

Design, Fabrication and Performance Analysis of a Microcontroller-Based Evaporative Cooling System Using Different Cooling Pad Materials



A thesis

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Department of Mechanical Engineering
SONARGAON UNIVERSITY (SU)

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Abstract

This paper focuses on the study and development of a microcontroller-based Evaporative Cooling System. The main objective of the project is to analyze the effectiveness of different cooling pads used in the system. A Node MCU microcontroller is used for monitoring and control purposes. Three different types of cooling pads are designed and tested to compare their cooling performance. Temperature and humidity data are collected using suitable sensors and analyzed to evaluate system performance. The results show that evaporative cooling is an energy-efficient and eco-friendly method for reducing air temperature and can be used as an alternative to conventional cooling systems.

Among the three cooling pads tested, the coconut pad showed the highest cooling effectiveness, achieving a maximum temperature reduction of about 4.78°C and an average reduction of approximately 3.8–4.0°C at a natural temperature of around 23.9°C. The honeycomb pad provided moderate cooling performance, with an average temperature reduction of about 2.4–2.6°C at a natural temperature of nearly 23.5°C. In contrast, the jute pad exhibited the lowest cooling effectiveness, producing an average temperature reduction of only 1.8–2.0°C at a natural temperature close to 24.0°C.

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Chapter 1

Introduction

1.1 Introduction

This research is based on the evaporative cooling where hot dry air can be passed through evaporative pad, get cooled and then be blown to a building space as illustrated in Figure 1.5. Simple evaporative cooling process provides cooling effect by adiabatic evaporation of water. The process can be demonstrated on a psychrometric chart as shown in Figure 1.6. In this example air at 30oC dry-bulb temperature and 20% RH passed through an evaporative cooling media making its state to change to a dry-bulb temperature of 18oC and 79% RH. That is lowering the temperature but increasing the relative humidity (RH).

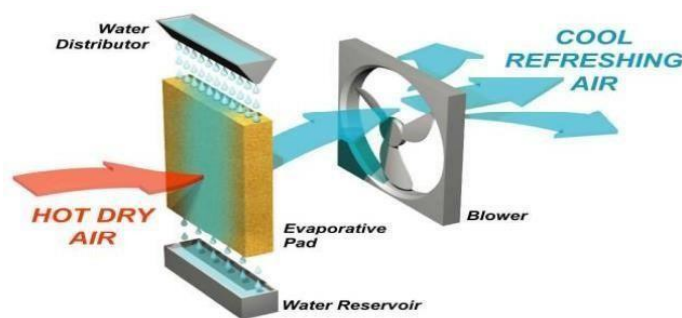


Figure 1.1: Basic evaporative cooling processes

In this research several novel evaporative cooling devices suitable for building cooling have been identified. These consist of direct evaporative cooling using porous ceramics; porous ceramics integrated with thermoelectric cooler and also indirect cellulose fibre (paper) tubes novel evaporative cooling systems. This chapter briefly outlines these novel evaporative cooling systems, the reasons for undertaking the research and the relevance to potential users.

1.2 Background Study

World energy consumption pattern showed that fossil fuels including oil, coal and gas are being consumed significantly higher than the environmentally friendly renewable energy sources as shown in Figure 1-1. This will result in increased CO₂ emission to the environment and subsequent climate change. Similarly the historical and projected share of primary world energy

consumption represented indicated continuous dominance on oil, gas and coal (International Energy Outlook, 2000). However, renewable energies which represent very small amount of the world energy consumption are receiving attention because of the falling trend in their costs as shown in and are also friendlier to the environment (TCS, 2007). Therefore in 1992 at the Environment and Development (UNCED, 1992) conference in Rio de Janeiro the European Union committed itself to stabilising and then reducing carbon dioxide (CO₂) and CFCs emissions into the environment. Introduction - Majority of the energy consumption in building for cooling or heating is derived from fossil fuels. It is therefore very vital to provide a less energy intensive system for space cooling which will replace or minimise dependency on the conventional vapour compression air conditioning systems. Usually buildings in hot climates are continuously heated by the sun and dry winds during the day time as shown in Therefore the wall mass acts as a heat storage medium emitting heat to the interior making the entire space warm and uncomfortable up to late evening periods. Evaporative cooling is one method of simulating natural cooling effects commonly experienced at or near seas and lakes during warm periods of the day and the same technique have long been realised to be used for the cooling of buildings. The evaporative cooling system can be integrated with a heat transfer unit such as thermo electrics or heat pipes to make the application of the system more flexible for either cooling with humidification or cooling without humidification. It can also be used as a heat sink to other cooling devices such as thermoelectric system. This research will deal with several novel evaporative cooling methods and their applications to provide comfortable cooling for building space. It will involve mathematical modelling and experimental investigation of the above mentioned evaporative cooling methods. These are novel evaporative cooling systems using porous ceramics and the porous ceramics-cum-thermoelectric cooling system. Then paper fibre horizontal tubes evaporative cooling system was developed. The proposed systems can be interchanged to be suitable for cooling with humidification or cooling without humidification.

1.3 Problem Statment

Traditional air conditioning systems consume significant energy and contribute to environmental issues due to their reliance on refrigerants. Evaporative cooling offers an eco-friendly alternative by utilizing the natural process of water evaporation to reduce air temperature. This system will use a DC fan to draw warm air through an evaporative pad moistened with water from a tank, resulting in cooler air being circulated in the desired space.

Water Management: Ensuring a continuous and sufficient water supply to keep the evaporative pad wet.

Energy Efficiency: Optimizing the system to minimize power consumption while maximizing cooling effectiveness.

System Durability: Designing components to withstand prolonged exposure to water and environmental conditions.

Temperature Control: Achieving consistent and controllable cooling based on environmental variables.

The system will be developed for small to medium-sized indoor or outdoor spaces. The solution should be scalable, with the potential to integrate additional sensors for monitoring temperature and humidity, as well as IoT capabilities for remote control and monitoring. The project aims to deliver a functional evaporative cooling system that reduces air temperature efficiently, operates on low power, and offers an environmentally friendly cooling solution for residential, commercial, or industrial applications.

1.4 Objectives

- To Study about Evaporative cooling system and the effectiveness of cooling pad on this device.
- To design a microcontroller based Evaporative Cooling system.
- To Construct the Structure and prepare 3 Different types of cooling pad for Performance analysis.
- To collect and analyze the corresponding data.

Chapter 2

Theory Of The Project

2.1 Introduction

This chapter includes the total over view of the device. In this chapter we have followed-up the theory of Cooling Pad, Water Pump, Water Tank, Pipe, Metal Angle, Sun Board, 220V AC Fan, SMPS, Node MCU, LCD Display, DHT11, DS18B20, Vero board, and other components. Here we can know that the total system overview of the projects. And we will also know that how the equipment are working with each other.

2.2 Theory

We've developed the system that can handle this critical switching situation perfectly.

2.2.1 Cooling Pad

Here we used 3 different types of evaporative pad. Three pads are build in three different materials, One of them made by coconut fiber, one of them made by paper with honey comb desing and one of them made by jute. Every single pad works to cool the inner temperature of Evaporator system and every pad are made in same measurement .



Figure 2.1: Cooling Pad

2.2.2 Water Pump

12 Volt water pump is a dc electric water pump motor that powered by a 12V direct current power supply. It use centrifugal force that generated by high speed rotated impeller to booster, transfer, lift or circulate liquids like water, oil, coolant for sprayers, car, fountain, shower, garden etc.



Figure 2.2: Water Pump

2.2.3 Water Tank

A water tank is a container for storing water, for many applications, drinking water, irrigation, fire suppression, farming, both for plants and livestock, chemical manufacturing, food preparation as well as many other uses. Water tank parameters include the general design of the tank, and choice of construction materials, linings. Various materials are used for making a water tank: plastics (polyethylene, polypropylene), fiberglass, concrete, stone, steel (welded or bolted,[citation needed] carbon, or stainless). Earthen pots, such as matki used in South Asia, can also be used for water storage. Water tanks are an efficient way to help developing countries to store clean water.



Figure 2.3: Water Tank

2.2.4 Plastic Pipe

A plastic hose pipe for a water pump is a flexible, cylindrical conduit used to transport water from one location to another. These hoses are commonly used in conjunction with water pumps to direct the flow of water for various purposes, including irrigation, drainage, cooling systems, and household water supply. They are made from various types of plastic materials and come in a range of sizes, strengths, and configurations to suit different applications.



Figure 2.4: Pipe

2.2.5 Iron Angle

Steel angle (also known as angle iron) is one of the world's most-used steel structural shapes due to its 90° L-shape and functional mechanical properties. Angle iron can be manufactured in steel and metal alloys in smaller bar and larger L-shape sizes.



Figure 2.5: Iron Angle

2.2.6 Sun Board

PVC Sun boards are Rigid PVC Sheets manufactured using foaming agent to foam the PVC Sheets. "Sun board" is our brand. This brand's popularity has made people remember the product

has Sun Board Sheets. These sheets are extruded from Virgin grade PVC granules using Italian machines.

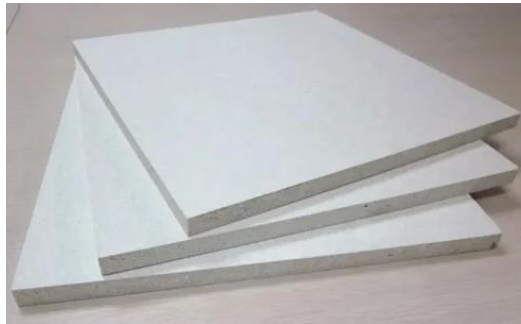


Figure 2.6: Sun Board

2.2.7 Exhaust Fan

An exhaust fan is a mechanical ventilation device designed to remove stale air, heat, moisture, odors, smoke, and airborne pollutants from an enclosed space and expel them outside. It helps maintain good indoor air quality by promoting proper air circulation and preventing the buildup of humidity and harmful contaminants. By removing excess moisture, they help prevent mold growth, corrosion, and structural damage, while also improving comfort and hygiene. In industrial settings, exhaust fans play a crucial role in controlling heat and removing fumes or dust generated during operations.



Figure 2.7: Exhaust Fan

2.2.8 Node MCU

Node MCU is an open-source firmware, hardware, and software development environment project developed initially for the Node MCU ESP8266 Wi-fi SoC chip based on LUA. The most spectacular features are: It is a low-cost, small, and powerful board.



Fig: 2.8 Node MCU

2.2.9 SMPS

Switched-mode power supplies (SMPS), sometimes referred to as switch mode power supplies, have become the workhorse of efficient power conversion, taking a mains voltage AC input and converting it down to a low voltage DC output.



Fig: 2.9 SMPS

2.2.10 LCD Display

The I2C LCD component is used in applications that require a visual or textual display. This component is also used where a character display is needed but seven consecutive GPIOs on a single GPIO port are not possible. In cases where the project already includes an I2C master, no additional GPIO pins are required.



Fig: 2.10: LCD Display

2.2.11 DHT11 – Temperature Sensor

The DHT11 is a basic, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (no analog input pins needed).

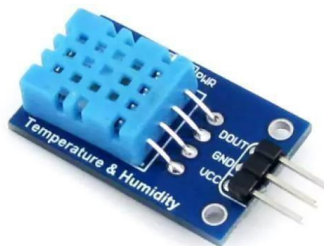


Figure 2.11: Temperature Sensor

2.2.12 DS18B20 – Temperature Sensor

DS18B20 - Programmable Resolution 1-Wire Digital Thermometer. Page 1. General Description. The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points.



Figure 2.12: DS18B20 – Temperature Sensor

Chapter 3

Design & Fabrication

3.1 Introduction

In this chapter fully cover with discuss design and fabrication of this project. Here we will discuss about developed block diagram and briefly describe about the circuit Diagram and also learn about working principle.

3.2 Block Diagram

In this Part of discussion we will describe about the block diagram of our system. Here you see that, we use here a Node MCU as a microcontroller to control this total system. Here We provide AC 220V power to 12v SMPS, it will provide 12V DC and then it will be converted to 5V DC voltage using a Buck Converter.

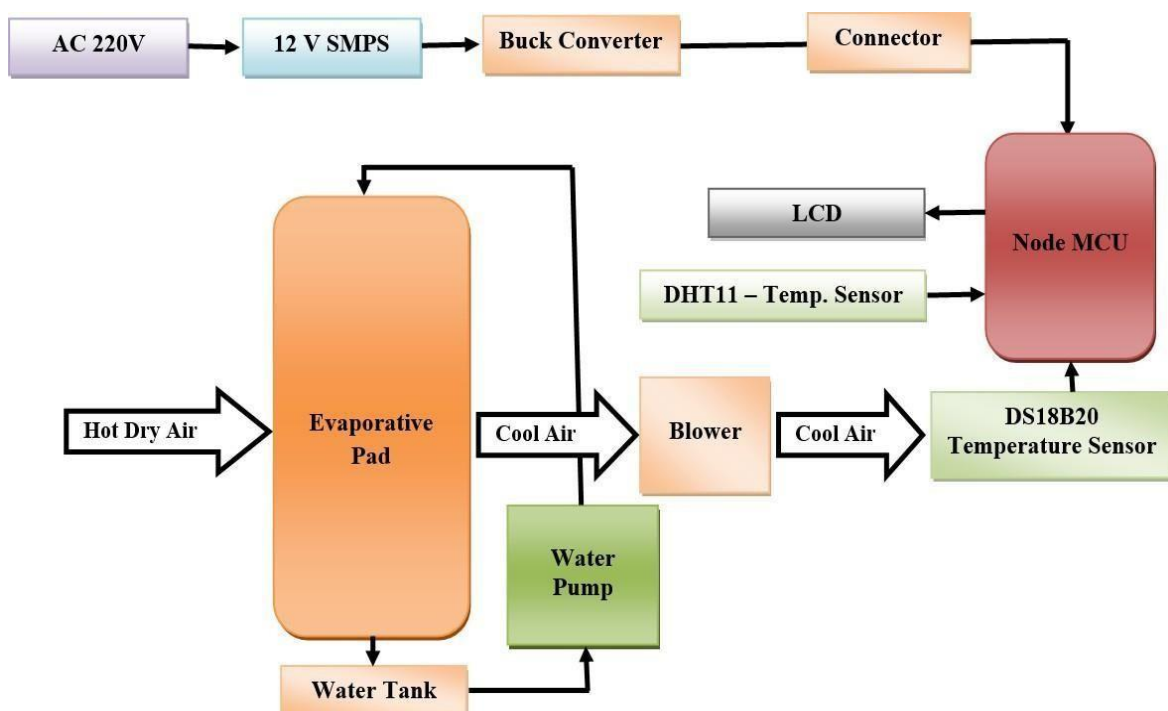


Fig: 3.1: Block diagram of Proposed System

This 5V DC power will be distributed to all components to run this system. we use here a 12V DC Water Pump to recycling water from water Tank to upper side of Evaporative Pad again and again . One 220V AC motor is used here to Blowing air from Evaporative Pad side to room side. To Read the temperature of this cool water we use here a water Proof Temperature sensor Named DS18B20. This Temperature will be read by using a node MCU and it will show in our LCD Display. LCD is used here to show all the operation output for manually monitoring. Here One another temperature sensor also used here to read the Natural Temperature of air. By seeing this both Temperature we can define that how much temperature are reduced by using our proposed system.

3.3 Circuit Diagram

In this Part of discussion we will describe about the Circuit diagram of our system. Here you see that, we use here a Node MCU as a microcontroller to control this total system. Here We provide AC 220V power to 12v SMPS, it will provide 12V DC and then it will be converted to 5V DC voltage using a Buck Converter.

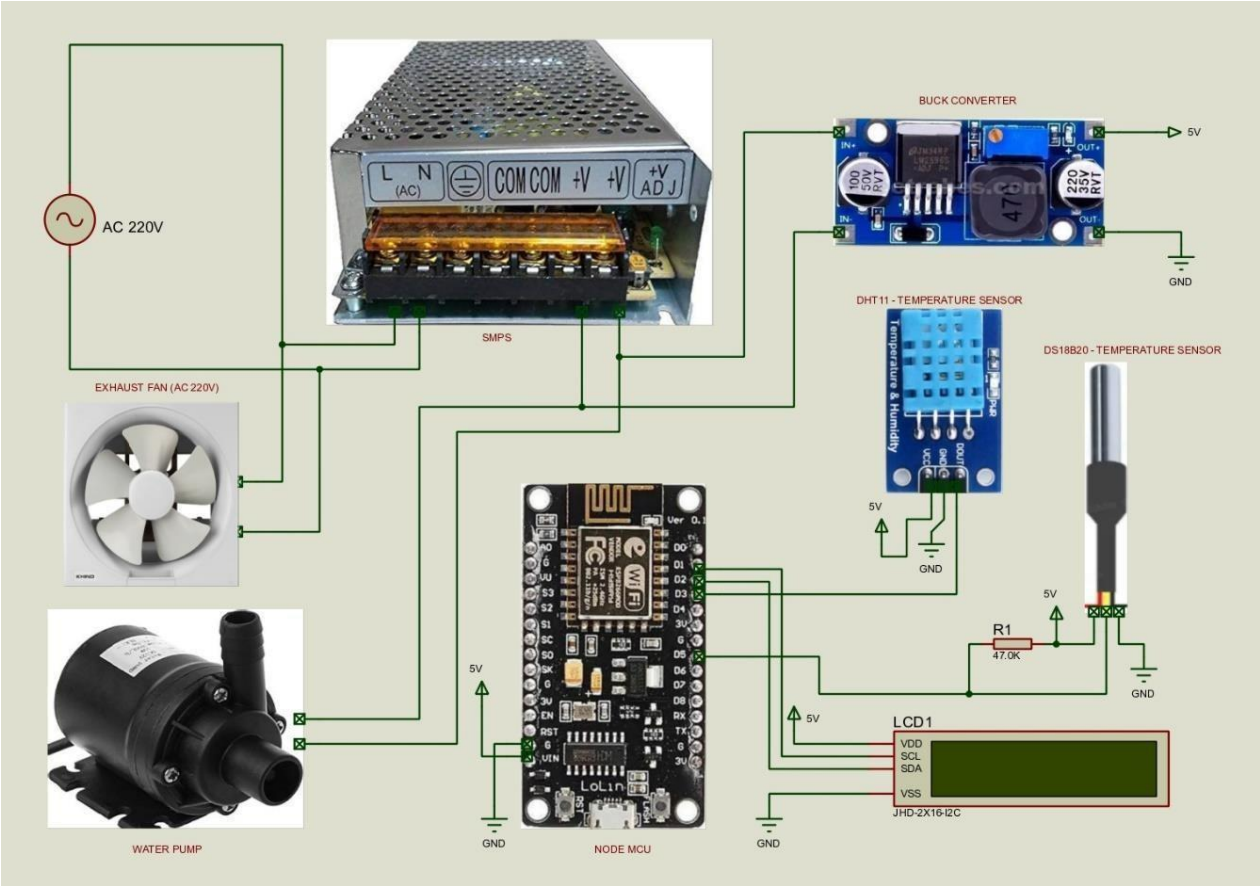


Fig. 3.2: Circuit diagram of Proposed System

This 5V DC power will be distributed to all components to run this system. we use here a 12V DC Water Pump to recycling water from water Tank to upper side of Evaporative Pad again and again . One 220V AC motor is used here to Blowing air from Evaporative Pad side to room side. To Read the temperature of this cool water we use here a water Proof Temperature sensor Named DS18B20. This Temperature will be read by using a node MCU and it will show in our LCD Display. LCD is used here to show all the operation output for manually monitoring. Here One another temperature sensor also used here to read the Natural Temperature of air. By seeing this both Temperature we can define that how much temperature are reduced by using our proposed system.

3.4 Project Overview

This is the full over view of our project. First of all we design here a metal frame then we set our all components and after that we covered total frame by using Sun Board. we use here a Node MCU as a microcontroller to control this total system. Here We provide AC 220V power to 12v SMPS, it will provide 12V DC and then it will be converted to 5V DC voltage using a Buck Converter.



Fig: 3.3: Final Project

This 5V DC power will be distributed to all components to run this system. we use here a 12V DC Water Pump to recycling water from water Tank to upper side of Evaporative Pad again and again . One 220V AC motor is used here to Blowing air from Evaporative Pad side to room side. To Read the temperature of this cool water we use here a water Proof Temperature sensor Named DS18B20. This Temperature will be read by using a node MCU and it will show in our LCD Display. LCD is used here to show all the operation output for manually monitoring. Here One another temperature sensor also used here to read the Natural Temperature of air. By seeing this both Temperature we can define that how much temperature are reduced by using our proposed system.

3.5 Working Principle

This section describes the complete working procedure of the proposed evaporative cooling system a Node MCU as a microcontroller to control this total system. Here We provide AC 220V power to 12v SMPS, it will provide 12V DC and then it will be converted to 5V DC voltage using a Buck Converter. This 5V DC power will be distributed to all components to run this system. we use here a 12V DC Water Pump to recycling water from water Tank to upper side of Evaporative Pad again and again . One 220V AC motor is used here to Blowing air from Evaporative Pad side to room side. To Read the temperature of this cool water we use here a water Proof Temperature sensor Named DS18B20. This Temperature will be read by using a node MCU and it will show in our LCD Display. LCD is used here to show all the operation output for manually monitoring. Here One another temperature sensor also used here to read the Natural Temperature of air. By seeing this both Temperature we can define that how much temperature are reduced by using our proposed system.

3.6 Conclusion

In this chapter we have discussed the block diagram, circuit description, working principle also show the real image of the project and others. In the later part of this paper we discussed the result & discussion of the project to make the concept clear to anyone.

Chapter 4

Result & Discussion

4.1 Introduction

This chapter contains the results obtained and discussion about the project. We have also covered discussions about advantages, disadvantages and limitation of current version of the protection system.

4.2 Construction Result

Here we will try to show the results of our project.



Fig: 4.1: Back Side View of our Project.



Fig: 4.2: Front Side View of our Project.

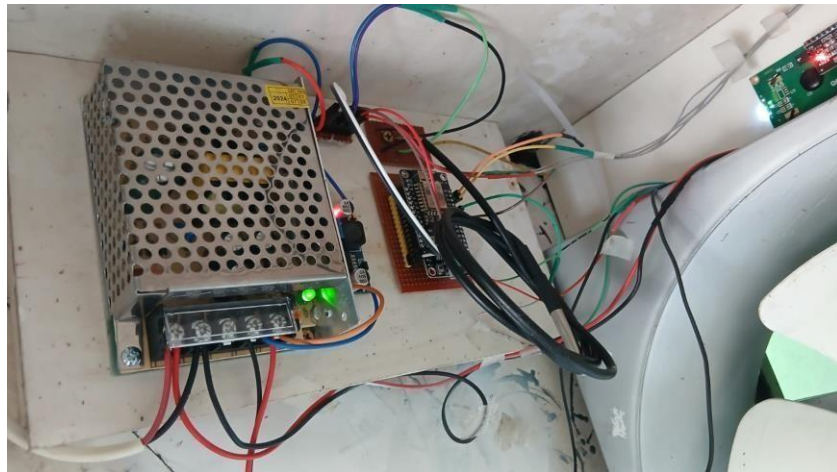


Fig: 4.3: Internal View of Blower Fan.



Fig: 4.4: Front View of Blower Fan.



Fig: 4.5: Evaporative Water Recycling using Coconut Fiber Pad.



Fig: 4.6: Evaporative Water Recycling using Jute Pad.



Fig: 4.7: Evaporative Water Recycling using Honey Comb (Paper Made) Pad.

4.3 Data Collection

Table 4.1: Data analysis from Coconut pad

Time	Natural Temperature	Cooling Temperature	Temperature Difference
02.00 PM	25.00 C	23.31 C	1.69 C
02.10 PM	25.00 C	22.18 C	2.82 C
02.20 PM	25.00 C	22.02 C	2.98 C
02.30 PM	25.00 C	21.40 C	3.60 C
02.40 PM	25.00 C	19.50 C	5.50 C

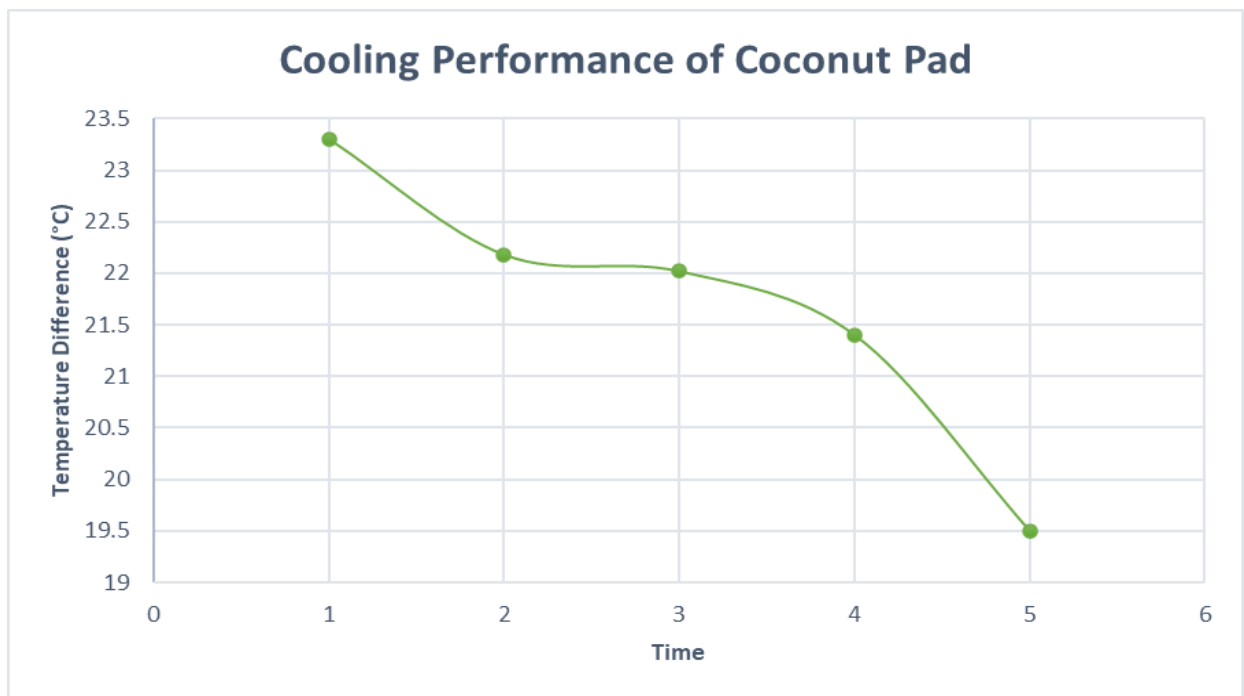


Fig: Graphical Analysis of Coconut Pad

Mathematical Expression

Work Input Calculation

The electrical power consumed by the system is calculated using the supplied voltage and current.

$$\begin{aligned} &\text{Given,} \\ &\text{Voltage, } V = 230 \text{ V} \\ &\text{Current, } I = 0.78 \text{ A} \end{aligned}$$

$$\begin{aligned} &\text{The power input is:} \\ &P = V \times I = 230 \times 0.78 = 179.4 \text{ W} \end{aligned}$$

$$\begin{aligned} &\text{The operating time of the system is:} \\ &t = 30 \text{ minutes} = 1800 \text{ sec} \end{aligned}$$

$$\begin{aligned} &\text{Therefore, the total work input is:} \\ &W = P \times t = 179.4 \times 1800 = 322,920 \text{ J} \end{aligned}$$

$$\begin{aligned} &\text{Converting into kilojoule:} \\ &W = 0.322920 \text{ kJ} \end{aligned}$$

Cooling Effect Calculation

The cooling effect of the system is calculated using the following relation:

$$Q = m \times C_p \times \Delta T$$

$$\begin{aligned} &\text{Where,} \\ &\text{Density of air, } \rho = 1.29 \text{ kg/m}^3 \\ &\text{Volume of air, } V = 10 \times 10 \times 10 \text{ cm}^3 = 0.001 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} &\text{The mass of air is:} \\ &m = \rho \times V = 1.29 \times 0.001 = 0.00129 \text{ kg} \end{aligned}$$

$$\begin{aligned} &\text{Specific heat of air:} \\ &C_p = 0.718 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} &\text{Temperature difference between inlet and outlet air:} \\ &\Delta T = 25 - 19.50 = 5.5 \text{ }^\circ\text{C} \end{aligned}$$

Thus, the cooling effect is:

$$\begin{aligned} &Q = m \times C_p \times \Delta T \\ &Q = 0.00129 \times 0.718 \times 5.5 \\ &Q = 0.00509 \text{ kJ} \end{aligned}$$

COP Calculation

Finally, the coefficient of performance of the system is calculated as:

$$\text{COP} = 0.00509 / 0.322920$$

$$\text{COP} = 0.0158 \approx 0.016$$

Table 4.2: Data analysis from

Time	Natural Temperature	Cooling Temperature	Temperature Difference
03.00 PM	25.50 C	23.40 C	2.10 C
03.10 PM	23.50 C	22.18 C	3.32 C
03.20 PM	23.50 C	22.02 C	3.48 C
03.30 PM	23.50 C	21.40 C	4.10 C
03.40 PM	23.50 C	20.21 C	5.29 C

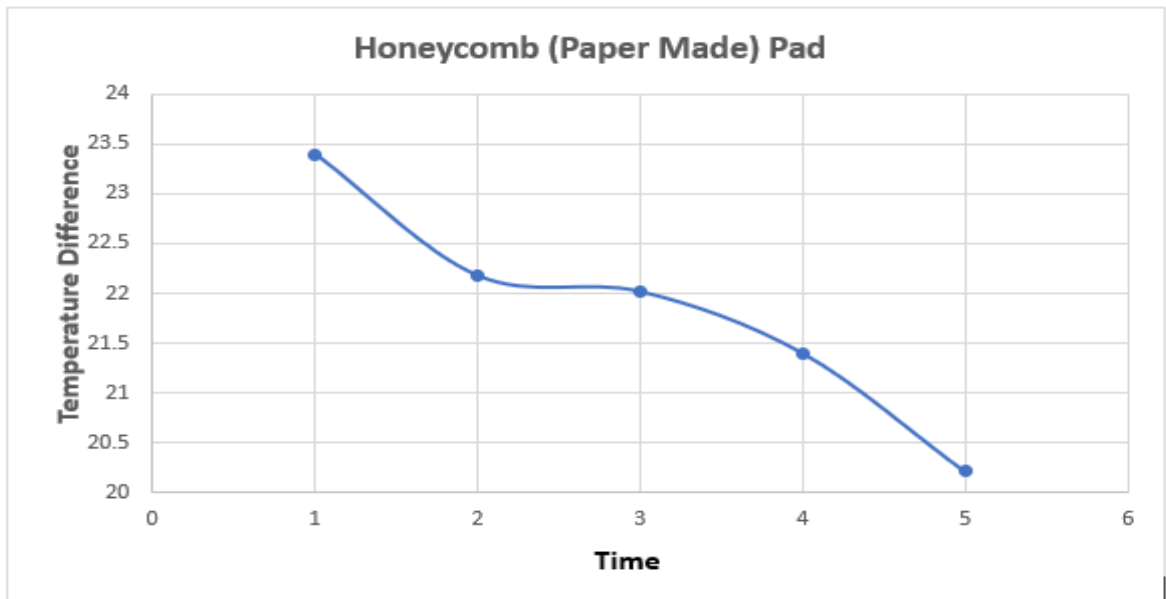


Fig: Graphical Analysis of Honeycomb (Paper Made) Pad

Mathematical Expression

Work Input Calculation

The electrical power consumed by the system is calculated using the supplied voltage and current.

Given,

$$\text{Voltage, } V = 230 \text{ V}$$

$$\text{Current, } I = 0.78 \text{ A}$$

The power input is:

$$P = V \times I = 230 \times 0.78 = 179.4 \text{ W}$$

The operating time of the system is:

$$t = 30 \text{ minutes} = 1800 \text{ sec}$$

Therefore, the total work input is:

$$W = P \times t = 179.4 \times 1800 = 322,920 \text{ J}$$

Converting into kilojoule:

$$W = 0.322920 \text{ kJ}$$

Cooling Effect Calculation

The cooling effect of the system is calculated using the following relation:

$$Q = m \times C_p \times \Delta T$$

Where,

$$\text{Density of air, } \rho = 1.29 \text{ kg/m}^3$$

$$\text{Volume of air, } V = 10 \times 10 \times 10 \text{ cm}^3 = 0.001 \text{ m}^3$$

The mass of air is:

$$m = \rho \times V = 1.29 \times 0.001 = 0.00129 \text{ kg}$$

Specific heat of air:

$$C_p = 0.718 \text{ kJ/kg}$$

Temperature difference between inlet and outlet air:

$$\Delta T = 25.50 - 20.21 = 5.29 \text{ C}$$

Thus, the cooling effect is:

$$Q = m \times C_p \times \Delta T$$

$$Q = 0.00129 \times 0.718 \times 5.29$$

$$Q = 0.00490 \text{ kJ}$$

COP Calculation

Finally, the coefficient of performance of the system is calculated as:

$$COP = 0.00490 / 0.322920$$

$$COP = 0.015$$

Table 4.3: Data analysis from Jute Pad

Time	Natural Temperature	Cooling Temperature	Temperature Difference
04.00 PM	24.00 C	22.43 C	1.57 C
04.10 PM	24.00 C	22.37 C	1.63 C
04.20 PM	24.00 C	22.18 C	1.82 C
04.30 PM	24.00 C	22.06 C	1.94 C
04.40 PM	24.00 C	21.80 C	2.26 C

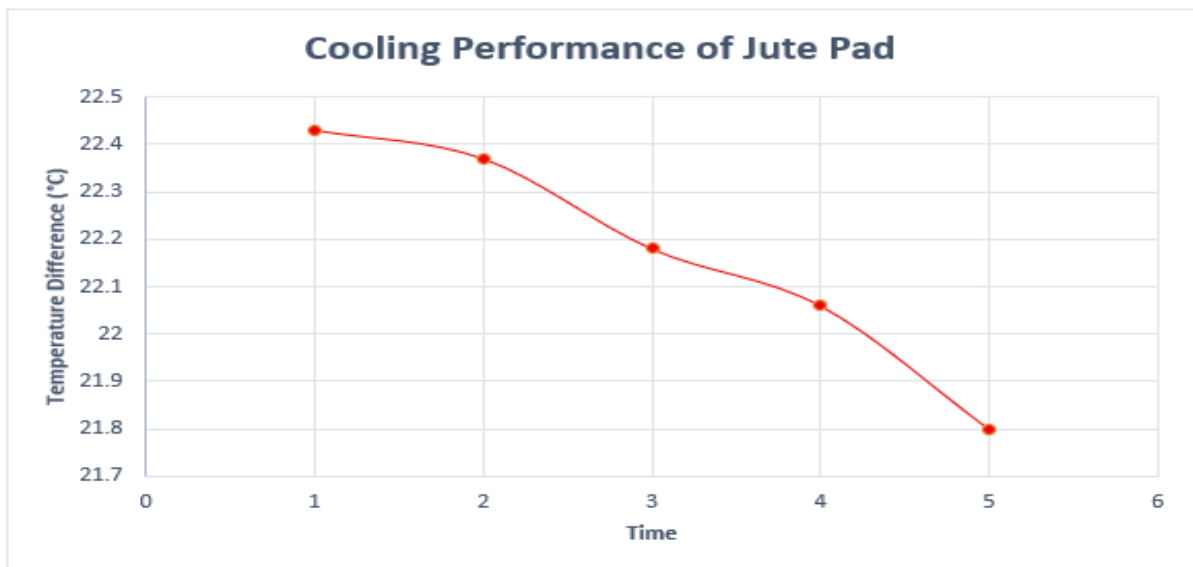


Fig: Graphical Analysis of Jute Pad

Mathematical Expression

Work Input Calculation

The electrical power consumed by the system is calculated using the supplied voltage and current.

Given,

Voltage, $V = 230 \text{ V}$

Current, $I = 0.78 \text{ A}$

The power input is:

$$P = V \times I = 230 \times 0.78 = 179.4 \text{ W}$$

The operating time of the system is:

$$t = 30 \text{ minutes} = 1800 \text{ sec}$$

Therefore, the total work input is:

$$W = P \times t = 179.4 \times 1800 = 322,920 \text{ J}$$

Converting into kilojoule:

$$W = 0.322920 \text{ kJ}$$

Cooling Effect Calculation

The cooling effect of the system is calculated using the following relation:

$$Q = m \times C_p \times \Delta T$$

Where,

Density of air, $\rho = 1.29 \text{ kg/m}^3$

Volume of air, $V = 10 \times 10 \times 10 \text{ cm}^3 = 0.001 \text{ m}^3$

The mass of air is:

$$m = \rho \times V = 1.29 \times 0.001 = 0.00129 \text{ kg}$$

Specific heat of air:

$$C_p = 0.718 \text{ kJ/kg}$$

Temperature difference between inlet and outlet air:

$$\Delta T = 24 - 22.43 = 1.57 \text{ }^\circ\text{C}$$

Thus, the cooling effect is:

$$Q = m \times C_p \times \Delta T$$

$$Q = 0.00129 \times 0.718 \times 1.57$$

$$Q = 0.00145 \text{ kJ}$$

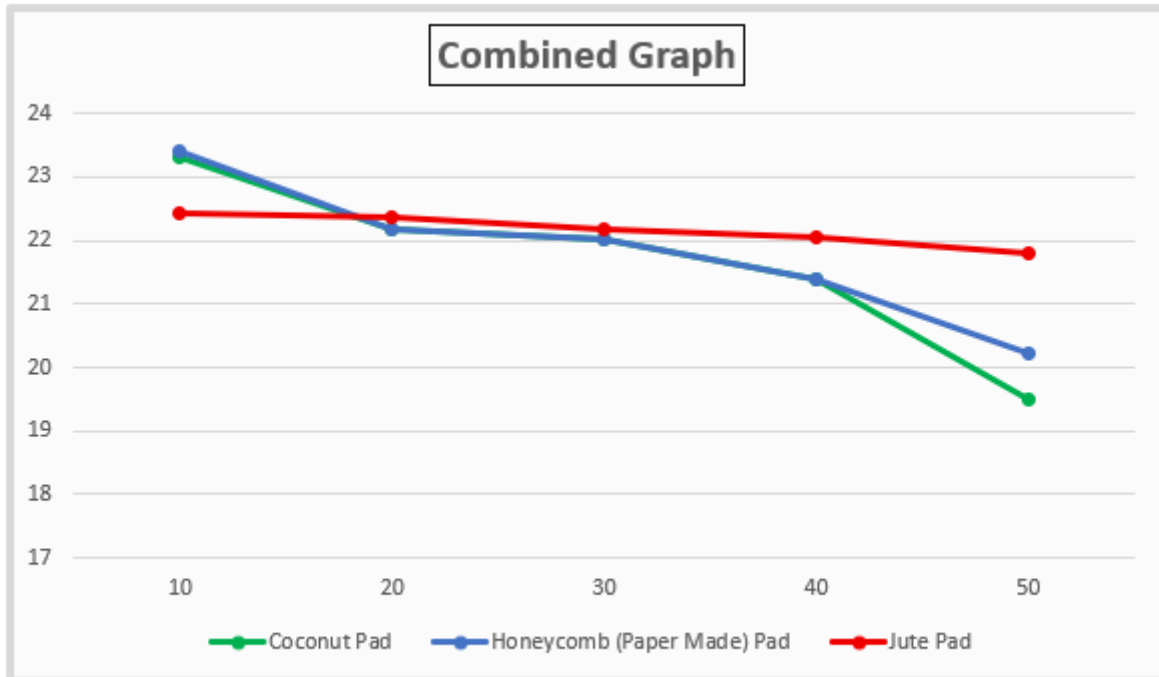
COP Calculation

Finally, the coefficient of performance of the system is calculated as:

$$\text{COP} = 0.00145 / 0.322920$$

$$\text{COP} = 0.00449 \approx 0.0045$$

4.4 Figure shows the combined graphical comparison of coconut, honeycomb (Paper Made) paper material, and jute pads.



The graph shows the variation of outlet air temperature with time for different cooling pad materials. It is observed that the honeycomb pad provides the highest temperature reduction compared to coconut and jute pads. Coconut pad shows moderate performance, while jute pad provides the least cooling effect. This indicates that cooling efficiency depends on the pad material, water retention capacity, and air contact surface area.

4.5 Advantage

Evaporator cooling systems, particularly those using the principles of evaporative cooling, offer several distinct advantages over traditional refrigeration and air conditioning systems. These advantages make them especially suitable for certain climates and applications. Here's a detailed look at the key benefits:

Energy Efficiency:

- **Low Power Consumption:** Evaporator cooling systems consume significantly less electricity compared to traditional air conditioning systems. They primarily use power for running fans and water pumps, which are much less energy-intensive than compressors in air conditioners.
- **Cost-Effective Operation:** Due to their lower energy requirements, they reduce operational costs, making them an economical choice for continuous cooling needs.

Environmental Benefits:

- **No Refrigerants:** Evaporator cooling systems do not use refrigerants, which are often greenhouse gases with high global warming potential (GWP). This makes them more environmentally friendly.
- **Low Carbon Footprint:** The reduced energy consumption leads to lower greenhouse gas emissions, contributing to a smaller carbon footprint.

Effective in Dry Climates:

- **High Cooling Efficiency:** In hot and dry climates, evaporator cooling systems are particularly effective. The low humidity enhances the evaporation process, leading to significant cooling.
- **Natural Humidification:** These systems also add moisture to the air, which can be beneficial in dry environments where increased humidity improves comfort.

Low Installation and Maintenance Costs:

- **Affordable Installation:** The initial installation cost is often lower than that of traditional air conditioning systems, especially for large-scale applications.

- **Easy Maintenance:** Maintenance is straightforward, often involving routine cleaning and occasional replacement of parts like cooling pads. This simplicity reduces maintenance costs and downtime.

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Air Quality Improvement:

- **Filtration and Fresh Air:** Many evaporative coolers draw in fresh outdoor air, which passes through water-saturated pads that act as filters, trapping dust, pollen, and other particulates. This can improve indoor air quality compared to recirculating systems that might accumulate and redistribute contaminants.
- **Cooling with Fresh Air:** They continuously supply fresh, cooled air instead of recirculating indoor air, reducing the buildup of indoor pollutants.

Comfort and Health Benefits:

- **Reduced Air Dryness:** Unlike conventional air conditioners that often dry out the air, evaporative coolers increase humidity levels, which can alleviate discomfort caused by dry air, such as dry skin and respiratory issues.
- **Evaporative Cooling Effect:** The natural process of evaporative cooling provides a gentle, moist breeze, often perceived as more comfortable and refreshing compared to the dry, cold air from traditional air conditioning.

Silent Operation:

- **Low Noise Levels:** Many evaporator cooling systems operate quietly, especially when compared to the noise generated by compressors in traditional air conditioners. This makes them suitable for use in residential areas, offices, and other noise-sensitive environments.

4.6 Disadvantages

While evaporative cooling systems offer numerous advantages, they also have some limitations and drawbacks that should be considered. Here are the key disadvantages of evaporative cooling systems:

Limited Cooling Capacity in High Humidity:

- **Reduced Effectiveness in Humid Climates:** Evaporative cooling systems rely on the evaporation of water to cool the air. In environments with high humidity, the air is already saturated with moisture, reducing its ability to absorb additional water. This limits the cooling effectiveness of the system.
- **Temperature Constraints:** They are less capable of achieving the low temperatures

possible with traditional air conditioning systems, especially when humidity levels are high.

Increased Indoor Humidity:

- **Potential for Excess Humidity:** By adding moisture to the air, evaporative coolers can raise indoor humidity levels. While this can be beneficial in dry climates, it can lead to discomfort in areas where the humidity is already high or when used in enclosed spaces without proper ventilation.
- **Risk of Mold and Mildew:** Higher humidity levels can promote the growth of mold and mildew, potentially leading to health issues and damage to structures or goods stored in the cooled area.

Water Usage:

- **Significant Water Consumption:** Evaporative coolers require a continuous supply of water to operate, which can be a limitation in regions where water resources are scarce. Although modern systems often recycle water to reduce wastage, they still consume water at a higher rate compared to traditional air conditioners.
- **Maintenance of Water Quality:** To prevent scaling, mineral buildup, and microbial growth, the water used in the system must be clean. This might necessitate water treatment or frequent replacement, adding to maintenance tasks and costs.

Air Quality Concerns:

- **Introduction of Outdoor Contaminants:** Since evaporative coolers draw air from the outside, they can bring in dust, pollen, and other pollutants unless they are equipped with proper filtration systems. This can be problematic for people with allergies or respiratory issues.
- **Potential for Odors:** If not properly maintained, the water and pads in the system can become sources of odors, which can be unpleasant in the cooled environment.

Maintenance Requirements:

- **Regular Cleaning and Replacement:** The cooling pads need regular inspection, cleaning, and periodic replacement to prevent the buildup of minerals, algae, and bacteria. Water pumps and distribution systems also require maintenance to ensure efficient operation.
- **Scaling and Mineral Buildup:** In areas with hard water, minerals can accumulate on the pads and other components, reducing efficiency and potentially causing blockages. This necessitates more frequent maintenance or the use of water softeners.

Lower Temperature Control Precision:

- **Less Precise Temperature Regulation:** Evaporative cooling systems typically do not offer the same level of precise temperature control as traditional air conditioning. They cool the air by a fixed amount relative to the outside temperature, which can be less effective in achieving and maintaining specific indoor temperatures.
- **Variable Performance:** The cooling effectiveness can vary widely depending on external conditions such as temperature and humidity, making it harder to achieve consistent indoor comfort.

Limited Applicability:

- **Not Suitable for All Climates:** Their performance is optimal in hot, dry climates. In regions with high humidity or where precise and significant cooling is required, traditional air conditioning systems may be more suitable.
- **Inappropriate for Enclosed Spaces:** Evaporative coolers are often less effective in tightly enclosed spaces without adequate ventilation because they can raise humidity levels excessively and recycle the same air.

Seasonal Use and Limitations:

- **Less Effective in Winter:** These systems are primarily designed for cooling and are not effective for heating or use during cold weather. In climates with significant seasonal temperature variations, a separate heating system would be necessary.
- **Dependency on External Conditions:** Their performance is directly tied to outdoor temperature and humidity, which can limit their effectiveness during varying weather conditions.

Health and Comfort Issues:

- **Potential for Legionella:** If the system is not properly maintained, stagnant water can become a breeding ground for bacteria such as Legionella, which causes Legionnaires' disease. Regular maintenance and water treatment are essential to mitigate this risk.
- **Air Quality and Comfort:** The increase in humidity might not be comfortable for all users, and can exacerbate conditions like asthma or allergies for sensitive individuals.

4.7 Applications

Smart Evaporative cooling systems are efficient and environmentally friendly solutions that utilize the natural process of evaporation to cool air. Unlike traditional air conditioning systems, which use refrigerants and consume significant amounts of electricity, evaporative coolers are simpler and can be more cost-effective in suitable environments. Here are various applications of evaporative cooling systems across different sectors:

1. Residential Cooling

- **Homes and Apartments:** Evaporative coolers are popular in homes, especially in regions with hot and dry climates. They provide a cost-effective way to maintain comfortable indoor temperatures.
- **Outdoor Spaces:** They can also be used to cool patios, decks, and other outdoor areas, making them more comfortable during the summer.

2. Commercial and Industrial Cooling

- **Warehouses and Factories:** These environments often generate a lot of heat from machinery and processes. Evaporative coolers can help maintain a safe and comfortable working environment.
- **Greenhouses:** By maintaining lower temperatures and higher humidity, evaporative cooling systems help in providing a suitable environment for plants.
- **Data Centers:** Evaporative cooling can be used to maintain optimal temperatures in data centers, reducing the risk of overheating and minimizing energy consumption.

3. Agricultural Applications

- Livestock Shelters: Cooling systems help keep livestock comfortable, reducing heat stress and improving productivity.
- Crop Storage: Proper cooling in storage facilities can prolong the shelf life of agricultural produce by maintaining appropriate temperatures and humidity levels.

4. Automotive and Transportation

- Vehicle Cabins: Some vehicles, especially in hot climates, use evaporative cooling to maintain comfortable cabin temperatures.
- Transport Refrigeration: It can be used in refrigerated trucks to keep perishable goods cool during transport.

5. Recreational and Public Facilities

- Sports Arenas and Gyms: Evaporative coolers help in maintaining comfortable conditions in large, open areas like sports facilities and gyms.
- Amusement Parks and Zoos: These systems are often used to cool large, open areas, providing a more pleasant experience for visitors.

6. Specialized Applications

- Mines and Underground Facilities: Cooling is crucial in underground environments to ensure the safety and comfort of workers.
- Military Applications: Portable evaporative coolers are used in temporary military setups to maintain bearable conditions in extreme climates.

7. Hybrid Cooling Systems

- Integrated with HVAC Systems: Evaporative cooling can be combined with traditional HVAC systems to reduce energy consumption, especially in pre-cooling intake air.
- Hybrid Cooling Towers: These systems combine evaporative cooling with mechanical refrigeration to improve efficiency in large-scale cooling applications.

8. Climate Control in Remote and Off-Grid Areas

- Remote Buildings: In areas without reliable electricity, evaporative coolers offer an effective solution for temperature control.
- Disaster Relief Camps: They are used in temporary shelters and relief camps where quick and cost-effective cooling is needed.

4.8 Conclusion

Evaporative cooling systems offer a versatile, efficient, and sustainable option for various cooling needs. Their applicability ranges from residential and commercial use to specialized applications in agriculture, industry, and transportation. While they have limitations, especially in humid climates, their advantages in terms of cost and environmental impact make them a valuable solution in appropriate settings.

Chapter 5

Conclusion

5.1 Conclusion

This In conclusion, Research and development in evaporative cooling have been going on for decades but still investigations are continuing for improvements. The technology is environmentally friendly and has the potential of minimising the dependency on hydro chlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) based conventional air conditioning systems. Interest in new methods and materials to find solutions to the problems associated with evaporative cooling is receiving the attention of researchers in order to make the technology more attractive. In the light of the above this research was embarked upon and investigated novel evaporative cooling systems based on direct and indirect evaporative cooling methods. The research initially carried out a review on evaporative cooling processes comprising of direct, indirect, combined direct and indirect and also desiccant based types. The review covered status and developments in evaporative cooling using porous ceramics. Theoretical studies covering the heat and mass transfer as well as psychrometric associated with evaporative cooling were presented because of their relevance in the modelling and performance evaluation of the novel evaporative cooling systems investigated. The research then focussed on the following novel evaporative cooling systems.

5.2 Future Work

The current/past R&D works and commercial activities have created significant technical advance and market development in IEC technology. These, however, also help identification of the problems, difficulties and barriers that are still in existence, which in turn stimulate the development of the forthcoming research and industrial activities.

In line with the above review based study, future research and development activities related to the IEC may be (1) heat exchanger structure and material.

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APPENDIX

Programing Code:

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <DHT.h>

LiquidCrystal_I2C lcd(0x27, 16, 2);

#define DHTPIN D3 // Digital pin connected to the DHT sensor
#define DHTTYPE DHT11 // DHT 11

#define ONE_WIRE_BUS D5
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);

DHT dht(DHTPIN, DHTTYPE);

void setup() {
  lcd.begin(16,2);
  lcd.init(); // initializing the LCD
  lcd.backlight(); // Enable or Turn On the backlight
  lcd.clear();

  Serial.begin(115200);
  dht.begin();

  sensors.begin();
```

```

lcd.setCursor(3, 0);
lcd.print("Evaporator");
lcd.setCursor(0, 1);
lcd.print("Cooling System");
delay(1000); // Wait for 2 seconds

}

void loop() {
  delay(500); // Wait for 2 seconds between measurements

  float humidity = dht.readHumidity();
  float temperature = dht.readTemperature();

  if (isnan(humidity) || isnan(temperature)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }

  sensors.requestTemperatures();

  float temperatureC = sensors.getTempCByIndex(0)+1.61;

  if(temperatureC == DEVICE_DISCONNECTED_C) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Sensor error");
    return;
  }
}

```

```
lcd.clear();  
lcd.setCursor(0, 0);  
lcd.print("C. Temp:");  
lcd.setCursor(10, 0);  
lcd.print(temperatureC);  
lcd.print(" C");  
  
lcd.setCursor(0, 1);  
lcd.print("N. Temp:");  
lcd.setCursor(10, 1);  
lcd.print(temperature);  
lcd.print(" C");  
  
delay(500);  
  
}
```