PERFORMANCE AND EFFICIENCY OF EVAPORATIVE COOLING TOWER IN RIYADH, SAUDI ARABIA

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ABSTRACT

Climate in the central part of Saudi Arabia is extremely hot and dry. Passive evaporative cooling systems are highly suitable and effective. Evaporative cooling towers were introduced in Saudi Arabia in the nineties of last century. This research paper aimed to investigate the performance and efficiency of evaporative cooling tower within hot and dry climate context. A full-scale evaporative cooling tower and rooms were built for this purpose. Evaporation within the tower was accomplished by spraying water over water bags made of special fabric 'heavy canvas'. The tower cools the room through the tower's lower opening. To compare the performance of the tower, another uncooled room was prepared as a control room. Weather station, calibrated thermocouples and automated data gathering system were provided to gather and record various types of measurements. Three modes of operation during summer were adopted: first, continuous operation of the water pump; second, continuous operation of the water pump together with the air-pushing fans; and third, operation of the water pump for 30 min every 5.5 h. Analysis of the collected measurements has shown that the third operation mode was the best. It showed reasonable reduction in room temperature, less water and electric consumption, and suitable humidity level within the room space.

Keywords: evaporative cooling tower, passive cooling.

1 INTRODUCTION

1.1 Riyadh's climate

The city of Riyadh, Saudi Arabia, is located in the central part of the Arabian Peninsula (24° 42‘ N – 46° 42‘ E), 600 m above the sea level. Riyadh's climate is considered hot and dry. Maximum dry bulb temperature in summer can reach 48°C, while in winter it might reach zero. July is the hottest month, while December and January are the coldest. The average yearly temperature range is 22°C, while the average daily range is about 13.8°C. The average relative humidity in summer is very low (less than 14% in July) and in winter it is considered reasonable (less than 50% in January). Wind speed rarely exceeds 30 knots. On the average it ranges between 5 and 8 knots. Maximum daily temperature and wind speed occur around 3 p.m. Winds prevail in June, July, August and September from north, north-west and north-east. With regard to thermal comfort, more than 40% of the year time needs cooling (Al Megren [1]).

1.2 Wind towers

Historically wind towers or catchers are ventilative techniques used for natural cooling. Bud-gir and Malqaf are indigenous names for various types of wind towers and wind catchers in Afghanistan, Arabian Gulf, Egypt, Iraq, Iran and Pakistan. Al Megren [1] described in detail the various types of wind towers and analysed their characteristics and performance.

In 1985, Cunningham et al. from the Environmental Research Laboratory, Tucson, Arizona, USA, and Givoni [2] developed a cooling tower with evaporation technique. The shape of

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Figure 1: Evaporative cooling towers in Princess Nourah University, Riyadh.

the tower was rectangular (1.8 m × 1.8 m × 7.6 m) with four openings in the upper part. Evaporation pads made of natural fibrous material (commercially called Cel-Deck) were installed beside the openings and moistened with water. Air in the upper portion of the tower cooled by evaporation and cold heavy air fell down on the lower part of the tower and passed through a lower opening into the room (Gunningham and Thompson [3]).

Tucson evaporative cooling tower model was introduced in Saudi Arabia in the nineties of last century and adopted in several building types such as mosques, hotels, and commercial, educational and residential buildings (Al-Saud & Al-Hemiddi [4]). The latest project that utilized evaporative cooling towers in Saudi Arabia is the one conducted by the University of Princess Nourah in Riyadh. The cooling towers were used to cool the inner courts of thirteen college buildings. Twenty-six rectangular (4.85 m × 4.85 m × 22 m) cooling towers have been used to cool 26 courtyards. Figure 1 shows how towers are being designed and located within the courtyard (AlOtaibi [5]).

2 RESEARCH PROBLEM

Evaporation within cooling tower is a challenging issue. Researchers designed and built a different evaporation system unlike the typical Tucson cooling tower. The system was based on a dual evaporation concept. The evaporation system was achieved through water bags made of strong and heavy fabric ‘heavy canvas’ and the water falling on the sides of the bags. The researchers wanted to examine the performance of the proposed system.

3 RESEARCH OBJECTIVES

The research objective can be summarized as follows:

- to investigate the thermal performance and efficiency of a dual evaporation system cooling tower under three modes of operation;
- to investigate the water consumption in each mode of operation;
- to determine the best mode of operation in terms of cooling efficiency and both water and electric consumptions.

4 RESEARCH METHODOLOGY

Researchers preferred to use a full-scale model to examine the performance of the tower. Full-scale tower gave the most accurate results about tower performance. Simulation models scaled either manually or using a computer do not reflect precisely all variables that influence directly or indirectly the thermal performance.

However, three steps were followed.

4.1 Designing and constructing the testing facility

Figures 2 and 3 consist of the following:

- cooling tower with the dual evaporation system;
- room connected with and cooled by the tower;
- reference or control room without cooling.

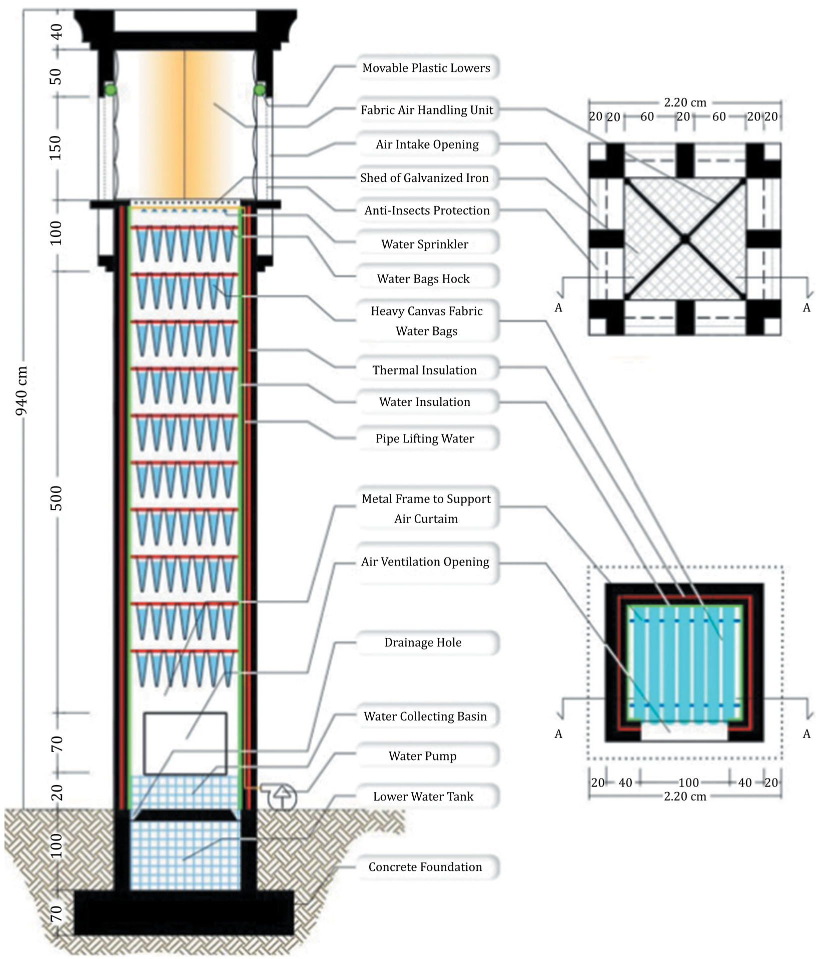

Figure 2: Cooling tower with the dual evaporation system.

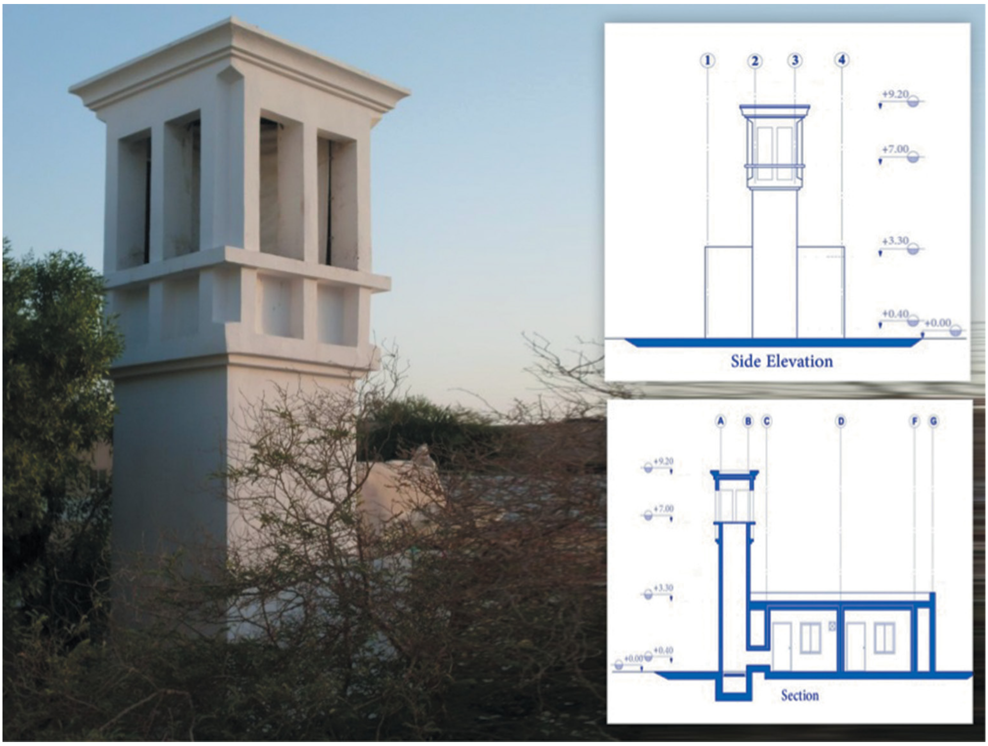

Figure 3: Designing and constructing the testing facility.

4.2 Preparing the digital monitoring system

The digital monitoring system measures and records temperatures, relative humidity and wind speed readings from different locations (Fig. 4). It consists of the following:

- seventeen calibrated thermocouples type T to measure dry bulb temperatures in seventeen locations within the testing facility;
- two water temperature sensors;
- water metre to measure water consumption;
- relative humidity sensor to measure humidity level within the room;
- complete weather station to monitor outside both dry and wet bulb temperatures, relative humidity, wind speed and direction, and solar radiation;
- data logger to collect and record readings from various locations and present them graphically.

4.3 Operation of the tower

The operation was completed for three modes in the summer season 2011:

- First operation mode: Continuous operation of water pump while the exhaust fans are off.
- Second operation mode: Continuous operation of both water pump and exhaust fans.
- Third operation mode: Operation of water pump for 30 min every 5.5 h.

Figure 4: The monitoring system consists of calibrated thermocouples type T, the weather station and data logger CR1000-XT.

4.4 Analysis of the huge sets

The data gathered from the three modes of operation were analysed using Microsoft Excel. Various charts were produced to present the performance of the tower in each mode of operation and to compare between them in order to find out the best mode among the three. Conclusions and recommendations were made for the application and operation of cooling towers.

5 ANALYSIS

5.1 Continuous operation of water pump while the exhaust fans are off

Figure 5 shows thermal conditions within the room that had been cooled by the cooling tower compared with the thermal condition of the control room and the outside temperature. The room cooled by the tower maintained a stable space temperature around 25°C. The control room space temperature was fluctuating between 38°C and 40°C. The outside dry bulb temperature was fluctuating between 33°C and 46°C and the wet bulb temperature was fluctuating between 16°C and 20°C. It is clear that the cooling tower was effective in bringing down the room temperature to 15°C and maintain the room temperature throughout the day between 24°C and 25°C. Around midday evaporation was more effective because relative humidity at that time was the lowest (7%) and the highest tower efficiency was 95%.

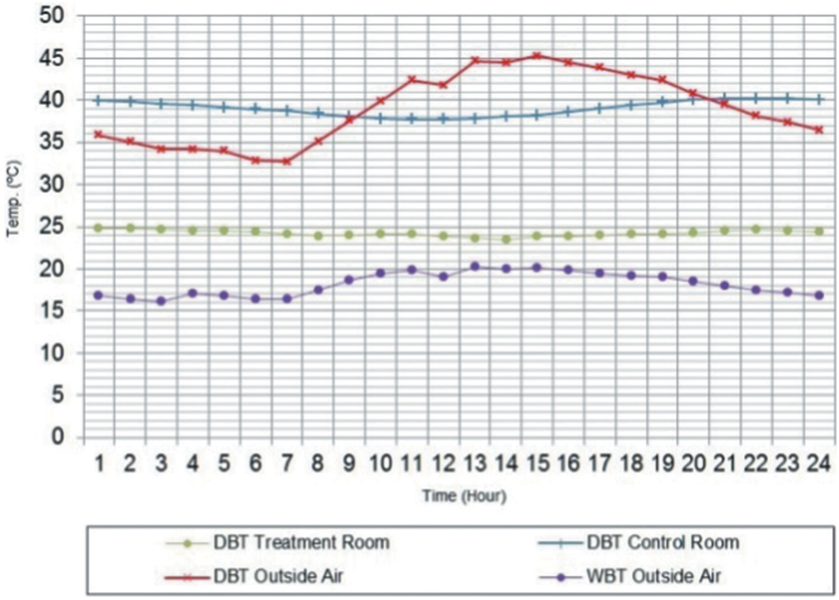

Figure 5: Thermal conditions within the room cooled by the cooling tower compared with the control room in the first operation mode.

The relative humidity within the room cooled by the tower ranged between 71% and 64% which is to some extent less comfortable. Average water consumed in evaporation process was 17 litre/h. Water consumption increases between 12 noon and 6 p.m.

5.2 Continuous operation of both water pump and exhaust fan

Figure 6 shows that although the outside maximum dry bulb temperature was 44°C and the relative humidity was almost 8%, the thermal conditions within the room cooled by the tower were almost the same as in the previous mode of operation. The room temperature stayed around 25°C and the relative humidity was between 60% and 68%. The contribution of the exhaust fan also was minimal in reducing the relative humidity and also in inducing water evaporation. Water consumption increase therefore was marginal.

5.3 Operation of water pump for 30 min every 5.5 h

Figure 7 shows that the air temperature within the room cooled by the tower was below 25°C, while the temperature of the control room ranged between 35°C and 37°C. The outside dry bulb temperature had ranged between 27°C and 43^{o}C. The lower temperatures achieved within rooms reflected the reduction in outdoor air temperature, especially during the night-time. Relative humidity was optimal and ranged between 50% and 62%. However, reducing the hours of water pump operation helped to keep humidity level within the acceptable range. Water consumption also, due to the limited hours of operation of water pump, reduced drastically. Average water consumption was found to be 7 L/h only. Electric consumption to operate water pump undoubtedly was decreased.

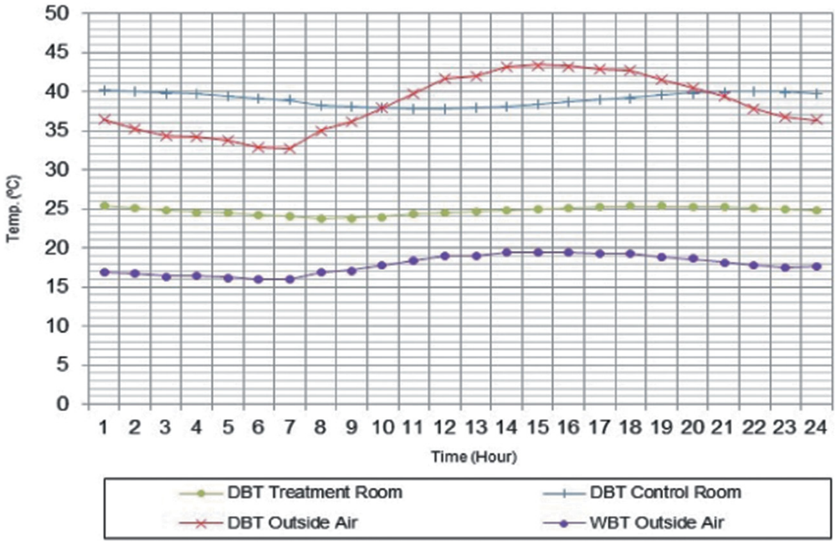

Figure 6: Thermal conditions within the room cooled by the cooling tower compared with the control room in the second operation mode.

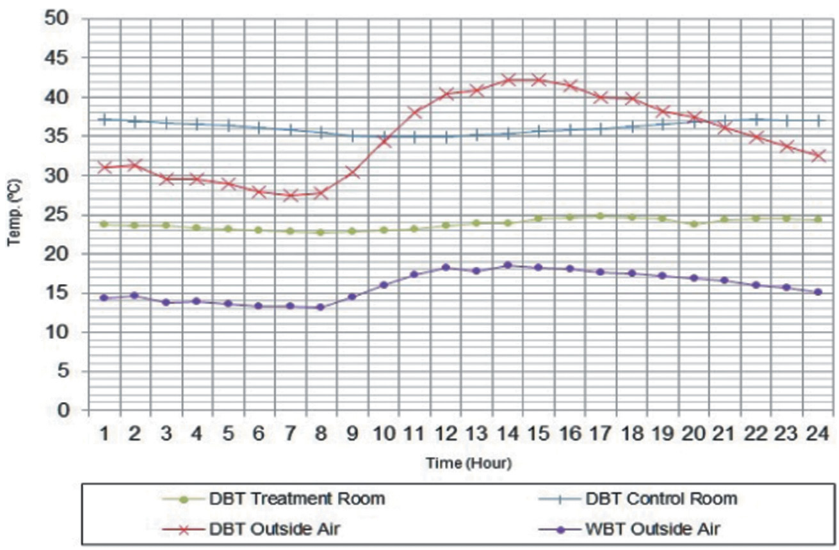

Figure 7: Thermal conditions within the room cooled by the cooling tower compared with the control room in the third operation mode.

6 DISCUSSION

Figure 8 shows hourly differences between the space temperatures of the cooled room and the control room for the three modes of operation. The difference ranges between 1.5°C and 3°C. It is obvious that the differences among the three modes operation are relatively small.

In terms of relative humidity, Fig. 9 proves that the third mode of operation was the lowest. Relative humidity in this option of operation ranged between 50% and 65%. This range, however, falls within the comfort limits.

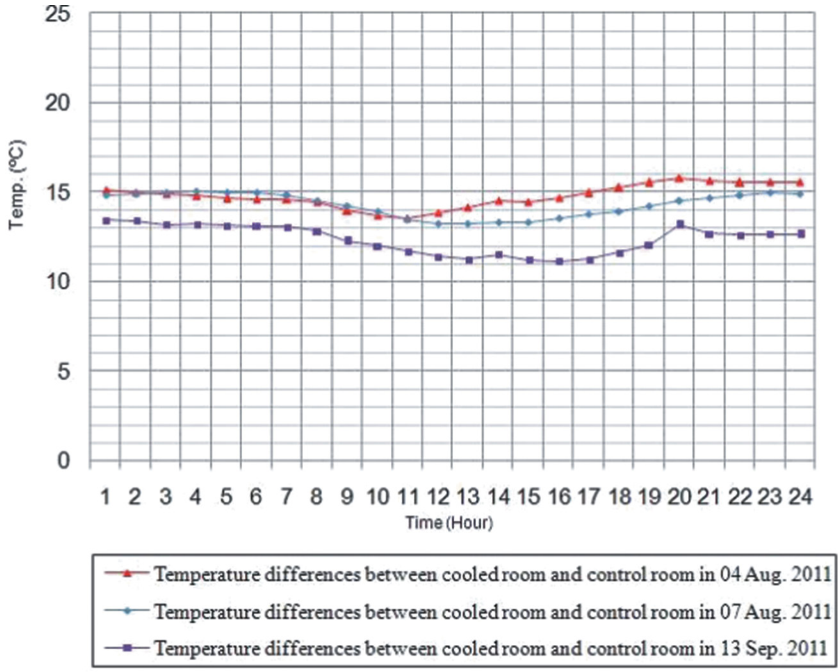

Figure 8: Differences between the space temperatures of the cooled room and the control room for three modes of operation.

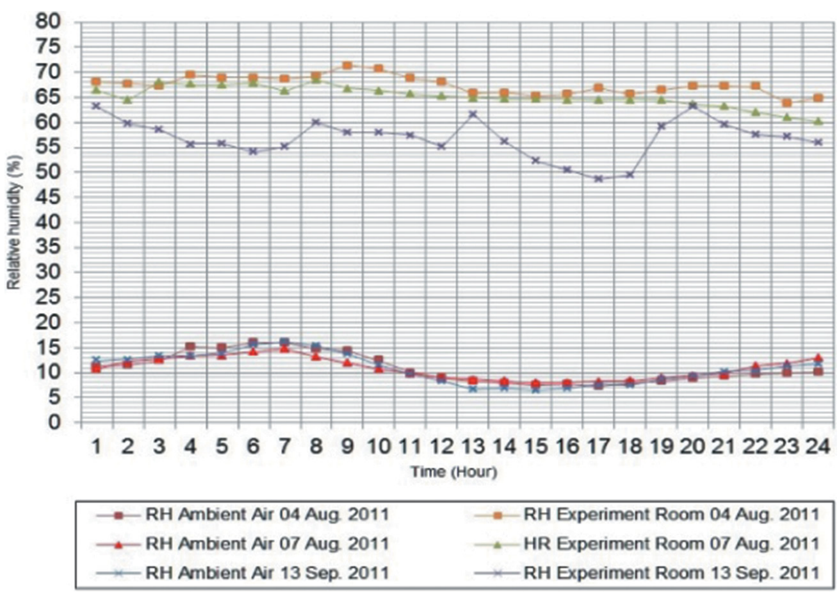

Figure 9: RH differences among the three modes of operation.

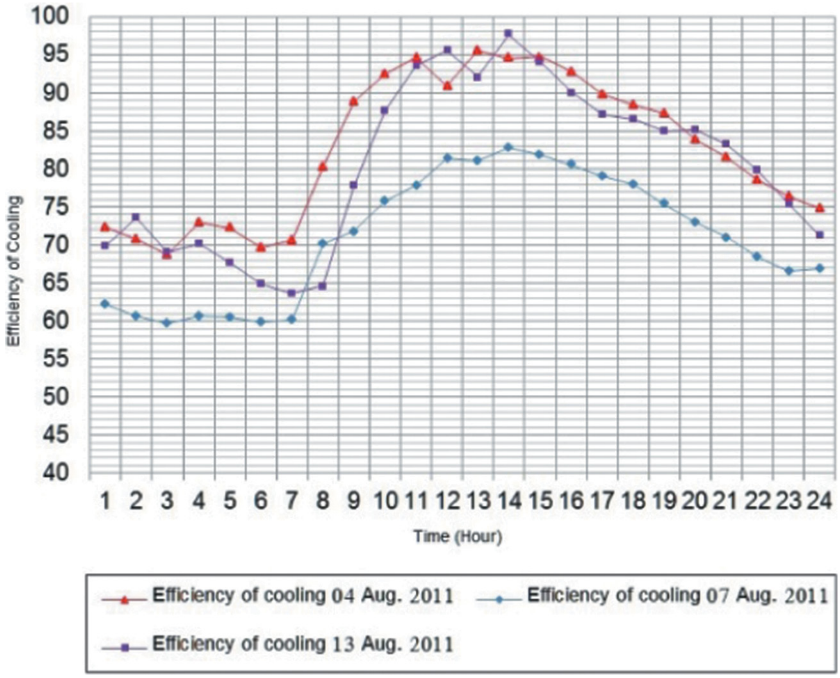

Figure 10: Cooling tower efficiency of three modes of operation.

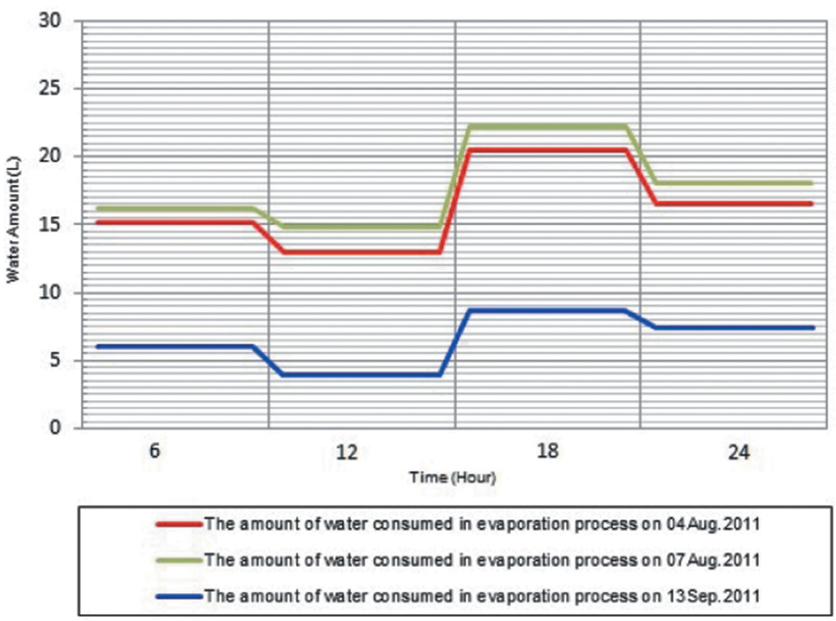

Figure 11: The amount of water consumed in the operation process and the differences among the three modes of operation.

The first and third modes of operation prove, as shown in Fig. 10, that both are similar in terms of tower efficiency and both are better than the second mode of operation.

With regard to water consumption, the third mode of operation as shown in Fig. 11 is significantly the lowest. It is less than one-third the consumption of other options of operation.

Electric consumption is the lowest in the third mode of operation since the exhaust fans are off and water pump operates partially.

It can be concluded that the third mode of operation is all in all the best among the three modes of operation.

7 RECOMMENDATIONS

Based on the research outcomes thermal comfort conditions can be achieved by applying evaporative cooling towers to cool buildings in hot and dry regions. The tower design developed by the researchers improved the potential for better efficiency of cooling and less consumption of both water and electric power. The design also helped to maintain higher cooling efficiency while controlling humidity within the acceptable ranges.

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