SUDAN UNVERSITY OF SCIENCS & TECHNOLOGY

COLLEGE OF GRADUATE STUDIES & SCIENTIFIC RESEARCH

# Effect of Heat Exchanger as a Pre Cooler on an Evaporative Cooling System

أثر المبادل الحراري كمبرد أول في نظام التبريد والتبخيرى

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# Abstract

This experiment was carried out to study the effect of a heat exchanger on the dry blub temperature drop and efficiency of the evaporative cooling systems. The experiment has been applied at ALkomor village out skirts of Wad Madni – Sudan in late January 2014 .

The heat exchanger was made of copper tubes, arranged in arrays. The length, the height and the diameter of the tube are 55cm, 60cm, and 1 cm respectively. The distance between tubes is 4 cm, the number of the tubes is 15 and attached to the evaporative cooling system. The Distance between evaporative cooling system and heat exchanger is 20cm.

Two evaporative cooling systems direct and combined have been used in this experiment. Dry blub temperature of both direct and combined evaporative cooling system were measured and tabulated. Efficiency and change in dry blub temperature in both devices were calculated.

High drop in dry blub temperature was obtained in the combined evaporative cooling system as an effect of the heat exchanger and high efficiency compared to the direct evaporative cooling system.

The efficiency of the combined evaporative cooling system was greater than that of the direct evaporative cooling system which were 69% and 40% respectively .

The significant difference in the efficiencies between the combined and direct evaporative cooling system as a result of this study, the combined system is recommended for the arid and semi-arid regions .

## الخلاصة

تهدف هذه الدراسة لدراسة تأثير المبادل الحراري علي التغير في درجات الحرارة الجافة و الكفاءة وذلك باستعمال جهازي تبريد تبخيري أحداهما بدون مبادل حراري (تبريد مباشر) والأخر مع مبادل حراري. صنعت أنابيب المبادل الحراري من النحاس. وضعت الأنابيب في صفوف والمسافة بين كل صف 4 سم وطول كل أنبوب 55 سم وارتفاعه 60 سم وقطر الأنبوب 1 سم وعدد الأنابيب 15 أنبوب.

طبقت هذه التجربة في الأسبوع الأخير من شهر يناير 2014 بقرية الكمر ضاحية ود مدني – السودان.

قيست درجات الحرارة الجافة للهواء الداخل لكل من الجهازين وحسبت الكفاءة للجهازين المستخدمين في التجربة باستخدام بعض المعادلات.

إنخفاض درجة الحرارة الجافة للهواء الداخل أعلي في جهاز التبريد التبخيري مع مبادل حراري ،كما أوضحت الدراسة أن جهاز التبريد مع المبادل الحراري أكبر كفاءة من جهاز التبريد بدون مبادل حراري 69% و40% علي التوالي .

نسبة للفروقات الواضحة بين كفاءة الجهازين توصي هذه الدراسة باستخدام أجهزة التبريد التبخيرية مع مبادل حراري في المناطق الجافة وشبه الجافة لكفاءتها العالية .

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I wish to express my deepest gratitude and sincere appreciation to my super visor Dr. yousif Hassan Mohammed Ali for his continuous encouragement, constructive criticism and helpful guidance.

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Thanks for all the staff of mechanical engineering department and my fellow students for their moral motivation . Special compliment and gratitude to my family for their unlimited assistance, patience and financial support.

Symbols :

| | | |
|---|---|---|
| A | heat transfer surface area | $m^2$ |
| $h$ | enthalpy | kJ/kg |
| $h_c$ | convective heat transfer coefficient | W/$m^2$K |
| $h_{fg}$ | latent heat of vaporization | J/kg |
| $\dot{m}_v$ | evaporative mass flux | $kg/sm^2$ |
| P | pressure | Pa |
| $P_v$ | partial pressure of water vapour | Pa |
| $P_{vs}$ | saturation pressure of water vapor at $T_{db}$, | Pa |
| $P_{wb}$ | saturation pressure of water vapor at $T_{wb}$, | Pa |
| $Q_v$ | sensible convection heat flux from air/vapour | W/$m^2$ |
| $Q_a$ | heat added by other means or source | W/$m^2$ |
| $Q_e$ | energy required for the evaporation | W/$m^2$ |
| $T_S$ | temperature at the surface | ℃ |
| $T_\infty$ | temperature at the free stream or bulk temperature | ℃ |
| $\omega_s$ | Surface specific humidity/ humidity ratio | kg(vapour)/kg(dry air) |

| | | |
|---|---|---|
| $\omega_\infty$ | free stream specific humidity/humidity ratio | kg(vapour)/kg(dry air) |
| $T_{db}$ | dry bulb temperature | ℃ |
| $T_{wb}$ | wet bulb temperature | ℃ |
| $v$ | specific volume, | $m^3/kg$ |
| $P_w$ | saturated vapour pressure for wet or water body surface | $N/m^2$ |
| $P_a$ | saturated vapour pressure ambient air surface | $N/m^2$ |
| $\omega$ | specific humidity/ humidity ratio | kg(vapour)/kg(dryair) |
| $\emptyset$ | Relative humidity | (%) |
| $\eta_{sat}$ | saturation efficiency | (%) |
| T | Temperature | ℃ |
| U | overall heat transfer coefficient | $W/m^2\,k$ |
| V | velocity | $m/s$ |
| $\rho_w$ | Density of water | $kg/m^3$ |
| $\rho_a$ | Density of air | $kg/m^3$ |
| $dm_v$ | Evaporative mass flux | kg/s.$m^2$ |
| $C_{pv}$ | Constant pressure of the vapour | $kJ/kgK$ |
| $C_p$ | Constant pressure | $kJ/kg\,K$ |
| $T_{in}$ | Inlet temperature | ℃ |
| $T_{out}$ | Outlet temperature | ℃ |

| | | |
|---|---|---|
| $\mu$ | dynamic viscosity | $kg/ms$ |
| $\rho$ | density | $kg/m^3$ |
| $C_{pa}$ | Constant pressure of the air | $kJ/kg\ K$ |

Abbreviation:

| | |
|---|---|
| DEC | direct evaporative cooler |
| IEC | indirect evaporative cooler |
| IDEC | indirect/ direct evaporative cooler |
| Re | Reynolds number |
| $db$ | dry bulb |
| $wb$ | wet bulb |

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# Chapter 1

## 1.1 Introduction

The rapid growth of world energy consumption has raised serious concerns over the depletion of energy resources and the associated environmental impact of global climate change. The increasing world energy consumption is caused by the facts such as continuous growth of world population, economic growth in emerging regions, the development of communication networks and the promotion of life style of developed nations. Over the last two decades, the world primary energy consumption (fossil fuels) has increased by 49% and carbon dioxide emissions by 43% [1]. Despite the latest energy review that the world energy consumption was decreased by 1.1% in 2009 due to the unpredicted global economic recession, energy consumption still continues to increase rapidly in several developing countries, specifically in some regions of Asia with rapid economic growth. So it is essential to reduce energy consumption that is by looking for other devices that consume lesser energy . It is well known that all the evaporative cooling system consume lesser energy than the other cooling devices .

Since Sudan lies in arid and semi-arid zone, adversely affected by the global climate change, it endures hot and dry long summer season with long day. The need for cooling devices may be greater if no responsible or positive measures be taken to curb the emission of carbon dioxide, methane gas and other oxides.

The increasing demand for evaporative cooling devices by both rural and urban people of Sudan, necessitate continuous flow of good, advanced and cheap evaporative cooling devices.

## 1.2 Problem Statement:

Cooling by evaporative cooling systems is limited by the degree of saturation. Sometimes, we need to attain cooler temperatures . So effort need to be made to reach cooler temperatures.

## 1.3 Objective:

To improve the efficiency of the evaporative cooling system and reach cooler temperatures.

# Chapter 2

# Theoretical background

## 2.1 Introduction

Evaporative cooling is an environmentally, friendly and energy efficient cooling method that only uses water as the working fluid to cool air through the simple evaporation of water [2]. Evaporative cooling systems utilize the latent heat of water evaporation, i.e. a kind of natural energy existed in the atmosphere, to perform air conditioning for buildings. Because, they have little dependency on fossil fuel energy, they are environment friendly. It is a technology that could substantially reduce the air conditioning cooling energy requirement in buildings and provide other important environmental benefits . Evaporative cooling systems (ECSs) work best in hot, dry climates [3], and it can also be used in more humid climates [4]. Evaporative cooling systems can be used for many commercial (e.g. kitchens and laundry rooms), industrial (e.g. spot-cooling in factories and warehouses) and agricultural applications (e.g. greenhouses and poultry sheds). As determined by local climates and comfort preferences, they can also be useful in some comfort cooling applications such as offices and retails [5]. For comfort cooling, evaporative cooling is most suited to dry climatic regions. Simple direct evaporative cooling systems with wetted pads (also known as desert coolers) have been widely applied in the dessert climate [6] . However, traditional direct evaporative coolers will increase the humidity of the air to a level that makes occupants uncomfortable

under humid climatic conditions. Two-stage ECSs with advanced and improved designs have been studied and developed in many countries [3]. It is a technology that could substantially reduce the air conditioning cooling energy requirement in buildings and provide other important environmental benefits [7].

### 2.1.1 Evaporative Cooling:

By definition evaporative cooling is the exchange of sensible heat in air for the latent heat of vaporization of water droplets on wetted surfaces. It can be used to cool building air directly by evaporation or indirectly by contact with a surface previously cooled by direct evaporation. Ideally evaporative cooling is adiabatic or constant enthalpy process meaning that sensible heat is extracted from the air (dry-bulb temperature (DBT) is reduced) while an equal amount of latent heat (in the form of water vapor) is added.

### 2.1.2 Basic Principles

Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Adiabatic evaporation of water provides the cooling effect. Latent heat is needed to evaporate the liquid and this heat comes from the liquid itself and the surrounding gas and surfaces.

### 2.1.3 The Major Benefits Of Evaporative Cooling Systems [8]:

Avoiding the use of ozone-depleting chlorofluorocarbons(CFCs)

Substantial energy and cost savings

Possible reduction of peak power demand

Improved indoor air quality when higher ventilation is adopted

Easily integrated into built-up systems

Simple manufacturing technology (suited to developing countries)

## 2.2 Evaporative Cooling Methods:

Basically evaporative cooling can be direct, indirect or combination of direct and indirect. The combination types are also called hybrid or integrated types. There are three main methods of achieving evaporative cooling and the choice of each depends on the type of application required.

### 2.2.1 Direct Evaporative Cooling

In this type of evaporative cooling relatively dry outside air is blown through a water-saturated medium (usually cellulose) or porous ceramics where it is cooled by evaporation. As stated in the principle of evaporative cooling, the contact between air and water causes small amount of water to evaporate. Subsequently the latent heat of vaporization causes simultaneous reduction in the air and water temperatures. Also a smaller amount of sensible heat is exchanged between the two streams. However, the latent heat transfer amounts to 80-95% of the total heat exchanged [3]. The type introduces moisture to the air until the air stream is close to saturation. So the dry bulb or sensible air temperature (DBT) is reduced while the wet bulbs temperature (WBT) stays the same. Direct evaporative cooling raises the relative humidity of the space being cooled. For building applications it will be more effective

when there is continuous flow of fresh air from ambient through the evaporative cooler to the building space and then exhausted out through the window. Figure (2.1a) shows the direct evaporative cooling process on a psychrometric chart. The fresh ambient air enters the DEC from state 1 and then delivered to the building space at state 2' instead of state 2. The cooling path 1-2' follows an ideal or adiabatic saturation curve in which the supply air is reduced from dry to wet bulb temperature of the inlet. Point2' on the curve is the theoretical limit corresponding to 100% of the cooling system efficiency. However, in actual practice because of some defects or other operational factors, the real cooling efficiency is limited to lower values between 70-90%. Similarly, the cooling paths are illustrated on a psychrometric chart with typical numerical values of the performance parameters in Figure (2.1a).

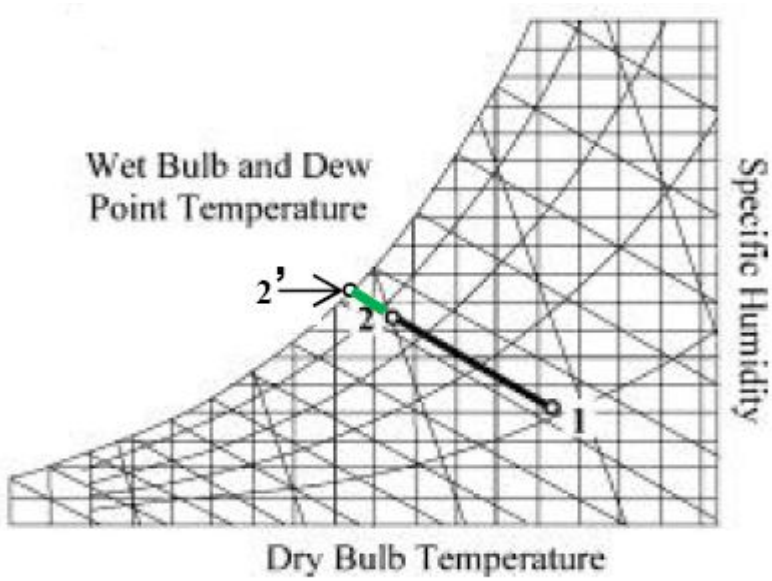


Figure 2.1 Cooling paths for direct evaporative cooler (Path 1-2' corresponds to 100% efficiency and path 1-2 correspond to efficiency of actual operation, less than 100%).

The saturation efficiency ($\eta_{sat}$), defined in the expression given below

$$\eta_{sat} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}} \quad \textbf{(2-1)}$$

Where:

$T_{db,in}$ - Is the dry bulb temperature at inlet.

$T_{db,out}$- Is the dry bulb temperature at outlet.

$T_{wb,in}$ - Is the wet bulb temperature at the inlet.

## 2.2.2 Indirect Evaporative Cooling:

With indirect evaporative cooling, secondary air stream is cooled by water. The cooled secondary air stream goes through a heat exchanger, where it cools the primary air stream. The cooled primary air stream is circulated by blower. Indirect evaporative cooling does not add moisture to the primary air stream. Both the dry bulb and wet bulb temperatures are reduced .The advantage of this type of cooler lies, therefore, in the resulting lower humidity(w), thus improving the thermal comfort, and in its potential applicability for regions where high temperature is accompanied by humidity much higher than those experienced in arid areas. As shown in fig (2.1b) on the psychometric chart, the intake air (state 1) is cooled at a constant humidity ratio toward the wet-bulb temperature of working air. Meanwhile, the temperature of the working air is decreased from state 1 to 3 along the isenthalpic line, as the thermal process of direct evaporative cooling.

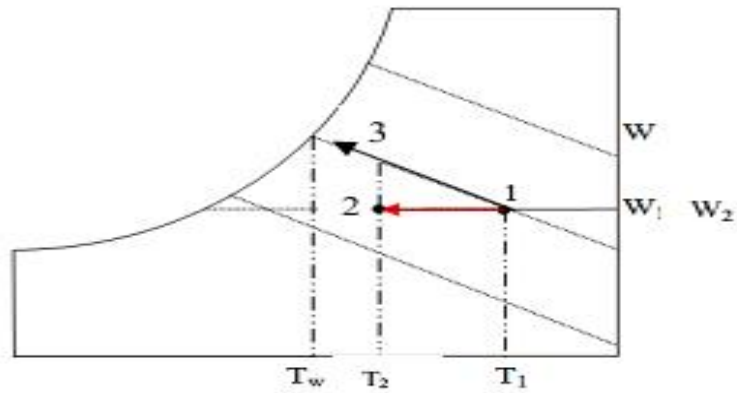


Figure 2.2 The thermal process showing on the psychometric chart

The wet-bulb effectiveness of current typical indirect evaporative cooling systems may range between 55% and 75% or higher, which is lower than that of direct evaporative cooling.

### 2.2.2.1 Cooling Capacity of Indirect Evaporative Cooling (IEC)

Also for IEC consisting of wet and dry air channels the cooling capacity can be evaluated from the following simplified energy balance equation.

$$Q_{iec} = Q_w = Q_a \qquad (2\text{-}2)$$

The above energy balance can be return in terms of the respective enthalpies of air flowing through wet and dry channels as follows:

$$Q_{iec} = \dot{m}_w\,(h_{wi} - h_{wo}) = \dot{m}_a\,(h_{ao} - h_{ai}) \qquad (2\text{-}3)$$

By considering the specific heat capacities the energy balance equation becomes:

$$Q_w = \dot{m}_w C_{pw}\,(T_{w,in} - T_{w,out}) \qquad (2\text{-}4)$$

$$Q_a = \dot{m}_a Cp_a (T_{a,in} - T_{a,out}) \qquad (2\text{-}5)$$

$$Q_{iec} = \dot{m}_w C_{Pw}\,(T_{w,in} - T_{w,out}) = \dot{m}_a C_{Pa} (T_{a,in} - T_{a,out}) \qquad (2\text{-}6)$$

Since heat transfer involved varies along the entire surface area of the heat transfer layer separating the dry and wet channels we then require the mean temperature difference, $\Delta T_m$ .The cooling capacity or thermal load can therefore be expressed in terms of the effective heat transfer area, overall heat transfer coefficient and the mean temperature difference. The relationship is shown below for heat exchanger.

$$Q_{iec} = A \times U \times \Delta T_m \qquad (2\text{-}7)$$

Where:

$$\Delta T_m = \frac{(T_{a,in} - T_{a,out}) - (T_{w,in} - T_{w,out})}{Ln\frac{(T_{a,in} - T_{a,out})}{(T_{w,in} - T_{w,out})}}$$

### 2.2.2.2 System Effectiveness / Efficiency:

Indirect evaporative cooling system efficiency correlation ($\varepsilon_{IEC}$) is given in the following expression [9]:

$$\varepsilon_{IEC} = 1.0819A^{0.185}(Re_w)^{0.0181}(Re_a)^{0.254} \qquad (2\text{-}8)$$

Where:

A - Effective heat transfer area of the heat exchangers of the indirect evaporative cooler .

$Re_w$ and $Re_a$ represent the Reynolds number for the water and air flowing through the wet and dry channels of the indirect evaporative cooler respectively. These dimensionless numbers are defined in the following expressions:

$$Re_W = \frac{\rho_w V_w D_w}{\mu_w}$$

$$Re_a = \frac{\rho_a V_a D_a}{\mu_a}$$

From the above relation it can be observed that the effectiveness or efficiency of indirect evaporative cooler depends on the Reynolds number of the flowing fluid as well as the effective heat transfer area of the heat exchanger.

### 2.2.3 Indirect/Direct Evaporative Coolers

Two-stage indirect/direct evaporative coolers can cool air to lower temperatures than are attainable with direct ("one-stage") evaporative coolers, and add less moisture to the indoor air. In these coolers, a first-stage indirect evaporative cooler lowers both the dry-bulb temperature (DBT) and WBT of the incoming air. After leaving the indirect stage, the supply air passes through a second-stage direct evaporative cooler. Figure (2.1d ) shows the cooling process on a psychometric chart. First-stage cooling follows a line of constant humidity ratio as no moisture is added to the primary airstream; the second stage follows the WBT line at the condition of the air leaving the first stage.

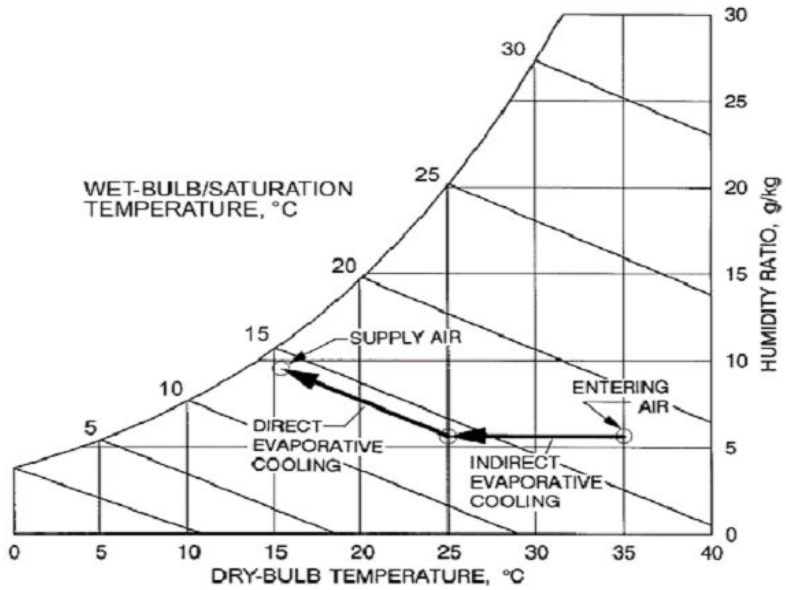


Figure 2.3 combined ( Indirect-direct) evaporative cooling process [8]

For the combined indirect/direct evaporative cooling system, efficiency correlation is based on the heat transfer area of the IEC heat exchanger part, the Reynolds numbers for water and air inside and outside IEC heat exchange tubes, the thickness or parking density of the DEC and mass flow rate of water and air in the DEC parking as given below [9]:

$$\varepsilon_{IEC}/\varepsilon_{DEC} = 0.95\, A^{0.743}(Re_w)^{-0.112}(Re_a)^{0.247} \qquad (2\text{-}9)$$

## 2.3 Basic Evaporative Cooling Psychrometric Properties Models :

Regardless of the type of evaporative cooling system, the following mathematical model can be used to evaluate the basic properties required for the performance evaluation of evaporative cooling systems. Figure a and b respectively show the process flow diagram and psychometric representation. These properties consist of

specific volume, humidity ratio, pressure, partial pressure of water vapour, saturation pressure of water vapour, enthalpy, dry bulb temperature, wet bulb temperature, dew point temperature, relative humidity and other related parameters.

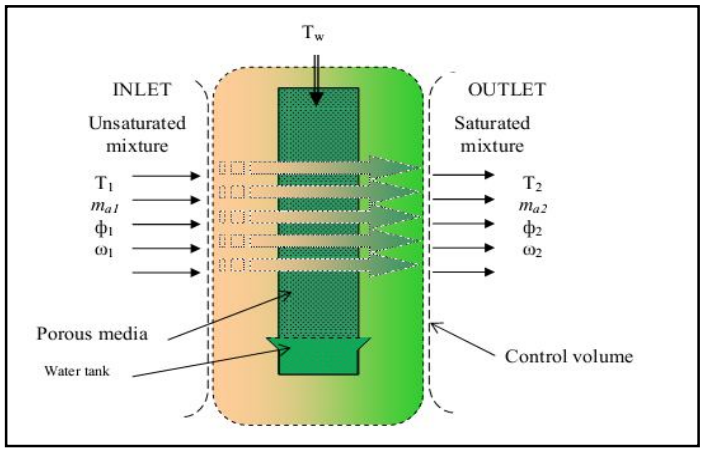


Figure 2.4 Schematic of an evaporative cooling process showing the basic Parameters.

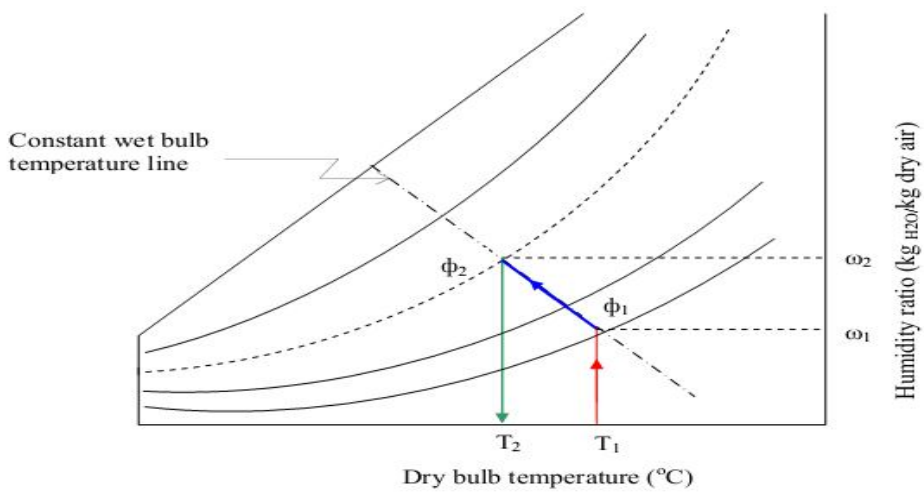


Figure 2.5 Psychometric chart representation of cooling and humidification involved in direct evaporative cooling process.

### 2.3.1 Specific Volume, Specific Humidity, Relative Humidity and Specific Enthalpy Determination Models:

The psychometric properties mentioned above are modeled in the following equations [10]:

• The specific volume can be expressed in terms of dry bulb temperature, absolute and vapour pressure as shown below:

$$v = \frac{R_a T_{db}}{P - P_v} \qquad (2\text{-}10)$$

Specific humidity can also be expressed in terms of the absolute and vapor pressures as in the equation given below:

$$\omega = 0.622 \frac{P_v}{P - P_v} \qquad (2\text{-}11)$$

• Relative humidity is given in the following equation:

$$\emptyset = \frac{\omega\,(P - P_v)}{0.622\,P_{vs}} \qquad (2\text{-}12)$$

It can also be computed by combining and simplifying equations Specific humidity and Relative humidity expressed as percentage as follows [11]

$$\emptyset = \frac{100\,P_v}{P_s} \quad [\%] \qquad (2\text{-}13)$$

The partial pressure of water vapor can be computed with the following equation.

$$P_v = P_w - \frac{(P - P_w)(T_{db} - T_{wb})}{1532 - 1.3\,T_{wb}} \qquad (2\text{-}14)$$

• The specific enthalpy of the moist air per kilogram of dry air is expressed in terms of the dry bulb temperature and humidity ratio as follows:

$$h = (T_{db} - 273) + \omega\,[\,1.86\,(T_{db} - 273) + 2501.3] \qquad (2\text{-}15)$$

## 2.3.2 Vapor Pressures, Wet and Dew Point Temperatures.

Other parameters that can be used in the model are given in the following equations:

• Computing saturation vapor pressure corresponding to a given dry bulb temperature.

$$\ln\left(\frac{P_w}{2337}\right) = 6789\left(\frac{1}{293.15} - \frac{1}{T_{db}}\right) - 5.03\ln\left(\frac{T_{db}}{293.15}\right) \qquad (2\text{-}16)$$

• Computing vapor pressure corresponding to a given wet bulb temperature.

$$\ln\left(\frac{P_{wb}}{2337}\right) = 6789\left(\frac{1}{293.15} - \frac{1}{T_{wb}}\right) - 5.03\ln\left(\frac{T_{wb}}{293.15}\right) \qquad (2\text{-}17)$$

• The wet bulb and dew point temperatures can be computed using the equations given below respectively [12]

$$T_{wb} = 2.265\sqrt{1.97 + 4.3T_{db} + 10^4\omega} - 14.85 \qquad (2\text{-}18)$$

$$T_{dp} = 26.13722 + 16.988833\ln(\emptyset P_a) + 1.04961[\ln(\emptyset P_a)]^2 \qquad (2\text{-}19)$$

## 2.3.3 Density and Specific Heat Capacities:

The density of the moist air can be computed with the following equation:

$$\rho = \frac{P - 0.387\emptyset P_s}{287\,T} \quad \left[\frac{Kg_{mois-air}}{m^3}\right] \qquad (2\text{-}20)$$

Where :

T - is the absolute temperature of the most air [K]

T = t + 273.15 and t = dry bulb temperature [C]

• The total specific heat capacity of the mixture consists of two different specific heat capacities expressed in the following expression:

$$C_P = C_{Pa} + \omega C_{Pv} \quad [\frac{kJ}{kgk}] \qquad (2\text{-}21)$$

Where the specific heat capacity of the dry air is given in the following equation:

$$C_{Pa} = 1.005 + 1.35\times 10^{-8}\,(t + 30)^2 \quad [\frac{kJ}{kgk}] \qquad (2\text{-}22)$$

While the specific heat capacity of the humid air can be computed with the following expression:

$$C_{Pv} = 1.864 + 0.095\,(\frac{t}{100}) + 0.0037\,(\frac{t}{100})^2 \quad [\frac{kJ}{kgk}] \qquad (2\text{-}23)$$

In both equations temperature t is the dry bulb temperature in(°C)

## 2.3.4 Convection Heat Transfer In Evaporative cooling:

Heat transfer will occur if the surface temperature (Ts) is different from the free stream temperature $(T_\infty)$that is $T_s \neq T_\infty$. The resulting local heat flux due to the convection heat transfers given in the following expression.

$$Q_V = Q_e \qquad (2\text{-}24)$$

The energy required for evaporation, $Q_e$ can be estimated as the product of evaporative mass flux ($\dot{m}_v$) and latent heat of vaporization ($h_{fg}$) as in equation (2-25) given below.

$$Q_e = \dot{m}_v \, h_{fg} \qquad (2\text{-}25)$$

Where:

$\dot{m}_v$ : is the evaporative mass flux, (kg/s.m$^2$)

$h_{fg}$ : is the latent heat of vaporization, (J/kg)

$$Q_v = h_c \, (T_s - T_\infty) \qquad (2\text{-}26)$$

In the above equation, $h_c$ is the convective heat transfer coefficient. This sensible convection local or elemental heat flux term in equation (2-24) can be expressed in terms of convective heat transfer coefficient and the temperature difference on the basis of an elemental area ($dA$) as follows :

$$\delta Q_v = h_c dA \; (T_s - T_\infty) \qquad (2\text{-}27)$$

## 2.3.5 Convection mass Transfer in Evaporative cooling:

Analogous to heat transfer, if the specific humidity or concentration of the air close to the surface ($\omega_s$) is different from the one at the free stream velocity($\omega_\infty$) that is $\omega_\infty \neq \omega_s$ then evaporative mass transfer will take place. The total evaporative mass transfer rate on an entire given surface is shown in the following expression [13]:

$$\dot{m}_v = \bar{h}_c A(\omega_s - \omega_\infty) \qquad (2\text{-}28)$$

Also elemental rate of mass transfer ($dm_v$) can be expressed in terms of mass transfer coefficient and difference in specific humidity [14] .

$$dm_v = h_m \rho_w dA \ (\omega_s - \omega_\infty) \qquad (2\text{-}29)$$

## 2.4 Cooling Pad Material:

The cooling pads utilized in evaporative air conditioners provide sufficient water-to-air contact area to promote water evaporation. Corrugated cellulose impregnated with wetting agents and rot resistance insoluble salts are the most widely used type of cooling pad material. Under proper maintenance these material should have a life time of ten years and can do an excellent job of cooling air. However, these pads are expensive. Aspen pads which were commonly used in the past are still being used but under certain conditions have a short life. They are also very susceptible to algae infestation that leads to rotting, compaction and subsequently air flow blockage. Therefore to efficiently operate an evaporative cooling system with aspen pads requires frequent and costly replacement of these pads. In choosing a pad material one should compare costs, life expectancy claims, cooling efficiencies, and probability of maintenance problems before selecting the one that is best for your operation. Since 1960 drip coolers featured excelsior pads made of aspen wood. Also other wood were tried along with fiber glass and woven paper but were found to have weaknesses that outweighed their advantages. However Aspen pads continue to be sold today because of low cost, limited-benefit cooling option. The

photo below shows a sample section of rigid media (A) on the left and aspen pad (B) on the right (Figure 2.1g).

A B

Figure 2.6 Section of (A) a rigid media (B) aspen pad materials

Aspen wood pad is a package of thin shredded wood slivers having a thickness of 3 to 5 cm and the material is spread equally over the pad-holder surface . Celdek cooling pads have higher saturation efficiency than Aspen pads. The saturation efficiency of a properly packed Aspen pad may reach 70% and it may decrease down to 50% after only a few weeks . The efficiency of Celdek pads varies from 70% to over 95%, depending on the thickness of the pad and air velocity .

## 2.5 Heat Exchanger:

### 2.5.1 Introduction:

A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particles and a fluid, at different temperatures and in thermal contact. Typical applications include heating or cooling of a fluid stream of concern an evaporation or condensation of single or multi component fluid stream [15].

Heat exchangers are used in a wide variety of applications. These involve power production, process, chemical and food industries, electronics, environmental production engineering, waste heat recovery, manufacturing industry, air conditioning, refrigeration and space applications. Over the past quarter century the importance of heat exchangers has increased immensely from the viewpoint of energy conservation, conversion, recovery and successful implementation of new energy sources. Heat exchangers constitute a multibillion dollar industry in the United States alone and there are over 300 companies engaged in the manufacture of a wide array of heat exchangers [16].

Heat exchangers can be classified in many different ways; for example, according to transfer processes, number of fluids and heat transfer mechanism, construction type and flow arrangements. Another arbitrary classification can be made, based on the heat transfer surface area/volume ratio into compact and non compact heat exchangers [16]. A fluid stream is considered unmixed when it

passes through individual flow channels or tubes with no fluid mixing between adjacent flow channels [15].

### 2.5.2 Uses and Applications Of Heat Exchanger:

Heat exchangers are used to transfer heat from one media to another. It is most commonly used in space heating such as in the home, refrigeration, power plants and even in air conditioning. It is also used in the radiator in a car using an antifreeze engine Cooling fluid. Heat exchangers are classified according to their flow arrangements where there are the parallel flow, and the counter flow. Aside from this, heat exchangers also have different types depending on their purpose and how that heat is exchanged.

Heat exchangers in large scale industrial processes are usually custom made to suit the process depending on the type of fluid used, the phase, temperature, pressure, chemical composition and other thermodynamic properties.

Heat exchangers mostly can be found in industries which produce a heat stream. In this case, heat exchangers usually circulate the output heat to put it as input by heating a different stream in the process. The fact that it really saves a lot of money because when the output heat no longer needed then it can be recycled rather than to come from an external source as heat is basically recycled. When used in industries and in the home, it can serve to lower energy costs as it helps recover wasted heat and recycle it for heating in another process. Typically, most heat exchangers use fluid to store heat and heat transfer can take the form of either absorption or dissipation.

For instance, heat exchangers are used as oil coolers, transmission and engine coolers, boiler coolers, waste water heat

recovery, condensers and evaporators in refrigeration systems. In residential homes, heat exchangers are used for floor heating, pool heating, snow and ice melting, domestic water heater, central, solar and geothermal heating. Of heat exchangers have different designs which depend on the purpose it is intended for course. Brazed heat exchangers, a collection of plates which are brazed together, are used for hydraulic systems like swimming pools, floor heating, snow and ice melting.

# Chapter 3

## 3. Literature Review:

Datta, et al., [6]. Found that evaporative cooling systems (ECSs) work best in hot, dry climates .

Camargo et al. [17] developed a mathematical model of direct evaporative cooler and presented experimental results of the tests with rigid cellulose media having wetted surface area of $370m^2/m^3$.The efficiency relation derived in terms of heat transfer coefficient, air mass flow rate, wetted surface area and humid specific heat is useful in predicting the performance of direct evaporative cooling (DEC) under different conditions. They concluded that the efficiency is more at higher dry bulb temperature and lower air speeds.

El-Dessouky et al. [9] have done extensive literature survey on evaporative cooling and evaluated performance of evaporative cooling units in Kuwait environment. They carried out theoretical and experimental study on small scale evaporative cooling unit using structured packing material of high density polythene with wetted surface area of $420m^2/m^3$. They used the combination of direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) without using cooling tower. They concluded that efficiency of IEC unit is less than DEC but a combination can reduce the temperature of incoming air below its wet bulb temperature (WBT).

Al-Juwayhel et al. [18] experimentally investigated thermal performance of a single stage and two stage evaporative cooler. They

used two different combinations of two stage cooler – one with cooling tower and the other without it. The effect of packing thickness and water flow to the packing was analyzed. Performance of two stage cooler with cooling tower was reported better than that without cooling tower which in turn was better than a single stage cooler.

El-Dessouky et al. [19] used the concept of pre-cooling the air before DEC without using cooling tower. Structured, sheath leaf and natural fiber packing was used as cooling media with varying thickness and flow of water. Effectiveness increased with packing thickness and water flow to IEC. Structured packing showed higher effectiveness than sheath leaf and natural fiber.

Chen et al. [20] developed heat and mass transfer model for thermal and hydraulic calculations of IEC performance. It can be used to analyze different evaporative cooler designs and conditions. They showed thermal calculations for tube type and plate type indirect evaporative cooler using room or outside air as secondary air. Cooling capacity and coefficient of performance are much higher when room air is used as secondary air.

Wu [21] monitored the performance of two stage evaporative cooling system for a residence for two separate periods. He found saturation efficiency of DEC as 88%. He recommended the use of indirect evaporative cooler alone in extremely humid morning conditions. He emphasized the need for standard method for measuring the performance of indirect or two stage cooler. He also

recommended the use of additional controls to accommodate sudden changes in summer monsoon season.

Eskra [22] described the concept of two stage cooling system which combines indirect and direct evaporative cooling for higher efficiency. He concluded that the two stage systems offer valuable energy conservation approach to total cooling with no conventional compression or absorption cooling required. Majority of the work on two-stage coolers has been carried out by direct experimentation and the results are analyzed. Combined theoretical analysis of plate heat exchanger type IEC and DEC with different media and shapes was not found in the literature as per our knowledge. The performance of a two stage cooler with wet surface plate heat exchanger type indirect stage and different shaped pads of Cellulose (CL) and Aspen (AS) media in direct stage were theoretically analyzed . Primary air flow rate is assumed to vary with constant secondary air flow rate. The analysis is based on the average of the most frequently occurring hot and dry ambient conditions in Bhopal, India.

# Chapter 4

## Experiment Components and Method

## 4 Components:

## 4.1 Direct Evaporative Cooling System:

In this experiment we used direct evaporative cooling devices as a control for this experiment . It is composed of the following components ( Figure 3.1a)

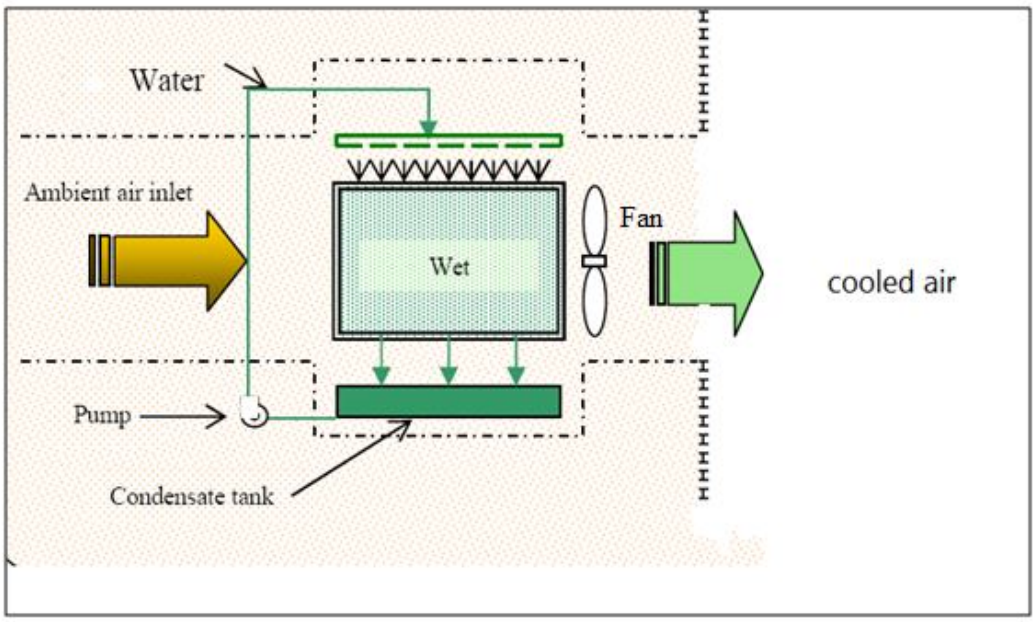


Figure 4.1 direct evaporative cooling system

### 4.1.1 Fan

It is an axial electric motor –driven fan composed of four wings. Its flow rate is 15 $^{m^3}/_{min}$ and its main role is to suck atmospheric air into the apparatus passing through the heat exchanger and cooling pad of direct evaporative cooling system and then into the building spaces.

Figure 4.2 Section of axial electric motor –driven fan

### 4.1.2 Pump:

A centrifugal pump was used in order to circulate water from water tank at the bottom of the direct evaporative cooling device to the heat exchanger and cooling pad at speed of 2900 rpm . The lifted water return back to the water tank by gravity.

Figure 4.3 Section of centrifugal pump

### 4.1.3 Cooling pad :

The cooling pad is the wet medium through which dry hot air passes and where evaporation takes place .There are many type of cooling pad such as (fibrous, cellouse ,ceramic, ect… ) but the type used in this evaporative cooling system is aspen wood type.

Figure 4.4 Section of Cooling pad

### 4.1.4 Water sprayer :

It is a Metallic pipe connected to the water pump with many holes . Its function is to spray water over the cooling pad of direct evaporative cooling system.

## 4.2 Heat Exchanger ( indirect evaporative cooling) :

It is locally made for the purposes of this experiment . It composed of a numbers of tubes made of copper , arranged in arrays . The length of the tube is 55cm , the height of the heat exchanger 60cm, the diameter of the tube is 1cm, and distance between each tube 4cm . the number of the tubes is 15 and attached to the direct evaporative cooling system (DECs). The Distance between DECs and heat exchanger is 20cm . The area (area between heat exchanger and DECs) represents the heat exchanger case was covered by plastic cover and it was completely air tight.

Figure 4.5 Section of heat exchanger

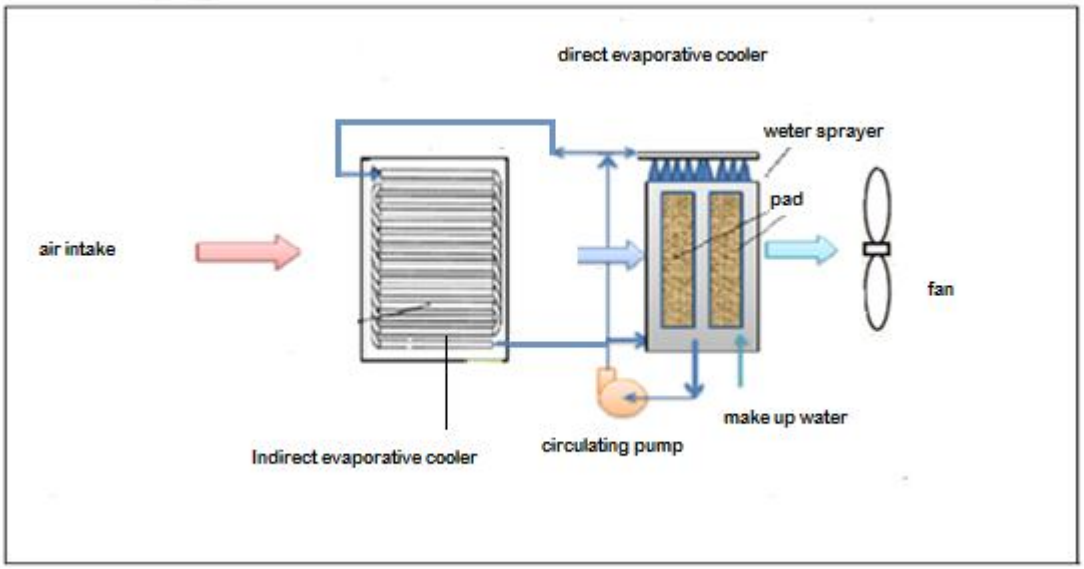


Figure 4.6 combined ( Indirect – direct ) evaporative cooling systems

## 4.3 Method:

The experiment was applied at ALKomor village out skirt of Wad Madani ,Sudan (latitude 14° 60° N,longitude 33° 38°).

Three types of evaporative cooling systems were used, direct, indirect ( heat exchanger alone) and combined evaporative cooling system .

$T_{in}$ $and$ $T_{out}$ were measured every hour for 7 hours started at 8:00 AM for direct evaporative cooling system , heat exchanger (indirect evaporative cooling system ) and of the combined

evaporative cooling system. The measured data were tabulated in tables. Table (4.1) shows change in dry blub temperature ($\Delta T$) and the efficiency of the direct evaporative cooling systems, table (4.2) shows change in dry blub temperature ($\Delta T$) of the indirect evaporative cooling systems and table (4.3) shows change in dry blub temperature ($\Delta T$) and the efficiency of the combined evaporative cooling systems. The efficiencies were calculated using equations (3.1)

$$\eta_{sat} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}} \qquad (3\text{-}1)$$

where :

$\eta_{sat}$- saturation efficiency

$T_{db,in}$ - Is the dry bulb temperature at inlet

$T_{db,out}$- Is the dry bulb temperature at outlet

$T_{wb,in}$ - Is the wet bulb temperature at the inlet

$\Delta T$ : $T_{db,in} - T_{db,out}$

Table (4 .1) Dry blub temperature of direct evaporative cooling system and efficiency

| Time(hour ) | $Tdb_{in}$(°C) | $Tdb_{out}$ (°C) | $Twb_{in}$(°C) | $\Delta T$(°C) | Efficiency (%) |
|---|---|---|---|---|---|
| 8:00 | 24.5 | 24 | 18 | 0.5 | 8 |
| 9:00 | 26 | 24.9 | 19 | 1.1 | 16 |
| 10:00 | 27 | 25 | 20 | 2 | 29 |
| 11:00 | 29 | 26.8 | 22 | 2.2 | 31 |
| 12:00 | 30.5 | 27.9 | 23 | 2.6 | 35 |
| 13:00 | 31.5 | 28.8 | 24 | 2.7 | 36 |
| 14:00 | 33.5 | 30 | 24.5 | 3.5 | 39 |
| 15:00 | 35.9 | 31.5 | 25 | 4.4 | 40 |

Table (4 .2) Dry blub temperatures of heat exchanger (indirect evaporative cooling system)

| Time (hour) | $Tdb_{in}$(°C) | $Twb_{in}$(°C) | $Tdb_{out}$(°C) | $\Delta T$ |
|---|---|---|---|---|
| 8:00 | 28 | 19 | 28 | 0 |
| 9:00 | 30 | 22 | 29.2 | 0.8 |
| 10:00 | 31.5 | 23 | 30.5 | 1 |
| 11:00 | 32.4 | 23.5 | 31.2 | 1.2 |
| 12:00 | 33.6 | 24.3 | 32.1 | 1.5 |
| 13:00 | 35.4 | 25 | 33.7 | 1.7 |
| 14:00 | 37 | 26.9 | 35.1 | 1.9 |
| 15:00 | 40 | 28.7 | 37.7 | 2.3 |

Table(4 .3) Dry blub temperatures of combined evaporative cooling system and efficiency

| Time (hour) | $Tdb_{in}$( °C) | $Tdb_{out}$ (°C) | $Twb_{in}$ (°C) | ΔT | Efficiency (%) |
|---|---|---|---|---|---|
| 8:00 | 28 | 26 | 19 | 2 | 22 |
| 9:00 | 30 | 27 | 22 | 3 | 35 |
| 10:00 | 31.5 | 27.3 | 23 | 4.2 | 46 |
| 11:00 | 32.4 | 27.7 | 23.5 | 4.7 | 53 |
| 12:00 | 33.6 | 28.3 | 24.3 | 5.3 | 54 |
| 13:00 | 35.4 | 29 | 25 | 6.4 | 60 |
| 14:00 | 37 | 30 | 26.9 | 7 | 67 |
| 15:00 | 40 | 32 | 28.7 | 8 | 69 |

# Chapter 5

## Analysis and Discussion

### 5.1 Dry Blub Temperature and Efficiency of Direct Evaporative Cooling System:

In this study, decrease in dry blub temperature in direct evaporative cooling system is mainly due to the arid climate which characterized by warm and cool winter. This result is in agreement with Costelloe 2003[4] who found that the evaporative cooling system can also be used in more humid climates (figure 5.1 ).

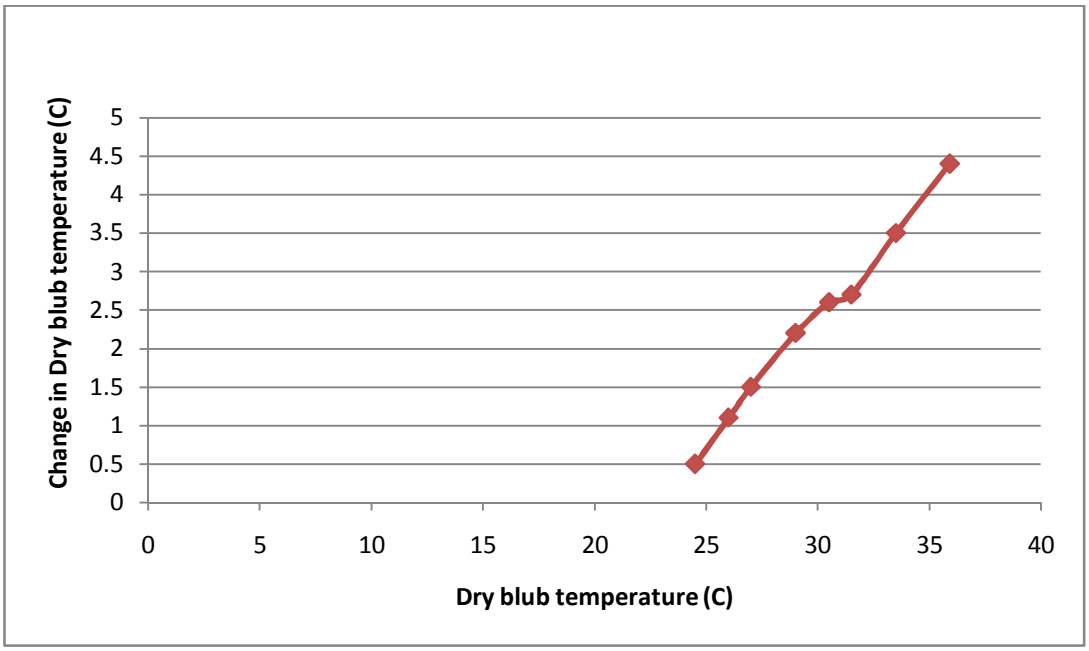


Figure 5.1 Change in dry blub temperature and dry blub temperature of the direct evaporative cooling system

Since the reduction in dry blub temperature is low the efficiency is also low (40%) because of the positive relation between the reduction in temperature and the efficiency. This

result is supported by Camargo et al. [17] ,who concluded that the efficiency is more at higher dry bulb temperature and lower air velocity figure (5.2).

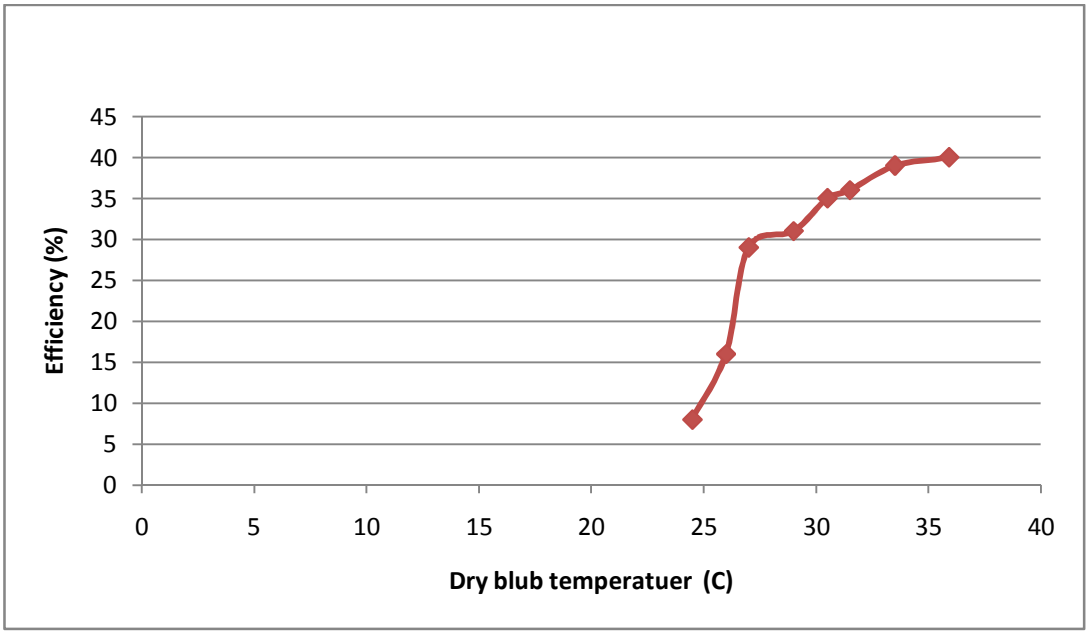


Figure 5.2 Dry blub temperature and efficiency of the direct evaporative cooling system.

## 5.2 Dry Blub Temperature of Indirect Evaporative Cooling System:

There was slow and slight decrease in dry bulb temperature, as affected by heat exchanger. The drop in dry bulb temperature ranged from 0.8℃----- 2.3℃ . The slight change in dry bulb temperature as affected by heat exchanger was due to the fact that not all the incoming air touches the tubes of the heat exchanger and consequently no heat exchange occurred in some amount of air because of presences of gaps between the tubes

(4 cm between each pipe) .More over the incoming air that touches the tubes of the heat exchanger doesn't find enough time to exchange heat between air and tubes due to the high velocity of the incoming air .

The efficiency of the heat exchanger (indirect evaporative cooling system) is almost negligible for the following reasons.

1- The effective heat transfer area is constant which is the surface area of the tubes of the heat exchanger .

2- The velocity of the incoming air is also constant since the fan used in this experiment is not changed and with fixed speed.

3- No change in humidity ratio because the slight reduction in temperature don't accompanied by any additional of moisture figure(5.3).

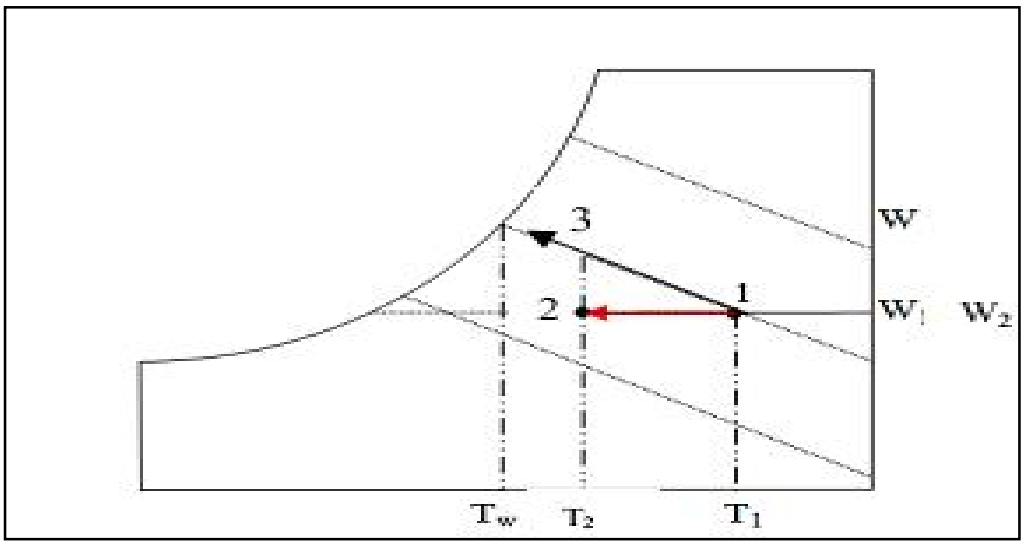


Figure 5.3 The constant humidity ratio of indirect evaporative cooling system

## 5.3 Dry Blub Temperature and Efficiency of Combined Evaporative Cooling System:

Decrease in dry blub temperature and wet blub temperature was greater in combined evaporative cooling system than direct evaporative cooling system figure( 5.4) , this due to the fact that reduction of entering air occurred at two phases ,at heat exchanger and at cooling pad while in direct evaporative cooling system occurred at cooling pad only. This result is similar to the finding of El-Dessouky et al. [9] who found that a combination can reduce the temperature of incoming air below its dry bulb temperature table (5.1).

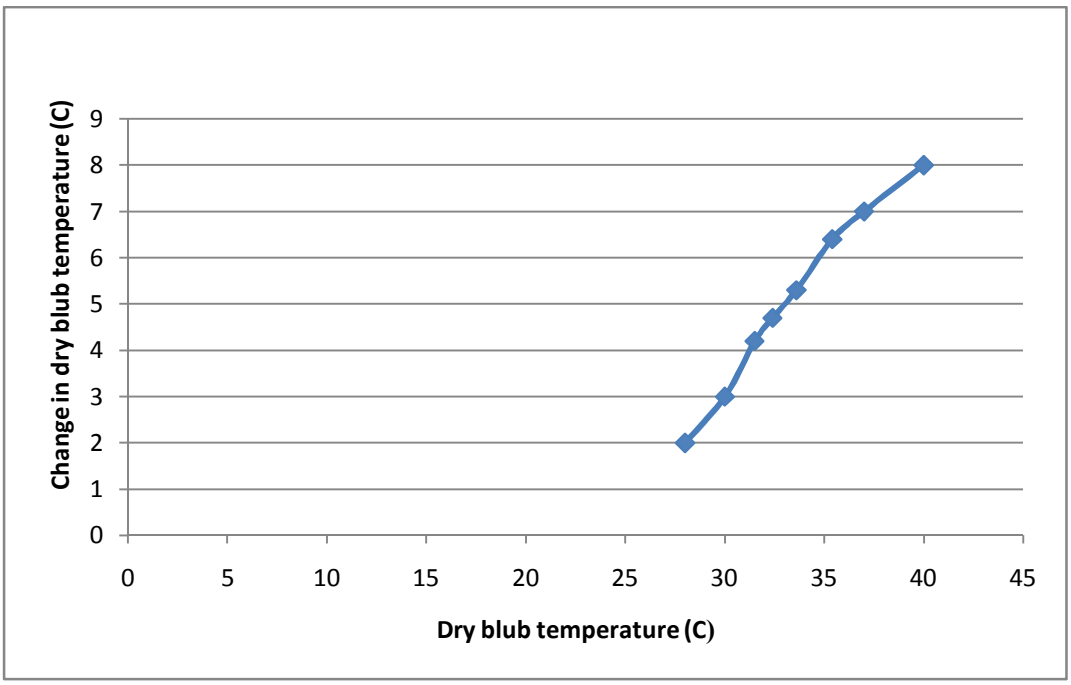


Figure 5.4 Change in dry blub temperature and dry blub temperature of the combined evaporative cooling system.

Table (5.1) Dry blub temperature and efficiency of direct and combined evaporative cooling system.

| Time (hour) | $\Delta T$ | | Efficiency (%) | |
|---|---|---|---|---|
| | Direct | Combined | Direct | Combined |
| 8:00 | 0.5 | 2 | 8 | 22 |
| 9:00 | 1.1 | 3 | 16 | 35 |
| 10:00 | 2 | 4.2 | 29 | 46 |
| 11:00 | 2.2 | 4.7 | 31 | 53 |
| 12:00 | 2.6 | 5.3 | 35 | 54 |
| 13:00 | 3.7 | 6.4 | 36 | 60 |
| 14:00 | 3.5 | 7 | 39 | 67 |
| 15:00 | 4.4 | 8 | 40 | 69 |

The efficiency of the combined evaporative cooling system obtained in this study was greater (69%) than the efficiency of the direct evaporative cooling system (40%) figure (5.5) and table (5.1). This is attributed to the effect of heat exchanger which reduce dry blub temperature and velocity of air stream and gives good chance to the air stream at cooling pad where exchange of heat between water and air stream takes place . This higher efficiency obtained also by Camargo et al. [17] . They concluded that the efficiency is more at higher dry bulb temperature and lower air speeds

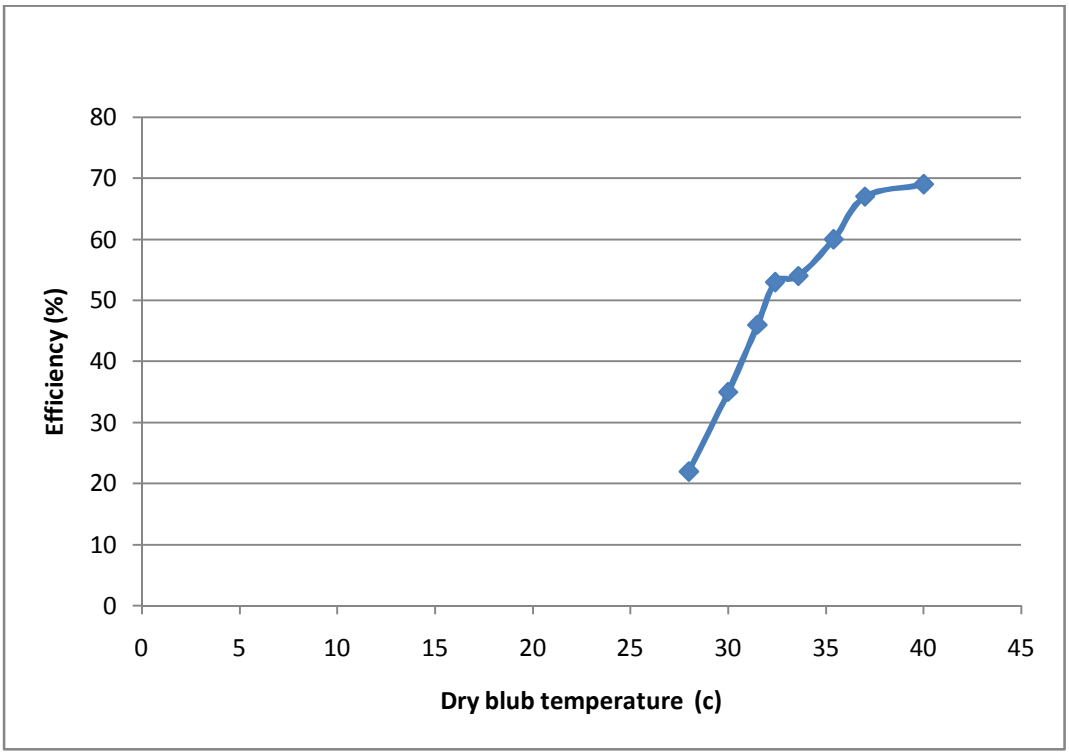


Figure 5.5 Dry blub temperature and efficiency of the combined evaporative cooling system

The advantage of the combined evaporative cooling system is that , it gives lower temperature and lesser moisture content which is comfortable for people .

# Chapter 6

## Conclusion and Recommendation:

### 6.1 Conclusion:

1- The study aimed to know the effect of heat exchanger on the dry bulb temperature and the efficiency of direct and combined evaporative cooling system .

2- The result showed that reduction of dry bulb temperature was greater in the combined evaporative cooling system than that of the direct evaporative cooling system .

3- The efficiency greatly increased in combined evaporative cooling system (69%) compared to the direct evaporative cooling system (40%).

4- Energy consumption of the two evaporative cooling system was the same .

### 6.2 Recommendation:

1-The positive result of this study on the effect of heat exchanger suggests that further investigation on the effect of size, length, number and material of tubes of heat exchanger, air velocity and cooling pads material should be carried ou.

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