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Research Article

Experimental study of a stand-alone earth to air heat exchanger for heating and cooling in arid regions

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ABSTRACT

Earth to air heat exchanger EAHE is a renewable technique based on a geothermal source. Arid regions are characterised by hard winter and summer weather conditions, which lead to a large thermal discomfort for the big part of the year. In this paper, we study by experiments the performance of stand-alone earth-to-air heat exchanger without external devices (fans, etc.), but only with the local climatic conditions of the region of Bechar (located in the Southwest of Algeria). The EAHE contains a PVC pipe with 66 meters of length and 110 mm of diameter, and it is buried at a depth of 1.5 m in an agriculture zone, where the annual undisturbed sub-soil at 1.5 m is 28°C. The stand-alone EAHE has the capacity to raise the air temperature by 10°C in the heating regime and reduce it by 11.9°C in the cooling regime. Furthermore, the relative humidity is raised by19% in the humidification regime and reduced by 27% in the dehumidification regime. The daily working regime was: 62.5% of heating (from 00h to 08h and from 18h to 23h) and 37.5% of cooling (from 09h to 17h) for the thermal regime, 62.5% of dehumidification (from 00h to 09h and from 18h to 23h) and 37.5% of humidification (from 10h to 17h) for the hygrometric regime. The stand-alone EAHE technique presents a great potential for the pre-heating, pre-cooling, and natural ventilation of dwellings and buildings in arid regions.

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INTRODUCTION

Arid regions like the South of Algeria are known for a large period of discomfort, which requires at least five months of cooling (from May to September) in the summer season. The use of HVAC (Heating, Cooling, and Air Conditioning) system leads to 40% of energy consumption rising in the building sector only. For the winter season, the temperature drops sometimes under 5°C (and sometimes under zero). It is important also to heat in the winter to reach the thermal comfort requirements in these regions. The major amount of this energy consumption is covered by fossil energies, where the conversion of renewable energies will be beneficial on the economic, environmental, and social aspects.

The South of Algeria is known for its potential for solar energy, wind energy. However, geothermal energy is less known in comparison with other renewable energies and it should be investigated.

The new vision of Algeria 2030, is based on renewable energies and their integration in electrical energy production and also for thermal comfort. The 2030 energy efficiency program covers all sectors of big consumption: construction, transport, and industry to reduce the consumption by 9% through the introduction of high-performance equipment and technologies. The high-energy performance buildings are also considered in this program by integrating the sun, wind, and geothermal in the designing process, which is called bioclimatic architecture. In addition, the building thermal insulation takes a big part of this program by using the Phase Change Material (PCM), Nano-Encapsulated Phase Change Material (NEPCMs), and local materials. PCM can promote insulation and thermal energy storage in both summer and winter [1–5]. It is a substance that releases/absorbs sufficient energy at the phase transition (solid to liquid or vice versa) to provide thermal insulation. PCM reduces the electricity cost;it is easy to be coupled with the building envelope with adepreciation price of the installation costs.

EARTH TO AIR HEAT EXCHANGER

Used since 3000-years B.C. [6–10], the earth to air heat exchanger EAHE technique is old heating, cooling, and natural ventilation strategy that is integrated not only in the buildings and living space but also in the food storage places. Just like Ground Air Collector (GAC) and earth air tunnel, the conception of the earth to air heat exchanger EAHE is very simple. A number of pipes that are made of local materials (clay, Polyvinyl chloride or PVC, steel, etc.) are buried underground at a defined depth, where the sub-soil undisturbed temperature stays constant around the year. The outside air enters from the inlet section of EAHE, it submits a thermal exchange (by convection) with the sub-soil by the medium of pipe material during its passage inside the device. We note that the pipe material should have good thermal conductivity. The outlet air gains some degrees in the winter ($T_{soil} > T_{outside\ air}$) and loses some degrees ($T_{soil} < T_{outside\ air}$) in the summer. As a result, we get natural pre-heating or heating in the winter season, pre-cooling or cooling in the summer season, natural ventilation and, reduced energy consumption for thermal comfort. EAHE can be coupled with other renewable energy techniques, such as the solar chimney, photovoltaic panel, etc. [11–13].

There are two configurations of EAHE: open loops (where the inlet and outlet sections are connected only by the pipe), and closed loops (where the inlet and outlet sections are connected by the pipe and the structure).

The heat transfer enhancement between the soil and air inside the tube is the major key EAHE success. Ghalambaz et al. [14] and Mehryan et al. [15–16] provide some useful tools to achieve this goal. Many investigators addressed the heat transfer characteristics and the fluid flow in various heat exchanger configurations under different limit conditions by using analytical, numerical, and experimental models. For example, see Zhu et al. [17], Vaza et al. [18], Kumar et al. [19], Ghosal et al. [20–23], Pongsoi and Wongwises [24], Tittelein et al. [25], Ramírez-Dávila et al. [26], Doğan and Erbay [27], Shukla et al. [28], Sharma et al. [29], Chel et al. [30], Diaz-Mendez et al. [31], Ravisankar et al. [32], Thiers et al. [33], Shukla et al. [34], Kumar et al. [35], Misra et al. [36–37], Darius et al. [38], Pourfayaz et al. [39], Oudjehani et al. [40], Menni et al. [41–43], Maurya and Singh [44], Sakhri et al. [45,50], Anand et al. [51], Ameur and Menni [52], and Mohapatra et al. [53].

For the EAHE research, Bansal is considered among the first researchers who talked about this technique in many research papers [54–56]. Bansal et al. [57] studied the effect of the soil type with different values of conductivity (0.52, 2.0, and 4.0 W/m.K) on the efficiency of air-ground heat exchanger with 100 m length, 0.2 m diameter, and air velocity of 5 m/s in the hot and dry region of Ajmer (India). They found that the air outlet temperatures were

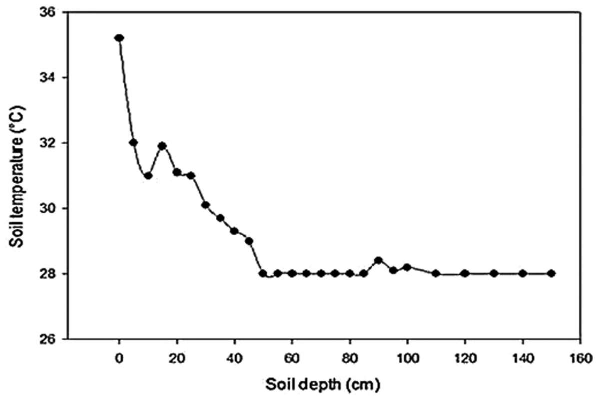

Figure 1. Site study vertical underground temperature profile 'September 2018'.

equal to 18.4°C, 18.7°C, and 18.4°C for thermal conductivities of 0.52, 2, and 4 W/m. K, respectively. Maerefat and Haghighi [58] and Mohammed et al. [59] studied the coupling of the EAHE with a solar chimney in the same building.

Li et al. [60] conducted an experimental investigation between May and August 2017 on the EAHE technique in China.They found a direct relationship between thethermal characteristics of soil and earth to air heat exchanger performance in the cooling purpose. The temperature drop by 14.6°C at the outlet section and the total cooling capacity was 8792 W.

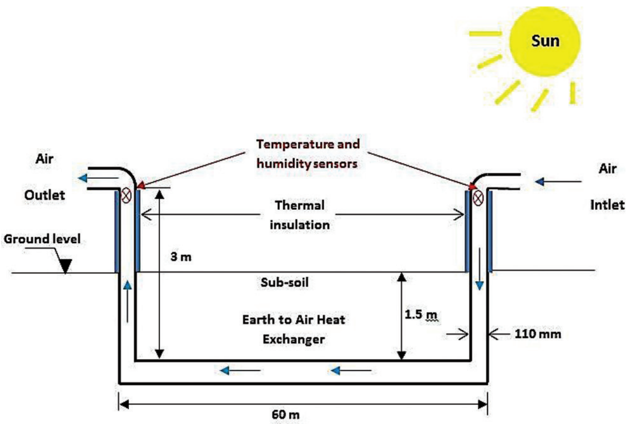

Figure 2. Experimental set-up of the stand-alone earth to air heat exchanger.

In this paper, the potentials of stand-alone earth air heat exchanger in the region of Béchar are investigated by experiments. The region of the study, which is located in the North-west of the city of Béchar, is classified as an agricultural zone activity. The vertical temperature profile of the site for September 2018 is presented in Figure 1. At a depth of 1.5 m, the annual undisturbed sub-soil temperature is 28°C.

STAND-ALONE EAHE EXPERIMENTAL SET-UP

The site of the study is located in an agricultural zone having sandy loam soil without treatments (see Figures 2 and 3).The characteristics of the experimental device are described as follow:

- PVC tube with a good thermal conductivity (λ = 0.2 W/m.K).
- The thickness of the PVC tube is 2 mm.
- Elbow: PVC elbows (110 mm of diameter) serve as inlet and outlet sections.
- The length of the underground horizontal tube is 60 m.
- The length of the vertical tube is 3 m for each part, where ½ of it is underground.
- Working fluid: atmospheric air.
- The inlet section is oriented in the direction of prevailing winds, and the outlet section is oriented in the opposite direction.

Figure 3. Stand-alone EAHE preparation.

– The vertical parts of the EAHE device are thermally insulated to eliminate the chimney effect.
– An openloop system is used.
– The depth of buried pipes is 1.5 m underground.
– The site altitude is 806 m.

To measure the EAHE effects, DL-53 wireless temperature and relative humidity sensors were placed at the inlet and outlet sections of EAHE (Figure 2).For the region of the study, 3.7 m/s was the annual mean wind speed. Figure 4 presentsthe mean wind speed across 30 years for the Béchar region (November 1977 to 2006). This important resource will be the driving force for the air circulation inside the device without any contribution of fans or other exterior devices. The inlet section has faced the North and the outlet section is directed to the South.

RESULTS AND DISCUSSION

The study of a stand-alone EAHE in arid regions is a combination of temperature and humidity analysis. The inlet of the earth to the air heat exchanger is exposed directly to the sunlight, which explains the higher temperature (39°C). But, even with this high temperature, the EAHE had the capacity to reduce this value until 27.6°C at the outlet section, which corresponds to a decrease by 11.4°C (Figure 5).

For the variation of the inlet temperature difference [Max-Min], the mean temperature was 32.14°C. The outlet section was characterised by 22.6°C for a temperature difference [Max-Min], which indicates the capacity of the system to stabilise this variation from 32.1°C at the inlet to 22.6°C at the outlet (approximately 9.54°C).

The analysis of the inlet temperature variation indicates how the outside climatic conditions such as air temperature and humidity, sunlight, and wind velocity can cause such variation from 36 or 37°C at 10 o'clock in the morning to 4°C in the early morning and night time, see Figure 6. For the outlet, the variation between the day's highest temperature is 29.3°C in and the lowest (7 to 8°C) during the nighttime was 22.6°C, which is more stable in comparison with the inlet. EAHE acts as a thermal regulator reducing the outlet temperature difference between the maximum and minimum values throughout the day.

To explain the EAHE capacities, the hourly mean temperature $\Delta T = T_{inlet} - T_{outlet}$ is calculated (Figure 7). The analysis of the difference in hourly mean temperature from day 1 to day 8 present the following working regime:

To describe the stand-alone earth to air heat exchanger working regime in an arid region, the daily mean temperature differences between the inlet and outlet sections are calculated. Twenty-four hours of the thermal behaviour of the experimental device from day 1 to day 8 show clearly the major behaviour of the stand-alone EAHE for the

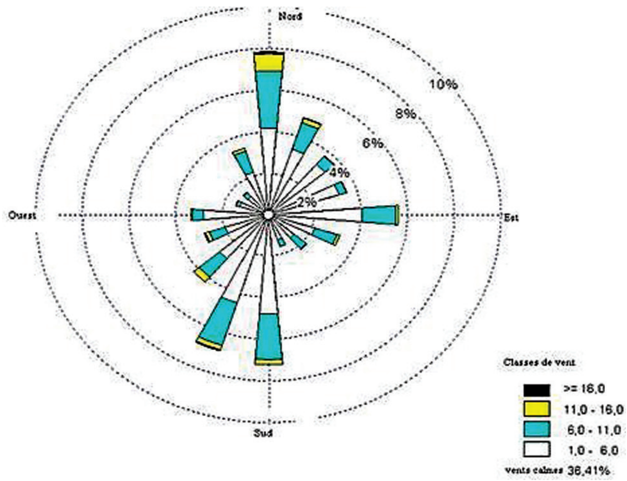

Figure 4. Wind rose of Béchar city – November (1977–2006) [49].

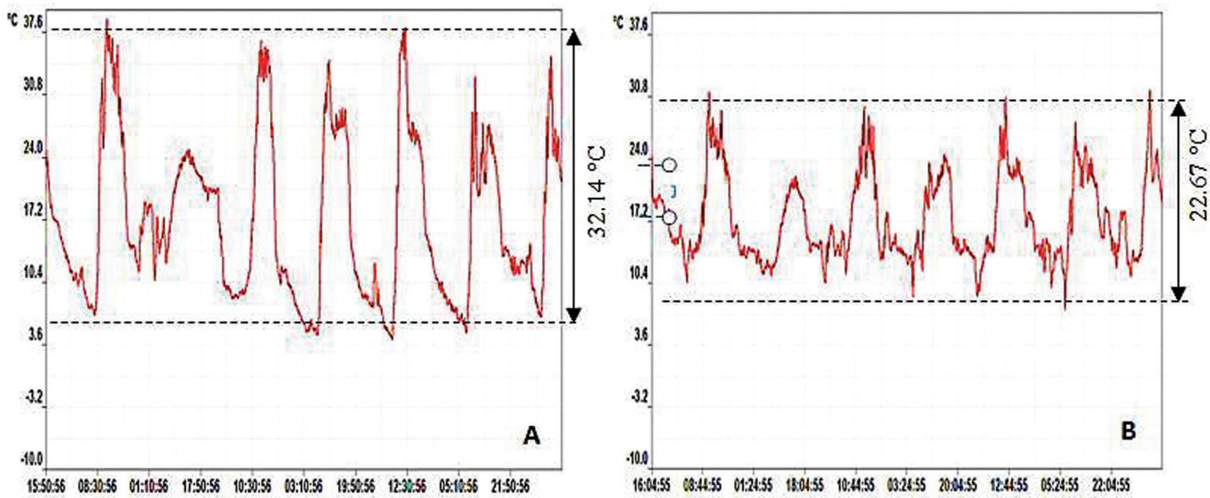

Figure 5. EAHE inlet (A) and outlet (B) [Max-Min] air temperature values (°C).

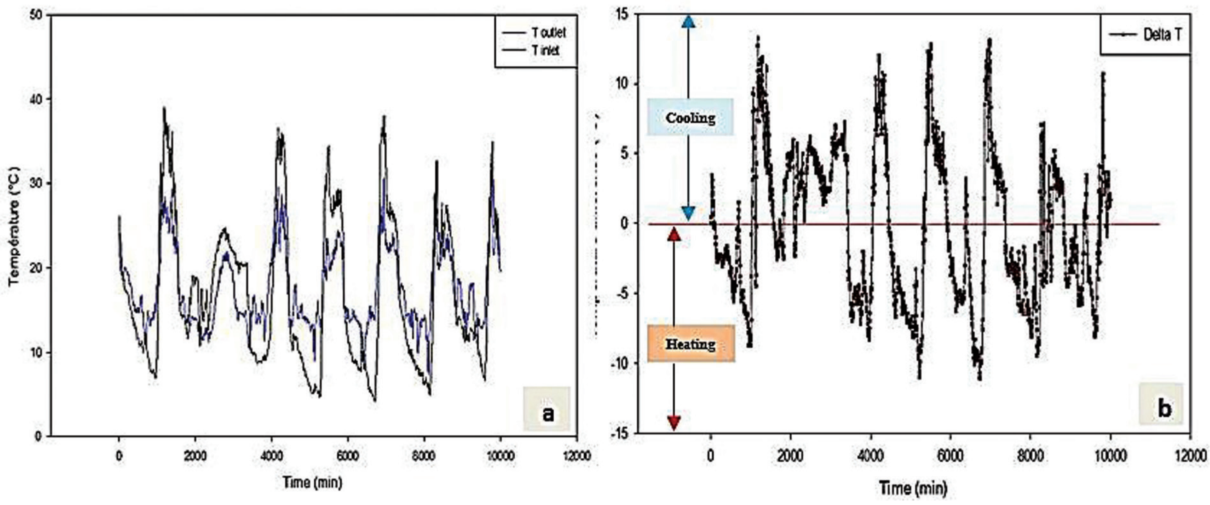

Figure 6. EAHE inlet and outlet temperature (left) and $\Delta T=T_{inlet}-T_{oulet}$ (right).

winter season. Day 3 makes the exception due to the big dependence on the local climate.

From 00h to 08h: in the early morning ΔT was negative ($T_{outlet}> T_{inlet}$), the outside air entering from the inlet is passing through the EAHE and becoming warmer (by 4 to 9°C). This regime presents the heating regime.

From 09h to 17h: because of the sunlight, the upper part of the pipe and the outside air become warmer. Passing inside the EAHE, the air loses some degrees and ΔT becomes positive ($T_{outlet}< T_{inlet}$). That's led to a cooling mode.

From 18h to 23h: After the sunset, the outside air temperature reduces. The system was able to rise the outlet temperature by 2 to 5°C in a heating regime.

For day 3, ΔT was positive during all the days ($T_{outlet} < T_{inlet}$) and the cooling regime was the only regime (a reduction in temperature by 0.5 to 6°C). This exception can be explained by the irregular blowing regime of winds during this day and sometimes Vwind ≈ 0 m/s.

It is also remarked that, generally, the air relative humidity that leaves the device changes with the change in inlet air temperature.The relative humidity in humidification is characterised by a maximum of 19% in the best case, and it is reduced in dehumidification phenomena by 27% in the best case.

CONCLUSION

Geothermal presents an advantageous energy source that can be used for many purposes, such as the production of electrical or thermal energy, use as a heat source or sink for building heating and cooling and many other applications. Based on the previous experimental measurements in the same site of the study, the annual undisturbed subsoil temperature of the site was found to be about 28°C. In our paper, an experimental study of a stand-alone earth to air heat exchanger EAHEthat works naturally without any exterior devices was performed. The purpose was to explore the performance of the EAHE under weather conditions(sun, air temperature and humidity, and wind speed). The obtained results showed the big potential of the stand-alone earth-to-air heat exchanger for the pre-heating or heating, pre-cooling or cooling, and natural ventilation of dwellings and buildings in arid regions. At the inlet and outlet sections of EAHE, values of the temperature were, respectively, as follows:

$T_{inlet\ min}$= 4.2°C (day 6) and $T_{inlet\ max}$ = 39°C (day 2), $T_{outlet\ min}$= 7.4°C (day 6) and $T_{outlet\ max}$ = 31.5°C (day 8). These results show clearly the range in which the system works without any contribution of an exterior device. The daily thermal analysis of the stand-alone EAHE showed that the daily work regime of the system is as follow:

From 00h to 08h: Heating regime

The outside air temperature was low, it entered from the EAHE inlet and passed through the device. The air temperature raised during its passage due to the thermal exchange between the air and the sub-soil by the medium of PVC pipe. Reaching the outlet, the air temperature raised by 4 to 9°C.

From 09h to 17h: Cooling regime

The outside air warmed up and the upper part of the EAHE inlet was exposed directly to the sunlight. The inlet air temperature reached sometimes 39°C. EAHE was able to reduce the outlet air temperature by 0.5 to 11°C.

From 18h to 23h: Heating regime

After the sunset and the reduction of outside temperature, the EAHE reduced the outlet temperature of air by

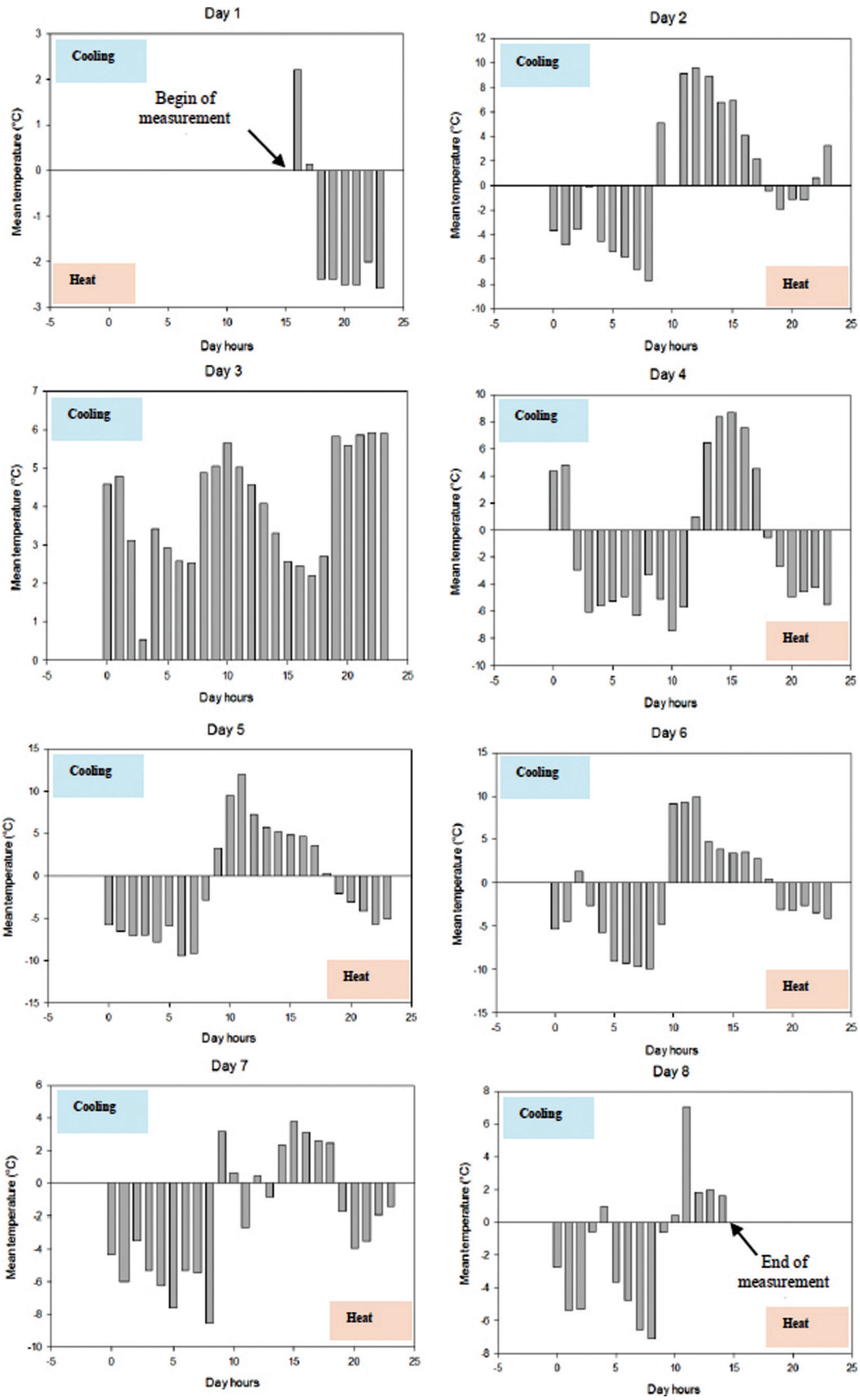

Figure 7. Daily mean temperature difference $\Delta T = T_{inlet} - T_{outlet}$.

approximately 0.4 to 5.5°C. This phase serves as a preparation for the next phase (00h to 08h).

Day 3 was characterised by a Cooling-Humidification regime for all the day, which confirmed the big dependence of the EAHE on weather conditions. If the wind changes its direction or the day was cloudy, the outlet parameters like temperature and humidity change also.

In an arid region and during the winter season under normal and ordinary climatic conditions (sunny day, wind blow in prevailing wind direction, normal exterior temperature and humidity), the stand-alone EAHE works in 24 hours as follow: 62.5% (heating) and 37.5% (cooling) for the thermal regime.

Stand-alone Earth to Air Heat Exchanger without any contribution of an exterior device like fans has given the following results and advantages:

- Increase of the air temperature by 10°C in the heating regime
- Reduction of theair temperature in the cooling regime by 11.9°C
- The EAHEreduced the relative humidity by 62.5% (RH_{outlet} < RH_{inlet}) generally between (00h to 09h and 18h to 23h) and increased it by 37.5% (RH_{outlet} > RH_{inlet}) between (10h to 17h).
- Creation ofthe dehumidification and humidification regimes in the same day, but this situation could lead to the development of micro-organisms inside the buried tube by condensation.
- Reduction of the need for fan or blower and reduce energy consumption.
- The system is 100% ecological, natural and renewable with zero green-house gases.

The EAHE technique seems much promoted for the pre-heating, pre-cooling, and natural ventilation of dwellings and buildings in arid regions.

For the next step of the study, earth to an air heat exchanger with solar protection of the upper part to eliminate the direct sunlight effect will be studied. For future works, a real scale room will be realised, where the earth to air heat exchanger will be connected to study its ability to enhancement of the inside thermal comfort in arid regions.

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AUTHORSHIP CONTRIBUTIONS

Concept: N. Sakhri; Design: N. Sakhri; Supervision: N. Sakhri.; Materials: N. Sakhri; Data: N. Sakhri; Analysis: Y. Menni; Literature search: Y. Menni; Writing: H. Ameur; Critical revision: A. J. Chamkha.

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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