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Effect of an Evaporative Cooler on the Thermal Performance of Passive Ventilation System Coupled with Earth air heat exchanger : An Experimental Investigation

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Abstract

An experimental study of a two-storey structure with a passive ventilation system is conducted in August, with the severe summer environment of Kut, Iraq. The experimental model consists of a solar chimney combined with a hybrid cooling system comprised of an Earth-air heat exchanger and an evaporative cooler. Each storey has a size of 1 m3, while the dimensions of the vertical solar chimney were 3m height, 1m width and 0.3m depth. The dimensions of the evaporative cooler were (0.3 * 0.3 * 0.6) m3; it has a two-nozzle water spray system and a low-power fan with a speed of 0.8 m/s. The Earth-air heat exchanger was 17 m long, 10.2 cm in diameter and 3 m deep under each floor. Two instances were investigated with and without Evaporative cooler(EV) for two separate daytimes (2-8-2021 and (3-8-2021). The findings revealed that EV increases the relative humidity inside each storey and enhances the thermal comfort rate. Based on recorded data, the relative humidity rate ranged from 35% to 42%, contrasted to the exterior relative humidity, which did not surpass 13%. In addition, the EV assisted in lowering the indoor temperature of each storey by 4 °C. Finally, due to the high solar radiation at the Kut city location in Iraq, the passive ventilation rates for the solar chimney were satisfactory for both storeys.

Keywords: Solar chimney, Earth-air heat exchanger , Evaporative cooler, Air change per hour, Temperature, Relative humidity

List of symbols :

SC : solar chimney — EAHE : Earth-air heat exchanger

EV : Evaporative cooler — ACH : Air change per hour

RH : Relative humidity — PVC : Polyvinyl Chloride

1st : first — 2nd : second

الخلاصة: أجريت دراسة تجريبية لمنشأة من طابقين مع نظام تهوية سلبية في آب / أغسطس ، مع بيئة الصيف القاسية في الكوت ، العراق. يتكون النموذج التجريبي من مدخنة شمسية مدمجة مع نظام تبريد هجين يتألف من مبادل حراره الهواء الأرضي ومبرد تبخيري. يبلغ حجم كل طابق ١ م ٣ ، بينما كانت أبعاد المدخنة الشمسية العمودية ٣ م ارتفاع ، ١ م عرض و ٠.٣ م عمق. كانت أبعاد المبرد التبخيري (٠.٣ * ٠.٣ * ٠.٦) م ٣. يحتوي على نظام رش الماء بفتحتين ومروحة منخفضة الطاقة بسرعة ٠.٨ م / ث. يبلغ طول المبادل الحراري بين الأرض والهواء ١٧ م وقطرها ١٠.٢ سم وعمقها ٣ أمتار تحت كل طابق. تم فحص حالتين باستخدام المبرد التبخيري (**EV**) وبدونه لمدة يومين منفصلين (٢-٨-٢٠٢١ و (٣-٨-٢٠٢١) وأظهرت النتائج أن **EV** تزيد من الرطوبة النسبية داخل كل طابق وتعزز معدل الراحة الحرارية. بناءً على البيانات المسجلة ، تراوح معدل الرطوبة النسبية من ٣٥٪ إلى ٤٢٪ ، على عكس الرطوبة النسبية الخارجية التي لم تتجاوز ١٣٪ ، كما ساعدت **EV** في خفض درجة الحرارة الداخلية لكل طابق بمقدار ٤ درجات مئوية. أخيرًا ، نظرًا لارتفاع الإشعاع الشمسي في موقع مدينة الكوت في العراق ، كانت معدلات التهوية السلبية للمدخنة الشمسية مرضية لكلا الطابقين.

1. INTRODUCTION

During the previous decades, the great demand for energy sources in air conditioning and heating operations exacerbated global pollution due to fossil fuels. As a result, it is critical to look for natural alternative techniques to replenish depleted energy sources. Solar chimney techniques are one method of passive ventilation by connecting them to the structures to be ventilated represented by air change per hour(ACH) in all storey of building . The operation of solar chimneys is based on the idea of the buoyant force due to variation density between hot and cold air. During the summer season in Iraq, ventilation slightly affects reducing the temperature or raising the relative humidity of the structures. As a result, employing EAHE technology is one of the ecologically beneficial choices. The EAHE is a system of air pipes penetrating through the ground at a specific depth to take advantage of the lower temperature inside the ground soil. The soil is thermally inert, and heat exchange occurs between the soil and the air inside the pipes. Because of Iraq's hot and dry climate, an evaporative cooler powered by solar panels can be combined with EAHE to reduce the temperature and increase the relative humidity of the air entering the buildings. The hybrid cooling system is a combination of EAHE and EV. The influence of the solar chimney (SC) with EAHE or SC with EV on the thermal performance of buildings has been examined in several investigations.

Abbas and Ali [1] studied the effect of the inclination angle of a solar chimney on the thermal performance of a room has a volume of 1 m^3 using Ansys fluent software. The data revealed that the highest thermal performance of a solar chimney was with an inclination angle of 45°, where the ventilation rate increased 31.9%, and the temperature decreased by 1.3 °C compared to a vertical solar chimney. Amr Sayed et al. [2] studied the effect of a solar chimney and an evaporative cooler on the thermal conditions of a room with dimensions (4*4*3.125) m^3 in the summer climatic conditions Assiut city, Egypt. The results showed that the ventilation rate was increased to 130.5 m^3/h, and the room temperature decreased by (10-11.5) c°. Mahran Rabbani et al. [3] examined the thermal performance of the modern design of the solar chimney system in the desert climate of Yazd city, Iran. The new model includes a test room with (3 * 2 * 3) m^3, a solar chimney, and a water spraying system installed on the window. The results revealed that the optimal diameter of the water spraying nozzle and mass flow rate were 30μm and 10 l/h, respectively. Also, according to the data, the water spraying system reduces interior temperature and improves indoor relative humidity by 8°C and 17%, respectively. The impact of a ground-air heat exchanger at a depth of 2 m beneath the earth on a cubic room with 2 m^3 connected to a solar chimney at an angle of 45° inclination was investigated by Ahmed A. SE et al., [4]. Low-power fans were used to increase the flow rate. The results showed a decrease in the average room temperature from 5 c° to 9 c°, and the ventilation rates were also increased. Rabbani [5] studied the thermal conditions of a room with dimensions of (4 * 4 * 5) m^3 connected to a vertical solar chimney 1.5 m high. The room connected to a Earth-air heat exchanger buried a 3 m deep connection to a water sprinkler system. The result showed that the ground-air heat exchanger and water sprinkler system reduced the room temperature from 8 c° to 14 c°, while the ACH rates increased due to the effect of the solar chimney. Amin et al. [6] investigated the impact of two different cases: ventilation and cooling. The first case is based on the combined effect of the solar chimney and the evaporative cooler, while the second case depends on the effect of the solar chimney with the ground air heat exchanger. The EAHE system with SC was optimal for buildings with low insulation, and the EV system with SC was optimal for buildings with high insulation, and this system could also benefit from it during the night. Hussein and Abbas [7] investigated the thermal performance of a two-storey structure in the climate conditions of Kut city, Iraq. Each story's structures are 1 m^3 in size and are connected to a southern solar chimney with a 3 m length and Earth-air heat exchanger with a 3 m depth and a 17 m length. The data indicated that the average temperature on the first floor was 307 K and 308 K on the second floor, while the average ambient temperature surpassed 314 K. Furthermore, the ACH rate for the first level was 7.25, while the ACH rate for the second floor was 5.83.

The primary goal of this research is to demonstrate the influence of evaporative cooling and earth air heat exchanger system on the thermal performance of two-storey buildings. In the present work, two instances are investigated. The first instance is a two-story structure connected by a solar chimney. In contrast, the second case incorporates adding an EV and EAHE system to achieve thermal comfort within the buildings during the summer season in Kut, Iraq.

2. MODEL DESCRIPTION

Two models are detailed in this section: a two-story building connected to a solar chimney with and without EAHE and EV.

2.1 Double storey building coupled with solar chimney

The model consists of a two-story structure connected with a solar chimney. The building's frame is made of wood with an 8 mm thickness, the volume of each floor is 1 m^3, and it has a window measuring (0.3*0.3) m^2. The solar chimney is connected to the building through a ventilation opening measuring (1 * 0.3) m^2 on each storey. The dimensions of the solar chimney were 3 m in height, 1 m wide and 0.3 m in depth. Transparent glass with a thickness of 4 mm covers three sides of the solar chimney[8]. While the fourth side, which is close to the structure, is composed of 1 mm thick black aluminium that extends along the solar chimney to absorb more solar energy. The building is insulated from the absorption board and its exterior roof with insulating material of Glass wool with 25 mm thickness to reduce heat transmission to the two-storey. Fig 1 shows the 3D design of the system.

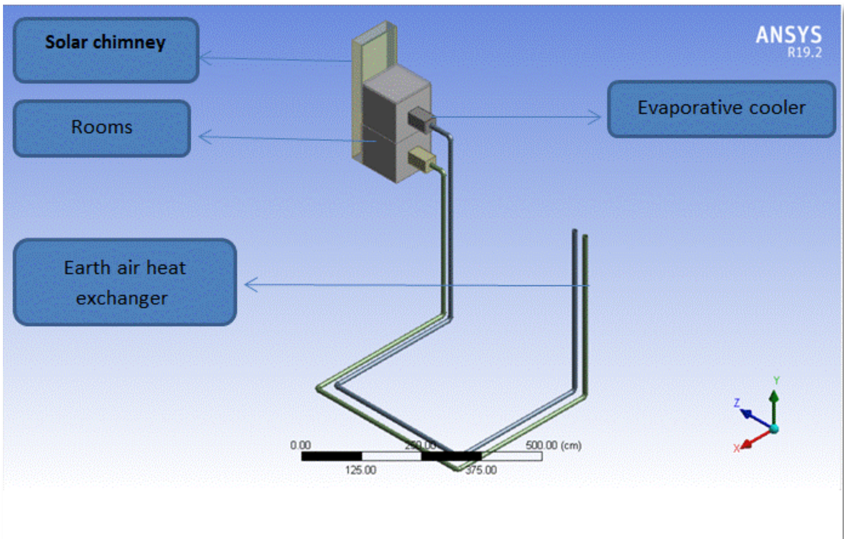

Figure 1 3D design of the system

Figure 2 Two-storey building coupled with solar chimney

2.2 Hybrid Cooling System (EAHE +EV)

The hybrid cooling system consists of two parts. The first part connected to the building is a direct type evaporative cooler with (0.3 * 0.3 * 0.6) m^3 constructed of wood and contains cellulose type wetting pads[9]. The evaporative cooler's water spray system comprises a pump with a flow rate of 0.55 L/min. At the end of each evaporative cooler, there are two spray nozzles and a low-power fan with a speed of less than 1 m/s. Solar panels power all electrical parts of pumps and fans run. The evaporative cooler is insulated with glass wool to reduce the heat load from the solar radiation falling on it. The evaporative cooler has a bottom tank that collects water from the evaporative cooler and is connected to the main water tank through plastic tubes to create a semi-closed water system. As shown in fig3.

Figure 3 Evaporative cooler

The Earth-air heat exchanger is an air-channel that extends under the ground soil with a depth of 3 m, a length of 17 m for the first floor and 18 m for the second floor, and a diameter of 10.2 cm . The heat exchanger pipes are 4 mm thick and constructed of PVC [10]. It is designed on the open type where the ambient air enters from the north side and exits from the opening associated with the evaporative cooler. Pipes coming out of the ground are insulated with glass wool to reduce the heat losses, as shown in fig4. Finally, the earth-air heat exchanger is linked to the evaporative cooler to create a hybrid cooling system that is cooling and humidifying the air before entering the two-storey. Fig5 shows the experimental integrated system.

Figure 4 Earth- air heat exchanger

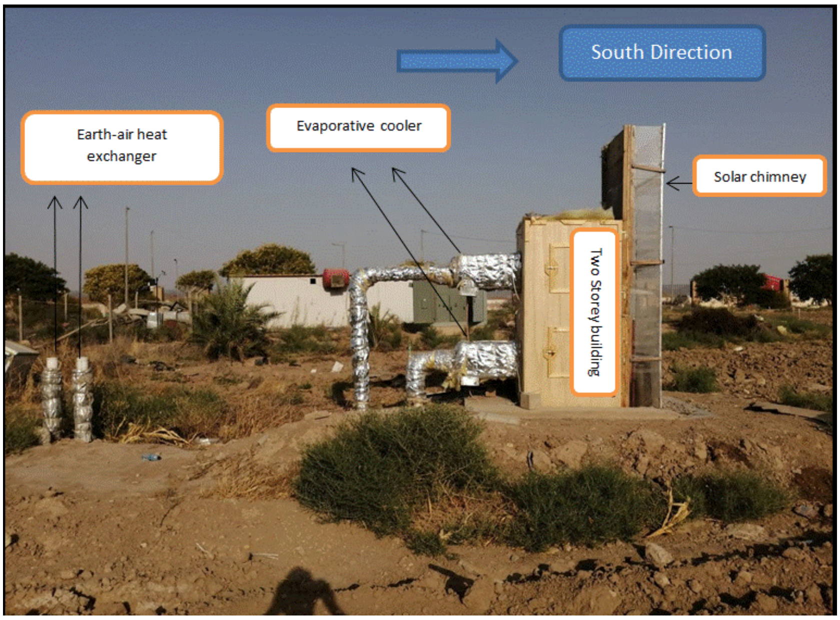

Figure 5 *Experimental* integrated system

3. MEASURING EQUIPMENT FOR EXPERIMENTAL TESTS

Figure 6 show The weather station (Davis® Vantage Pro2 Weather station) was used to measure the external temperature conditions also solar meter device (TES-1333R) was used to measure the intensity of solar radiation with accuracy (±10 w/m^2) as shown in fig 7. To measure the temperature of the air inside the building, the ground soil and the tank water, type k thermocouples were used with Error (±2.2 c^o) , and the relative humidity sensor type (goa bros) was used to measure the relative humidity inside each floor with error ratio1% as shown in fig 8 and fig 9 . Fig 10 show The device (Sentry ST733) was used to measure the air velocity at the chimney openings to calculate the ACH value with error ratio 0.03% . The Data Logger (Pico technology)with Accuracy(±0.5c^o) and a computer connection were also used to read the thermocouple scales and save them in digital files as shown in fig 11 .

Figure 6 Weather Station

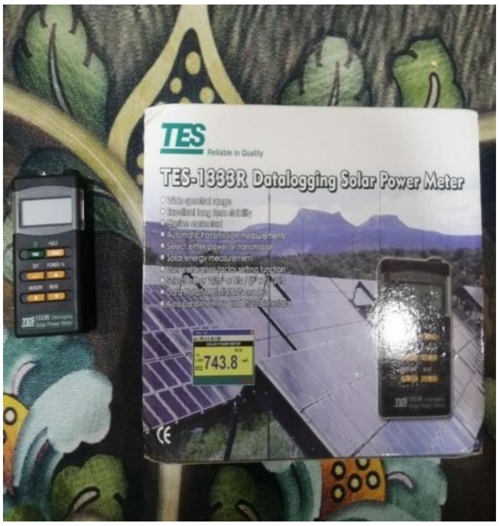

Figure7 Solar Meter

Figure 8 thermocouples type (K)

Figure 9 RH sensor

Figure 10 Anemometer type of (Sentry ST 733)

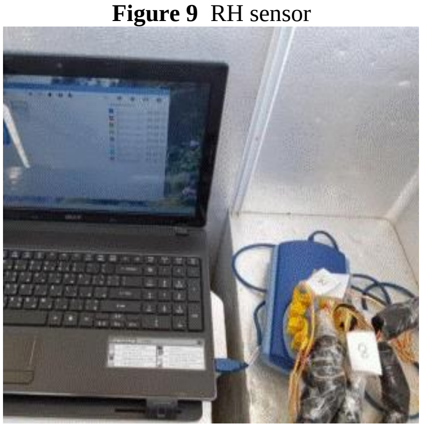

Figure 11 Pico technology

4. EXPERIMENTAL CASE STUDY

Two cases are studied for two consecutive days (2-8-2021) and (3-8-2021) in the summer climate of Kut city, Iraq. In the first case, the effect of the evaporative cooler is investigated when it is connected to a passive cooling system, which is linked to the Earth-air heat exchanger.

The effect of the evaporative cooler on several par parameters such as air change per hour (ACH), indoor temperature and relative humidity is examined for six daytime hours from 8 am to 6 pm for the day (2-8-2021). While the second case was identical to the first but without an evaporative cooler. The two cases outcomes are compared, and the impact of the evaporative cooler on the passive cooling system is determined.

5. RESULTS AND DISCUSSIONS

5.1. Results of the first case on (2-8-2021)

Table 2 depicts the thermal conditions for the daylight hours in kut city, Iraq, on 2-8-2021. According to the table, the peak solar intensity was 955 W/m^2 at 2 pm, then progressively fell to 310 W/m^2 at 6 pm. Moreover, the ambient temperature increases from 8 am and reaches a maximum value at midday (318 K) and then gradually decreases, especially in the afternoon. The average relative humidity for the tested day was 13%, whereas the water tank and soil temperature remained nearly constant during the testing day.

Table1: Experimental data for the day (2-8-2021)

NO.	TIME (h)	Radiation Solar (w/m^2)	Ambient Temperature (k)	Soil Temperature (k)	Water tank Temperature (k)	Relative humidity (kg/kg)%
1	8	490	312.8	292	297	18
2	10	760	316	294	301	12
3	12	950	318	296	303	12
4	14	955	318	296	303	12
5	16	600	315	294	301	12
6	18	310	314	294	300	12

The relation between air change per hour (ACH) and test hours is illustrated in fig 12. The experimental data shows that (ACH) begins to rise gradually after 8:00, peaks at 14:00, and drops to the lowest value at 18:00. The maximum value of (ACH) were (11 and 9.2) for the first and second floors, respectively. In contrast, the lowest value for two-storey was (4.5 and 4) due to solar intensity and sunlight orientation effects. The value of ACH for the first floor is always higher than for the second floor and for all test hours. This is due to the difference in length of the solar chimney column between the first and second floors, where the length of the chimney column for the first floor is 1 m longer compared to the second floor.

The effect of the hybrid cooling system, which consists of an evaporative cooler and a Earth-air heat exchanger, on the average indoor temperature of the building is shown in fig 13. the hybrid cooling system reduced the temperature by an average of 13c^o for the first floor and 10 degrees for the second floor compared with the ambient temperature. In addition, the indoor temperature was 305 K for the first floor and 306.2 for the second floor, while the ambient temperature was 318 K at 12:00. While the lowest temperature was recorded at 8:00, where it recorded 300.3 K for the first floor and 300.7 K for the second floor, as the ambient temperature was 312.8 K. The temperature of the second floor is always higher than the first floor for all hours of testing, due to direct solar radiation on the second floor, while the first floor is isolated and misleading under the second floor

Fig 14 illustrated the effect of the evaporative cooler on the relative humidity inside the two-storey building. The relative humidity increased on the first and second floors, reaching a range of (35-42%), whereas the ambient relative humidity was 13%. therefore, due to the usage of an evaporative cooler, the relative humidity has increased, and this shows the effect of the evaporative cooler by increasing the relative humidity three times compared to the surroundings.

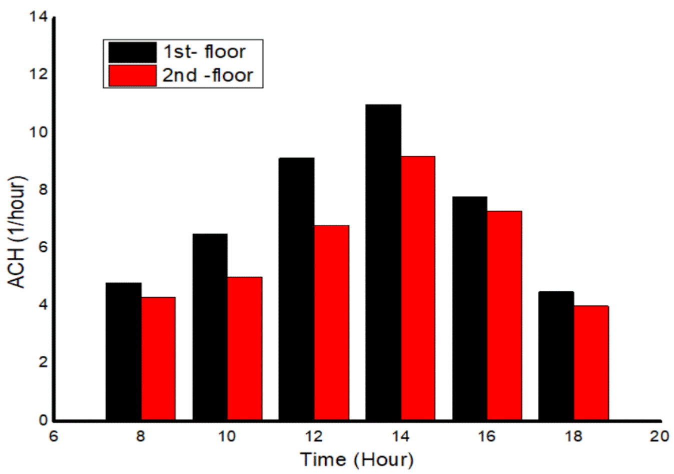

Figure12: ACH of two floors of day (2-8-2021)

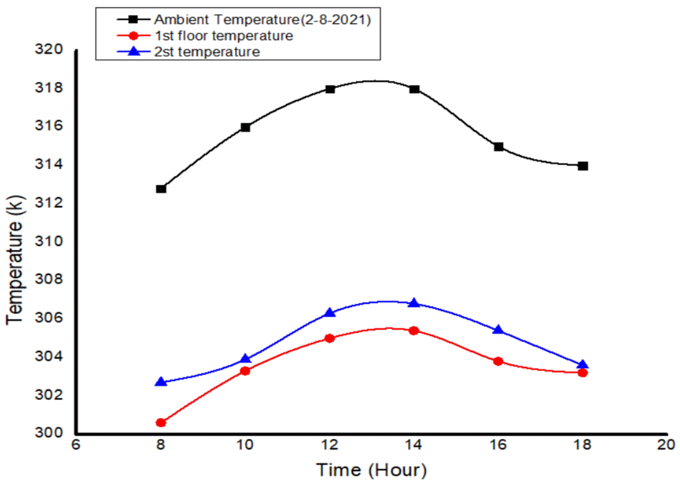

Figure13: The temperature of the two floors compared to the surroundings

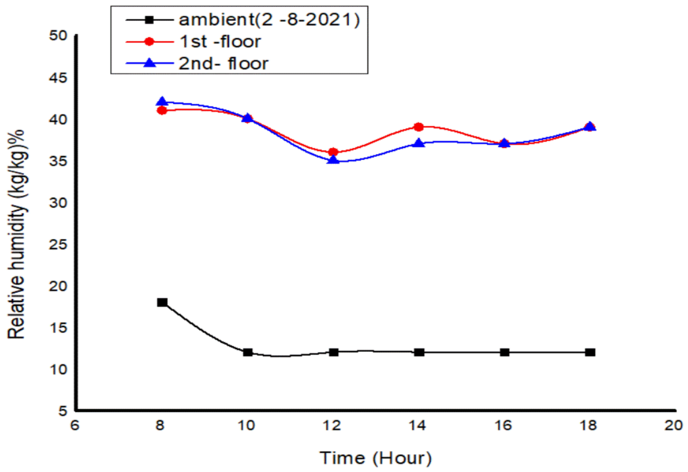

Figure14: The relative humidity of the two floors compared to the surroundings

5.2. Results of the second case on (3-8-2021)

Table3: Experimental data for the day (3-8-2021)

NO.	TIME (h)	Radiation Solar (w/m2)	Ambient Temperature (k)	Soil Temperature (k)	Relative humidity (kg/kg)%
1	8	550	315	292	15
2	10	750	318	295	12
3	12	950	323	297	12
4	14	955	323	296	10
5	16	546	319.5	296	10
6	18	320	317	295	10

Table 3 shows the intensity of solar radiation for the day 3-8-2021, where it was the lowest value at 18:00 and amounted to 320 w/m2, while the highest value was at noon, where it recorded 950 and 955 w/m2 at 12:00 and 14:00, respectively, as in the sun's radiation, The highest temperature was at the afternoon hours, and it was recorded at 323 K for 12:00 and 14:00 together, while the lowest temperature was at 8:00 and recorded at 315 K. The table also shows the average relative humidity, which was 11.5% less than on the day of 2-8-2021, by 2.5%.

The highest ACH rates were recorded at 14:00, where they were 13.2 & 10.8 for the first and second floors, respectively, while the lowest value was at 18:00, and they were 7.7 & 5.5 for the first and second floors, respectively, as shown in fig 15.

The temperature drop due to the effect of EAHE only (without the action of the evaporative cooler) was lower than the first case where the average temperature of the first and second floors for the six test hours was 309.2 K and 310.4 K, respectively. Fig 16 shows that the highest temperature was at 14:00, reaching 311 K for the first and 312.5 for the second, while the lowest temperature was at 18:00 and its value was 307 K and 308.7 K for the first and second, respectively.

In the second case, there is no improvement in the relative humidity inside the building due to the absence of the main factor affecting the increase in relative humidity, which is the evaporative cooler, which increases the moisture content inside the air. % while its average for the day outside was 11.5%, as shown in fig 17.

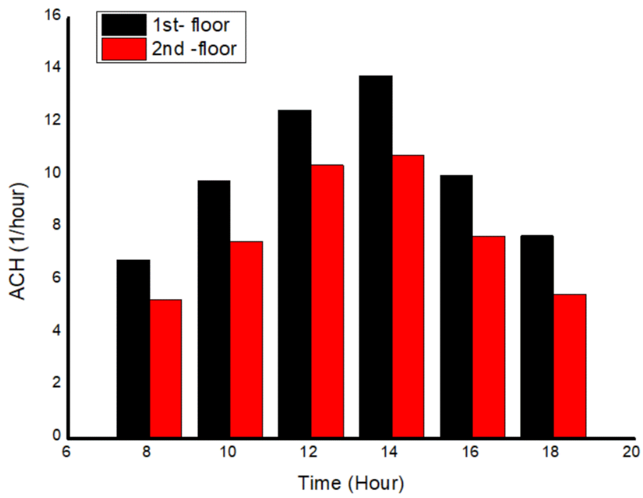

Figure 15: ACH of two floors of day (3-8-2021)

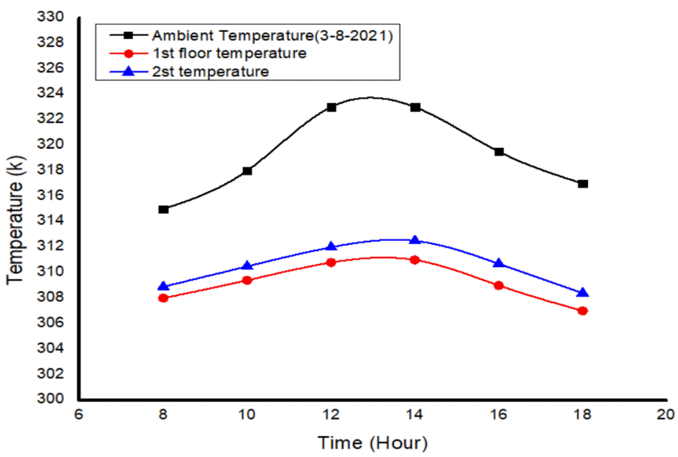

Figure16: The temperature of the two floors compared to the surroundings

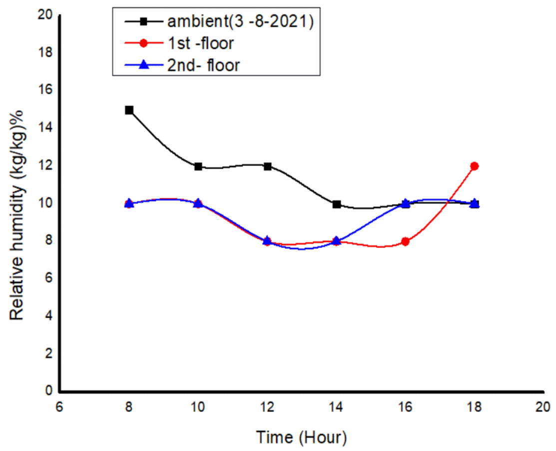

Figure17: The relative humidity of the two floors compared to the surroundings

6. EFFECT OF EVAPORATIVE COOLANT ON PASSIVE VENTILIATION SYSTEM

Practical results showed that the evaporative cooler increased the relative humidity inside the building and on both floors to the thermal comfort zone for its occupants, which was more than 35% at all hours of testing for the first day.

Due to air carrying particles and water vapour in the air, ventilation represented by ACH value decrease 2-4 ACH due to the heaviness of humidified air compared to dry air, but by a small value compared to the second case where EV is not used.

The use of evaporative cooler increased the temperature reduction inside each floor by 5-7 °C compared with the case of using EAHE only. Fig 18, Fig 19 and Fig 20 show comparisons of the experimental results for both cases and for both floors on three parameters ACH, temperature and relative humidity

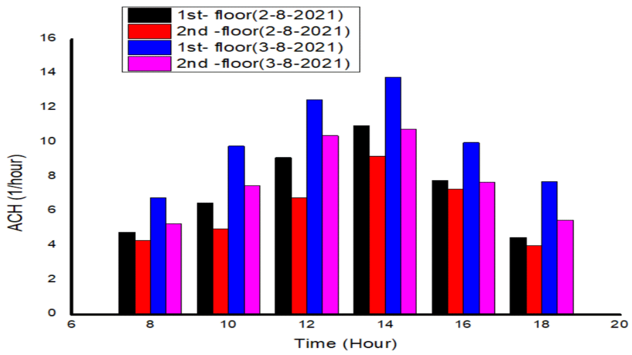

Figure 18: ACH comparison for two days and both floors

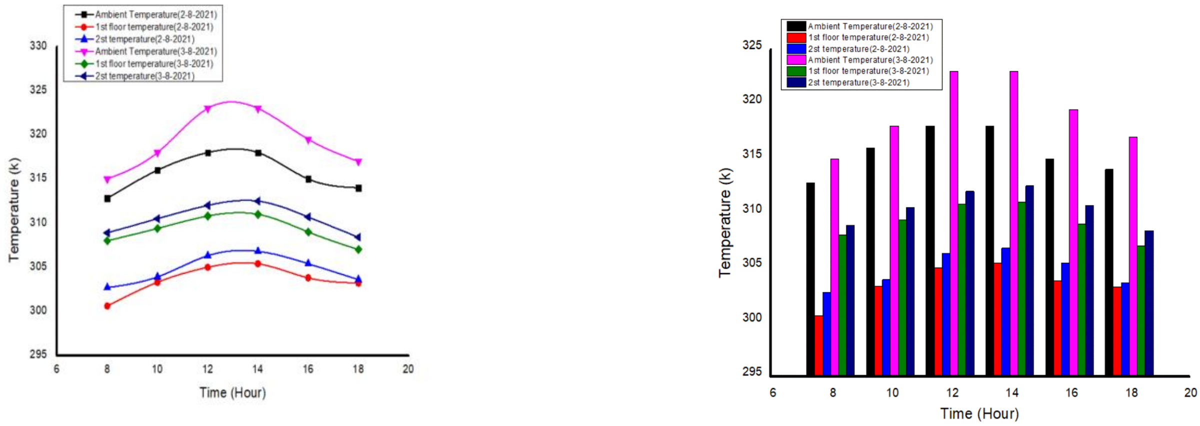

Figure 19: The temperatures comparison for ambient &both floors for two days

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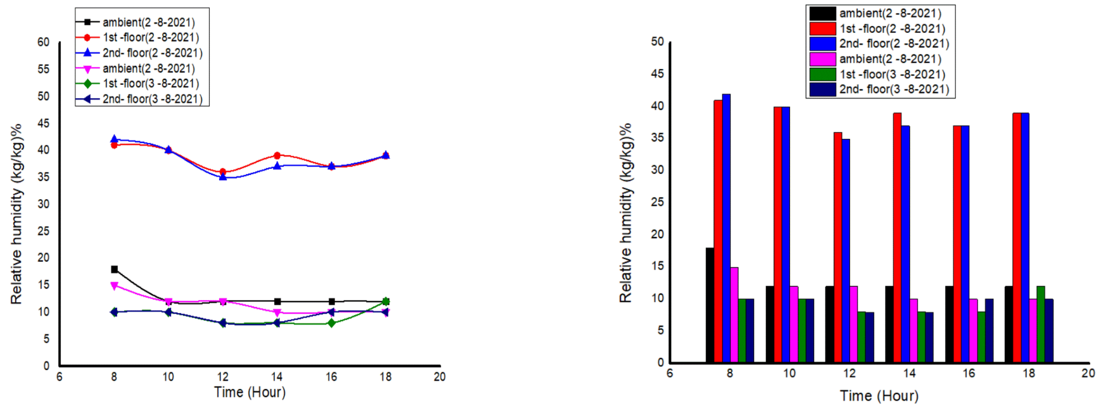

Figure 20: The Relative humidity comparison for ambient &both floors for two days

7. CONCLUSION

In this experimental research, the passive ventilation system coupled with the ground air heat exchanger and the addition of an evaporative cooler was studied to determine the effect that occurred inside a two-story building with and without the evaporative cooler. The results show an increase in the relative humidity until reaching thermal comfort levels (35-42)% for the occupants of the space in the building, as the temperature decreased when adding by 13 °C and 10 °C for the first and second, respectively, and the ACH rates were acceptable for ventilation inside the building and for both floors together.

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