

Enhancing thermal comfort in residential buildings: assessment of a passive cooling system in a hot temperate climate

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Abstract. The thermal efficiency corresponding to an earth-to-air heat exchanger (EAHE) of $d = 40$ mm diameter, in the temperature climate zone similar to Beni Mellal, has been presented. This paper's focus to determine the exact length of pipe that is required to reach desired comfort conditions in the exit of this system. TRNSYS software is used for detailed simulation of these summer characteristics. The results are encouraging; on the hottest day in July, EAHE reduces the air temperature at the inlet from 44.6 °C to an outlet temperature of about 27.85 °C producing a total cooling around 16 °C.

Keywords: Energy efficiency, buildings, thermal Performances, passive cooling, earth-air heat exchanger, TRNSYS.

1 Introduction

The world's population and economy are growing so rapidly, and the energy security pollution-governance challenges we face have become so serious that researchers are being forced to consider alternative revolutionary systems of energy management in our search for a sustainable future. Heating and cooling contribute to around 32% of the global final energy consumption today. By 2050, it's estimated that global air conditioning demand (AC) will grow from today's 1.6 billion units to a staggering 5.6 billion units, which means it would put an additional strain on electricity consumption being almost triple the current number of consumption.

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The widespread use of conventional air conditioning, ventilation and heating systems has major disadvantages, such as high electricity usage, elevated peak loads on the grid, and critical environmental impacts such as climate change and depletion of ozone [2]. Additionally, because backup power plants must be built to satisfy peak demand, these innovations worsen indoor air quality and raise the marginal cost of electricity. In order to avoid a systemic energy catastrophe, scholarly attention has shifted to the development of passive and environmentally friendly air conditioning technologies.

One of the most well-known forms of energy exchange is heat transfer, which occurs when two locations come into contact with a temperature differential, via a heat exchanger employed in both heating and cooling systems. Indeed, the study and functioning of equipment like steam generators, furnaces, exchangers, evaporators, condensers, etc. require an understanding of heat transfer.

The EAHE is among the most efficient passive systems. This surface geothermal system provides seasonal thermal effects by using the ground's inertia as a sink or source of heat, with air acting like heat transfer fluid. The theory is based on the movement of outside air through a network of underground pipes, allowing for direct heat exchange with the subsoil [3, 4].

At appropriate depth, the earth temperature remains lower in summer and higher in winter. Thermal stability can be utilized to control the temperature of structures [5]. In winter, the air is heated, and in summer, it is cooled. As a result, integrating an EAHE system greatly reduces primary energy use while improving indoor thermal comfort [6-8].

Several studies have shown that geometric parameters such as pipe diameter and length have a direct influence on the EAHE system's efficiency [9]. It has been demonstrated that extending pipe length improves the difference temperature between the system's input and exit throughout the summer (May-September) [10]. Conversely, an excessive increase in diameter can reduce thermal efficiency.

The primary purpose of this study is to examine the impact of duct length on meeting thermal comfort thresholds and to determine the appropriate size during annual heat waves. The ultimate goal of this technique is to improve occupant comfort while reducing the energy footprint of buildings.

2 Methodology

2.1 Location and weather data

The study focuses on the city of Beni Mellal, Morocco (32.36°N, -6.4°E), as diagrammed in Figure 1. The analyses are based on a sample meteorological dataset from the year 2024. The statistics show a temperate environment with significant temperature range, ranging from a low of 2.12°C (reported on January 11) to a high of 44.55°C (recorded on July 21). The temperate climate is characterized by wide temperature swings.

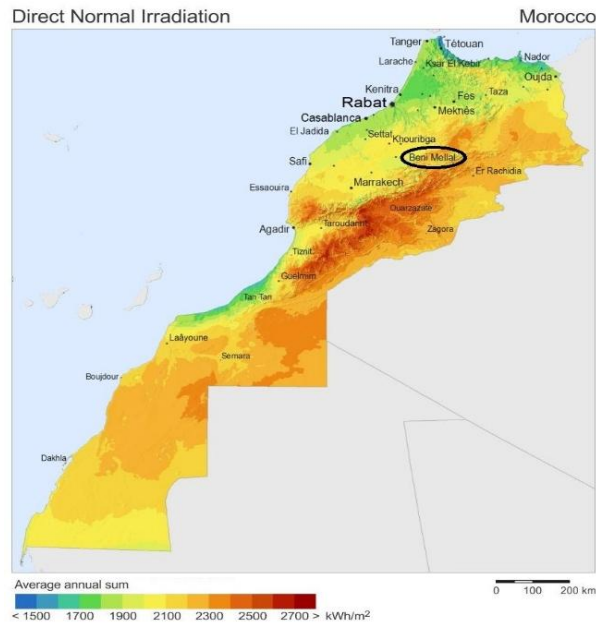


Figure 1. Beni Mellal City’s location and variations in Morocco’s sun radiation (direct normal radiation).

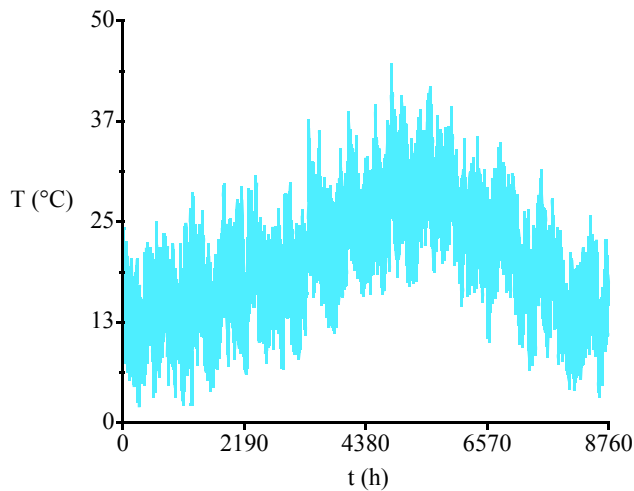


Figure 2. Atmospheric temperature T (°C) for the year of 2024.

2. 2 Models of dynamic simulation

TRNSYS (Transient System Simulation) software was used to do the dynamic thermal simulation, which is a benchmark tool for simulating building thermal behavior. The EAHE system was modeled with the ‘Type 556’ component. To maximize calculation time while keeping appropriate temporal precision, a time step of one hour was used. The simulation

period considered ranges from July 10 to July 30, 2024, which are important in determining the cooling demands.

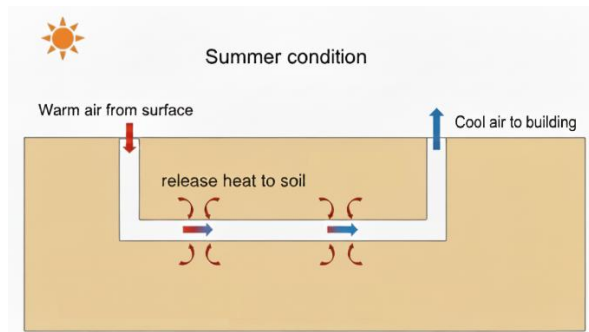


Figure 3. EAHE as a summertime passive cooling system: simplified schematic

The investigated system is composed of a single polyvinyl chloride (PVC) pipe laid horizontally with an average depth of 3 m. Thermophysical characteristics of soil, air and PVC material so on which necessary to the stable heat exchange are included in simulation parameters. Table 1 reports the properties at the average ambient temperature of 20 °C.

Table 1. Thermophysical properties [12].

	Thermal conductivity (W/m.K)	Specific heat (kJ/kg.K)	Density (kg/m ³)
Soil	1.4	1.3	1400
Air	0.025	1.01	1.16
PVC	0.17	1.3	1400

3 Results and Discussion

The main findings from the dynamic thermal simulations used in this investigation are shown graphically and discussed in this section. The results refer to temperature variations in the outlet of the EAHE during continued operation from 10 th to 30 th July 2024, as previously mentioned.

Figure 4 shows a curve of the EAHE exit temperature variation according to the length of the pipe. Overall, this figure shows that increasing the length of the pipe leads to a decrease in the EAHE outlet temperature. Consequently, a decrease in outlet temperature of EAHE fluctuation range that's because the thermal inertia of ground and increase in the heat transfer surface between the ground and the exchanger. The temperature of thermal comfort is achieved at a length of 40 m. It can be noted that the variation range of the temperature of thermal comfort is between [18°C and 28°C]. As the length of the pipe increases, there is a considerable damping of air temperature at well outlet. The air temperature in the outlet decreases for longer pipe lengths. This parameter significantly influences the heat exchanger's responsiveness.

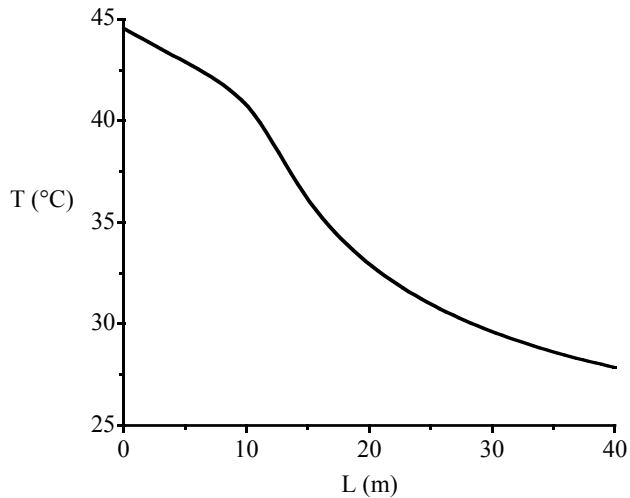


Figure 4. Changes in the EAHE’s outlet temperature, T_{out} , with length (L)

The thermal responses of the AGHE are provided in Figure 5 with consideration of two air temperatures, T_{in} and T_{out} of which their difference has been optimized at a length of 40 m. It reveals that the exterior air has quite low temperature and it fluctuates largely in July whose lowest value is 16°C and the highest one equals to 44.6°C. Unlike ambient air, outlet air temperature of the exchanger is very constant due to the fact it differs little from 25°C and 27.85°C. System’s passive temperature stabilization is evident from the data. In comparison to the ambient conditions, the maximum and minimum temperatures for EAHE were reduced by about 17 and increased by about 9°C on average, respectively. These thermal stabilization results demonstrate that the EAHE is a successful system at reducing temperature swings and keeping an indoor space in close proximity to thermal comfort, even in extreme weather conditions.

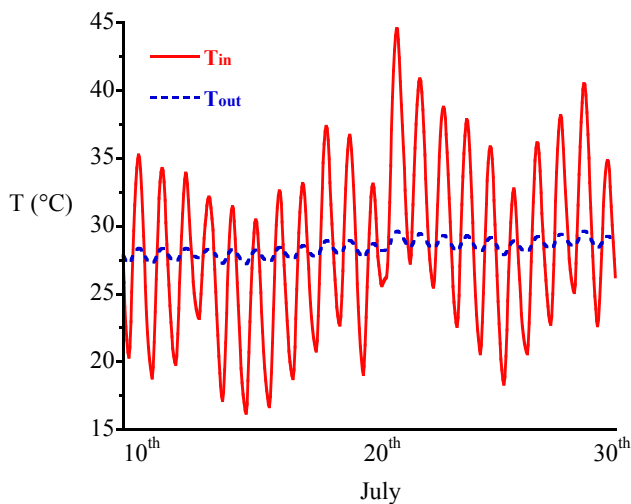


Figure 5. T_{in} and T_{out} temperature variations of the EAHE for the period between 10th and 30th July

Figure 6 accurately captures T_{in} and T_{out} evolution of the tube during critical hours on July 21th and 22th, which represent the worst-case scenario for the climate in Beni Mellal. Figure 6 shows that, despite the exceptional intensity of radiation and air temperature, the outlet temperature curves (All) all converge toward a stable state. Analysis of the curves for these specific dates proves that the system does not saturate. During its 24 hours of operation, Even when the outside air is at its warmest (around 5:00 p.m. on July 21), the exchanger manages to extract enough heat to lower the temperature to 27.85°C. The results showed that the maximum temperature differential between the T_{in} and T_{out} was 17°C at the hottest days with small differences during the morning, revealing some potential for the EAHE to cool ambient air in very hot regions during its summer operating mode. This particular case demonstrates that the earth at a three-meter depth maintains a constant temperature, acting as a heat shield. Analysis of this Figure for these two days confirms that the exchanger is sufficiently sized to ensure a healthy and cool indoor environment, even during the hottest periods of the year. These integrated cooling systems optimize thermal comfort and energy efficiency in buildings.

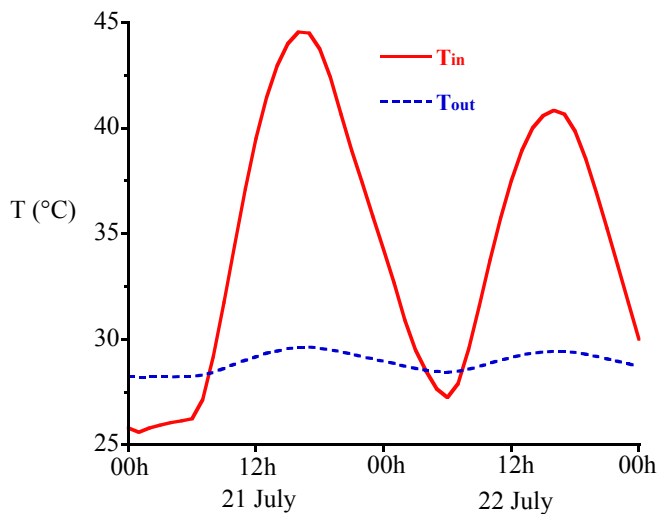


Figure 6. Temperature variations, throughout time, T_{in} and T_{out} in the hottest days of July

4 Conclusion

In order to determine the ideal heat exchanger length, we used the TRNSYS program to simulate the outcome in this research.

According to the findings, the EAHE may lower the air temperature by roughly 17°C. For a distance of forty meters, the thermal comfort temperature is attained. Furthermore, in a temperate region like the Beni Mellal city, the comparatively low soil might lower the electricity expenses for air cooling. The findings demonstrate that the EAHE can be a useful thermal system for building air freshening because it keeps the air temperature at about 27 degrees Celsius. In order to improve energy efficiency, we conclude that the Moroccan thermal code promotes the application of passive cooling technologies in temperate regions.

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