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Investigation of Evaporative Cooling System Applied for Environmental Camps in Taif City, Saudi Arabia

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Abstract

In the frame of Saudi Arabia vision 2030, energy saving techniques is considered as one of the most important strategies to reduce the oil dependency in electrical energy production. Moreover, the energy saving techniques can be also considered as one of the renewable energy sources. In the present work, an investigation of an evaporative cooling system (ECS) is performed in order to reduce the energy required for thermal comfort in environmental camps located in Taif city, Saudi Arabia. The initiative of environmental camps in Taif city has been recently announced by the General Authority for Tourism and National Heritage in cooperation with Ministry of Environment Water and Agriculture.

In the present work, the sackcloth is used as a pad material with a specified thickness in the ECS in order to reduce the air temperature to the thermal comfort temperature by using suction fan system. An experimental model is designed as a test chamber having dimensions of 0.7m3. The experimental measurements included the measurement of some operating parameters such as external and internal temperature, relative humidity, air speed during the experiments. The results showed that a temperature difference of about 9oC can be obtained with only about 30% increase in the air relative humidity. In general, the obtained results from the present study prove that the ECS can be considered as an effective and low-cost solution for environmental camps especially for tourism sectors in Taif city, Saudi Arabia.

Keywords: Evaporative cooling system, Experimental measurements, Environmental Camps, Tourism sector, Taif city, Saudi Arabia.

I. INTRODUCTION

Recently, a great interest has been given in Saudi Arabia vision 2030 to renewable energy resources in order to generate 9.5 Giga-watts in the near future. In such context, energy saving techniques can reduce the total energy consumption to some extent and hence, it is considered as a new source of renewable energy that can contribute significantly to the sustainable energy management. More than 70% of the generated electricity in Saudi Arabia is used on air conditioning and cooling [1]. Cooling technology can be found in many applications, such residential and commercial buildings, industrial sectors, and even in tents constructed for Hajj and Umrah accommodation. Moreover, obtaining thermal comfort in tents used either for official festivals such Okaz market or in tourist regions distributed over Saudi Arabia is required. Therefore, new trends in cooling technology can play vital role in energy saving strategy related to Saudi Arabia vision 2030. An effective method to meet this demand is the evaporative cooling system, especially in a Saudi Arabia where the temperature in summer/spring is quite high.

Evaporative cooling is a thermodynamic process, known also as adiabatic saturation of air, is one of the most commonly cooling methods applied to keep the indoor temperature and humidity at the thermal comfort level in environmental camps and green cottages applications [2]. The suitability to the local climate conditions and the availability of resources are considered as the main challenges of the evaporative cooling system.

Generally, there are three different types of evaporative cooling system; namely, roof evaporative cooling, fan–pad and fog/mist technologies. More detail about that can be found in [3]. In comparison with the mechanical refrigeration, evaporative cooling has less power consumption and it is not harmful to the environment. Moreover, evaporative cooling can provide the purpose of cooling of environmental camps very well where the quantity of heat to be removed can be very large and, consequently, the mechanical refrigeration is not economical. Depending on the existing humidity ratio and dry bulb temperature of the ambient air, a large temperature difference can be achieved [4].

Evaporative cooling usually uses very small power consumed in water recirculation pump or air fan. The driven air is cooled by passing through wetted surface known as cooling pad. The incoming air loses a certain amount of sensible heat so increases an equal amount of latent heat of water vapor, and consequently, the relative humidity (water vapor content) of air increases.

Three different types of evaporating cooling can be found in literature, namely; direct, indirect and combined evaporating cooling [5]. The direct type is based on the conversion of sensible heat to latent heat, where the hot outside air passes a porous wetted medium. The minimum temperature that can be obtained is the Wet-Bulb Temperature (WBT) of the entering air. In the indirect evaporative cooling system, no moisture is added to the incoming air.

Recently, an attention has been given to investigate the thermal process of the evaporative cooling either numerically, analytically or experimentally [6-9]. The main objectives of the more recent research on evaporative cooling system are the investigation of performance, suitability and effectiveness of new pad materials subjected to a wide range of operating conditions. Recently, the performances of Cellulosic pads made out of Kraft and NSSC corrugated papers in three flute sizes have been experimentally examined [8].

In order to make evaporative cooling system more useful and efficient in different applications, such as residential and industrial sectors, poultry, greenhouses, as well as storage warehouse, different pad materials have been experimentally tested [4]. In such context, three different pad materials were selected namely; coconut, jute fiber, sackcloth according to the locally available pad materials in Bangladesh [4].

In the present study, the sackcloth is selected as a pad material that surrounds a woody designed model from three sides and the roof of the model. On the front side of the model two suction fans are fitted to extract the air from the surrounding. The internal woody walls of the designed model are covered with Palm fronds in order to give a beautiful internal view and to clean the incoming air.

In the following section, detailed description of the designed model is presented. The measuring devices are defined and the experimental procedure is explained. Finally, the obtained results are illustrated and discussed in order to draw the final conclusion of the present investigation.

II. EXPERIMENTAL METHODOLOGY

In the present study, a test chamber with dimension of 0.7m3 has been constructed using an engineering wood of the known type Medium-density fiber board (MDF). The four walls of the chamber as well as the chamber top were similar in design and shape, as shown in Fig. 1.

Fig. 1. The design shape of the chamber walls and top

The internal surface of the chamber's walls is covered with Palm fronds in order to give a beautiful internal view and to clean the incoming air from dust and any suspended materials. However, the external surface of the chamber's walls as well as the chamber top surface is covered with the pad material, as shown in Fig.2. One side of the chamber is left without pad material and a small door is opened on it. In this side, two suction fans were fitted and driven in case of fan-pad system. The specifications of the suction fans used are shown in Table 1.

Fig. 2. The design shape of the chamber walls and top surface

Table 1. The specifications of the suction fans used

Model	Consumption	Speed	Dimensions	
JES 16	24.5 W	1800 rpm	24 x 24 cm	

The two suction fans are fitted as shown in Fig. 3, with their faces inside the chamber and on the top part of the fourth wall. These suction fans can be driven manually in case of fan-pad system.

Fig. 3. The two suction fans fitted on the test chamber

In the present study, a water spraying system is used in order to make the pad material wet for all times during the experiment. A reservoir with a height of 3 m over the ground feeds the water to a system of perforated PVC pipes with a diameter of 1/2". Three pipes are used around the test chamber. Each pipe has a length of 70 cm and is fitted with 7 holes 2 mm in diameter and distributed over equally distances. A drainage system is designed to collect the water from the pad material and to drive it through a piping system to a glass water pool, as shown in Fig. 4. The complete designed evaporative cooling system is located in our laboratory in Taif University in an open place exposed to the sun light for all times, as shown in Fig. 5.

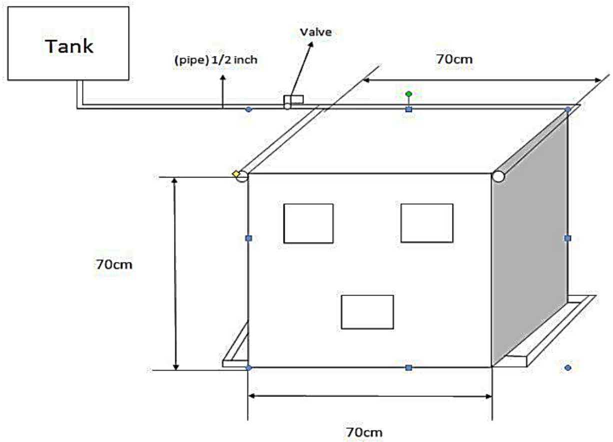

Fig. 4. A sketch of the designed model with a drainage system

The experimental measurements procedure is carried out as follows: the water is allowed to wet the pad material for the three walls through the water spraying system for about ten minutes while the suction fans were off. The operating parameters include the external and the internal temperatures as well as the relative humidity were measured in order to show the effect of the wetted pad material on the internal temperature of the incoming air. Then, the suction fans are operated for further ten minutes to draw the air from outside to the interior

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space of the chamber. The operating parameters were measured in such case to show the effect of using the fan-pad system.

Fig. 5. The designed model with different components

III. MEASURING DEVICES

In the present study, a digital temperature humidity battery meter is used for measuring relative humidity and temperature reading. The device specifications can be shown below in Table 2. For measuring the drawn air by the suction fan, a digital anemometer is used, where its specifications can be also shown in Table 2.

IV. RESULTS AND DISCUSSION

In the present section, the obtained experimental results are presented and discussed. The measurements were carried out in different days, shown in Table 3 below, in order to show the effectiveness of the designed model according to the Taif city-local weather.

The data collected from the experimental measurements include the external air temperature, the internal air temperature, the external relative humidity, the internal relative humidity in case of with/without induced fan system. Moreover, from the temperature measurements obtained, a so-called calling efficiency can be calculated according to the following equation:

$$\eta_{cooling} = \frac{T_{ext} - T_{in}}{T_{ext}} \quad (1)$$

Where Text, and Tin are referred to the external temperature and the internal temperature, respectively.

Table 2. The specifications of the measuring devices used

 	Multifunctional "℃/℉/RH%" button You can select humidity or temperature display at a LCD screen. You can also switch easily between Celsius and Fahrenheit Ambient and WB Range: -20 to 60°C (-4 to 140°F) Precision: ±1.0°C (0 to 45°C), ±1.5°C(-20 to 0°C,45 to 60°C) Resolution: 0.1°C/°F DP Range: -50 to 60°C (-58 to 140°F) precision : ±1.0°C (0 to 45°C), ±1.5°C(-50 to 0°C,45 to 60°C) Resolution: 0.1°C/°F RH Range: 0 to 100%RH Accuracy : ±3.0% RH(20% to 80%), ±4.0% RH(0% to 20%,80% to 100%) Resolution: 0.1%
 	• Proster Anemometer: m/s: 0.40~30.0 ±(2.0% reading+50); ft/m: 80~5900 ±(2.0% reading+50); km/h : 1.4~108.0 ±(2.0% reading+50); mile/h: 0.9~67.0 ±(2.0% reading+50); Knots: 0.8~58.0 ±(2.0% reading+50) • CFM: 0 to 99990 0 to 9.999ft2; CMM: 0 to 99990 0 to 9.999ft2; CMS: 0 to 9999 0 - 9.999 m^2 • Multi-function: Reading hold, maximum, minimum, etc. for Hand-held or Fixed Measurement. • Portable and Professional: Large LCD display backlight measuring instrument, easy to read data in dark. • Power Supply: 9V6F22 Battery (Included), low battery indicator with auto power off functions.

Table 3. The experimental measurements carried out in different days

Day	Sunday (1)	Tuesday (2)	Sunday (3)	Monday (4)	Sunday (5)	Monday (6)	Thursday (7)
Date	10-03-19	12-03-19	17-03-19	18-03-19	31-03-19	1-04-19	4-4-2019
External Temp.	31 °C	27.5 °C	31.6 °C	30.6 °C	29.9 °C	26 °C	29.9 °C
External Rel. Humidity	22.4 %	30.4 %	34.7 %	31.8 %	35.3 %	21.5 %	21 %
Internal Temp. /WOF	26.5 °C	23.4 °C	24 °C	28.6 °C	27.7 °C	23 °C	24.5 °C
Internal Temp. /WF	21.6 °C	22.6 °C	22.2 °C	25.2 °C	25.1 °C	20.5 °C	20.7 °C
Rel. Humidity /WOF	44.5 %	52.4 %	47 %	45 %	49.6 %	54 %	52 %
Rel. Humidity/WF	53.8 %	53.8 %	50 %	45 %	50 %	50 %	50.1 %

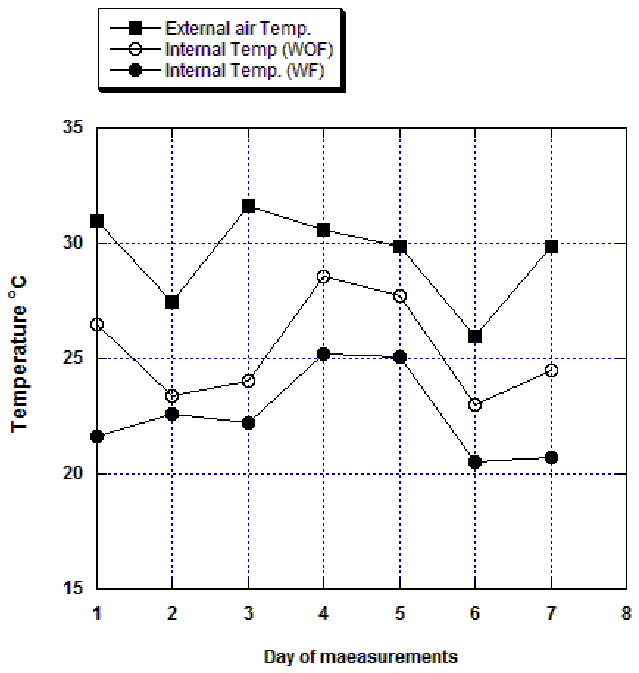

Fig. 6. External and internal temperature distribution with/without induced fans

Fig. 6. shows the external as well as the internal temperature distribution during the different days of experiments. The internal temperature is measured firstly without using the induced fans and after a period of time (about ten minutes).

Then the induced fans are driven and the internal temperature is further measured after the same period of time. It can be seen that, in case of without fans (WOF), the internal temperature is reduced with maximum difference of about 7 °C for day 3 in the Table 1. However, this value can be increased to about 9 °C by using the fan system (WF). These results indicate that the implementation of the induced fan system can decrease the internal temperature (WOF) with about 30%.

According to the reduction of the external temperature of the incoming air, the air relative humidity increases. Fig. 7 shows the increase of the air relative humidity due to the decrease of the external temperature and by using induced fan system. The maximum increase of the relative humidity reaches about 30% over the external air relative humidity. This can be referred to the dry weather found in Taif city, Saudi Arabia, which can increase the effectiveness of the proposed evaporative cooling system.

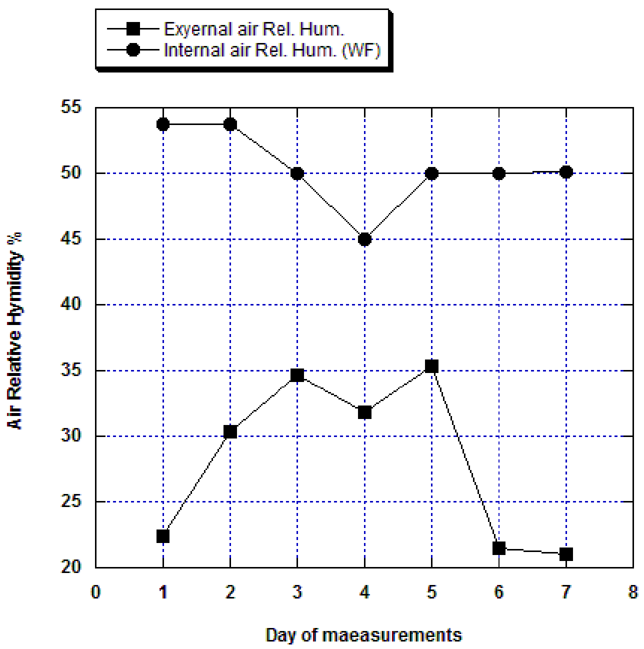

Fig. 7. External and internal relative humidity with induced fans

According to equation (1), a so defined cooling efficiency, can be calculated from the temperature difference obtained through the experimental measurements. Fig. 8 shows that, the application of the induced fan system can increase the cooling efficiency of the proposed evaporative system to about 32%, while without using fans; the cooling efficiency reaches its maximum value of about 24%.

V. CONCLUSION

In the present experimental investigation, a design of evaporative cooling system is performed. The measurements were carried out according to Taif city, Saudi Arabia local weather conditions. The sackcloth is used as a pad material with a specified thickness in order to reduce the internal air temperature to the thermal comfort temperature. An induced fan system is applied for increasing the inlet air flow to the designed test chamber. The results showed that an increase of the cooling efficiency of the designed system due to the application of the induced fan system. The maximum cooling efficiency obtained is about 30% with a temperature difference of about 9ºC and a relative humidity of about 50%. In general, the obtained results from the present study prove that the ECS can be considered as an effective and low-cost solution for environmental camps especially for the tourism sectors in Taif city, Saudi Arabia.

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