Energy and Buildings 119 (2016) 20–27

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Psychometric and thermodynamic analysis of new ground source evaporative cooling system

İlhan Ceylan [a], Alper Ergün [a,*], Bahadır Acar [a], Mustafa Aydin [b]

[a] Karabuk University, Faculty of Technology, Department of Energy Systems Engineering, 78050 Karabuk, Turkey
[b] Karabuk University, Technical Education Faculty, Department of Machine Education, 78050 Karabuk, Turkey

ARTICLE INFO

Article history:
Received 15 November 2015
Received in revised form 3 February 2016
Accepted 6 March 2016
Available online 9 March 2016

Keywords:
Psychometry
Evaporative cooling
Ground source
Energy efficiency

ABSTRACT

Evaporative cooling can be defined as the refreshment effect created by having water come into contact with ambient air. During this contact, liquid becomes gas or evaporates and absorbs heat from the air. Technically, this heat comes from the evaporation of latent heat. Evaporative cooling has been used in many applications due to its low cost. However, a considerable amount of water is needed for this kind of cooling. It is a very effective cooling method in the areas with low relative humidity and for particular areas of a building. For example, it is appropriate in workshops, recreation facilities, factories, dry cleaning rooms, greenhouses, laundries and commercial kitchens, where comfort is not very important in terms of humidity. The aim of this study was to reduce relative humidity to a comfortable level during cooling of the site with an evaporative cooling system. The evaporative cooling system was designed to be ground-sourced and was analyzed thermodynamically and psychometrically. Using an experimental system, we analyzed absorbed sensible heat from air, latent heat gain and cooling pad efficiency. The results indicated a refreshment efficiency of 38% on average, with relative humidity at 54% on average.

1. Introduction

Ambient temperature in enclosed sites and agricultural production structures such as a greenhouse, poultry house and shelter can reach very high values in the summertime for hot climate areas. This causes thermal discomfort in humans and for animals that are being raised. As such, high temperatures can affect the development and health of those living or using various structures. Therefore, ambient temperature should be reduced to appropriate values for animals and/or people in order to maintain production and use of these structures.

One approach to increase thermal comfort is to provide air movement in high spaces and wall-less areas and create suitable shade to prevent the penetration of direct daylight to the sites. This approach, however, would not be adequate if the site temperature is above 30 °C. A known and very effective method for reducing site temperature to suitable conditions in climatic factors above 30 °C is to refresh the environment with a vapor compression cooling cycle (VCCC) that eliminates sensible heat from the site. Current systems, however, are costly and especially so for agricultural/animal production structures. As an alternative to this method, evaporative cooling systems in which sensible heat is transformed to latent heat have recently appeared [1–3]. Evaporative cooling systems have a lower cost than VCCC. The need for alternative cooling systems instead of those that contribute to greenhouse gas emissions has become imperative with the growing concern and attention of the world community to global warming. An evaporative cooling system is an alternative environmentally-friendly cooling system. Increasingly, evaporative cooling systems are being used to increase building energy efficiency and as sustainable approach [4].

Studies on evaporative cooling can be summarized as the following. It is thought that evaporative cooling systems working more efficiently in the areas with low relative humidity and can be used in humid areas during the day and in periods when the temperature is high. Kim et al. [5] did an experimental analysis of a liquid desiccant and an evaporative cooler working with 100% outdoor air. They used a process air cooler to increase free cooling and energy performance for the desiccant solution in the proposed system. Zhang et al. [6] expressed that evaporative cooling systems used in buildings are a very efficient energy-saving technology. They investigated dynamic evaporation and heat transfer processes in two stages by using a climatic wind turbine aimed at providing a reliable experimental method for building evaporation cooling research. Chiesa & Grosso [7] compared different simple simulation models for a passive down current evaporative cooling system by using experimental data. This work helps designers to make a choice between different calculation models. Anisimov &

* Corresponding author.
E-mail address: alperergun@karabuk.edu.tr (A. Ergün).

http://dx.doi.org/10.1016/j.enbuild.2016.03.017
0378-7788/

Nomenclature

Cp	Specific heat (kJ/kgK)
HE	Ground source heat exchanger
h	Enthalpy (kJ/kgK)
ECE	Evaporative cooling efficiency (%)
LHR	Latent heat rate
SHR	Sensible heat rate
$\dot{m}$	Mass flow rate (kg/s)
η	Efficiency (%)
Q	Heat (W)
SH	Sensible heat
LH	Latent heat
RH	Relative humidity (%)
T	Temperature (°C)
t	Time (h)
V	Volt (V)
DC	Direct current
VCCC	Vapor compression cooling cycle
A	Ampere (A)
U	Velocity (m/s)
Hp	Horsepower

Subscripts

T_{DBTPi}	Dry bulb temperature of the inlet of the pad (°C)
T_{DBTPo}	Dry bulb temperature of the outlet of the pad (°C)
T_{WBTPi}	Wet bulb temperature of the inlet of the pad (°C)
T_{Pi}	Inlet temperature of the pad (°C)
T_{Po}	Outlet temperature of the pad (°C)
$\dot{Q}_{HE}$	Absorbed heat by ground in the ground-water heat exchanger (W)
$\dot{Q}_{LH}$	Latent heat gain (W)
$\dot{Q}_{SH}$	Sensible heat loss (W)
$\dot{m}_w$	Mass flow rate of water (kg/s)
$\dot{m}_{air}$	Mass flow rate of air (kg/s)
Cp_w	Specific heat of water (kJ/kgK)
Cp_{air}	Specific heat of air (kJ/kgK)
T_{HEi}	Inlet temperature of heat exchanger (°C)
T_{HEo}	Outlet temperature of heat exchanger (°C)
W_f	Fan power (W)
W_p	Pump Power (W)
Pi	Pad inlet air
Po	Pad outlet air
h_{Pi}	Inlet enthalpy of the pad (kJ/kgK)
h_{Po}	Outlet enthalpy of the pad (kJ/kgK)

Pandelidis [8] performed numerical analysis of heat and mass transfer in indirect evaporative cooling systems for various current methods. Xu et al. [9] used an evaporative cooling system in order to solve the problem of excessive heating resulting from solar radiation in greenhouses and to maintain the greenhouse temperature at required moisture-temperature levels. Armanasco et al. [10] did performance analysis of a cooling system with open circuit solar power that was integrated with an evaporative cooler with liquid desiccant in the north of Italy. Xie and Jiang [11] compared two different indirect evaporative cooling systems that produced cooling air and cold water. Jain and Hindoliya [12] did performance analysis of two new evaporative cooling pad materials.

This study designed a ground source evaporative cooling system that is unique from the systems identified in an extensive literature review. The system was investigated in thermodynamic and psychometric terms by adjusting the amount of air blowing to the site, the amount of air absorbed from the site and the amount of pulverized water.

Table 1
Technical specification of equipments used in the system.

Pump (two number)	6 bar
System control card	12 V
Heat exchanger	1/4 – 3/4 Hp
Dimmer, speed control card (two number)	12 V
Fan (five number)	12 V – 0.25 A
Coolpad	10 × 15 × 50 cm
Power supply	12 V – 15 A – 180 W

2. Materials and methods

In this study, an evaporative cooling system was designed and manufactured with a cooling pad. The design and experimental system are shown in Fig. 1. The system consists of a cooling water circulation line, ground source line and cooling pad line. The number 1 pipe in the ground source line is the return pipe line of the heat exchanger embedded in number 2 ground. The number 3 line is the inlet pipe line of the heat exchanger. The circulation of this line is provided by the pump noted as number 4. The water is passed from the ground source heat exchanger and gathered at the number 5 depot. The cooling pad line, which is the second line in the system, is circulated by pump number 6. The control of this pump was set to operate for 4 min with a control card circuit as indicated by number 7 and then pauses for one minute. The cold water from the number 6 pump is transmitted to the cooling pad with the number 9 pipe line and the water as indicated by number 10 is transferred to a cooling pad (number 11) via pulverizing nozzles. Meanwhile, the process of cooling is realized via the number 12 fan. The drainage of cooler water flowing over the cooling pad with the number 13 line was provided and stored again. Fresh air was taken in via the number 16 fan so as to compensate the moisture balance at the cooled site indicated by number 14 and was given off via the number 15 fan. The system was activated for two different air velocity conditions under positive pressure and with DC dimmers indicated by number 8 and 17, which were used to adjust air velocity.

A timer control card was used for the water pulverizing equipment and a dimmer was used to regulate fan air velocity in the system. The energy of the system came from a 12 V power source. Table 1 provides details on the equipment used in the system.

An electronic circuit was prepared for the designed and produced system. The circuit performs automatic control so that the water does not flow continuously. The pumping of the water in the system lasts for 4 min. After this time, the pumps stop for one minute so that the relative humidity of the environment does not increase. In the meantime, fans dry the surface of the cooling pad. The flow diagram for the prepared control card is provided in Fig. 2.

As seen in Fig. 1, two fans are used inside to supply and exhaust air. A dimmer was used to regulate fan air velocity. Two situations were considered, Case A and Case B when the site is under positive pressure. The air velocity was 1.3 m/s–1 m/s in Case A and 2.3 m/s – 2 m/s in Case B. Table 2 provides test condition details for Case A and Case B. Measurement devices and properties used in the system are provided in Table 3.

2.1. System performance analysis

An equation called refreshment efficiency (%) is usually used for performance calculation of evaporative cooling systems [13,14]. This equation is given below.

$$\eta = \left[\frac{T_{DBTPi} - T_{DBTPo}}{T_{DBTPi} - T_{WBTPi}}\right] \quad (1)$$

Here, T_{DBTPi} is the dry bulb temperature of the air inlet of the pad; T_{DBTPo} is the dry bulb temperature of the air outlet of the pad; T_{WBTPi} is the wet bulb temperature of the air inlet of the pad.