EXPERIMENTAL STUDY OF WATER BASED AIR CONDITIONING SYSTEM FOR SPACE COOLING

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UNIVERSITI SAINS MALAYSIA

2022

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July 2022

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfilment of the requirement to graduate with honors degrees in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

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ACKNOWLEDGEMENT

All praises to Allah S.W.T, the almighty and the most merciful, for His wills giving me the strength and hope to complete my Final Year Project (FYP). First and foremost, I would like to express my gratitude to my final year project supervisor, Ir. Dr. Chan Keng Wai for his guidance and support throughout the project. I am thankful for all his contribution and knowledge that helped me to overcome the obstacle I came across in the completion of this project.

Next, I would also like to acknowledge with much appreciation to the crucial role of the staff of Engine Lab of School of Mechanical Engineering, Mr. Mohd Zalmi Yop who has provided a helping hand for my work in the laboratory. Besides, appreciation to the course coordinator Dr. Muhammad Fauzinizam Bin Razali, who has provided a proper a guidance and tolerance throughout the course.

Furthermore, I am grateful to my parents Mr. Azmin Bin Ayob and Mrs. Wathi Binti Abdul Wahid, my fellow friend and my colleagues for their continuous support and words of encouragement providing me emotional and financial support for me to complete this project.

Last but not least, special thanks to the authority of Universiti Sains Malaysia (USM) especially to School of Mechanical Engineering (SoME) for providing good facilities needed to complete this project and thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Air Conditioning
COP	Coefficient of Performance
DEC	Direct Evaporative Cooling
IEA	International Energy Agency
GWP	Global Warming Potential
IEC	Indirect Evaporative Cooling
LPM	Liter Per Minute
ODP	Ozone Depletion Potential
RH	Relative Humidity
USM	Universiti Sains Malaysia

LIST OF APPENDICES

EQUATION

$T_W = T\ atan[0.151977\,(RH\%\,8.313659)^{0.5}] +\ atan(T + RH\%) - atan(RH\% - 1.676331) + 0.00391838(RH\%)^{1.5} atan(0.023101RH\%)\ 4.686035$	(3.1)
$\eta_W = \frac{Ambient\ temperature - Condeser\ surface\ temperature}{Ambient\ temperature - Wet\ bulb\ temperature} \times 100\%$	(3.2)

ABSTRAK

Sistem penghawa dingin adalah satu kemestian di hampir semua kawasan perumahan. Terdapat pelbagai teknik penyejukan penyejatan yang telah diperkenalkan untuk meningkatkan prestasi peralatan asas ini. Namun, penyejukan menggunakan bahan pendingin sama ada sintetik atau semulajadi masih boleh menjejaskan alam sekitar. Dalam projek ini, penyejukan ruang dimaksudkan dengan min sistem penghawa dingin berasaskan air. Sistem penyaman udara akan menggunakan sistem penyejukan penyejatan terus dan air sebagai penyejuk. Prestasi sistem penyejukan akan disiasat melalui eksperimen. Sistem penyaman udara menggunakan penyejukan penyejatan langsung dan air sebagai penyejuk dibina dengan mengubahsuai sistem penghawa dingin kewujudan semasa. Pemampat dalam unit pemeluwap akan digantikan dengan pam air untuk mengedarkan air di dalam kitaran penyejuk. Manakala sistem penyejukan penyejatan terus akan dipasang semula ke unit pemeluwap untuk menurunkan suhu pada pengambilan udara pemeluwap. Pad media penyejuk akan digunakan untuk mengurangkan suhu udara dan meningkatkan prestasi sistem penyejukan. Kadar aliran isipadu air di dalam gegelung penyejuk dipelbagaikan untuk menyiasat peningkatan prestasi. Eksperimen yang dijalankan akan membawa dua tujuan utama. Tujuan pertama adalah untuk mengukur kecekapan sistem penyejukan penyejatan dengan kadar aliran isipadu yang berbeza dalam gegelung penyejukan. Tujuan kedua eksperimen adalah untuk mengukur prestasi sistem penyejukan. Keputusan eksperimen menunjukkan sistem penyejukan dengan aliran isipadu air 6.25×10-5 m3/s. mempunyai kecekapan tertinggi iaitu 44.83%. Eksperimen juga menunjukkan perbezaan suhu maksimum dan min masing-masing 6.56^{O}C dan 4.62^{O}C apabila kadar aliran isipadu air dalam paip ialah 6.25×10-5 m3/s.

ABSTRACT

Air conditioning system is a must in almost all residential area. There is various evaporative cooling technique that have been introduced to improve the performance of this basic appliances. However, cooling using the refrigerant whether it is synthetic or natural can still affect the environment. In this project, space cooling is intended by the mean of water-based air conditioning system. The air conditioning system will use a direct evaporative cooling system and water as refrigerant. The performance of the cooling system will be investigated through experiment. The air conditioning system using the direct evaporative cooling and water as refrigerant is built by modifying the current existence air conditioning system. The compressor in the condenser unit will be replaced with water pump to circulate the water inside the refrigerant cycle. While the direct evaporative cooling system will be retrofitted to the condenser unit to lower the temperature at the condenser air intake. Cooling media pad will be used to reduce the air temperature and improve the performance of the cooling system. The water volume flow rate inside the cooling coil is varied to investigate the performance enhancement. The experiment conducted will carry two main purposes. The first purpose is to measure the efficiency of the evaporative cooling system with different volume flow rate in the cooling coil. The second purpose of the experiment is to measure the performance of the cooling system. The experiment result shows that cooling system with water volume flow of 6.25×10^{-5} m^3/s. has the highest efficiency of 44.83%. The experiment also shows the maximum and mean temperature difference of $6.56^{O}C$ and $4.62^{O}C$ respectively when the water volume flow rate in the pipe is 6.25×10^{-5} m^3/s.

CHAPTER 1

INTRODUCTION

1.1 Research Background

The purpose of air conditioning is to create a certain level of personal comfort in an internal environment. Many factors can be the determinant of air conditioning such as temperature, humidity and air flow. The personal comfort can be achieved by balancing and finding the best possible combination of all the factors. The temperature is the most common way people would describe a comfort condition. Using air conditioning system, the temperature can be adjusted by heating or cooling the air. Air Humidity or relative humidity indicate the amount of water vapor in the air. Humidifying or dehumidifying is a process of adding or removing water vapor from the air, thus affecting the comfort condition of a space. Air flow is also an important factor in the air conditioning process. Increasing or decreasing the air flow in the space can affect the comfort condition of personal in the space.

Many approaches have been taken to improve the performance of the air conditioning system. Evaporative cooling system is one of the approaches that used water to improve the performance of the system(Alhamdo et al., 2015). Introducing the water directly to air stream via mist spray or introducing it indirectly using a media can enhance the performance, reduce the emission and optimize the energy consumption

The environmental impact of the refrigerant in air conditioning system is undeniable even with the study and improvement that is made to the refrigerant. Water as refrigerant is an easy option of environmentally friendly refrigerant. However, the application of water as a refrigerant in a cooling system requires a lot of consideration.

Space cooling demand has been high as ever and the reason behind the rise is due to increasing in the size of population, increasing in the desire for a thermal comfort provided by air conditioning and warmer climates. There will be two main opportunities for space cooling which is increasing cooling thermal comfort and reducing the energy used to provide the cooling(Katili et al., 2015).

1.2 Problem Statement

According to International Energy Agency (IEA), the number of individual cooling units or system in use in the residential sector worldwide rises from 850 million in 2016 to 3.7 billion in 2050. With that amount units, a slight inefficiency in the process can result into huge power loss. Performance enhancement of the air conditioning system reduce the power consumption. Easily available, non-toxic, and environmentally friendly is some of the desirable properties of water compared to ammonia, carbon dioxide, and sulphur dioxide as refrigerant. Hence this project will explore the usage of water in air conditioning system for space cooling. The space cooling is intended to cool the indoor space below the ambient temperature and reducing the energy that is used to provide the cooling.

1.3 Objectives

i) To design a water-based air conditioning system for space cooling.

ii) To investigate the performance and the efficiency of the designed cooling system.

1.4 Scope of Research

The prototype of the cooling system is done using commercially available component. The prototype is based on a conventional split AC unit. The split AC unit need to be modified to fit the water-based system. The compressor in the condenser unit is removed and replaced with water pump. The direct evaporative cooling system is design to be retrofitted to the existing condenser unit.

After completing the prototype, experiment is conducted. The data that need to be obtained for the analysis is relative humidity, temperature and volume flow rate. Arduino programming is needed to operate the water flow sensor. The experiment is conducted to determine efficiency of the direct evaporative cooling system and the performance of the cooling system to cool space.

Due to the lack of proper device to measure the water and electrical consumption accurately, the water and electrical consumption is not considered in this project. The change of pressure of water in refrigerant cycle is also neglected.

1.5 Thesis Organization

This thesis is divided to several chapter. There are total of 5 chapters including this chapter. Chapter 1 cover the research background, problem statement, objectives, scope of research and thesis organization.

Chapter 2 represent the comprehensive literature review, journal, article and research work that are related to this project. The literature review includes the air conditioning system and its component, evaporative cooling and water as refrigerant.

Chapter 3 will explain the methodology used to conduct the research work. In this chapter experiment and its setup is discussed.

Chapter 4 present the result and discussion of this project. The data obtained from the experiment is analyzed.

Chapter 5 summarizes the project and provide an insight for future work on the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The literature review findings, discussed in this section, focus on the air conditioning system and its component. The literature on the evaporative cooling is also explored to widen the vision on the evaporative cooling system. The literature about the enhancement of evaporative cooling is collected to seek the best possible upgrade for the system. The usage of water as refrigerant is also explored to open more sustainable solution for the space cooling.

2.2 Air Conditioning System

Air conditioning system achieved the space cooling by removing the heat from the space with the introduction of cooler air flow. Temperature, humidity and air flow are the main determinant of comfort condition of an air conditioning system. The temperature of the space can be controlled by increasing or decreasing the heat transfer to the space. While humidity of the air is affected by addition or removal of water vapor from the space. Lastly, the air flow refers to the velocity of air in the space.

2.3 Component of Air Conditioning

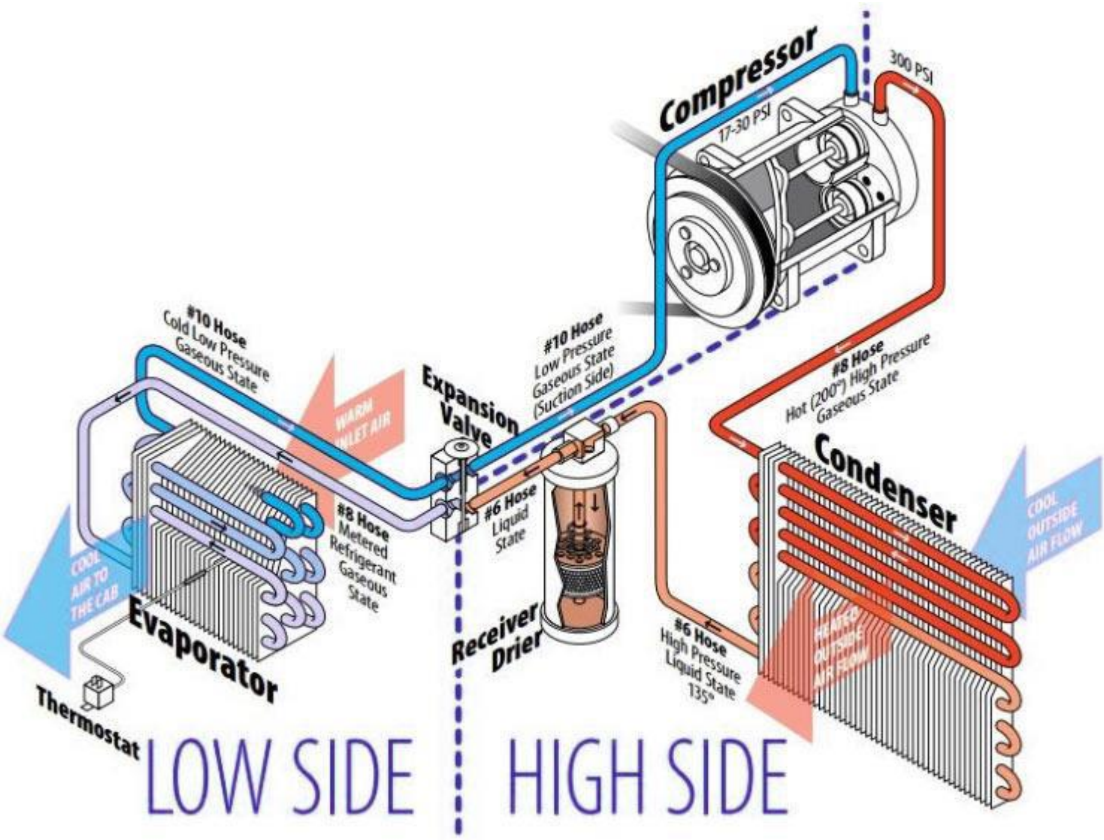

Figure 2.1 The Main Components of The Air Conditioning System.
Source:(*Important Parts Of Air Conditioner | Mastercool*, n.d.)

Figure 2.1 The Main Components of The Air Conditioning System. Source:(*Important Parts Of Air Conditioner | Mastercool*, n.d.)shows the main components of the refrigerant cycle inside an air conditioning system. Air conditioning system mainly comprise of four components that are used to circulate the refrigerant in a cycle to provide cooling to the space. The first component of the air conditioning system is the compressor. The compressor pressurized the low temperature refrigerant gas raising the gas temperature and pressure. The compressor also provides the circulation of refrigerant in the cycle. The second component is the condenser. Condenser coil is attached to fan that blow air over the coil facilitating the heat transfer from the refrigerant to the outdoor air. The gas refrigerant is converted to liquid refrigerant with the loss of heat. Next, the expansion valve further cools down the liquid refrigerant and reduce its pressure before entering the evaporator coil. The final component is evaporator coil performs the opposite function from the condenser coil by absorbing the heat from the indoor space and cooling the space with the help of a fan. The temperature of cool liquid refrigerant increases as it passes the evaporator coil.

2.4 Evaporative Cooling

Evaporative cooling is a water-based cooling process, and it is one of the predecessors of air cooling. In addition to being a cooling system by itself, evaporative cooling can also be used with on top of other cooling system to enhance the performance, reduce the emission and optimize the energy consumption(Heidarinejad et al., 2009). Direct Evaporative Cooling (DEC) and Indirect Evaporative Cooling (IEC) are the two principle method in evaporative cooling.

2.4.1 Direct Evaporative Cooling

In DEC, the water particle will be directly in contact with the air stream resulting into the heat and mass exchanges between the air and water. The heat from the air is absorbed by the liquid water, converting the water to vapor state. The mass of the water vapor is absorbed by the air until it is close to saturation. The air that undergoes the DEC is cooled and humidified.

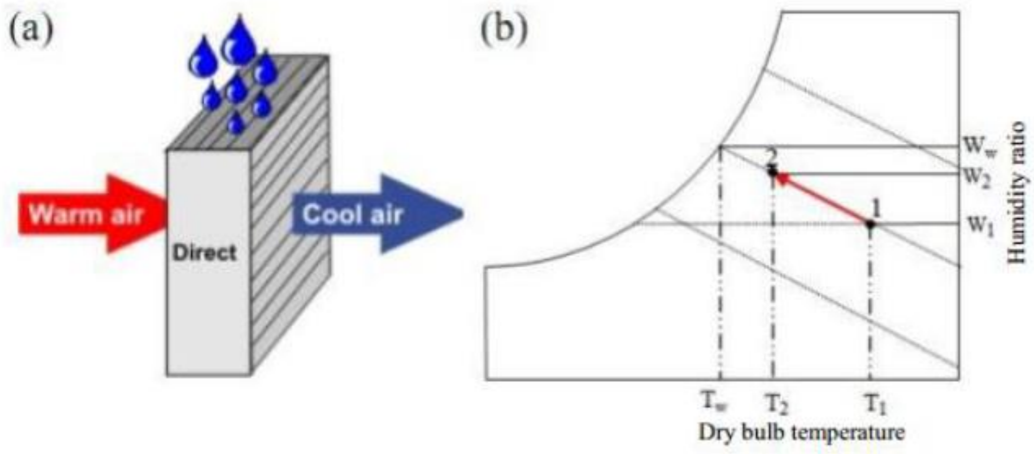

Figure 2.2 Direct evaporative cooling system. (a) Structure of DEC. (b) Psychometric illustration. Source: Pistochini & Modera, 2011

Figure 2.2(a) illustrated the structure of DEC where water is in direct contact with the warm air producing cool air. The psychometric chart in Figure 2.2 (b), shows the isenthalpic process experienced by the warm air. The heat absorbed by the water decrease the dry bulb temperature of the air and the mass of water vapor added to the air increase the humidity ratio of the towards saturation or wet bulb temperature. Despite the cooling effect that can be achieved using the DEC, the highly humid air will accelerate rusting process of metal components and promote mould growth. The DEC system could be divided into two category which is the active DEC and passive DEC. active DEC require an electrically powered component to operate, while passive DEC does not require electrically powered component and only rely on the natural phenomena.

2.5 Wet Bulb Temperature

Wet bulb temperature is achieved when the air is cooled by adding water vapor increasing the relative humidity to 100%. Wet bulb temperature can be an important indication for the performance of a DEC system. According to (Stull, 2011a), the wet bulb temperature can be determined by the function of ambient temperature, T and relative humidity, RH. The equation to calculate the wet bulb temperature, $T_{W:}$

$$T_W = T\ atan[0.151977\,(RH\%\ 8.313659)^{0.5}] + \ atan(T + RH\%) - atan(RH\% - 1.676331) + 0.00391838(RH\%)^{1.5} atan(0.023101 RH\%)\ 4.686035 \quad (1)$$

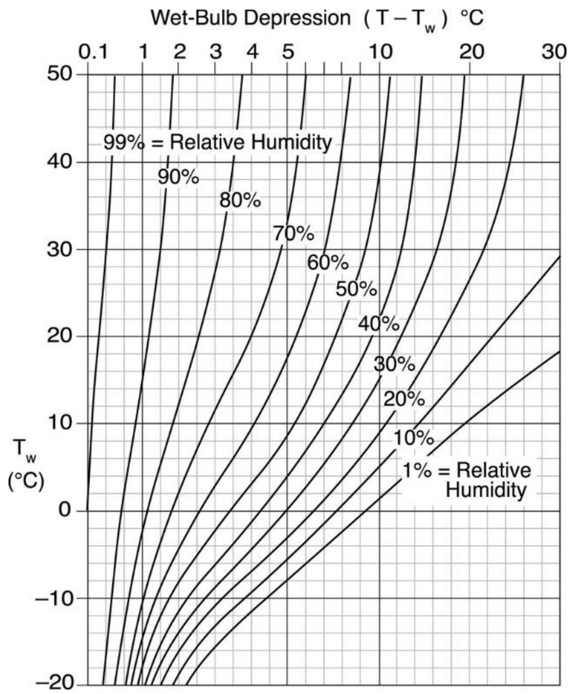

Figure 2.3 Psychrometric Graph for Standard Sea Level Pressure of 101.325kPa. Source: (Stull, 2011b)

Figure 2.3 shows the psychrometric graph for standard sea level pressure of 101.325kPa. The data to plot the psychrometric graph is obtained from the calculation of relative humidity in percent using set of forward analytical psychrometric equations. Equation (1) derived is an empirical inverse solution found by a function fit to the data from Figure 2.3.

2.6 Performance Enhancement

Throughout the time, researchers and professionals have been modelling and conducting experimentation to improve the performance of air conditioning system by integrating the evaporative cooling into the system(Ndukaife & Nnanna, 2018). The common strategy that is used by many researchers to improve the AC system performance is to decrease the temperature of the ambient air flow through the condenser coil. The cooling of ambient air temperature can be achieved by injecting the water particle into ambient air flow or by using a wet medium to provide moisture in the air(Xuan et al., 2012).

2.6.1 Mist Precooler

Yu et al., 2018, developed an air-cooled chiller with mist precooler. In the study, a mist precooler is designed to be retrofitted to existing air-cooled chiller. The mist precooler is chosen for it ease of installation and negligible air-flow resistance. Using this method, the researcher was able to enhance the coefficient of performance (COP) by 4% to 8% by reducing the compressor power. (Yang et al., 2012), also addresses the application of air-cooled chiller with water mist in a subtropical climate. The experiment was conducted on a chiller plant with water mist system. The result obtained from the experimental study shows a temperature drop in the range of 9.4K to 0.5K for the dry bulb temperature of the air entering the condenser from the ambient temperature. The maximum condensing temperature drop is 7.2K and the COP of the system is improved up to 18.6%.

2.6.2 Evaporative Cooling Pad

Wet media or evaporative cooling pad is infamous for its application in DEC. There are many factors and characteristic that have been taken into consideration in determining the best possible working condition for evaporative cooling pad. According to ASHRAE Handbook-HVAC Systems and Equipment (2008), active DEC can be classified by the type of wet media used and the three main types of wet media are Random media DEC, Rigid media DEC and Remote media DEC.

Table 2.1 Main Types of Active DEC Systems. Source: (Amer et al., 2015)

System type	Evaporative media	Effectiveness	Features
Random media	Excelsior or plastic fiber/foam supported by plastic frame.	>80%	Low effectiveness. Short lifetime. Hard to clean.
Rigid media	Blocks of corrugated materials: Cellulose, plastic, fiberglass.	75-95%	High initial cost. Longer lifetime. Cleaner air.
Remote pad	Random or rigid pads mounted on wall or roof of building.	75-95%	Higher power consumption. Bacteria growth.

Figure 2.4 Types of DEC System Pads. Source:(Amer et al., 2015)

Table 2.1 shows the main types of active DEC system along with evaporative media, effectiveness and the features for each system. The different types of DEC system pad are shown in Figure 2.4.

(Martínez et al., 2016), conducted an experimental study on energy performance of split air-conditioner using variable thickness evaporative cooling pads coupled to the condenser. The experiment is done using commercially available component which is the conventional air conditioning unit for residential usage and pre-cooling system from a commercial cellulosic pad. The pre-cooling system thickness varied from 50mm to

150mm with the increment of 50mm which is the thickness of each cooling pad. The experiment is also compared with the condition without the pre-cooling system. The pre-cooling system with 100mm thickness pad provided the best option as it reduces the compressor power consumption up to 11.4% and increasing the cooling capacity up to 1.8%.

The flow rate of cooling pad discharge water can also affect the performance of the evaporative cooling system using evaporative cooling pad. (Mainil et al., 2021), has conducted an experimental study by varying the cooling pad discharge water flowrate of 0.8 lpm, 1.04 lpm and 1.2 lpm and the cooling load is fixed at 2 kW. The experiment concluded that the cooling pad discharge water flowrate provides the best performance by increasing the COP by 12.95% and reduces the compressor work by 6.57%

2.7 Water as Refrigerant

Regardless of the strategy applied to enhance the performance of the cooling system, it cannot be denied that the underlying problem of the air conditioning system is the environmental effect of the refrigerant itself which includes ozone depletion potential (ODP) and global warming potential (GWP)(Pistochini & Modera, 2011).

A study has been conducted by (Kilicarslan & Uller, 2005) comparing R718 (water) as refrigerant to other common refrigerant, natural refrigerant (R717 and R290) and synthetic refrigerant (R134a, R12, R22 and R152a). The study implemented computer coding to simulate simple vapor compression cycle. Based on the simulation, R718 gives the highest COP compared to other refrigerant when the evaporator temperature is above 35°C and temperature lift which is the temperature difference between evaporator and condenser is either relatively small (<10°C) or relatively high (30°C).

Deshpande et al., 2020, has conducted an experimental study of water as refrigerant in air conditioning system. In this study, the compressor is replaced by desert cooler acting as cooling tower to cool down the water temperature form the evaporator outlet. The usage of water as refrigerant is due to concern on the human health impact of other refrigerants. The system was able provide 4°C to 5°C temperature reduction compared to conventional cooler and 6°C to 8°C temperature difference compared air conditioner.