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Testing the performance of a solar energy cooling system in Baghdad city

Key words: cool buildings, solar chimney, ground heat exchanger, weather conditions

Introduction

The search for alternative ways to cool the air in the hot long season instead of using the electric power has become an important issue due to the severe shortage of electric power generation in the last two decades due to the deterioration of the infrastructure. According to Iraqi Meteorological Organization, the air temperature recordings in 2018 have exceeded 50°C. Hence, adopting renewable energy technologies such as solar cooling is one of the good solutions to the power problem in the country. In addition to this good feature, using the renewable energy would reduce fossil fuel consumption and pollutant gas emissions into the atmosphere. The energy can have many forms such as kinetic, potential, electromagnetic, nuclear, sound,

light or photo-energy, and gravitational (Mohamed, 2017). Energy is important issue for human development, and acts as a key factor in determining the economic development of all countries (Atwan, Kasim, Jasim & Hameed, 2020). Fossil fuels are burned by power plants, transportation methods and by different industries. This results in emitting large amounts of pollutants, which endanger human health, has a negative impact on the economy and destroys the natural environment.

While most of today's energy is derived from fossil fuels, new technologies offer a range of electricity generation and cooling and heating options where they are required. These new options contain renewable energy technologies (Haghighi & Maerefat, 2015). Internal conditions in most buildings are uncomfortable because of extreme outdoor weather conditions and the incorrect locations of windows and doors that implements natural ventilation (Zaidan,

Abed & Jasim, 2019). Consumption of high-grade energy has risen considerably with growing needs to obtain thermal comfort conditions inside buildings, residential complexes, greenhouses, cattle buildings, etc. (Bisoniya, 2015). Passive system terminology is applied to buildings that have, as integral parts, elements that admit, absorb, store, and emit solar energy; thus, reducing the need for more energy for comfort heating. These elements have something to do with the right orientation of the buildings, the right dimensions of openings, the use of terrace and other shading devices, and the use of insulation and thermal mass (Kalogirou, 2014). A passive strategy for cooling buildings can be obtained from natural ventilation. Effective ventilation and thermal comfort are of great significance in rural areas and in hot climate. One of the natural ventilation techniques that are used for conditioning buildings and which can participate to progress the energy efficiency of facilities are solar chimneys (Saifi, Settou, Dokkar, Negrou & Chennouf, 2012). Solar chimney has been frequently adopted in buildings to save energy by enhancing the natural ventilation (Shi et al., 2019). It can be defined as a natural-draft system that uses solar radiation to move air upward and thus transforms solar energy into kinetic energy of air. The use of constant pressure air density decreases with the increase in temperatures. Air with higher temperature than that of ambient air is driven upwards by the buoyancy forces. A solar chimney makes use of this physical phenomenon (Charvat, Jicha & Stetina, 2014). A second technique called ground heat exchanger, can be utilized which is a heat transfer device

that exchanges heat between two or more process fluids (Zohuri, 2017). This technique is known by many different names such as the buried pipe system, underground air tunnel, earth tube heat exchanger and earth air tunnel. A variety of applications such as building thermal comfort, animal residence and agricultural greenhouses utilizes this system (Taib, Anuar & Ibrahim, 2015). It is an ancient technique that has been used for thousands of years with high efficiencies especially in the hotter and drier climates (Ariffin, Sanusi & Noor, 2014). The cooling tubes system consists of long pipes buried underground with one end connected to the house and the other end to the outside (Zaki, Amjad & Almssad, 2007). Passive techniques are used to decrease the effect of the climate impacts on buildings by using insulating materials and air control system, which mean saving energy and reducing the demanded for cooling (Abed, Zaidan & Jasim, 2019). This system works automatically as a result of the pressure difference between hot and cold air as the air flows from areas of higher pressure (cold air) to areas of lower pressure (hot air).

Our research aims to design a cooling system that depends on water and solar energy that can be used to cool houses or poultry fields and other facilities in areas adjacent to rivers, lakes, marshes and other water bodies.

Correlation in the broadest sense is a measure of an association between variables. In correlated data, the change in the magnitude of one variable is associated with a change in the magnitude of another variable, either in the same (positive correlation) or in the opposite (negative correlation) direction. Most

often, the term correlation is used in the context of a linear relationship between two continuous variables and expressed as Pearson product–moment correlation (Schober, Boer & Schwarte, 2018). The correlation coefficient (r) is a test of the linear relationship between the calculated and measured value which is defined by:

$$r = \frac{\sum_{i=1}^N (y_i - \bar{y}) (x_i - \bar{x})}{\left[\left\{ \sum_{i=1}^N (y_i - \bar{y}) \right\} \left\{ \sum_{i=1}^N (x_i - \bar{x}) \right\} \right]^{0.5}} \quad (1)$$

where:

N – number of the values,

y_i – estimated value,

x_i – measured value,

\bar{y} – mean value of the estimated values,

\bar{x} – mean value of the measured values.

Material and methods

The current study was carried out in Baghdad during April and May 2020. The constructed design is an innovative cooling system that consists of a test room, a chimney and a heat exchanger (Figs. 1 and 2). The test room (1 m³ size volume) was built by using sandwich



FIGURE 1. Images of the system

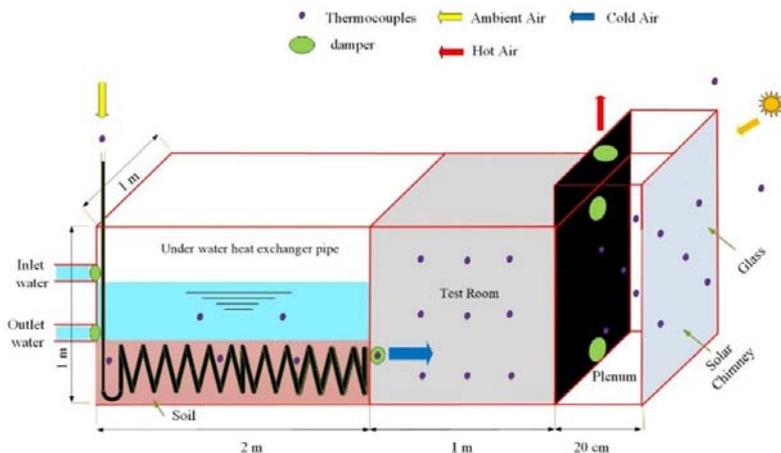


FIGURE 2. The system diagram

panel material with a thickness of 5 cm. This room is connected to a solar chimney (20 cm length, 1 m width and 1 m height). The front side of the chimney was made of glass panels facing the geographical South. The other side consists of a metal plate painted black to enhance the absorption of solar energy during daytime. The heat exchanger was made of aluminum pipe (16 m length, 20 cm diameter).

The air inside the chimney heats up, rises and floats to the top of the chimney and exits from the ventilation hole. This movement of air will lead to an imbalance in air pressure causing to draw the cold air from the test room through the heat exchanger. The latter was buried with a layer of 20 cm thick mixed soil placed at the bottom of a submerged basin. The heat exchanger inlet exposed to the outside air and the outlet is connected to the test room. The basin that contains the water and the heat exchanger was made of galvanized iron plates of 1 mm thick. It was surrounded from outside by a layer of mixed soil 5 mm thick. It is also insulated with a sandwich panel material (2 m length, 1 m width, 1 m height). To study the effect of weather conditions on the performance of the system, the weather parameters such as solar radiation, ambient air temperature, wind speed and relative humidity were measured using an automatic weather station. In addition, a grid of 20 thermocouples were used to measure the temperature at the various parts of the system during test process. These parts include water and soil in the bottom of the water basin, inlet and outlet air, heat exchanger, test room and solar chimney. The measurements were recorded by

Data Locker that stores data and which powered by solar energy.

The efficiency of the cooling system (E_{ff}) was calculated using the following equation (Zaidan et al., 2019):

$$E_{ff} = \frac{(T_{in} - T_{out})}{T_{in} - T_w} \cdot 100 \quad (2)$$

where:

T_{in} – inlet air temperature of the heat exchanger,

T_{out} – outlet air temperature of the heat exchanger+,

T_w – water temperature.

Results and discussion

The changes in temperatures of test room, chimney, water, air at heat exchanger inlet and outlet and the solar radiation for April are visualized in Figure 3. The results show that temperatures begin to rise gradually. Maximum temperatures were recorded to be 23.5°C in test room at 3 pm, 56.95°C in chimney at 2 pm, 30.57°C for inlet air at 2 pm, 18.36°C for water at 5 pm, and 19.43°C for outlet air at 5 pm. By the same approach, the results of May were also visualized in Figure 4. Maximum temperatures were recorded to be 27.01°C at 3 pm at test room 56.76°C in the chimney at 2 pm, 33.97°C for in let air at 2 pm, 21°C for water at 5 pm and 22.08°C for outlet air at 5 pm. It is clear that the temperature of the system was changing according to the change in solar radiation. Those changes in the temperature are identical to those published in 2012 study (Saifi et al., 2012).

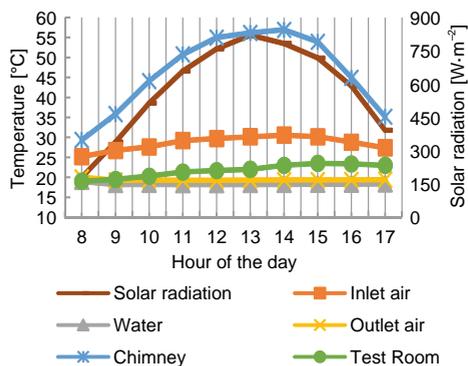


FIGURE 3. Temperature changes and solar radiation with the time in April 2020

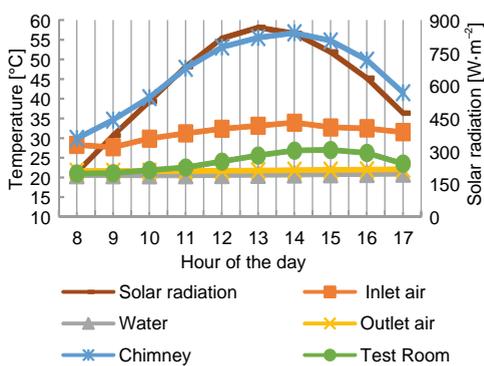


FIGURE 4. Temperature changes and solar radiation with time in May 2020

The difference between test room temperature and ambient air temperature during April is shown in Figure 5. The minimum difference was recorded to be 3.2°C at 8 am while the maximum difference (8.35°C) was recorded at 4 pm, it was during May. The minimum and maximum values of temperature were recorded to be 4.63 and 9.49°C at 8 am and 5 pm, respectively (Fig. 6). Thus, it is obvious that temperature of the test room was less than that of the ambient air.

The effectiveness of the system was calculated as the rate during the period (April and May 2020) using Eq. (2) and

data in Table 1. The results of effectiveness for April and May were 89.01 and 89.5%, respectively. The results are almost identical to those stated by Zaidan et al. (2019) where the cooling efficiencies were 92.6 and 90.05%. A relationship was found between the cooling efficiencies and the factors related to the weather conditions by finding Pearson correlation coefficient in Eq. (1). Table 2 shows the weather data during study period. This relationship is seen in Figure 7 between the intensity of solar radiation and the efficiency of the system during daytime in April. A 0.91 correlation coefficient was obtained from the relationship between

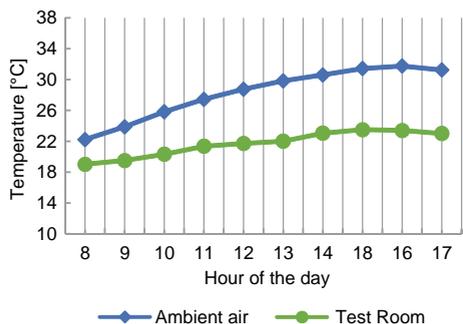


FIGURE 5. The difference in ambient air and test room temperature in April 2020

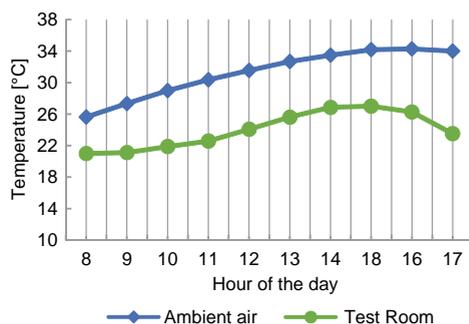


FIGURE 6. The difference in ambient air and test room temperature in May 2020

TABLE 1. Temperatures of inlet air, water, outlet air and efficiency for April and May 2020

Time	April				May			
	inlet air temperature [°C]	water temperature [°C]	outlet air temperature [°C]	temperature efficiency [%]	inlet air temperature [°C]	water temperature [°C]	outlet air temperature [°C]	temperature efficiency [%]
08:00	25.20	18.98	20.03	83.11	28.30	20.60	21.66	86.23
09:00	26.75	18.21	19.28	87.47	27.72	20.59	21.65	85.13
10:00	27.66	18.25	19.33	88.52	29.91	20.57	21.64	88.54
11:00	29.21	18.18	19.27	90.11	31.24	20.58	21.67	89.77
12:00	29.73	18.18	19.27	90.56	32.40	20.63	21.72	90.73
13:00	30.16	18.21	19.31	91.79	33.17	20.69	21.78	91.26
14:00	30.57	18.25	19.35	90.07	33.97	20.77	21.87	91.66
15:00	30.19	18.27	19.37	90.77	32.75	20.84	21.94	91.47
16:00	28.82	18.30	19.39	89.63	32.48	20.91	22.00	90.57
17:00	27.39	18.36	19.43	88.15	31.52	21.00	22.08	89.73

TABLE 2. Weather data for April and May 2020

Time	April				May			
	ambient air [°C]	wind speed [m·s ⁻¹]	solar radiation [W·m ⁻²]	relative humidity [%]	ambient air [°C]	wind speed [m·s ⁻¹]	solar radiation [W·m ⁻²]	relative humidity [%]
08:00	22.22	0.74	179.9	63.7	25.63	0.61	203.9	51.7
09:00	23.87	0.87	339.1	60.3	27.34	0.97	372.8	49.4
10:00	25.81	1.22	514.8	55.4	28.98	1.33	527.6	47.1
11:00	27.44	1.68	659.4	52.0	30.36	1.51	687.0	43.7
12:00	28.74	1.77	759.0	47.0	31.54	1.87	816.0	40.4
13:00	29.82	1.59	821.0	43.4	32.68	2.05	866.1	38.0
14:00	30.60	1.37	783.7	41.1	33.48	2.04	839.3	35.7
15:00	31.42	1.32	718.1	38.5	34.18	1.99	754.1	33.4
16:00	31.75	1.33	592.1	37.1	34.28	1.86	634.5	33.8
17:00	31.24	1.33	392.2	36.1	34.00	2.59	474.4	33.0

them. This indicates that the relationship is very strong, which means that solar radiation is the most important element of the weather condition affecting the system. The results also proved that there is a direct relationship between the inten-

sity of solar radiation and the efficiency of the system's efficiency in May during daylight hours, correlation coefficient reached 0.89, as seen in Figure 8.

Figure 9 shows the relationship between temperature and system effective-

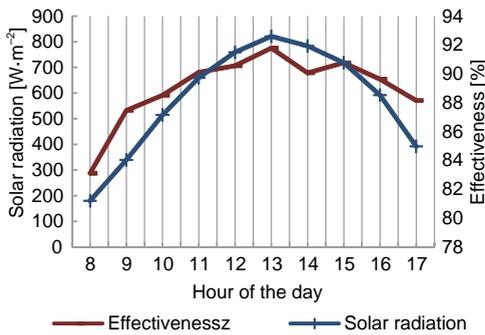


FIGURE 7. The relationship between solar radiation and cooling efficiency in April 2020

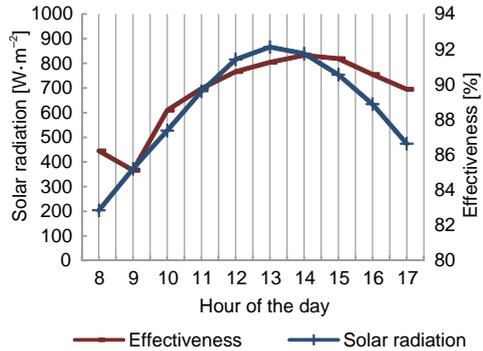


FIGURE 8. The relationship between solar radiation and cooling efficiency in May 2020

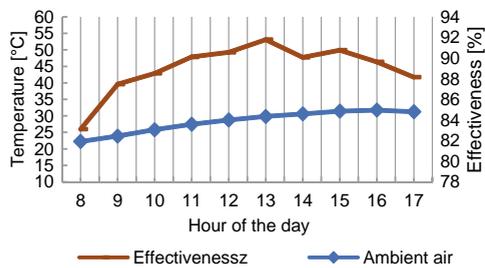


FIGURE 9. The relationship between temperature and cooling efficiency in April 2020

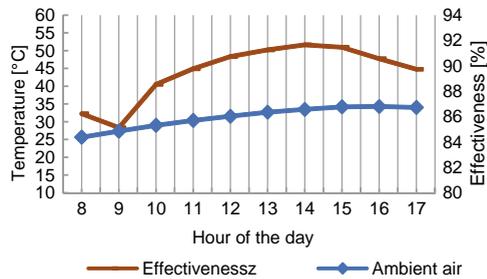


FIGURE 10. The relationship between temperature and cooling efficiency in May 2020

ness changes in April. This relationship has a positive direct correlation coefficient of 0.747. Another relationship between the system's efficiency and temperature in May can be established (Fig. 10). This relationship was positive, and the correlation coefficient of 0.882. This indicates that the increase in temperature lead to the increased of evaporation documenting the efficiency of the system.

Moreover, another relationship between the efficiency and wind speed in April was established as seen in Figure 11. The relationship was found to be direct and the correlation coefficient is 0.82. Figure 12 demonstrates the rela-

tionship between system efficiency and wind speed in May. The relationship is direct and the correlation coefficient is 0.814. The increase in wind speed leads to increase in evaporation and hence enhances the efficiency.

Figure 13 shows the relationship between system efficiency and relative humidity in April. The relationship was found to be negative, and the correlation coefficient of -0.665 . Finally, the relationship between system efficiency and relative humidity in May were analyzed as shown in Figure 14. The figure indicates that the relationship was of a negative nature, and the correlation coefficient of -0.843 .

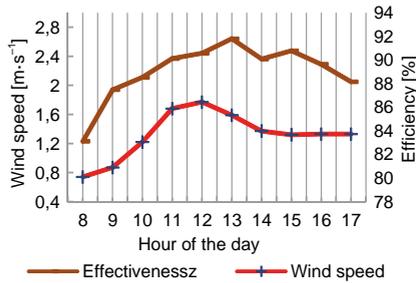


FIGURE 11. The relationship between wind speed and cooling efficiency in April 2020

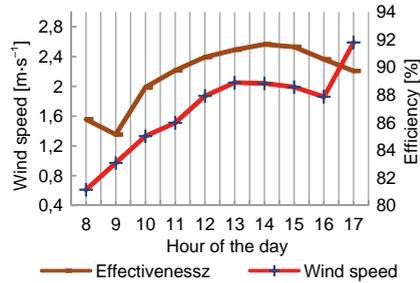


FIGURE 12. The relationship between wind speed and cooling efficiency in May 2020

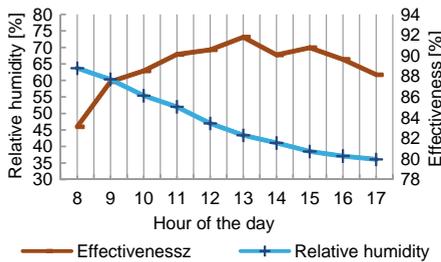


FIGURE 13. The relationship between relative humidity and cooling efficiency in April 2020

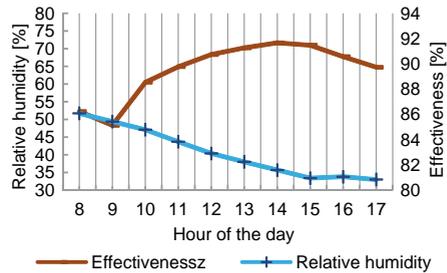


FIGURE 14. The relationship between relative humidity and cooling efficiency in May 2020

The reason for the negative relationship is the relative humidity reduces evaporation which occurs in the water basin. This process is inertial as it does not increase the water temperature (cooling). The heat that water gains from ambient air is lost by evaporation, which makes the water maintain its relative temperatures.

Conclusions

1. The system showed a significant difference in the air temperatures between the test room and the ambient air for April and May 2020. The maximum difference was 8.35°C at 4 pm in April and 9.49°C at 5 pm in May.

2. The cooling efficiency of the system reached maximum values of 89.01% in April and 89.5% in May.
3. There was a positive direct relationship between cooling efficiency and the weather elements such as solar radiation, temperature and wind speed, the correlation coefficient was 0.91, 0.747, 0.82 in April and 0.89, 0.882, 0.814 in May. However, there was a negative relationship between the system efficiency with relative humidity, the correlation coefficient was -0.665 in April and -0.84 in May.

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Summary

Testing the performance of a solar energy cooling system in Baghdad city. Renewable energy resources have become a promissory alternative to overcome the problems related to atmospheric pollution and limited sources of fossil fuel energy. The

technologies in the field of renewable energy are used also to improve the ventilation and cooling in buildings by using the solar chimney and heat exchanger. This study addresses the design, construction and testing of a cooling system by using the above two techniques. The aim was to study the effects of weather conditions on the efficiency of this system which was installed in Baghdad for April and May 2020. The common weather in these months is hot in Baghdad. The test room of the design which has a size of 1 m³ was situated to face the geographical south. The test room is thermally insulated and connected to a solar chimney which generates a convection current to draw the air out of the room through a heat exchanger. The heat exchanger was submerged in a water tank of 2 m length, 1 m width and 1 m height. It was also covered with a layer of soil mixture with a thickness of 10 cm. The experiment simulates the natural conditions of a shallow water surface, connected to the room from the other side. The study results

revealed that the air temperature inside the test room was lower than that of the ambient air outside. Pearson correlation coefficient showed that there was a strong direct relationship between solar radiation, temperature and wind speed from one side and the cooling efficiency from the other side. Also, there was a negative correlation between relative humidity and cooling efficiency.

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