PERFORMANCE COMPARISON BETWEEN DIFFERENT TYPE OF EVAPORATIVE COOLING SYSTEMS

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SUPERVISOR'S DECLARATION

I hereby declare that I have lead this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature : ....
Name of Supervisor : ....
Date : ....

DEDICATION

To my beloved family especially my father,

Tham You Fock

And also to my beloved mother,

Teng Sait May

Who keep me continuously motivated with their great support and encouragement

throughout my Bachelor Degree program

ABSTRACT

The phenomenon of evaporative cooling is a common process in nature, whose applications for cooling air are being used since the ancient years. Evaporative cooling is simply based on the phenomenon of reducing the air temperature by evaporating water on it, hence it meets this objective with low energy consumption. Unlike air conditioning system, evaporative cooling is environmentally friendly with no greenhouse emissions. In this paper the performance of different types of cooling system approaches are being compared by improving the current evaporative systems. There are 3 different types of evaporative cooling system which are wet string, wet cylinder and multi water droplet. Improvements for evaporative cooling systems included modifications on changed of material of string, added more holes on wet cylinder and decreased the length of syringe. For temperature measurement, USB TC-08 data logger and thermocouple are used as instruments to measure the temperature of air during the experiment. The temperature was measured and recorded in the duration of 1 hour with 10 second interval of time. The temperature difference between inlet air and outlet was obtained to determine the performance of each evaporative cooling system. The results show that the multi water droplet evaporative cooling system has the best performance of cooling effect.

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CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

DEC	Direct Evaporative Cooling
IEC	Indirect Evaporative Cooling
CHF	Critical Heat Flux
CFD	Computational Fluid Dynamic
PDA	Phase Doppler Anemometer

LIST OF SYMBOL

c_a	=	Dry air specific heat
c_v	=	Vapour specific heat
T_{a1}	=	Inlet temperature
T_{a2}	=	Outlet temperature
T_w	=	Water temperature
X_1	=	Inlet moisture content
X_2	=	Outlet moisture content
h_{fg}	=	Water evaporation
$\dot{m}_{da}$	=	Dry air mass flow rate
$\dot{m}_{wv}$	=	Rate of water consumption required for the evaporative cooling process
η	=	Cooling efficiency
T_{wb}	=	Wet bulb temperature of cooled air
$\dot{m}''$	=	Mass flux
q''	=	Heat flux
$c_{p,v}$	=	Specific heat of vapor
$c_{p,l}$	=	Specific heat of liquid
T_{sat}	=	Saturation temperature
T_{wall}	=	Wall temperature
T_{spray}	=	Spray temperature

CHAPTER 1

INTRODUCTION

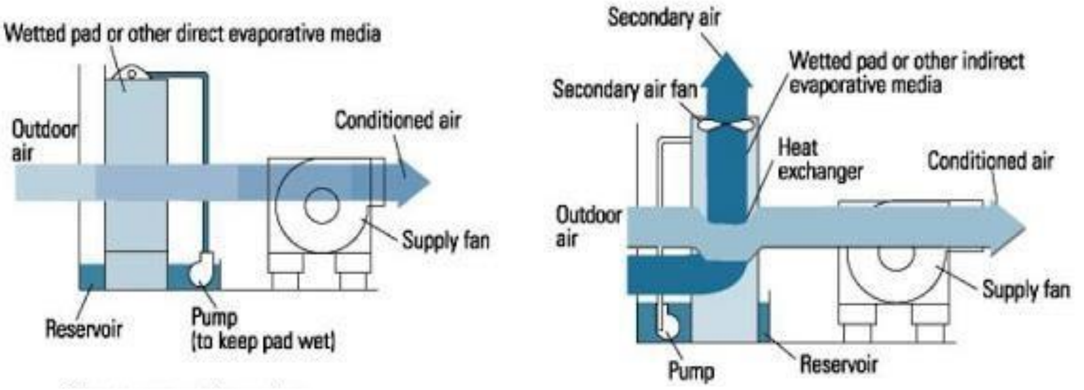
1.1 Background

Air conditioning system plays an imperative role in life. It has become more popular in life not only for human being but also for flora and fauna to create comfortable environment. The air conditioning system has one drawback which is it consumes a large amount of energy and releases greenhouse gases to the environment. Evaporative cooling is one of the alternatives to cool the air and it occurs naturally. The most common example the human experience is perspiration or sweat. When perspiration occurs, it absorbs heat from human body and evaporates to the air to cool human body (Kapilan et al., 2016).

Evaporative cooling system is a system that cools air and reduces the air temperature through the water evaporation process. The water must have heat applied to it to change from a liquid to a vapor. An evaporative occurrence means the heat is removed from the water that remains in liquid state then resulting in a cooler liquid. This evaporative cooling process is consuming less energy and no greenhouse gas emissions compared to air conditioning system. There are 2 main principle methods of evaporative cooling are commonly used, direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) (Sirelkhatim et al., 2012).

DEC is the earliest, the most straightforward and common form of evaporative air conditioning. DEC can be applied only in places where relative humidity is low. This is because DEC adds moisture to the cool air and this might increase the relative humidity and create discomfort to user. Figure 1.1(a) shows the schematic diagram of a conventional DEC system that consists of evaporative media from wettable and porous material, fan blows air through the wetted medium, water tank, recirculation pump and water distribution system. DEC system is based on the conversion of sensible heat into latent heat of evaporated water. The sensible heat loss by the air is equal to the latent heat gain and the enthalpy of air is remain unchanged, since the process is adiabatic.

On the other hand, IEC involves heat exchanger to cool the air without increasing its moisture content and undergoes heat and mass transfer occurring in the heat exchanger. A conventional IEC system as shown in Figure 1.1(b) that consists of a heat exchanger, small fan, pump, water reservoir and water distribution lines. In this system, there are two streams of air, namely wet and dry passages. In dry passage, primary air is cooled and it is separated with secondary air and water flow in wet passage. The heat is removed from primary air through impermeable separating wall and evaporates water into secondary air, wet passage is where the evaporation occurs. Hence, evaporation in wet passage and heat removal in dry passage and both happen simultaneously causes heat and mass transfer (Rabah et al., 2013).



(a) Direct evaporative cooling system (b) Indirect evaporative cooling system

Figure 1.1: Schematic diagram of (a) direct evaporative cooling system and (b) indirect evaporative cooling system (Bhatia, 2012)

1.2 Problem Statement

Now, one of the popular issue that people concern about is climate change. The use of chlorofluorocarbon based refrigerants in the air-conditioning system increases the global warming and causes the climate change. Air conditioning system gives cool air but at the same time brings greenhouse gases to the environment. The climate change is expected to present a number of challenges for the built environment and an evaporative cooling system is one of the simplest and environmentally friendly cooling system. Evaporative cooling also the oldest method to cool the air with less energy consumption. One of the drawback of evaporative cooling is the temperature of cooled air is lower than that of air conditioning. There are several types of evaporative cooling system need to be discussed about which are wet cylinder, wet string and multi water droplet evaporative cooling system. The performance of these evaporative cooling system is compared after some modifications are made on the evaporative cooling system. Hence, the design of evaporative cooling system is the key to cool the air efficiently.

1.3 Objective

The objectives of this project are as follows:

1. To improve current evaporative cooling system

2. To compare the performance of different type of cooling system approaches

1.4 Scope of Project

The scopes of this project are:

1. The three different types of evaporative cooling system are improved with some modifications, which are refer to wet cylinder, wet string and multi water droplet evaporative cooling system.
2. The performance of each type of evaporative cooling system are compared and based on the temperature difference of the air.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the literature review by referring journals, books, articles and any material regarding the project to obtain the data. Evaporative cooling system had been studied by many researchers before. Some of the topic are the history of evaporative cooling system, principle of evaporative cooling system, type of evaporative cooling system, application of the cooling system and many others. Some of the topics will be discussed in this chapter.

2.2 History of Evaporative Cooler

Evaporative cooling is a physical phenomenon with natural concept of pushing warm air through water or water-soaked pad to create a cool air with small amount of air moisture added to the air, the faster the rate of evaporation the greater the cooling effect. There have been various designs over the years. In early Ancient Egyptian times, paintings portray slaves fanning large and porous clay jars filled with water to cool the rooms of royal inhabitants which is a very early form of evaporative cooling ("The Interesting History," 2017). The common people of Rome cooled their home by hanging wet mats over the doors and windows of their homes in order to get a sense of cool breeze.

The first man made coolers that trapped wind and funnelled it past water at the base of the towers and into a building. This in turn kept the building cool at the time. In 1800 B.C the new England textiles factory began to use the evaporative cooling systems to cool their mills by using the air washers passed air through water spray (Liberty et al., 2013).

There is different type of evaporative cooler were constructed such as bamboo cooler and charcoal cooler. Bamboo coolers were constructed with bricks with hessian cloth which were used to wrap the bricks (Kapish et al., 2018). Other than that, charcoal coolers were produced because of its very porous structure that can hold water as air flows across this wet wall the temperature of air is decreased due to the loss of heat through evaporation of water (Chris, 2013). Rusten (1985) portrayed a few sorts of evaporative cooling that was been utilized in New Delhi, India in which a wetted tangle with fan was utilized to cool a nearby eatery.

2.3 Principles of Evaporative Cooling System

Evaporative cooling is the process by which the evaporation of water causes the cooling effect and hence reduce the temperature of a substance. The conversion of sensible heat to latent heat can cool the air by evaporating water and decreasing in the ambient air temperature (Patil et al., 2013). Sensible heat is the exchange of heat that changes the temperature of the system but without changing other physical state of the system such as volume or pressure. Contrarily, latent heat only changes the physical state of a substance without the change of temperature by evaporation or condensation (John and Will, 1997). This cooling system has been used on various scales from small space cooling to large industrial applications.

Air conditioning and refrigeration technologies are different with evaporative cooling because evaporative cooling can provide effective cooling simply require a water supply and electrical power. By wetting a surface and allowing the water to evaporate the effective cooling can be produced. Same principle when human is sweating during physical exertion the body is cooled by evaporating sweat from the skin and the cooling effect can be sensed. This simple concept of evaporative cooling is the fundamental for more mechanized and complex evaporative cooling systems.

The cooling effect achieved by the evaporative cooling system can result in high relative humidity of the air as the air that is unsaturated with moisture can absorb a certain additional amount of water vapor, in which case the heat contained in the air is absorbed by the vaporization of the water. This liquid-to-vapour phase change causes the simultaneous cooling of the air and of the water remaining in liquid state (Taye and Olorunisola, 2011).

Evaporative cooling occurs when air, that is dry, passes over a wet surface, the rate of evaporation of water is directly proportional to the cooling effect of the air (Liberty et al., 2013). The efficiency of an evaporative cooler depends on the humidity of the surrounding air. Dry air causes greater cooling because dry air can absorb a lot of moisture. Conversely, if the air that is saturated with water, there is no evaporation and no cooling occur. Generally, an evaporative cooling structure is made of a permeable material that is fed with water. Hot dry air is drawn over the material. The humidity of air in increased as the water evaporates into the air and in the meantime the temperature of the air is reduced (Kapilan et. al., 2016).

The water content in the saturated air increases faster than the temperature. Therefore, evaporative cooling is more effective in regions with hot and dry climates. Conversely, the potential for evaporative cooling decreases and tends to nil when air is close to humidity saturation levels. In humid climates, evaporative cooling may however be used at the condenser level in conventional refrigeration systems or heat exchangers for industrial processes (Lazzarin, 2015).

2.4 Direct Evaporative Cooling System

The conversion of sensible heat to latent heat is the fundamental principle of direct evaporative cooling (DEC). The working principle of DEC is by introducing water directly passes a porous wetted medium or water-soaked pad by using a blower to pull air. The air is filtered, cooled and humidified after passes through the permeable wetted medium. A recirculation pump keeps the permeable medium wet. These components combine to increase the rate of natural heat exchange process (Bhatia, 2012).

As the water absorbs heat from the air, the water evaporates and cools the air. The humidity of air increase causes the dry bulb temperature of the decrease, as a matter of fact, this is an adiabatic saturation process (Sirelkhatim and Emad, 2012). Some of the sensible heat of the air is changed into latent heat when water in the wetted medium is changed into water vapor and diffused into the air. The wet bulb temperature of the entering air is the minimum temperature that can be obtained.

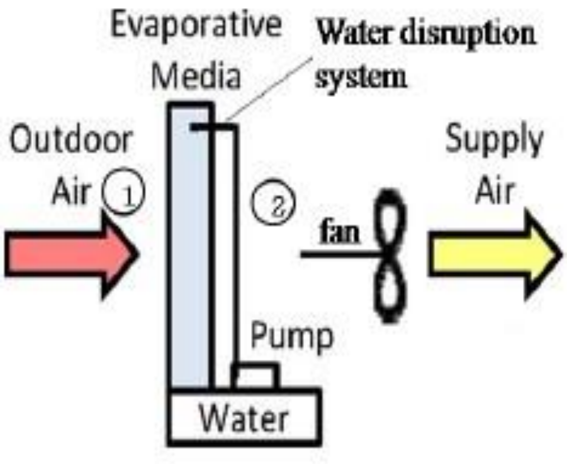


Figure 2.1: Schematic diagram of direct evaporative cooling (DEC) system (Boukhanouf et. al., 2015)

Spray humidifiers also considered one of the direct evaporative cooling. Spray humidifiers or spray nozzles deliver moisture to atmosphere using compressed air to ensure evaporation occurs. Prophet's Mosque in Medina, Saudi Arabia consists of the world's largest evaporative cooling system by using spray. The climate in Medina is hot and dry all year round and the temperature often rises to 50°C during day time. The King of Saudi Arabia saw an outdoor air conditioning system that vaporized water and having a cooling effect during a visit to the USA. Therefore, the King asked for installing a similar cooling system under the sun umbrellas in Medina. Water pumps and spray elements are installed in the mosque when all the systems are operating 50,000 litres of water can be vaporized in an hour. This successfully decrease the temperature across the site of up to 10°C (Leo Rasmussen, 2013).

Figure 2.2: The world's largest evaporative cooling system in Medina, Saudi Arabia (Leo Rasmussen, 2013)

The direct evaporative cooling has some major limitations including the increase in humidity of air may be undesirable, the lowest temperature that can be obtained is same as the wet bulb temperature of the outside air and the high concentration and precipitation of water deposits on the permeable wetted medium or other parts which causes blockage and corrosion and required frequent cleaning, replacing and servicing (Liberty et al., 2013).

2.5 Indirect Evaporative Cooling System

Indirect evaporative cooling (IEC) comprises of a heat exchanger and direct evaporative cooler. Unlike DEC, IEC uses the evaporative effect that add no moisture to the supply air system. IEC lowers the temperature of air via some type of heat exchanger arrangement, in which a secondary airstream is cooled by water and which in turn cools the primary airstream (Xie and Jiang, 2010). The cooled air never comes in direct contact with water or environment. In indirect evaporative cooling system both the dry bulb and wet bulb temperatures are reduced.