# DEVELOPING A MULTI WATER DROPLETS EVAPORATIVE COOLING SYSTEM

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**in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering (with Honours)**

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# DECLARATION

I declare that this thesis entitled "Developing a multi water droplets evaporative cooling system" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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# APPROVAL

I hereby declare that I have read 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 :...........................................................

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Date :...........................................................

# DEDICATION

To my beloved family, friends and teachers

# ABSTRACT

Climate change is becoming undeniably significant every day which is beneficial neither for human population nor the planet. This directly affect thermal comfort level in our surroundings. However, it is difficult to curb it all at once. It is important to look into possible aspects that can be explored and studied that may contribute towards the betterment of the environment. Cooling systems are closely related as they are observed to be crucial in altering indoor ambience according to human comfort level. Even though the conventional options seem to be efficient in this matter, continuous usage or mishandling results in environmental damage. Hence, it is important to explore alternative options that may serve the same purpose in a better way. The purpose of this study is to develop a evaporative cooling system using multi water droplets approach and investigate the performance of the system by testing different configurations of multi water droplets. An experimental setup was developed consisting a flow straightener, water supply system, fan and evaporation chamber. The droplet generator is fabricated using a metal plate and syringes to form water droplets. All components mentioned was fabricated and enclosed in a support frame to form a cooling system. The experiment is then conducted using plain water and cold water. Three type of configurations were tested in the evaporation chamber by altering the number of opened and closed syringes which are named as Configuration A, B, and C. Thermocouples and a data logger were used to collect the temperature readings of inlet, test section and outlet air. Performance of the system is determined based on its capability to reduce temperature of the inlet air. The research has shown that a multi water droplets evaporative cooling system is capable of reducing temperature. The findings of this study showed that the highest average temperature difference between air inlet and air outlet in Experiment 1 to be 0.74°C and 1.06°C in Experiment 2. Besides that, Configuration B as the most suitable configuration among all three configuration tested.

## *ABSTRAK*

*Perubahan iklim sedang menjadi setiap hari adalah sesuatu yang tidak dapat dinafikan. Ianya adalah sesuatu yang tidak baik untuk populasi manusia dan planet ini. Isu ini secara langsung mempengaruhi paras keselesaan terma di persekitaran kita. Walaubagaimanapun, ia adalah sukar untuk membendungnya sekaligus. Adalah penting untuk melihat aspek-aspek yang berkemungkinan yang boleh menyumbang yang dapat diterokai dan dikaji menjuru kepada kesejahteraan alam sekitar. Sistem penyejukan berkait rapat kerana ia diperhatikan sebagai sesuatu yang sangat penting dalam penggubahan persekitaran dalaman mengikut tahap keselesaan manusia. Walaupun pilihan konvensional adalah cekap dalam perkara ini, penggunaan berterusan atau pengendalian yang salah akan berakhir dalam kerosakan kepada alam sekitar. Oleh itu, adalah penting untuk meneroka pilihan alternatif yang boleh memenuhi tujuan yang sama dengan cara yang lebih baik. Tujuan kajian ini adalah untuk membangunkan sistem penyejukan penyejatan dengan menggunakan pendekatan titisan air dan menyiasat prestasi sistem dengan menguji konfigurasi titisan air berbilang yang berlainan. Suatu persediaan eksperimen telah dibangunkan yang terdiri daripada pelurus aliran, sistem bekalan air, kipas dan kamar penyejatan. Penjana titisan air dibuat menggunakan plat logam dan picagari untuk membentuk titisan air. Semua komponen yang disebutkan disediakan dan disertakan dalam satu bingkai sokongan bagi membentuk sebuah sistem penyejukan. Eksperimen ini kemudiannya dijalankan menggunakan air biasa dan air sejuk. Tiga jenis konfigurasi telah diuji dalam bahagian rig ujian dengan menggantikan bilangan picagari yang dibuka dan tutup yang telah dinamakan konfigurasi A,B, dan C. Thermokopel dan peralatan catatan data digunakan untuk mengumpul data mengenai perbezaan suhu antara udara masuk dan keluar. Prestasi sistem ditentukan berdasarkan keupayaannya untuk mengurangkan suhu udara masuk. Penyelidikan telah menunjukkan bahawa sebuah sistem penyejukan penyejatan titisan air mempunyai keupayaan untuk mengurangkan suhu. Hasil kajian ini menunjukkan bahawa purata suhu perbezaan di udara masuk dan udara keluar yang tertinggi dalam Eksperimen 1 ialah 0.74°C dan 1.06°C dalam Eksperimen 2. Selain itu, konfigurasi yang paling sesuai di antara tiga konfigurasi yang diuji ialah Konfigurasi B.*

## ACKNOWLEDGEMENTS

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# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF APPENDICES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| CFC | - | Chlorofluorocarbon |
| DEC | - | Direct evaporative cooler |
| GWP | - | Global warming potential |
| LDD | - | Liquid desiccant dehumidification |
| min | - | Minutes |
| ODP | - | Ozone depletion potential |
| PCT | - | Passive cooling techniques |
| PDEC | - | Passive downdraught evaporative cooling |
| RIEC | - | Regenerative indirect evaporative cooler |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| 2D | - | 2-Dimensional |
| $\dot{M}$ | - | Flow rate |
| $\delta$ | - | Plate thickness |
| $D_1$ | - | Distance between manifolds and heat exchanger face |
| $D_2$ | - | Distance between nozzles |
| $D_3$ | - | Distance between manifolds |
| $h$ | - | Net channel height |
| L* | - | Net plate length and width |
| o | - | Outside air |
| $pt$ | - | Plate pitch |
| T, t | - | Temperature |
| w | - | Water |
| wb | - | Wet-bulb |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The world population in the year of 2017 is hitting 7.5 billion [1]. It is continues to rise every other day which results in excessive consumption of fossil fuel resources, increase in economic and environmental issues related with global warming, also, climate change [2]. These phenomenon occurs as we look forward to the betterment comfort living. Therefore, it is important for us to focus on energy and environmental conservation. This is where the conventional air conditioning system comes into question. They consume a large amount of electrical energy besides creating residue that are harmful to the environment which is why a more efficient air conditioning option is favourable. Evaporative cooling technology is well known for its potential high efficiency and cheaper production and running cost [3]. These aspects are relatable when compared with the existing air conditioning systems such as the vapour compression, absorption/adsorption and thermoelectric refrigeration systems taking into account regions with dry and hot climate as well as more temperate climates. An evaporative cooling system cools the air based on water evaporation concept. Water has considerably large enthalpy of vaporization, which is why the air temperature can be reduced by phase transition from liquid to vapour. A typical evaporative cooling system does not require any mechanical refrigeration making it in line with low energy consumption. Besides, water will be used as the medium neglecting any usage of chlorofluorocarbon (CFC) that are harmful for the environment.

A multi water droplets approach satisfies these aspects and they work the same as an direct evaporative cooling system. A direct evaporative cooler, will take in outside air through the help of a fan and blown through a medium that is water saturated which will be cooled via evaporation. Direct evaporation cooling systems assist in moistening the air until the humidity in the surrounding region has risen to a significant level. However, traditionally they require the help of an evaporative pad which is moistened by water. This becomes the medium that stands in between outside air and indoor air. Multi water droplets approach took place as the medium in this study without the use of an evaporative pad. This study is focused on an evaporative cooling system built using multi water droplets approach which will be tested on different configurations.

## 1.2 Problem Statement

Commercial cooling system in the market currently is observed to be energy consuming. Constant draining of non-renewable energy sources is neither good for the climate or the environment. Therefore, it is important implement cooling system with a higher efficiency which is compatible with the energy conservation policy. Moreover, commercial cooling systems produce residues that are dangerous to the environment if there is a leakage. This is because commercial cooling system requires the usage of refrigerants. These refrigerants exhibit global warming potential (GWP) and ozone depletion potential (ODP). It is also notable that existing cooling system requires high initial cost. Hence, a alternate option that is efficient, cost effective, and environmental friendly should be considered.

Evaporative cooling system may serve as an alternative cooling system taking into account benchmarks such as low-cost, energy conserving and environmental friendly [3]. A multi water droplet approach in an evaporative cooling system can be a good option when compared to the existing air conditioning system as it requires low running cost, does not use refrigerants that are hazardous and consumes less energy due to the absence of compressor.

## 1.3 Objectives

The objective of this project are as follows:

1. To develop an evaporative cooling system using multi water droplets approach.
2. To determine the performance of evaporative cooling system by testing different configurations of multi water droplets.

## 1.4 Scope of Project

The scopes of this project are:

1. The evaporative cooling system is built based on multi water droplets approach and tested with three different configurations in the test section.
2. Temperature changes occurring to the ambient air or air inlet, air outlet and test section throughout the experiment was measured and tabulated based on type of configuration and condition of water tested which is natural running water and cold water.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

A comfortable environment is what allows us human being to be able to focus and be effective in any activity that we intend to do. Aspects such as thermal comfort plays important role in bringing the best out of a desirable environment. Thermal comfort is defined as the state of comfort a person has with his or her surrounding environment. However, towards the effort of achieving high level of thermal comfort, natural resources are being exploited in a huge volume [5]. This in turn result in environmental damage and unhealthy practices that causes bad effects to climate. Therefore, it is important to study and practice an effective cooling method that does no harm to the nature and serve the purpose of achieving desired level of human comfort.

This second chapter reviews studies and researches carried out in relation to evaporative cooling technologies. It includes type of air conditioning system that comprises evaporative cooling as its core technology. Section 2.2 explains the idea of evaporative cooling and technologies involved in air conditioning application. In section 2.3, direct evaporative cooler traits and study related to it is discussed. Meanwhile, indirect evaporative coolers are reviewed in section 2.4. Combination of both direct and indirect evaporative coolers or also known as hybrid evaporative coolers are reviewed in the section 2.5. Studies focusing on the evaporation rate are presented in the section 2.6.

## 2.2 Evaporative Cooling

Heat and mass transfer process is the core of evaporative cooling that utilizes the evaporation of water for air conditioning process. In this process, high volume of heat is exchanged from air to water which simultaneously decreases the air temperature. There are three main types of evaporative coolers. First, direct evaporative coolers, indirect evaporative coolers and combination of direct and indirect evaporative coolers [8]. Evaporative cooling is known to be a efficient option in thermal management and controlling the temperature across a wide scope of natural and artificial applications [6]. Existing air conditioning technology such as thermoelectric refrigeration, vapour compression, and absorption or adsorption when compared with evaporative cooling shows that it is a better choice. Aspects such as cheaper cost and possibility of higher efficiency is what evaporative cooling technology is made of regardless of dry and hot weather or milder climate [9].

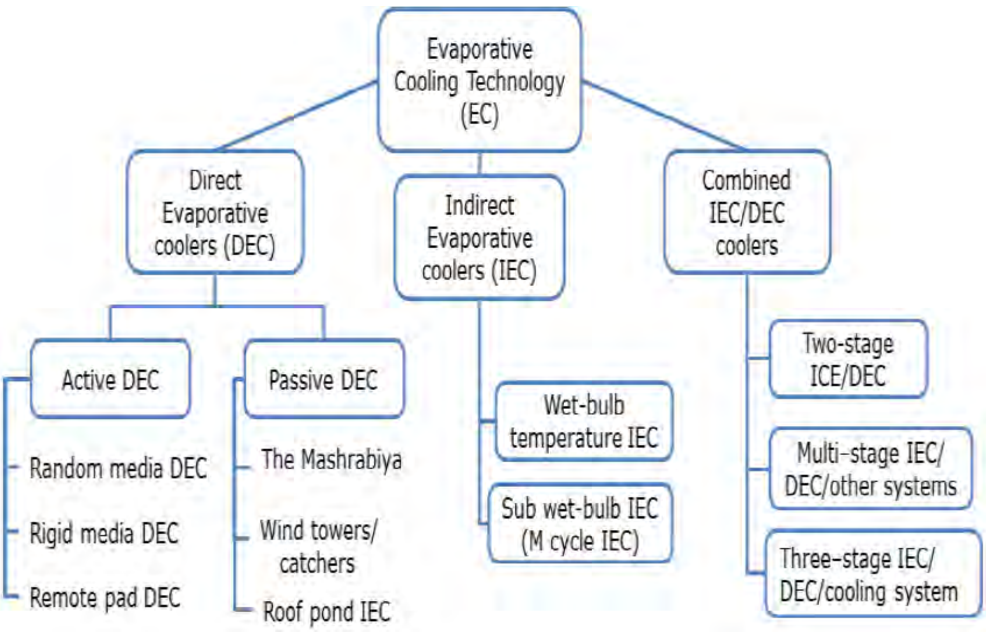


Figure 2.1 Types of evaporative cooling [9]

## 2.3 Direct Evaporative Coolers

Direct evaporative cooling is known to be the earliest and easiest form of evaporative cooling. This system works in a manner that ambient air flows coming into contact with water which allows the conversion of heat, mainly sensible to heat. Various ways of implementation can be observed across a lengthy timeline for air conditioning purposes such as placing pad with water holding traits as a screen through the flow of air. Direct evaporative coolers maybe classified into two different groups, namely active or passive direct evaporative coolers. They differ mostly in terms of power consumption where active direct evaporative cooler requires electricity for operation while passive direct evaporative coolers does not require power consumption [17].

Huang et al. (2014) discussed the issues in application of evaporative cooling in a subway station in their research [10]. The study is focused at Lanzhou, China subway station particularly during summer. Parameters determined for the outdoor design are dry-bulb temperature and wet-bulb temperature. Packing performance test were done with fixed face velocity of 3 m/s and varying packing thickness. Types of packing tested consist of stainless steel, aluminium foil, plant fibre, glass fibre, and polymer. It is observed that maximum direct evaporation cooling efficiency is obtained when the water spray density is at 5400 kg/($m^2$h) regardless of the type of packing tested. The research concludes that stainless steel packing is suitable a direct evaporation cooler to be installed in a subway station.

Figure 2.2 Physical prototype figure [10]

Chiesa et al. (2017) conducted a study on the integration of passive downdraught evaporative cooling (PDEC) in buildings [11]. An experimental setup is done and tested within laboratory for tabulation of data. Based on information gained in data collection of five days, system dimensioning is done. It is found that PDEC systems can be installed conveniently in existing buildings without causing any damage to the design. Also, performance of nozzles at low pressure can be obtained from low cost ones as well and water usage can be reduced significantly at the presence of recirculation pumps.

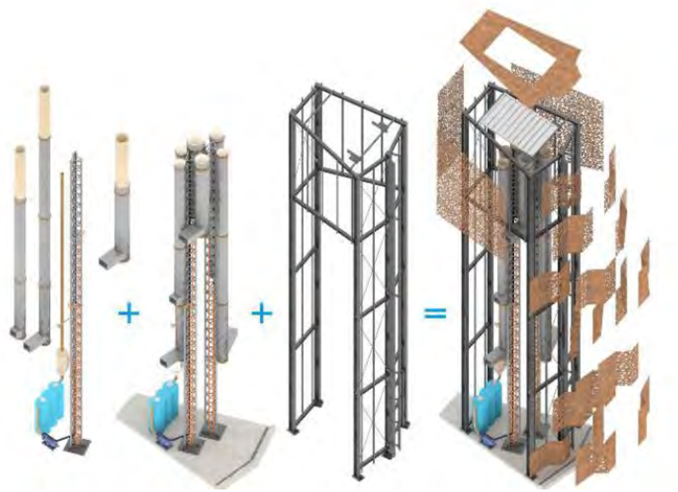

Figure 2.3 Proposed PDEC system [11]

Han et al.  (2017) investigated the application and develops water retaining bricks on the roof which has air conditioning ability accordingly during summer and winter [12]. The research team experimented their test location on three different configurations; 1) roof with water retaining bricks, 2) roof with radiation shield, 3) ordinary roof. Parameters taken into account are ambient temperature, relative humidity, ordinary roof temperature, roof temperature with bricks, indoor temperature with bricks, and indoor temperature without bricks. The study revealed that maximum cooling capacity can be achieved by using roof with water retaining bricks and radiation shield. Besides, water retaining bricks may not perform up to expected standard in winter.

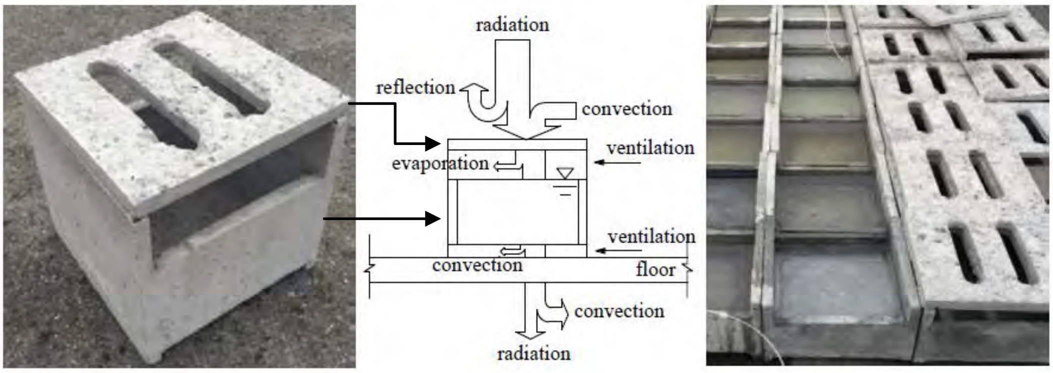

Figure 2.4 Water retaining brick structure and heat transfer mechanism [12]

## 2.4 Indirect Evaporative Coolers

An indirect evaporative cooler works based on the decrement of air sensible heat keeping its humidity constant. This serves as an notable advantage when compared to direct evaporative coolers. Parts that make up a typical indirect evaporative cooler include fan, water reservoir, pump, and distribution lines with plates that creates space between working fluids[18].

De Antonellis et al. (2017) conducted a study on developing an indirect evaporative cooling system model since they are seen as a efficient choice of cooling system in data center facilities [13]. The cooler being analysed is attached with a cross-flow plate heat exchanger, spray nozzles and a pump. In order to monitor the performance of the system, the temperature and humidity ratio is measured. Measurement of air conditions are done by coupling temperature and by using a relative humidity sensor. However, it is notable that measurement process was not an easy one since there less available space and constantly changing air and water conditions. The findings from the experiment concludes that indirect evaporative cooler has the capability of reducing the air temperature which is based on the air and water flow rate. When there is a higher flow rate of water, higher area for heat and mass transfer is present.

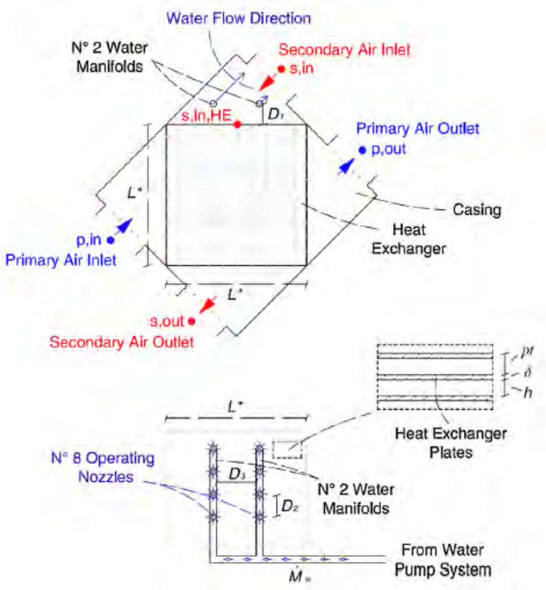


Figure 2.5 Schematic diagram of indirect evaporative cooler being studied [13]

Sosa and Gómez-Azpeitia (2014) have done a study that presents the cooling potential of indirect evaporative cooling system in arid climates [14]. The experiment was conducted in five different Passive cooling techniques (PCT) tested onto the top section of experimental apparatus in a arid climate. The aim is to figure out which system would have lowest energy and water consumption and efficiency rate equivalent to existing air conditioning system. The results of the study confirms that evaporation cooling is the best option of air conditioning in hot and dry climate. Besides, one of the techniques, exposing roof pond to the night sky, has the ability to cool down which gives them the trait of the best cooler and economical in terms of water usage. As a conclusion, the roof pond method is to be observed as a possible replacement to existing cooling system having the said traits to be applicable which gives way for it to be further studied and put into use.

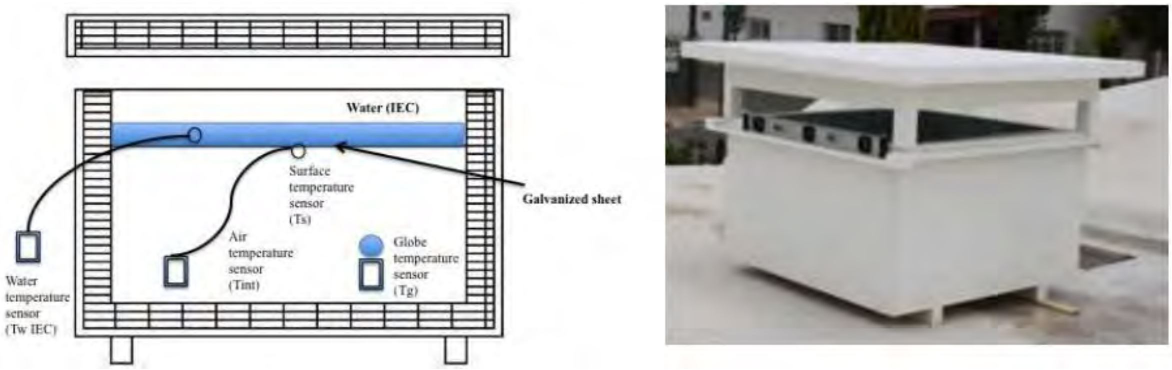


Figure 2.6 Indirect evaporative cooler with shading devices [14]

## 2.5 Hybrid Evaporative Cooling System

Since both direct evaporative cooling system and indirect evaporative cooling system both have their benefits and drawbacks based on application, bringing together both technologies together or even other air conditioning related systems may have greater possibility of higher performance and efficiency rate. Despite , the high possibility of potential hybrid evaporative cooling system or Direct-Indirect evaporative cooling system comes with price. They cost much higher in the commencing stages and are more complex than direct and indirect evaporative cooling system [19].

Chen et al. (2017) focused on liquid desiccant dehumidification and evaporative cooling system comprising dehumidification of ambient air in the dehumidification unit and cooling process in the evaporative cooling section [15]. The mentioned system is