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Habitat Cooling by a Canadian Well in Ouagadougou (Burkina Faso): Numerical Approach

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Authors' contributions

This work was carried out in collaboration among all authors. Author BK designed the study and wrote the manuscript. Authors SK and BZ performed the numerical analysis. Author GWPO, MO, VZ, XC and DJB managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

In the Sahelian zone, air cooling in house by air-soil heat exchanger is an alternative in the context of insufficient of electrical energy. This work is about cooling of a habitat in Ouagadougou by numerical approach. Numerical results provided a better understanding of the influence of parameters such as tube length, air velocity and soil temperature on the thermal efficiency of this system. We analyze the effects of parameters such as renewal air flow rate, soil temperature and number of tubes. The results show that during the hot periods of the day, the Canadian well cool air in habitat.

Keywords: Sahelian zone; cooling; house; air-soil heat exchanger.

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1. INTRODUCTION

The Canadian well also called air-soil heat exchanger (ASHE) is a geothermal system that uses the thermal inertia of the soil to heat or cool a part of the air intended for a habitat. The principle consists to inject into a habitat, an air flow from outside that is forced beforehand to flow in a pipe buried at a certain depth in the soil [1,2]. It is considered as a green energy technology of tremendous potential for building energy supply [3,4]. As the main equipment in the system for heat transfer, the soil heat exchanger transfers heat between fluids in the tube and surrounding soils [5,6].

The Sahelian zone is characterized by a very high temperature, a large part of the year. Moreover, humidity of air is weak. To provide thermal comfort during the hot periods of the year like March, April and May, people uses generally the electric air conditioning which is expensive and difficult to access. Faced with this situation, the Canadian well presents itself as an alternative to cool the habitat. In Burkina Faso, B. Kaboré et al. [7] carried out an analytical study of the operation of an air-soil heat exchanger in the meteorological conditions of the city of Ouagadougou for the year 2014. The results made it possible to understand the influence of certain parameters (the soil depth, the length of the tube and the air flow rate…) on the annual operation of the air-soil heat exchanger. These results also showed that this system responds favorably to Ouagadougou meteorology.

The Canadian well has been the subject of many works, both numerical and experimental. One of the works of Hollmuller [8] is, today, one of the main references in the domain of Canadian well (or air-soil heat exchangers). Based on a thorough theoretical modeling but also on many in-situ measurements, the author establishes simple rules for the design of air-ground heat exchangers. One of the references also in the field of air-ground heat exchangers is the work of Stéphane Thiers [9]. The author has made a mathematical model that gives the soil temperature at any time and at any depth, taking into consideration the thermal behavior of the soil. In Burkina Faso, Woodson et al. [10] carried out an experimental study of the evolution of the soil temperature in the case of an air-ground heat exchanger. They showed that at 1.5 m depth, the soil temperature was approximately 30.4°C. The many good of numerical study performed by David Amitrano [11], propose objective criteria for the choice of parameters of heat exchange by forced convection in a buried tube.

The aim of our work is to evaluate from the physical parameters (the renewal air flow rate, the soil temperature, the number of tubes), the effect of the Canadian well on the habitat cooling during the hot periods of the day.

2. MATERIALS AND METHODS

2.1 Description of the Cooling System

The cooling system consists of a poly vinyl chloride (PVC) pipe (U-type) of horizontal length 15 m, diameter 16 cm and placed at a depth of 1.5 m (slope of approximately 2%) in the soil. The habitat is made of cement block and metal roofing. The following Fig. 1 describes the system [12].

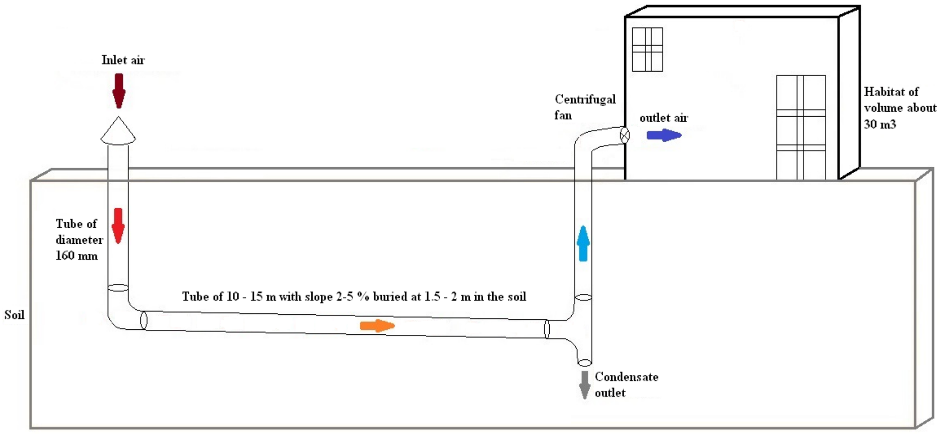


Fig. 1.Scheme of the system ASHE-habitat

Table 1. Thermal and physical properties of materials of habitat [13-15]

Materials	Density (kg m^{-3})	Thermal conductivity (W m^{-1} K^{-1})	Thermal capacity (J kg^{-1} K^{-1})
Wall	1000	0.83	1000
Roof	7800	50	450

In theory as in practice, there is a possibility to consider several tubes (2, 3 or 4 tubes) in the same condition as that of Fig. 1.

Table 1 gives the thermal and physical properties of the materials.

2.2 Mathematical Formulation

The scheme of thermal exchanges in the habitat is described in Fig. 2.

The mathematical model is constructed on the nodal method.

The energy balance at the component i of the habitat can be written as:

$$e_i \rho_i c_{pi} \frac{dT_i}{dt} = DFSA_i + Q_{mi} + \sum_j \sum_X h_{Xij} (T_j - T_i) \qquad (1)$$

$DFSA_i$: Density of solar flux absorbed by (i) (W m-2)

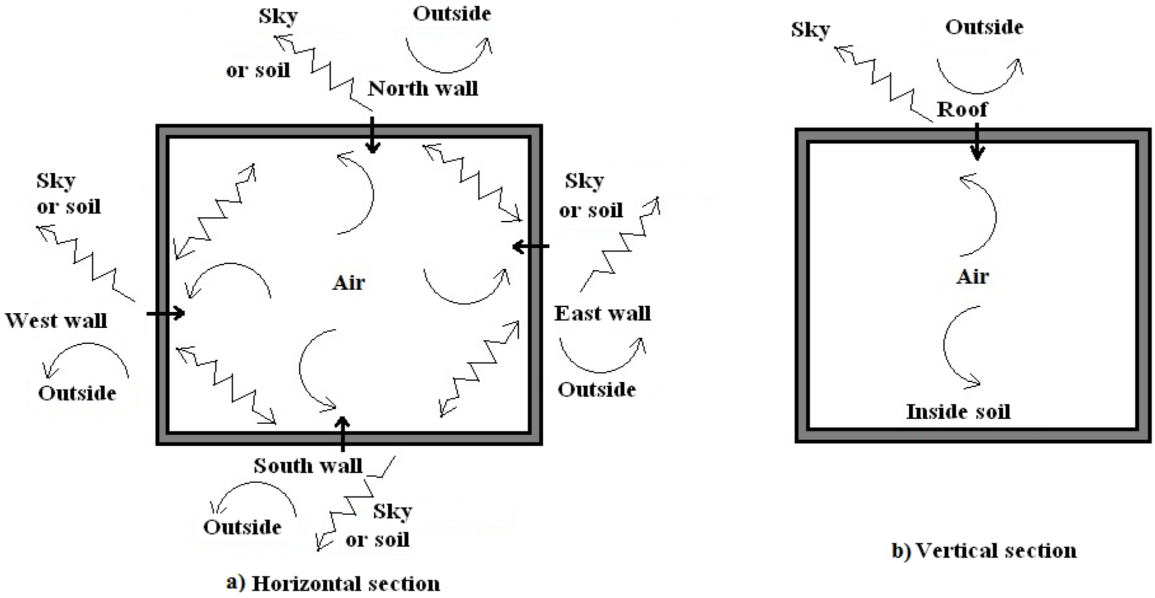
Q_{mi} : Mass flux density exchanged in (i) (W m-2)

h_{Xij} : Coefficient of heat exchange between (i) and (j) (W m-2 K-1)

We apply equation (1) to the various environments of our system. Mass transfers are not counted.
The heat transfer coefficients by convection or radiation are calculated using correlations reported in literature.

We use a finite difference method implicit as in the case of the air-soil heat exchanger. In order to reduce the calculation time, we choose 300 seconds like time step. We solve the difference equations by the method of Gauss, choosing a precision equal to 10^{-3}.

This choice is completed by the following initial conditions: the unknown temperatures are assumed to be equal to the ambient air temperature.



a) Horizontal section

b) Vertical section

Fig. 2. Scheme of thermal exchanges in the habitat

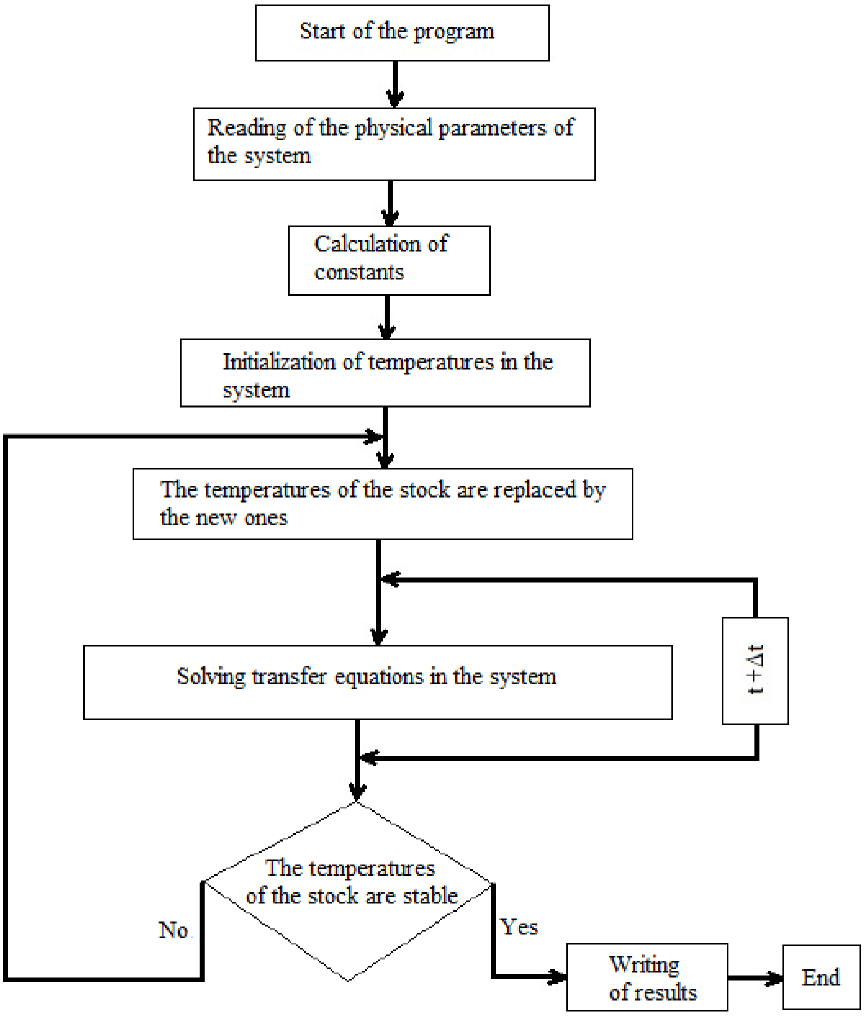


Fig. 3. Algorithm of simulation program

The program is run using the FORTRAN calculation code. We perform a habitat coupling with an air-to-ground heat exchanger (ASHE) for cooling the air. This allows us to study the influence of the heat exchanger on the thermal behavior of the habitat during a year. The meteorological data used concern the average hourly ambient air temperature for the city of Ouagadougou from 2014. These data are measured in the meteorological station. They are integrated into the simulation program.

3. RESULTS AND DISCUSSION

3.1 Effect of Canadian Well on Habitat Cooling

For this part, the values attributed to the parameters are as follows:

- Average soil temperature at 1.5 m depth: 302.1 K;
- Tube length: 15 m;
- Habitat volume: 32.8 m^3;
- Air flow rate of Canadian well: 257.8 m^3/h.

The simulations led to the following results on Fig. 4.

Fig. 4 shows that during the hot periods of the day,between 10 am and 6 pm, the air temperature in the habitat with Canadian well is lower than that without Canadian well. For the month of April at 12 am, the ambient air temperature is 309.19 K. At the same time, air temperature in the habitat without exchanger is 313.79 K and that with exchanger is 307.29 K. Thus, the Canadian well contributes to the cooling of the air inside the room by decreasing the temperature of 6.5 K. During the hot periods of the day, between 10 am and 6 pm, the

Canadian well contributes to cool the air in sufficiently reducing the air temperature in habitat.

These values show additional supply of heat to the air by Canadian well.

For the rest of the work, we will focus on the month of April. Indeed, it is the hottest month in Burkina Faso [16]. On Fig. 4, we find also that among all the months, it is during April that the cooling by the Canadian well is more important.

3.2 Effect of the Renewal Airflow

The values attributed to the parameters are as follows:

- Average soil temperature at 1.5 m depth: 302.1 K;
- Tube length: 15 m;
- Habitat volume: 32.8 m^3;
- Air flow rate of Canadian well: 98.4 m^3/h; 164 m^3/h; 257.8 m^3/h.

We varied the rate of renewal air from the Canadian well in order to observe its effect on the cooling of the habitat. The results obtained are given by the Fig. 5.

Fig. 5 shows that during the hot periods of the day, between 10 am and 6 pm, the temperature of the air in the habitat decreases, as the renewal airflow increases. For the month of April at 12 am, the ambient air temperature is 309.19 K. At the same time, for air flows rate of 98.4 m^3/h, 164 m^3/h and 229.6 m^3/h the air temperatures in the habitat are respectively 310.02 K, 308.56 K and 307.61 K. We notice that air flow rate of 98.4 m^3/h is not sufficient for Canadian well to cool habitat air, because the renewal air is warmer than the surrounding air. On the other hand, for a air flow rate of 164 m^3/h or 229.6 m^3/h, the Canadian well cools the air in the habitat with a decrease of 0.63 K or 1.58 K.

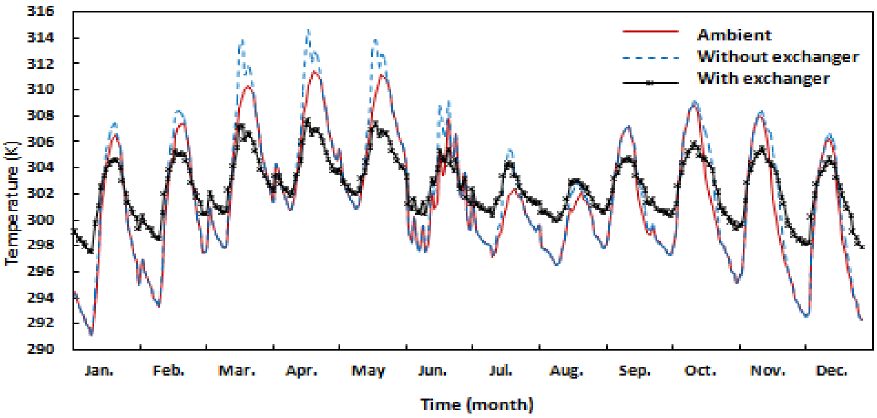


Fig. 4. Effect of Canadian well on air temperature in habitat during a year

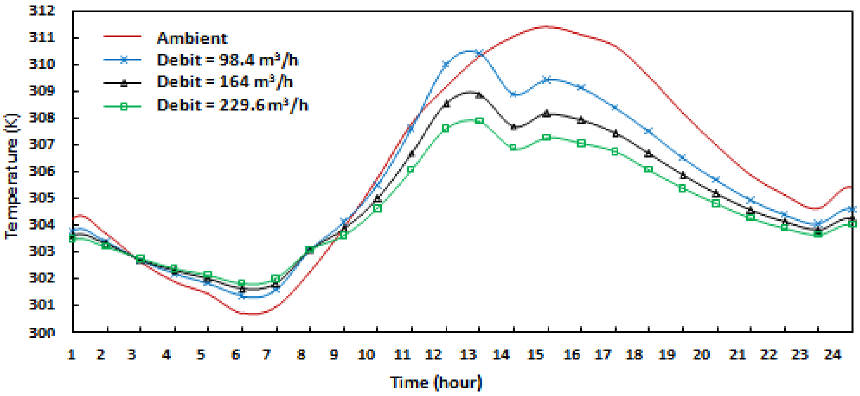


Fig. 5. Effect of the renewal airflow on air temperature in habitat during April

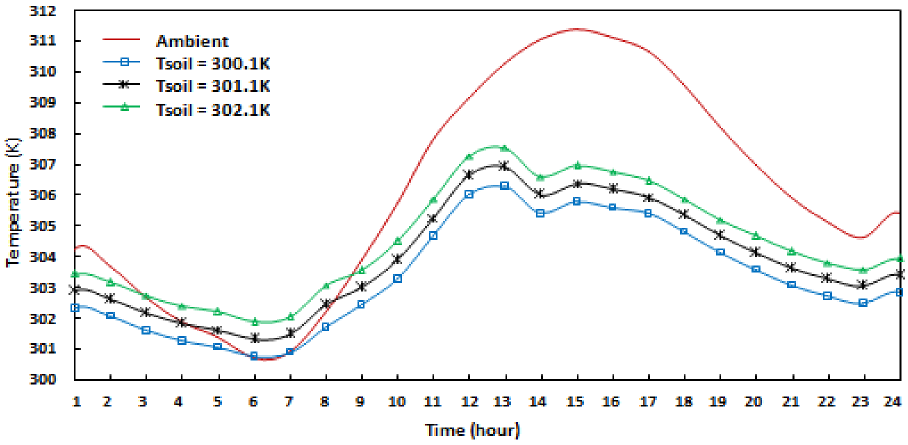


Fig. 6. Effect of soil temperature on air temperature in habitat during April

3.3 Effect of Soil Temperature

In this part, the values attributed to the parameters are as follows:

- Tube length: 15 m;
- Habitat volume: 32.8 m^3;
- Air flow rate of Canadian well: 257.8 m^3/h;
- Soil temperature: 300.1 K; 301.1 K; 302.1 K.

We varied the soil temperature in order to observe its effect on the cooling of the habitat.

The simulations led to the following results on Fig. 6.

Fig. 6 shows that during the hot periods of the day, between 10 am and 6 pm, the temperature of the air in the habitat decreases, as the soil temperature decreases. For the month of April at 12 am, the ambient air temperature is 309.19 K. At the same time, for soil temperatures of 300.1 K, 301.1 K and 302.1 K, the air temperatures in the habitat are respectively 306.03 K, 306.66 K and 307.29 K. These results show that the temperature of the soil greatly influences that of the air in the habitat. This is explained by the fact that the temperature of the renewal air is depending of the soil temperature. The choice of this parameter must be made from a compromise between the depth of the search and the cost of the investment.

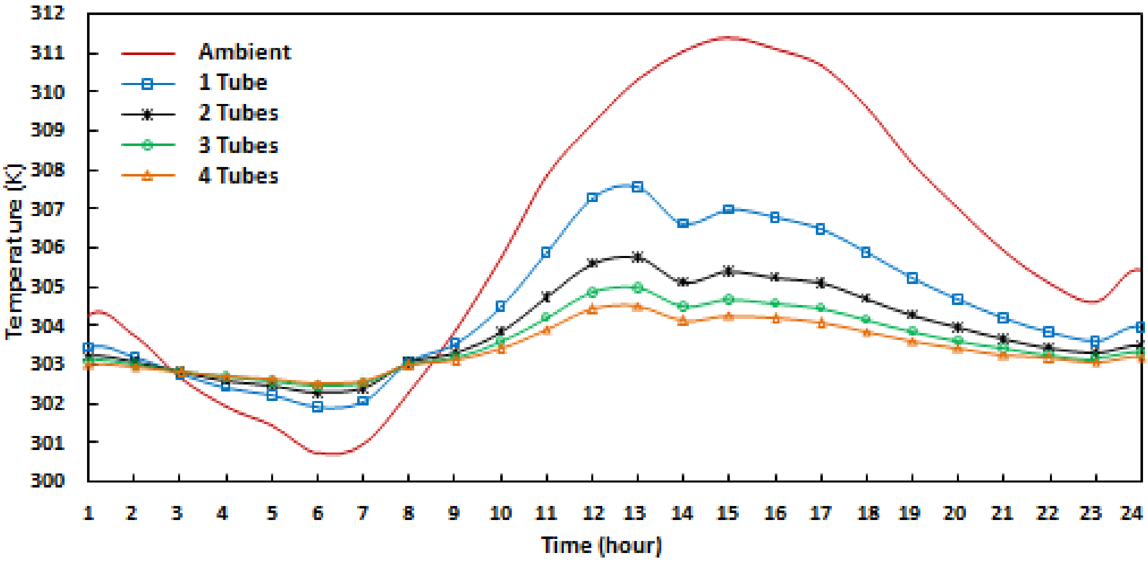


Fig. 7. Effect of number of tubes on air temperature in habitat during April

3.4 Influence of the Number of Tubes on the Temperature of the Air in the Habitat

Since there is a possibility of having several identical tubes in parallel (2, 3 …)in the same configurations as that of Fig. 1, we simulate their effect on the cooling of the habitat. This is intended to reinforce the cooling capacity of the Canadian well.

The values attributed to the parameters are as follows:

- Average soil temperature at 1.5 m depth: 302.1 K;

- Tube length: 15 m;
- Habitat volume: 32.8 m^3;
- Air flow rate of Canadian well: 257.8 m^3/h.

We varied the number of tubes in the Canadian wellin order to observe its effect on the cooling of the habitat. The results obtained are given by the Fig. 7.

Fig. 7 shows that during the hot periods of the day, between 10 am and 6 pm, the temperature of the air in the habitat decreases, as the number of tubes increases. For the month of April at 12 am, the ambient air temperature is 309.19 K. At the same time, for 1tube, 2 tubes, 3 tubes and 4 tubes the air temperatures in the habitat are respectively 307.29 K, 305.61 K, 304.86 K and 304.43 K. The number of tubes influences significantly the temperature of the air in the habitat.

4. CONCLUSION

In this paper, we evaluated from the physical parameters (the renewal air flow rate, the soil temperature, the number of tubes), the effect of the Canadian well on the habitat cooling during the hot periods of the day in Ouagadougou.

Transfers equations are been solved by using an implicit numerical scheme and the method of Gauss with an iterative procedure. We applied to the habitat, the numerical code written in Fortran language. For this, we used weather data from Ouagadougou for the period from 1992 to 2001.

Our results show that during the hot periods of the day, especially between 10 am and 6 pm:

The air temperature in the habitat with Canadian well is lower than that without Canadian well.

The temperature of the air in the habitat decreases, as the renewal airflow increases.

The temperature of the air in the habitat decreases, as the soil temperature decreases.

The temperature of the air in the habitat decreases, as the number of tubes increases.

All of these results show that during the hot periods of the day, the Canadian well contributes to the cooling of the air in the habitat. The studied parameters (the renewal air flow rate, the soil temperature, the number of tubes) have considerable effects on the cooling by the Canadian well. Therefore, the choice of optimal values for these parameters will increase the thermal performance of the system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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