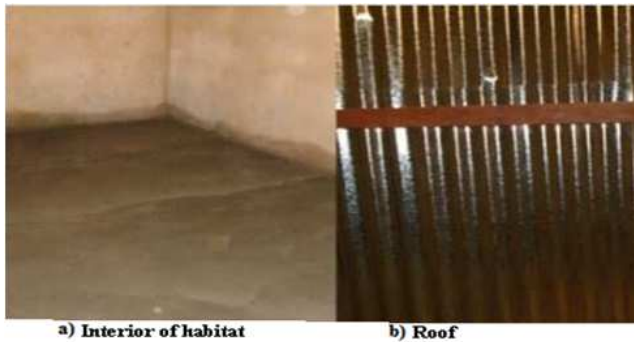

a) Interior of habitat   b) Roof

Figure 3. Some parts of experimental habitat.

The previous exchanger is connected to a volume room 32.82 m^3 (3.30m x 3.25m x 3.06m). This building has a door of dimensions 2m x 0.8m, a window size of 0.8m x 0.8m and a metal roof (without ceiling). A layer of cement is placed on the inner walls of the wall. Figure 3 describe some parts of this habitat.

2.3. Experimental Protocol

The experimental work consists in measuring, on the one hand, the temperature of the air from the inlet of the tube to the outlet in steps of 2 m in length and, on the other hand, the temperatures of the ambient air, air in the habitat and soil at 1 m and 1.5 m depth.

These measurements are made using type K thermocouples composed of nickel + chromium alloy and nickel + aluminum alloy (5%) + silicon [10]. Indeed, this type of thermocouple is resistant to radiation. They are connected to two programmable temperature loggers (MIDI LOGGER GL 220) (see figure 2). The accuracy of these devices is 1% for temperatures between 20 °C and 50°C [9]. The accuracy of Type K thermocouples is $\pm$ (0.05% of reading + 1.0°C) for temperatures between -100°C and 1370°C [11]. The measurement of the air velocity at the exit of the tube is performed by a PCE - AM 81 type anemometer. Its accuracy is 0.1 m/s.

The measurements took place during the period from June 2016 to May 2017, one (01) year. For each month, we performed a (01) week of measurements.

In Figure 4, the numbered dots indicate the areas where the thermocouples are placed. For the measurements, we considered a total of 15 locations of thermocouples.

Table 1. Measurement periods.

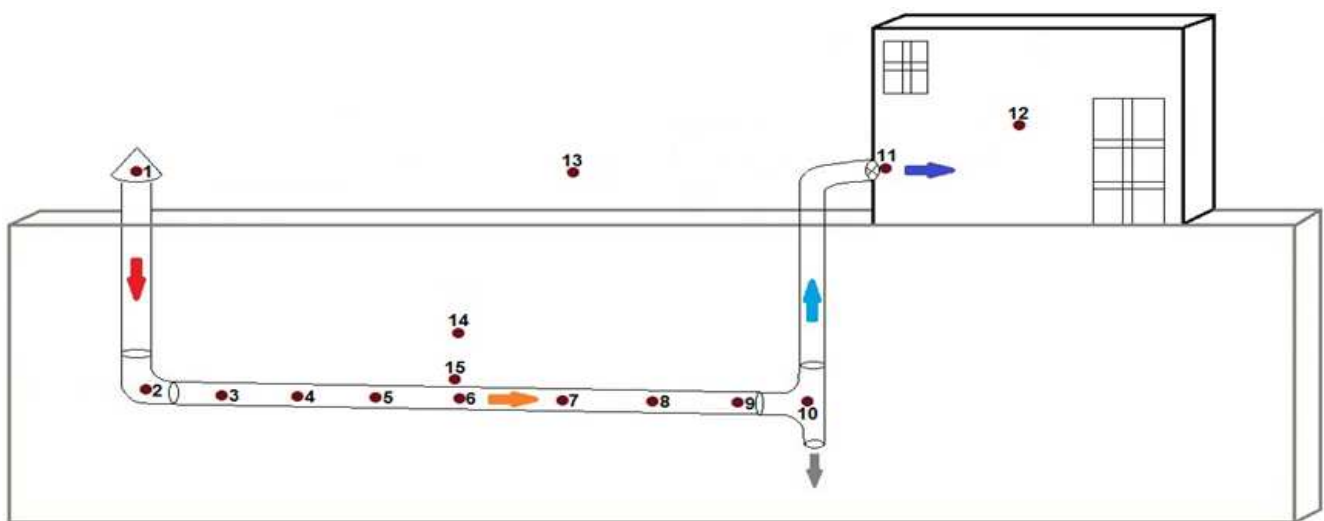| Year	Month	Typical day [12]	Measurement periods
2016	June	11	18 - 24
2016	July	17	14 - 20
2016	August	16	13 - 19
2016	September	15	14 - 20
2016	October	15	12 - 18
2016	November	14	15 - 20
2016	December	10	24 - 30
2017	January	17	14 - 20
2017	February	16	13 - 20
2017	March	16	13 - 18
2017	April	15	11 - 17
2017	May	15	11 - 17

Figure 4. Location of thermocouples on the system.

The measurement periods are recorded in Table 1. These are chosen according to the typical day of each month. A typical day, for a given month, represents the average day.

3. Results and Discussion

In this part, the results obtained during the different experimental measurements are presented.

3.1. Evolution of Temperature in the System in June 2016 and April 2017

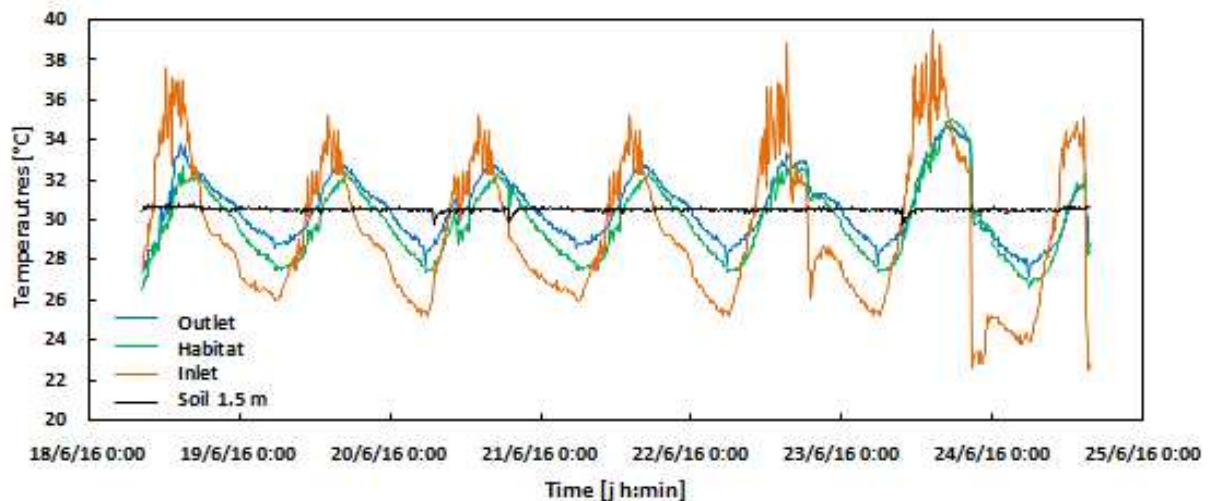Figure 5 shows the evolution of temperatures in the system in June 2016.

Figure 5. Evolution of temperatures from 18 to 24 June 2016.

In Figure 5, that during the day, the amplitude of the air temperature at the entrance is greater than that of the air temperature at the outlet of the exchanger. This is the case of June 23, where the maximum temperature of the air at the entrance is noted at 14h28min and is 39.5°C. On the other hand, the maximum temperature of the air at the exit is noted at 17:08 min and is worth 34.7°C. This means that there is a damping of 4.8°C and a thermal phase shift of 2h40min. This time shift increases heat exchange [13]. We also note that the soil temperature remains almost constant and is about 30.5°C.

The temperature curve of the air in the dwelling has the same profile as that of the air temperature at the outlet of the exchanger. That of the outlet air is less than that of the air in the habitat throughout the day. But during the night, the temperature of the air at the exit is higher than that of the air in the habitat. At night, there is a heating of the air in the habitat. The system must be stop at this time.

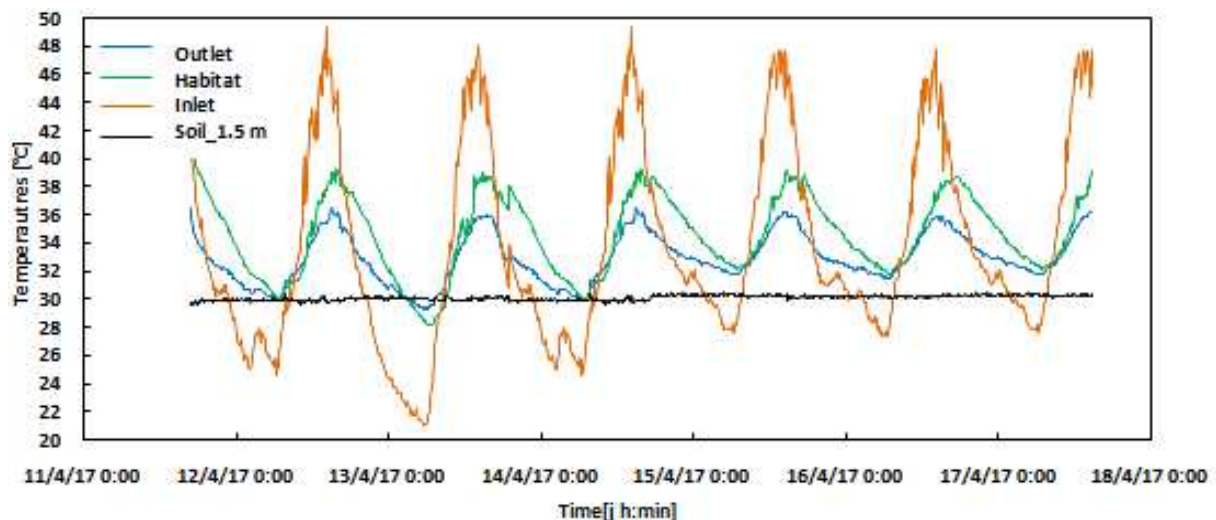Figure 6 shows the evolution of temperatures in the system in April 2017.

Figure 6. Evolution of temperatures from 11 to 17 April 2017.

In Figure 6, we observe that the temperature of the air at the exit of the tube is lower than that of the ambient air during the hot periods of the day. During the month of April, there is a cooling of the air along the tube during the day. On April 14th, the maximum air temperature at the entrance is noted at 14:20 and is 49.4°C. On the other hand,

the maximum temperature of the air at the exit is noted at 3:10 pm and is worth 36.5°C. This means that there is a damping of 12.9°C and a thermal phase shift of 50min. For this same day, the maximum temperature of the air in the habitat is noted at 3:10 pm and is 39.1°C. There is a temperature difference of 10.3°C between the inside and the outside of the habitat. This reflects the influence of the air-ground heat exchanger on the air temperature in the habitat. We also note that the soil temperature remains almost constant and is 30.2°C.

3.2. Evolution of Temperature Along the Tube in June 2016 and April 2017

Figure 7 shows the evolution of the air temperature along the inner wall of the tube in June 2016. For this, we consider for each day, the period at which air temperature at the entrance is maximum.
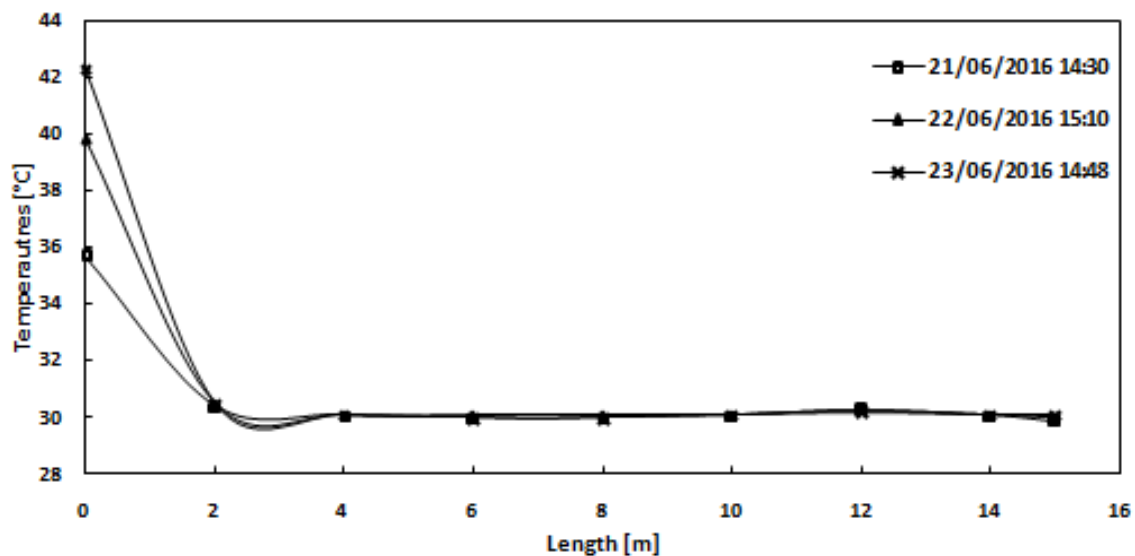

Figure 7. Evolution of temperature along the tube in June 2016.

We observe in Figure 7 that the maximum air temperatures decrease along the tube. These divergent temperatures decrease and homogenize until reaching to 15 m a value of about 30.5°C. A significant drop in temperature (between 6°C and 13°C) is noted. This decrease corresponds to a distance of the entry equal to 15 m. From 4m of travel in the tube, there is a thermal equilibrium between the temperature of the air in the tube and that of the soil (30°C). The appearance of elbow between 2m and 4m of course, is due to the rapid drop in the temperature of the air in the tube. This shows that the convective (forced) exchange of air with the walls of the tube is important at the entrance of the exchanger.

Figure 8 shows the evolution of the air temperature along the inner wall of the pipe in April 2017. For this, we consider for each day, the period at which the air temperature at the entrance is maximum.
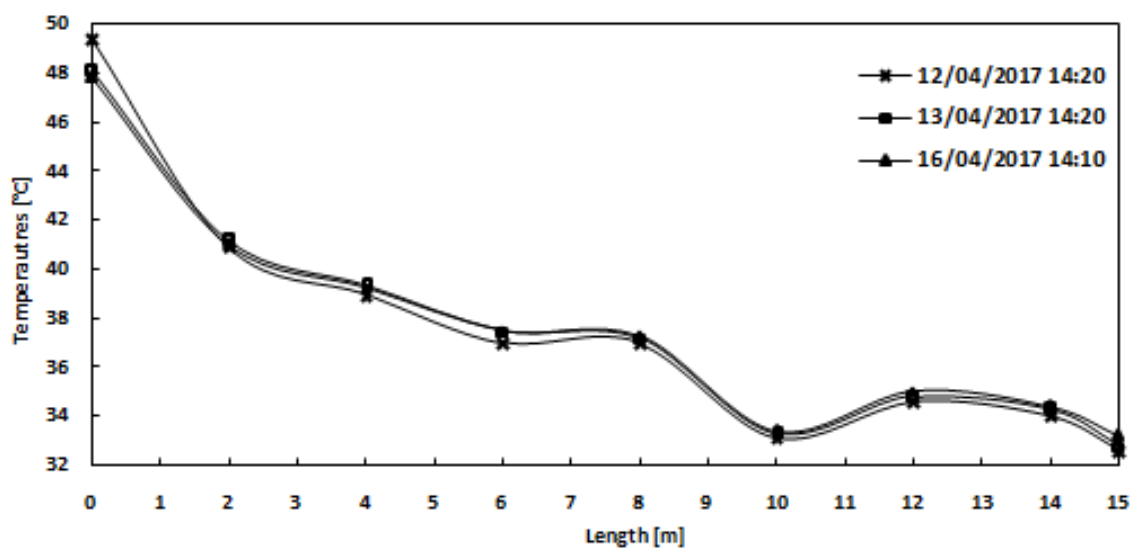

Figure 8. Evolution of temperature along the tube in April 2017.

We observe in Figure 8 that whatever the air temperature at the inlet, it decreases along the tube until reaching 15 m a value of about 33°C. We note a drop in temperature (between 15°C and 17°C). This shows that there is a good cooling of the air along the tube. It should also be noted that all the curves have the same profile and beyond 6 m the temperature of the air oscillates to the exit. For the month of April 2017 we do not note a stabilization of temperatures in the tube.

3.3. Annual Evolution of Temperature in the System

Figure 9, following, describe the annual evolution of the air temperatures at the inlet of the exchanger, the air at the exit, the air in the habitat and the soil at 1.5 m of depth.
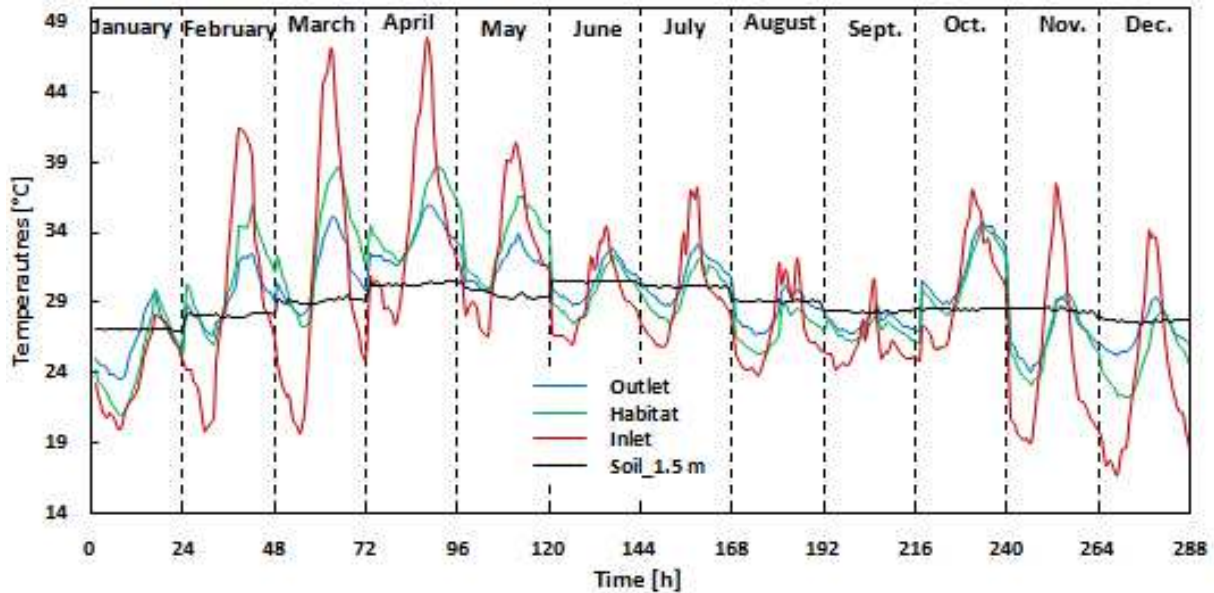

Figure 9. Annual evolution of temperature in the system.

In Figure 9, we observe during the hot periods of the day (during the months of February, March and April) a high difference between the air temperature at the inlet of the heat exchanger and that of the air to the output. In April, this difference can reach 12.9°C. We also note (in April) a difference (cooling) of 10.6°C between indoor air temperature and outdoor air. With regard to the soil temperature, it varies during the year between 26.9°C and 30.5°C. Its minimum value is noted in January and its maximum value is noted in June. During the day, the ground temperature is lower than that of the air at the inlet of the exchanger. This promotes cooling of the air along the tube during the day. On the other hand, at night, the temperature of the ground is higher than that of the air at the entrance of the exchanger. The system therefore operates in heating mode during the night. It is preferable in the Sahelian zone to stop the operation of the exchanger, in order to keep the air of the habitat at a low temperature.

3.4. Evaluation of the Thermal Phase Shift, the Damping of the Air Temperature and the Thermal Efficiency of the ASHE

The thermal phase shift Δt [hour] is a time offset given by the following equation 1:

$$\Delta t = t_2 - t_1 \qquad (1)$$

t_1 the time at which the air temperature at the inlet of the exchanger is maximum;

t_2 the time at which the air temperature at the outlet of the exchanger is maximum.

The damping ΔT [°C] of the air temperature in the exchanger is a temperature difference given by the following equation 2:

$$\Delta T = T_{\max\_entrée} - T_{\max\_sortie} \qquad (2)$$

$T_{\max\_entrée}$, maximal temperature of air at the inlet of t he exchanger;

$T_{\max\_sortie}$, maximal temperature of air at the outlet of the exchanger.

The thermal efficiency ε [%] of the exchanger is a very important parameter that takes into account the temperatures of the air and that of the soil. Its expression is also given by equation 3 [14]:

$$\varepsilon = \frac{T_{entrée} - T_{sortie}}{T_{entrée} - T_{sol}} \qquad (3)$$

Avec:

$T_{entrée}$, temperature of air at the inlet of the exchanger;

T_{sortie}, temperature of air at the outlet of the exchanger;

T_{sol}, temperature of soil.

Table 2 below shows the values of the thermal phase shift, the damping of the air temperature and the thermal efficiency of the ASHE.

Table 2. *Thermal phase shift, the damping of the air temperature and the thermal efficiency of the ASHE.*

Date	Thermal phase shift	Thermal damping	Thermal efficiency
June 23, 2016	2h40	4.8°C	64.44%
July 14, 2016	1h20	6.3°C	72.34%
August 13, 2016	40min	5.1°C	78.46%
Sept. 17, 2016	2h40	4.4°C	54.90%
Oct. 17, 2016	1h10	2.7°C	35.11%
Nov. 17, 2016	50min	11.6°C	83.05%
Dec. 25, 2016	50min	7.2°C	80.22%
January 16, 2017	30min	1°C	32.43%
February 14, 2017	1h20min	11.4°C	70.90%
March 16, 2017	50min	13.1°C	69.63%
April 16, 2017	1h10min	11.9°C	68.00%
May 15, 2017	1h00min	5.9°C	65.25%

In Table 2, we observe that the thermal phase shift and the damping of the air temperature are higher during the hot months than the cold months of the year. On March 16 and April 16, 2017, the thermal phase shifts are respectively 50min and 1h10min. For these same periods, the air temperature damping in the ASHE is respectively 13.1°C and 11.9°C. The thermal efficiency values of the ASHE are higher than 50% during the hot months of the year. According to the literature, this reflects the good functioning and the good quality of the experimental device [15]. For the months of August, November and December, the thermal efficiencies are high. This is explained by the fact that the air temperature at the outlet of the exchanger is close to that of the ground. Indeed, on August 13 at 1:50 pm, the air inlet temperature is 35.7°C, that of the air outlet is 30.6°C and that of the soil is 29.2°C. There is therefore a difference of 1.4°C between the outlet air temperature and that of the soil.

We can thus affirm that the more the difference between the temperature of the air at the exit and that of the soil is weak, the better is the thermal efficiency. According to the work of David Bartolomeu [16], the greater the difference between the air temperature at the inlet and that of the soil, the better the thermal efficiency of the exchanger.

4. Conclusion

In this paper, an experimental study of a Canadian well (or air soil heat exchanger) for cooling the air of a habitat was conducted. The device was made on the physics platform at University Joseph KI-ZERBO. Temperature measurements were conducted during the period from June 2016 to May 2017.

The results obtained allowed to understand the functioning of this system and to analyze its efficiency in terms of thermal comfort. Our results show that the soil temperature varies during the year between 26.9°C and 30.5°C. Whatever the air temperature at the entrance of the ASHE, the temperature at the exit is close to that of the ground. For the months of June, July, October, November 2016, February and May 2017, the temperature drop varies between 5°C and 13°C. For the months of August, September, December 2016 and January 2017, the temperature drop varies between 2.5°C and 9.8°C. For months of March and April 2017, the temperature drop is between 14.6°C and 16.4°C. Thus, in times of high heat the

device damped well the air temperature. These results show that during hot periods of the day (between 11:00 and 16:00), ECAS cools warm air for the habitat. The thermal efficiency of ECAS varies globally between 32% and 84%. In addition, it is above 50% during the hot months (February, March and April) of the year. We also note that the more the difference between the air temperature at the outlet of the heat exchanger and that of the ground is small, the better the thermal efficiency.

Finally, the results show that our experimental setup is of good quality. Indeed, in practice, the thermal efficiency is between 20% and 70%. A heat exchanger of good quality should have a thermal efficiency of at least 0.5 (or 50%) whatever the operating conditions [15].

Acknowledgements

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