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Dynamic modelling of an earth-to-air heat exchanger for air cooling on the building in hot temperate climate of Beni Mellal Morocco

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Abstract – *In this article, we examined the passive cooling techniques built into a building in hot temperate climate. Our work aims to reduce the energy demand for cooling and progress the thermal comfort of building by decreasing overheating hours. The dynamic simulations of the energy performance in a building with an earth-air heat exchanger (EAHX) are performed in the summer period using TRNSYS software. The building is situated in Beni Mellal city (Morocco) where the climate is a hot temperate one. The results of the simulations show a significant potential for air cooling. Indeed, for the hottest day of July (retained for this study), when the outside temperature is 44.8 °C and the cooled temperature (inside) is 29 °C, the difference of 15.8 °C is obtained. Also, an evaluation of the relative humidity is provided. Finally, we recommend that the Moroccan thermal code encourage the use of passive cooling techniques; precisely in temperate climate.*

***Keywords**: Energy efficiency, building, earth-air heat exchanger, passive cooling, TRNSYS*

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I. Introduction

Buildings energy consumption in Morocco arranged second, after transport, with 25% of total energy uptake in this country, including 7% for the services sector and 18% for residential [1]. The energy consumption of Moroccan buildings is predictable to an increment rapidly in the next years for two reasons; the first is significant increase of household equipment rate in HVAC facilities, hot water and lighting due to the lower prices of these facilities and the amelioration of living standards. And the other is substantial development of the buildings sector.

Over the last decade, there has been an uprising interest in implementing cooling and heating systems for buildings focused on renewable energy sources. Because of its high thermal inertia, the ground attenuates the temperature variations that occur at the earth surface. Furthermore, it causes a difference between the temperature in the soil and that at the surface [2].

Methods for exploring geothermal energy are ground source heat pump, geothermal electricity, earth-air heat exchanger (EAHX) etc. Among of them, an EAHX has the advantages of a simple system, low operation cost and easy implementation [3].

To supply comfortable Circumstances in the Buildings of sufficient ground space, a passive technology of cooling or heating, known as an EAHX can be utilized efficiently and effectively. It is also nominated earth tube heat exchanger, ground source heat pump, ground tube heat exchanger or Canadian well. The idea of utilizing ground thermal inertia for air conditioning is not a new method, but a modified concept that goes back to the last decades. The air used is oftentimes outside air for ventilation, but also rentable for totally or partially managing the construction thermal loads. The climatic conditions affect strongly the system performances.

Thus, at adequate depth, the ground temperature is lower / (higher) than that of the external air during the summer / (winter). The constant temperature in the ground can be used for cooling and heating applications [4]. In case of the outside air is sucked through the EAHX system, in which the pipes inhumed in the soil; the air can be heated during the winter and cooled heated during the summer. Consequently, the EAHX can minimize the energy destined for cooling or heating or furthermore it enhances the thermal comfort in the buildings [5-7].

Several researchers have studied the impact of pipe diameter and length and found that, these parameters affect the performance of EAHX system [8]. In the EAHX system, the difference in air temperature between outlet and inlet sections of the pipe is improved by increasing the length of the pipe [9]. But weakened with the increase in the diameter of the pipe [10-12]. In a recent works, the authors install two EAHX systems (U-shaped pipe) to evaluate the dry and wet EAHX system performance. They observed that the knee point position is greater in dry EAHX compared to the wet EAHX system[13,14].

The objective of the current article is to study a dynamic thermal simulation in a building with integrated the EAHX for a hot-dry climate city of Beni Mellal-Morocco- along the period between the months of May and September of 2020.

II. Methodology

II.1. Weather data and location

The meteorological data used in this study were taken from a typical year weather file for the city of Beni Mellal, (32.36°N, -6.4°E). Several pertinent weather data are presented in Figure 1 and Figure 2 for the atmospheric temperature and relative humidity respectively, for five months from May to September of 2020.

The ambient temperature of theses five months varies between 8.1 °C and 44.8 °C which are the lowest and highest temperatures observed during this period at May and July respectively. The large amplitude of the temperature perturbations is the characteristic of a hot temperate climate.

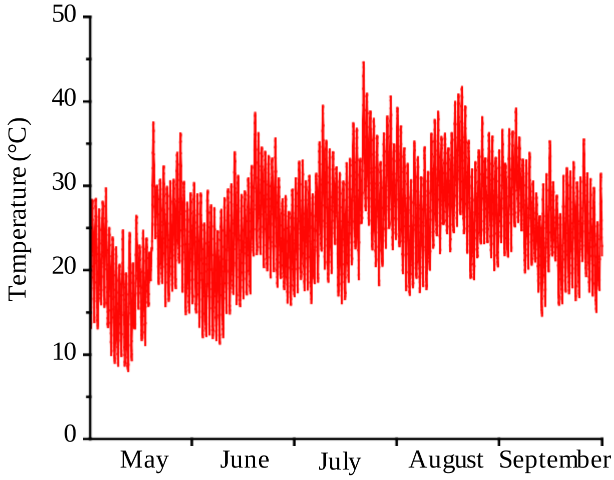

Figure 1. Ambient temperature (°C) for the period from 1st May to 30th September 2020

More the air is warm, more it contains the vapor. Conversely, when the air cools the vapor condenses and forms liquid water droplets: the saturation threshold increases with temperature.

From the figure the relative humidity varies between 30% and 65% for the five months. When the temperature increases, during the hot month, the relative humidity decreases and vice versa, at the cold month. An increase in the relative humidity accompanies this decrease in temperature as is observed in Figures 1 and 2. In the month of July the temperature reaches up to 45 °C and the climate are hot in this city most often. Consequently, fresh air is necessary for the inhabitants of the region to live healthy life with their good mental and physical health.

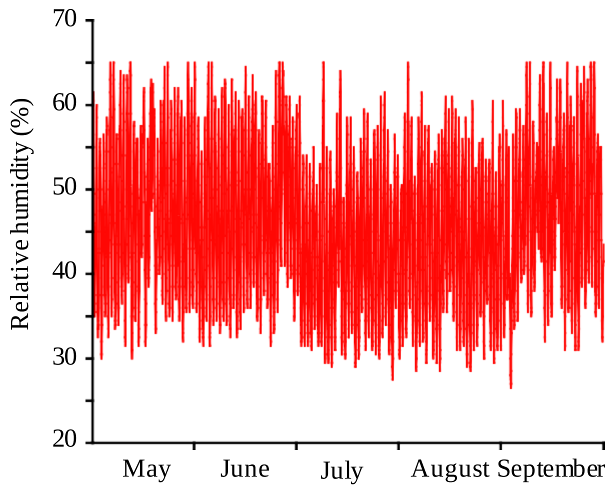

Figure 2. Relative humidity (%) for the period from 1st May to 30th September 2020

II.2. Reference building

The building is a concrete hypothetical one which represents a typical villa building in country of Morocco. The studied building is located in Beni Mellal and is North-facing built on a floor area of 109 m^2, with a ceiling height of 2.8 m. It consists of a ground floor composed of seven pieces distributed over the whole area building as shown in Figure 3.

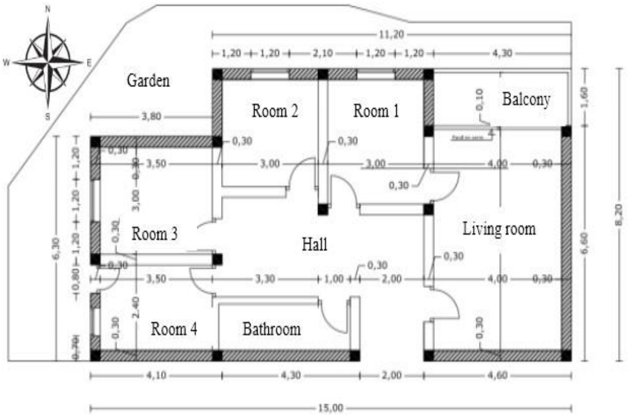

Figure 3. Building 2D plan

II.3. Dynamic simulation models

In this article, dynamic thermal simulation was carried out through TRNSYS which designates Transient System Simulation software to simulate the building. The systems are simulated using components called "types" that are interconnected through time-dependent inputs and outputs. The building was simulated using Type 56 (TRNBuild) and connected to the soil using an Earth-Air Heat Exchanger (EAHX) Type 556 [15]. A time step of 1h was used to reduce computation time.

The building was Split into 7 thermal zones as it is presented in figure 3. Each room was specified as a thermal zone in order to find detailed information on each one of them. The study is made for room 1 and the simulation starts on 1st May and ends on 30th September for the year of 2020. For the computational study, the effect of the inclination pipe and its vertical parts is not considered into account since the horizontal part of the pipe is long enough. Thus, the EAHX is formed by only 1 pipe of PVC (polyvinyl chloride) with 35 m length. The pipe is assumed horizontal, and inhumed at the mean depth of 2.5 m. The thermo-physical characteristics of the PVC pipe, soil and air at average ambient temperature (20 °C) are reported in Table 1.

Table 1. Physical properties

	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

III. Discussion of the results

In this part, the essential results obtained by means of the dynamic thermal simulations carried out in this study are plotted and discussed in detail. The results concern the variations of the relative humidity and temperature with and without the EAHX in continuous operation over the period of the year 2020 (1st May - 30th September of 2020), as mentioned above. It should be noted that the results are presented for the room 1.

Figures 4 and 5 illustrate the Temperature evolution and Relative humidity in the room 1 respectively, with and without integration of the EAHX. The air temperature in the building passed 35 °C in the hottest day localized on July, but with the integration of the EAHX, this temperature is varied between 20°C and 29 °C; which corresponds to the range of the thermal comfort temperature. On the other hand, the corresponding relative humidity is around 40%, Although the outside temperature reaches more than 44 °C. The relative humidity shows a decrease profile when the system (EAHX) has a preheating effect (see Figure 5). We note that the EAHX could be used also for the air preheating; for example, the beginning of the month May (see Figure 4), but this aspect is not treated since we are only interested in the building cooling.

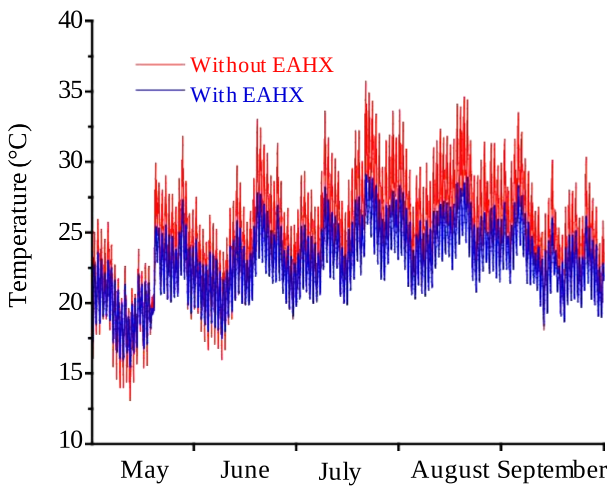

Figure 4. Ambient temperature (°C) in the room 1 for the period from 1st May to 30th September 2020

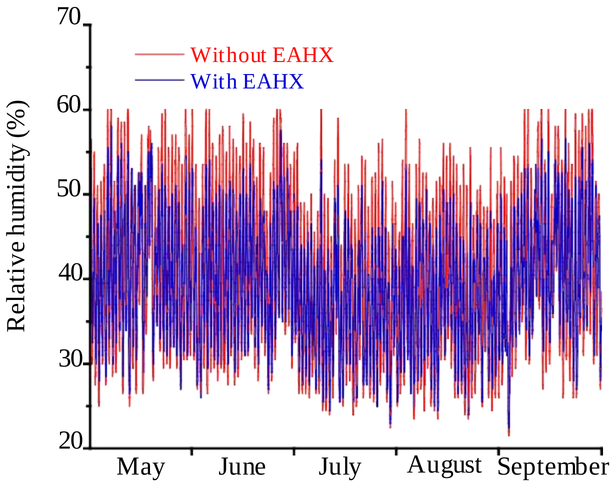

Figure 5. Relative humidity (%) in the room 1 for the period from 1st May to 30th September 20220

As a complement, Figure 6 and Figure 7 present the time evolution of the evaluated temperature and relative humidity respectively, in the studied room, during a typical days of summer (the three hottest days of the year) corresponding to July 19th, 20th and 21th of 2020.

It is noted that the maximum / minimum temperature, in the studied room, is obtained for the 19th July and equal to 35.8 °C / 25.2 °C. This affects the thermal comfort zone caused by the lack of refresh. The air temperatures obtained at the outlet of EAHX is varying in the range of 23 °C - 29 °C; which gives a fairly significant difference of 6.8 °C between the temperature inside the studied room and that of the cooled air (see Figure 4).

Note that the ambient air temperature in the outside which occurs at 19th July is 44.8 °C, while the temperature of the air cooled by the EAHX is 29 °C; which gives a fairly significant difference of 15.8 °C (see Figure 1 and Figure 6). The percentage of this reduction is about 35%. Consequently, the above results show that the earth - air heat exchanger is a system more adapted to air refreshing in the buildings inside Beni Mellal city, since it provides a quasi-constant air temperature of approximately 26 °C, with relative humidity that is almost 40% when the temperature in outside exceeds 40 °C.

The relative humidity of the air varies with the room temperature. When the temperature increases, during the day, the relative humidity decreases and vice versa, at the night. The growth of the air relative humidity accompanies this decrease in temperature as is observed in Figures 6 and 7. Thus, the relative humidity of the ambient air varies between 25% and 55% while the humidity of the air refreshed oscillates between 27% and 50%. This range of variation in relative humidity does not present any risk of condensation.

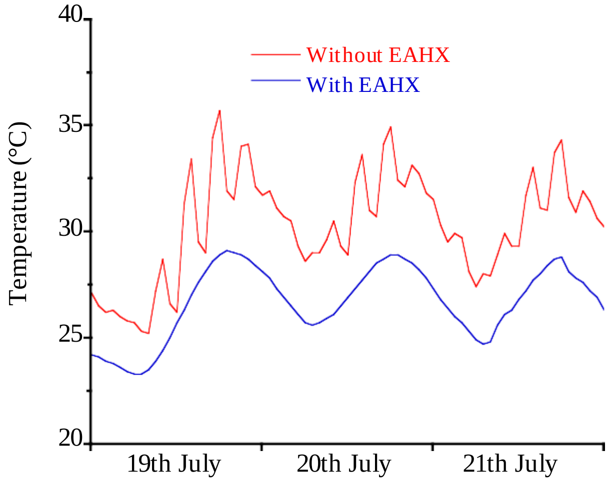

Figure 6. Temperature (°C) inside the room 1 for three hottest days of the year

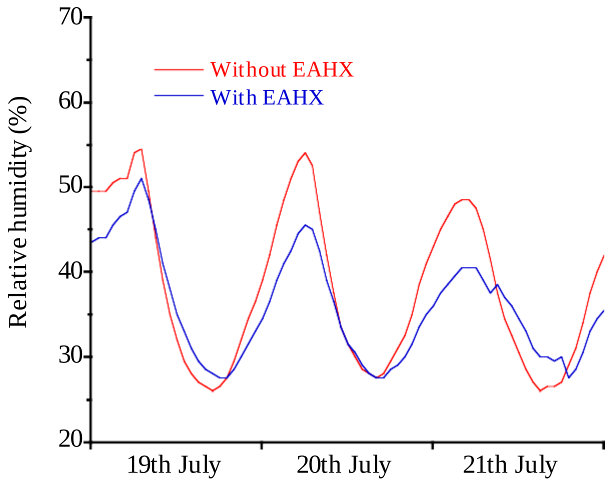

Figure 7. Relative humidity (%) in the room 1 for three hottest days of the year

IV. Conclusion

In this study, we focused on reduction the demand for cooling energy in a typical building by blocked overheating through the installation of the EAHX. The reference building was divided into 7 thermal zones and simulated in TRNSYS 18.

The dynamic simulation of the EAHX shows that this system serve air temperature decrease up to 15.8 °C for the hottest day established in July. The obtained results reveal that the EAHX is a thermal system more adapted to air refreshing in the building, as it provides a quasi-constant air temperature of approximately 26 °C, with relative humidity that is about 40% when the outside temperature exceeds 40 °C. Globally, these results indicated that the EAHX is an efficacious system for air refreshment inside the building in hot temperate climate as in Beni Mellal region, because it provoke an adequate air temperature for human comfort in the hot season (May-September). Furthermore, in such climate the EAHX can also be used for air heating.

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