SUSTAINABLE EVAPORATIVE COOLING DEVICE INTEGRATED WITH RESIDENTIAL AIR CONDITIONING SYSTEMS

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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CHAPTER 1: INTRODUCTION

Background

The demand for air-conditioning is increasing annually, owing to the worldwide increase in the overall mean temperature. Pakistan is no different, and according to the Ministry of Climate Change of Pakistan, the average temperature over Pakistan will increase corresponding to an average increase in global surface temperature by 2.8-3.4°C by 2100. The Ministry also quotes that the decades of the 2020s and 2050s alone will experience an increase in temperature by 1.31°C and 2.54°C respectively.

Cities of Punjab and Balochistan easily touch 40-45°C during the summer months. This high $T_{ambient}$ causes an increase in the ΔP developed by the compressor, reduced coefficient of performance (COP), more electricity consumed, and deteriorating compressor life. According to [Lam,2000], when $T_{ambient}$ goes above 35°C, the COP of most AC units goes from 2.7-3.2 to 2.2-2.4. Yau and Pean in 2014 concluded that for every 1°C increase in $T_{ambient,}$ the COP and cooling capacity decrease by 2%.

This increase in temperature translates to an increased demand for air conditioning, which is backed by the fact that Pakistan has the fifth-greatest potential demand for air conditioning [Lucas David, 2019]. Simply put in numbers, in 2018, Pakistan accounted for 0.7% of the total global demand for air conditioning which translated to an estimated demand of 824,000 units [JRAIA, June 2019].

All this data proves one thing; the demand for air-conditioning is not waning anytime soon. The problem is air-conditioners consume a lot of energy; a 1 Ton DC-Inverter consumes 900W/h [KE website Pakistan]. Air-conditioners in Pakistan typically run from May up till the monsoon season in August. According to the Pakistan Social and Living Measurements survey conducted during 2018-2019, 2.4 million households in Pakistan own an air-conditioner.

If we take a very conservative assumption that all the 2.4 million households are equipped with a 1-ton inverter AC that is operational for only 4 hours each day; then according to the K-Electric energy calculator, that figure comes up be 17.28mWH or 17,000 units of electricity consumed per day. This is not sustainable for Pakistan where energy is already scarce.

Research has shown that the COP and compressor energy consumption can be improved by pre-cooling the ambient air before it enters the condenser coils. Yangetal (2012a) used water mist to achieve this and thus increased COP by 18.6%. This result is explained by the fact that ΔP is directly proportional to $T_{condensor}$ and $T_{condensor}$ is directly proportional to $T_{ambient}$. The lower you can keep $T_{ambient}$, the higher the COP and the lesser the energy consumed.

Our goal is to manipulate $T_{ambient}$ and lower its value so that we reduce ΔP and hence improve COP and energy consumption values. Pakistan currently does not have a cost-efficient, self-sustainable cooling device that can be readily installed on orthodox AC units. This, coupled with our second crucial motive of reducing the grid load as Pakistan already faces a shortage of 6500 MW as of June 2025, were crucial for designing the evaporative cooling device. This device will also bring about other benefits to consumers as well like lower electricity bills.

We plan to do this by installing a sustainable evaporative cooling device that will increase AC COP and reduce energy consumption, will be able to seamlessly integrate with the AC units in Pakistan to avoid installation complications, will be cost-effective so that the majority of people can install it on their AC's, will comply with industry standards, codes and regulations concerning HVAC systems and will be thoroughly tested before being deployed.

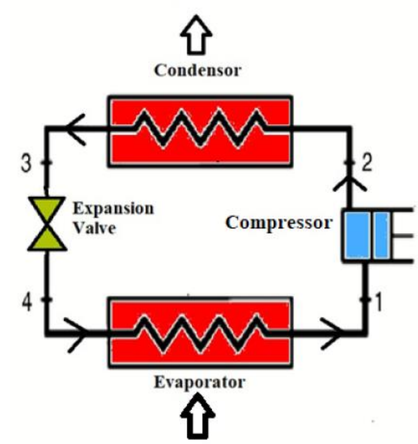
The evaporative cooling will be achieved by spraying misty water through nozzles onto the ambient air, hence reducing its $T_{ambient.}$. The study and its results back our device; dropping the $T_{ambient}$ by 4°C prior to its entry in the condenser coils can decrease power consumption by 6.1% and increase cooling capacity by 30% [Experimental study on an air-cooled air conditioning unit with spray evaporative cooling system, Hua Yang, Na Pei, 2021].

CHAPTER 2: LITERATURE REVIEW

Vapor-Compression Cycle

The vapor compression cycle is the fundamental thermodynamic cycle that underlies the operation of the air conditioning systems. The process is described as:

- **Vaporization:** The cycle begins with the refrigerant entering the evaporator coil as a low-pressure liquid. As it absorbs heat from the indoor air, it evaporates into a low-pressure vapor. This stage cools the indoor air.



- **Compression:** The low-pressure vapor is then drawn into the compressor, where it's compressed to a high-pressure, high-temperature vapor. The compression process increases the energy and temperature of the refrigerant.

- **Condensation:** The high-pressure, high-temperature vapor then flows into the condenser coil located outside the space being cooled. Here, the refrigerant condenses back into a high-pressure liquid as it releases heat to the surrounding air. This stage is where the heat absorbed from the indoor air is expelled to the outside environment.

- **Expansion:** The high-pressure liquid refrigerant then passes through an expansion valve or capillary tube, where its pressure is rapidly reduced. This causes a sudden drop in temperature and pressure, resulting in the refrigerant partially evaporating and cooling significantly. This cooled, low-pressure liquid-vapor mixture then enters the evaporator coil to begin the cycle again.

Evaporative Cooling:

Evaporative cooling refers to a process by which the temperature of air is lowered through the evaporation of water. This natural phenomenon occurs when water molecules

transition from a liquid state to a vapor state, absorbing heat energy from the surrounding air in the process. The result is a decrease in the air temperature.
Evaporative cooling is most effective in hot, dry climates where humidity levels are low because the air has a greater capacity to absorb moisture. However, its effectiveness diminishes in areas with high humidity, as the air is already saturated with moisture and cannot absorb much more.

Existing Cooling Systems:

1. **Wet Curtain Technology/Cellulose Cooling Pad**

Ndukaife used a cellulose cooling pad of varying thickness (2-6 inches) to determine the influence of pad thickness in cooling the ambient air. The pads trapped water and cooled the ambient air as it passed through it using the principles of evaporative cooling.

The typical high ambient air temperatures of the summer months were mimicked using a heater. The system was run for 4 hours, in 1 hour increments. The main factors affecting the evaporative cooling process were the media pad thickness, velocity of the incoming air, temperature of the ambient air, and the relative humidity.

The results showed that a 1C drop in ambient air temperature caused the refrigerant condensing temperature to drop by 0.6C. The reduction in refrigerant condensing temperature is important because it reduces the power consumption of the compressor which inevitably increases COP. It was found that the COP increased by up to 44% (COP increased by 4% for every 1C drop in refrigerant condensing temperature) and the energy consumed was reduced by 20%.

The energy reduction translated into electricity savings of $0.04 per hour of operation. The only cost incurred was that of the water, 0.34 liters of water was consumed for every percent increase in COP.

The main drawback of this evaporative cooling technique is the vast amount of water it uses; Pakistan doesn’t have the water resources in the regions of Sindh and various areas in Punjab to provide for the continuous water flow.

The cellulose pad will also not work well in semi-humid regions like Islamabad, and Rawalpindi where we intend to test it initially.

2. Using condensate water

Sawan opted to use condensate water obtained from the drain and synchronized its ejection for evaporative cooling with the ON/OFF state of the compressor. This experiment was carried out in a controlled environment initially in the first stage and then in real-world conditions in the final stage to investigate the energy demands of office space in Beirut for June, August, and October. These months were chosen as such because each has different RH and ambient temperature values.

The results show that 5%, 4.5%, and 5.3% of energy savings were recorded in June, August, and October respectively. The glaring issue of this experiment is that the condensate water collected from the drain is not enough to meet the evaporative cooling demand in the hot months of June and August; as indicated in the experiment itself, the condensate water was only able to fulfill the demand in October, a month where AC units are typically not used in the majority of Pakistan.

Hence, we will be maintaining an adequate supply of pH-neutral water in a tank to fulfill the evaporative cooling demands.

3. Mist-spray Evaporative Cooling

The method of evaporative cooling using mist spray, observed in select European countries, cannot be directly replicated in Pakistan due to discrepancies in the design and sizing of outdoor units for air conditioners. These variations pose challenges in implementing the same model design of the cooling device within the Pakistani context.

Temperature/Climate zones

The Pakistan Meteorological Department conducted research to categorize the country into four regions based on its humidity levels. They utilized an annual dataset of the Precipitation-Effectiveness Index to delineate areas and cities according to varying humidity ranges.

1. Rain Forest (wet) where PE index value is greater than or equal to 50

2. Forest (humid) where PE index value ranging between 34-49

3. Partly Forest (less humid) PE index values ranging between 20-33

4. Arid (dry) less than 20

This device will perform optimally in areas characterized by lower humidity levels and dry conditions. Below are some cities in Pakistan that exhibit such humidity levels.

Location	**Annual PE Index**
Quetta	20.5
Faisalabad	15.5
Sargodha	19.6
Gupis	12.3
D-I-Khan	12.1
Badin	8.9
Bhawalnagar	8.8
Karachi	8.4
Multan	7.9
Gilgit	7.0
Hyderabad	6.5
Bhawalpur	6.3
Sibbi	6.2
Nawabshah	5.0
Pasni	4.6

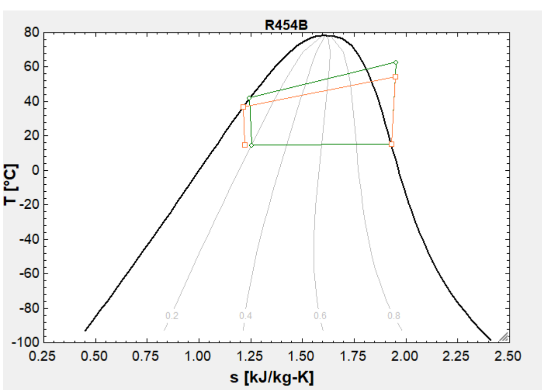
Table-1: Annual PE index of Pakistan over 50 years period (1959-2008)

CHAPTER 3: METHODOLOGY

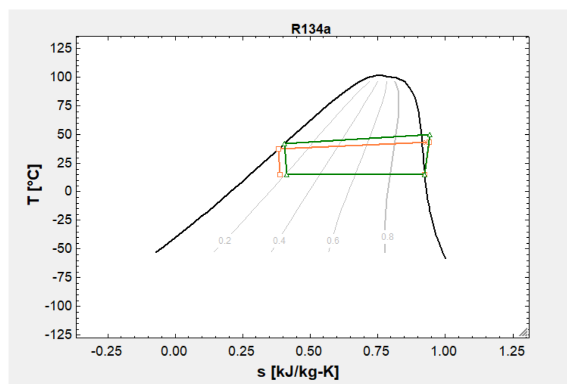
Effect of Evaporative Cooling on Air Conditioner Performance:

In the literature review, we identified the regions that have hot, dry and less humid conditions where the device is expected to exhibit better performance. Considering Multan as the designated region for device installation, it's essential to note that the temperature ranges from 39°C to 45°C during the summer months, spanning from April to July. Determining the ambient temperature necessary for maintaining optimal condenser temperature is crucial. This targeted temperature will effectively reduce the compressor load to a reasonable extent, thereby enhancing the Coefficient of Performance (COP) of the Air Conditioner.

Using the EES software, we find out the Compressor Load of an Air Conditioner for the high temperature range we have in summers. Using the evaporative cooling we are reducing the temperature which will effectively reduce the compressor load as shown in the following T-s diagram.



(Refrigerant-454B) T-s diagram



(Refrigerant-134A) T-s diagram

DEFINING THE KNOWN PARAMETERS

$P_1 = 101.325$ [kPa]

$T_1 = 40$ [C] Input Temperature

$rh_1 = 0.3$ Relative Humidity

$VOLUME_{FLOW,RATE} = 1.5$

$MASS_{FLOW,RATE,H2O} = 0.004616$

$SPECIFIC_{ENTHALPY,WATER} = 2.26 \times 10^6$

$SPECIFIC_{HEAT,CAPACITY,AIR} = 1005$

$U = 200$ Heat transfer coefficient

$AREA_{COILS} = 1.4$ Area of coils in meter square

$Pin = 1000$ [W] power input

PSYCHOMETRIC CALCULATIONS

$\rho = \rho\,(AirH2O, T = T_1, R = rh_1, P = P_1)$ air density

$mass_{flow,rate,air} = \rho \cdot VOLUME_{FLOW,RATE}$ mass flow rate of air

$heat_{transfer,rate} = MASS_{FLOW,RATE,H2O} \cdot SPECIFIC_{ENTHALPY,WATER}$ Calculate heat transfer rate

$temperature_{drop} = \dfrac{heat_{transfer,rate}}{mass_{flow,rate,air} \cdot SPECIFIC_{HEAT,CAPACITY,AIR}}$ Calculate temperature drop

CONDENSER CONIDITONS

$Tcond_{in} = 60$ [C] Hot fluid inlet temperature

$Tcond_{out} = 51$ [C] Hot fluid outlet temperature

$Tair_{in1} = T_1$ Cold fluid inlet temperature before evap cooling

$Tair_{out} = T_1 + 9$ [C] Cold fluid outlet temperature

$Tair_{in2} = T_1 - temperature_{drop}$ Cold fluid inlet temperature after evap cooling

Calculate Delta Tlm1

$\delta_{t1} = |Tcond_{in} - Tair_{in1}|$

$\delta_{t2} = |Tcond_{out} - Tair_{out}|$

$$\delta_{Tlm1} = \frac{\delta_{t1} - \delta_{t2}}{\ln\left[\dfrac{\delta_{t1}}{\delta_{t2}}\right]}$$

Calculate Delta Tlm2

$\delta_{Temp1} = |Tcond_{in} - Tair_{in2}|$

$\delta_{Temp2} = |Tcond_{out} - Tair_{out}|$

$$\delta_{Tlm2} = \frac{\delta_{Temp1} - \delta_{Temp2}}{\ln\left[\dfrac{\delta_{Temp1}}{\delta_{Temp2}}\right]}$$

FINAL CALCULATIONS

$Qcond_1 = U \cdot AREA_{COILS} \cdot \delta_{Tlm1}$ Calculate Q cond without cooling

$Qcond_2 = U \cdot AREA_{COILS} \cdot \delta_{Tlm2}$ Calculate Q cond with cooling

Calculate COP 1 (Without evap cooling)

$$COP_1 = \frac{Qcond_1}{Pin}$$

Calculate COP 2 (With evap cooling)

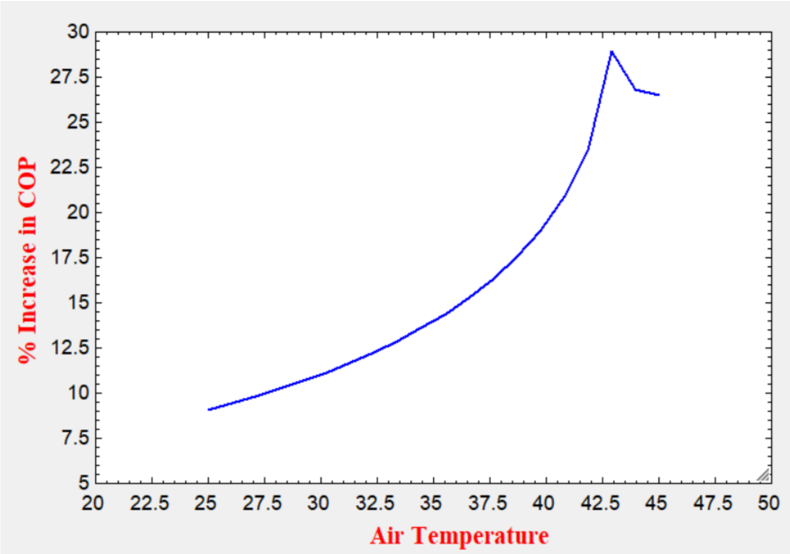
$$COP_2 = \frac{Qcond_2}{Pin}$$

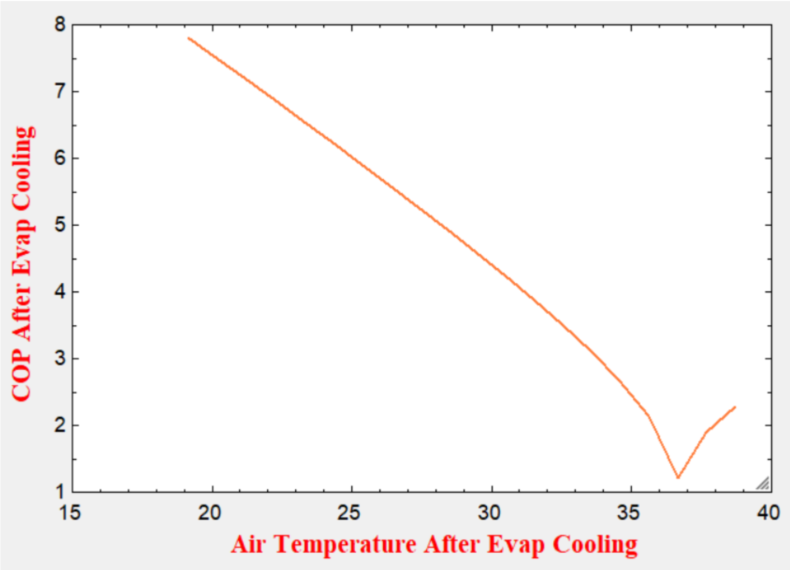
Percentage increase in COP

$$Percentage_{COP} = \left[\frac{COP_2 - COP_1}{COP_1}\right] \cdot 100$$

Observations reveal a notable increase in the Coefficient of Performance (COP) with a decrease in the condenser temperature. Notably, COP values exceeding 4 are observed for temperatures below 30°C for both refrigerants, a level that may be challenging to achieve in practical settings. The prevalence of R-410A in air conditioning systems leads us to anticipate achievable outcomes from this refrigerant. However, encountered errors in Engineering Equation Solver (EES) while solving for R-410A pose challenges to this expectation.

Achieving effective cooling and reducing the temperature to 37°C has proven instrumental in alleviating the COP by 15-16%. Consequently, this reduction in load directly translates to decreased electricity consumption, aligning with our primary objective.





Cooling Device Model Design

We now have to reduce the condenser temperature to 35-37^{o}C using the evaporative cooling device for a 1-ton Air Conditioner. The outdoor unit has the sizing of 810x280x585 (mm).

Different components of this device are described below:

Mounting Plate: This component is affixed to the top of the condenser coil side of the Air Conditioner outdoor unit using the zip ties ensuring stability and precise alignment for effective operation. Its primary function is to provide support for the piping, with nozzles attached at this position, while also serving as a shed for protection. Specifications of the plate are as follows:

- Material: Acrylic sheet
- Dimensions: 3 x 1 ft
- Thickness: 3 mm

3 nozzles are fixed to the plate in such positions to cover the entire condenser coil area using zip ties, ensuring stable positioning and optimal misting coverage.

Piping: The piping system is configured to elevate the cooled water from the storage tank to the height where the nozzles are attached to the mounting plate. This configuration involves selecting pipe sizes and designing the layout to accommodate the necessary lift height while ensuring an efficient flow of the water. This ensures that the water reaches the desired height with sufficient pressure to effectively distribute it through the nozzles for optimal misting performance. Description for different sizing of pipes used are as follows:

- Pipe Material: Polyurethane Plastic
- Water storage tank connection:
  - Hose diameter: 10 mm
  - Length: 3 feet
  - This hose carries a larger volume of water at lower pressure and connects the pump directly to the water storage tank.
- Nozzles connection:

- Hose diameter: 6 mm
- Length: 3 feet
- This hose likely carries a smaller volume of water at higher pressure and connects the pump to the nozzles, which are used for misting spray.

Nozzle: A misting spray nozzle is used to atomize water into fine droplets, creating a mist or fog-like spray pattern. These nozzles have a compact design with a small orifice through which pressurized water passes. In this configuration, a total of 3 misting spray nozzles are positioned to provide complete coverage of the entire condenser coil area. The entire condenser coil area is effectively covered, ensuring optimal heat dissipation and overall device performance.

(Calculating Flow Rate and Sizing of Nozzle)

$T2=37℃$ (temperature to be achieved after cooling)
$T1=42℃$ (ambient inlet temperature)
$\omega1= 0.0155kg/kg$
$RH1=30\%$

Firstly calculating Psat at $T2 = 37℃$
$Psat= 6.274KPa$
$RH=e/esat\times100\%$
$RH2= 100\%$
As, $e=esat$

Then using psychometry, for $T2=37℃$ and $RH2=100\%$

$\omega2=0.0411$

As per the design of cooling system, $T1-T2=5℃$

$\omega2-\omega1=\dot{m}H20\dot{m}air$
$0.0256 \times \dot{m}air=\dot{m}H20$
$\dot{m}air=$ Volumetric flow rate Specific volume at T1
Volumetric flow rate for typical AC=0.165m3/s
Specific volume at 42℃=0.915
$\dot{m}air=0.18kg/s$

Now using $\omega2-\omega1=\dot{m}H20\dot{m}air$

$\dot{m}H20 = 4.616\times10-3kg/s$

$\dot{m}H20 = 1.538\times10\text{-}3kg/s$ for each nozzle

$P1+12\rho v12+\rho gh1=P2+12\rho v22+\rho gh2$
$v2=\sqrt{}2\rho(P1-\rho gh1+12\rho v12-\rho gh2)$
$v1=v\ pump=Q/A=1.62ms\text{-}1$
$P1=\rho gh = 9800Pa$

(Putting the value v2 becomes)

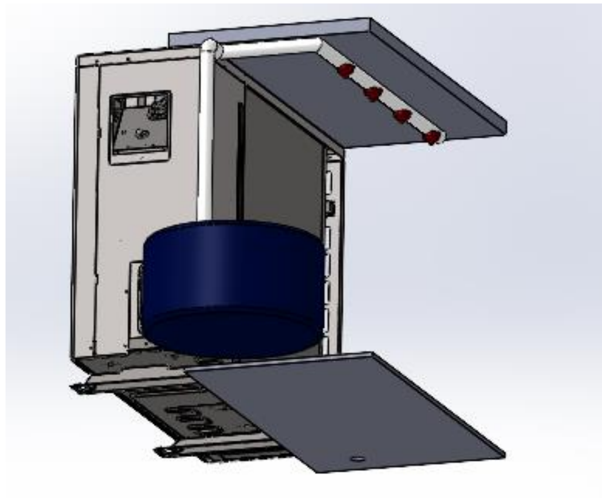
$v2=6.46ms\text{-}1$
As $\dot{m}H20 = A\times v\times\rho$
$=\boldsymbol{\pi}4 * D2 * 6.46*1000$
$D2=3.031*10\text{-}7m$
D= 0.55mm **(Nozzle Diameter)**

DC Water Pump: The DC Water pump delivers the necessary pressure for misting nozzles. The pump is compact and lightweight, easily portable, and can be deployed wherever required. The pump serves the purpose of elevating water from the tank to the outdoor unit's designated height. Specifications of the pump are:

- **Voltage:** 12V DC (9-14.4V)
- **Power:** 72 Watts
- **Current:** 6 Ampere
- **Flow Rate:** 6.0 LPM
- **Pressure Range:** 150 psi

Storage Tank: For optimal functionality of the evaporative cooling system, we used employ an insulated water tank with a capacity of 15 liters. It is imperative to maintain the stored water at a cooled temperature to enhance its effectiveness in the evaporative cooling process.

Connectors: Connectors serve the essential purpose of linking pipes of varying sizes together and attaching nozzles to the pipe network within the misting system. They ensure a secure and leak-free connection, enabling efficient distribution of water. Different connectors used in this device are 10 to 6 mm converter, 6 mm T-connector and 6 mm elbow connector.



Evaporative Cooling Device Design attached to outdoor unit

Automated control system: This Arduino-based circuit integrates DHT sensor readings, psychrometric calculations, pump control based on temperature and humidity thresholds, and LCD display for showing the percentage increase in COP. It also calculates COP with and without evaporative cooling and displays relevant parameters on the serial monitor.

Components:

- Arduino: Serves as the central control unit, receiving data from the DHT11 sensor, performing calculations, and controlling the relay.
- DHT11 Sensor: Measures temperature and humidity, providing data to the Arduino.
- Relay: Acts as a switch, controlling the pump based on the Arduino's signal. (Active Low - ON when signal is LOW)
- LCD: Provides a display for calculated values such as temperature, COP, etc.

Connections:

Relay (Active-LOW):

- Terminal 1: Ground
- Terminal 2: Connected to 5V power
- Terminal 3: Connected to Arduino's Pin 3 for control

DHT11 Sensor: Connected to Arduino's Pin 2 for data transmission.

- Pump: Connected to the relay's output. When the relay is activated (Operated by Arudino's Pin 13), it allows power to flow to the pump, turning it on.
- Solar Power: Connected to the relay along with the pump. When the relay is activated, solar power is used to operate the pump.

Operation:

1. The DHT11 sensor continuously monitors temperature and humidity levels.

2. The Arduino processes the data received from the sensor and performs psychrometric calculations.

3. Using the calculated values, the Arduino determines the air density and computes the temperature drop (Delta T).

4. A Temperature (e.g.30-40°C) and Relative humidity (e,g 30-80%) range for pump operation is predefined.

5. The Arduino compares the measured temperature with the predefined range.

If the temperature falls outside the range (e.g., 35°C within 30-40°C), the Arduino activates the relay by sending a LOW signal.

This connects the solar power to the pump, activating it to provide cooling.

If the temperature falls within the range, the Arduino sends a HIGH signal to the relay, deactivating the pump.

Additional Information displayed on Arduino Serial Monitor

- Current temperature
- Relative humidity
- Air density
- Mass flow rate of air
- Mass flow rate of water
- Heat Transfer Rate

- Temperature drop
- Delta T(LM)
- Qcond (Condenser Heat Transfer before and after cooling)
- COP (Coefficient of Performance before and after cooling)
- Percentage increase in COP

This circuit exemplifies the capabilities of Arduino in monitoring environmental parameters, making calculations, and controlling devices to ensure efficient and sustainable operation.

Additional Information displayed on LCD Display: Percentage increase in COP

- **Air Density Calculation:**

$$\rho = \mathrm{Density}(AirH2O, T = T[1], r = rh[1], P = P[1])$$

- **Mass Flow Rate of Air:**

$$\mathrm{mass\_flow\_rate\_air} = \rho \times \mathrm{VOLUME\_FLOW\_RATE}$$

- **Heat Transfer Rate:**

$$\text{Heat transfer rate} = \text{Mass flow rate of water} \times \text{water specific enthalpy}$$

- **Temperature Drop:**

$$temperature\_drop = (heat\_transfer\_rate)/(air\ mass\ flow\ rate \times Specific\ heat\ capacity\ of\ air)$$

- **Delta Tlm Calculation (Without Evaporative Cooling):**

$$\Delta T_{\mathrm{lm1}} = (\Delta T_1 - \Delta T_2)/(\ln(\Delta T_2 \div \Delta T_1))$$

$$\Delta T_1 = | T_{\mathrm{cond\_in}} - T_{\mathrm{air\_in1}} |$$

$$\Delta T_2 = | T_{\mathrm{cond\_out}} - T_{\mathrm{air\_out}} |$$

- **Delta Tlm Calculation (With Evaporative Cooling):**

$$\Delta T_{\text{lm1}} = (\Delta Temp_1 - \Delta Temp_2)/(\ln(\Delta Temp_2 \div \Delta Temp_1))$$

$$\Delta Temp_1 = | T_{\text{cond\_in}} - T_{\text{air\_in1}} |$$

$$\Delta Temp_2 = | T_{\text{cond\_out}} - T_{\text{air\_out}} |$$

Condenser Heat Transfer (Without Evaporative Cooling):

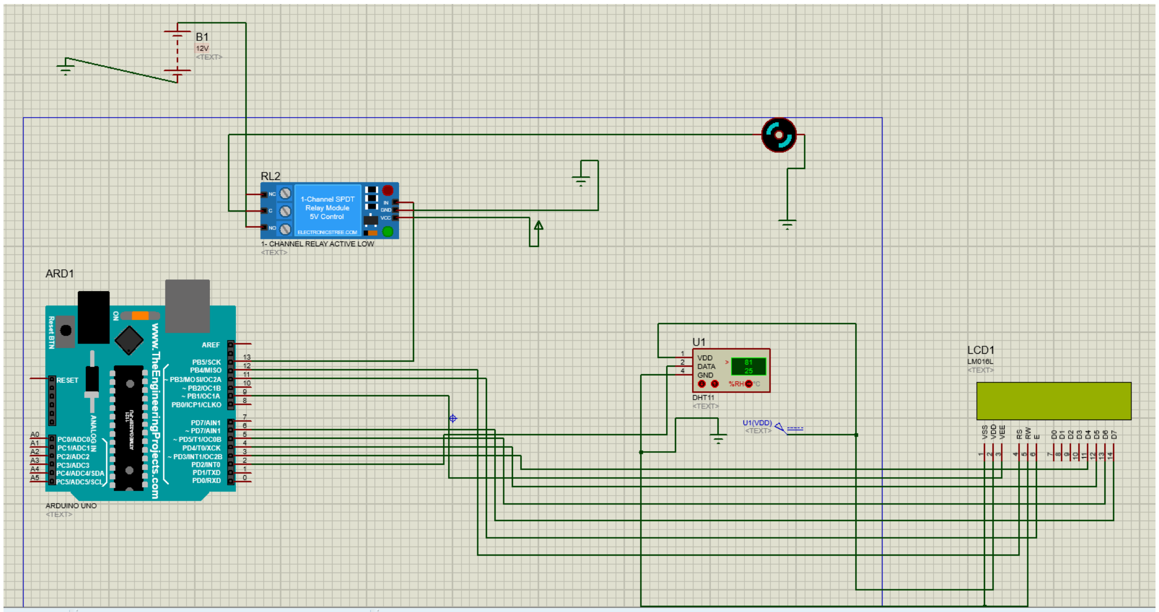
$$\text{COP1} = Q_{\text{cond1}}/\text{Pin}$$

Condenser Heat Transfer (With Evaporative Cooling):

$$\text{COP2} = Q_{\text{cond2}}/\text{Pin}$$

COP Calculation (Without Evaporative Cooling):

$$\text{Percentage\_COP} = ((\text{COP2} - \text{COP1})/\text{COP1}) \times 100$$




```
#include <DHT.h>
#include <LiquidCrystal.h> // Include the LCD library

// Define pump control pin
#define PUMP_PIN 13        // Digital pin connected to the pump

// Define DHT sensor pin and type
#define DHT_PIN 2          // Digital pin connected to the DHT sensor
#define DHT_TYPE DHT11     // Type of DHT sensor being used (DHT11, DHT22,
DHT21)
DHT dht(DHT_PIN, DHT_TYPE);

// Constants for psychrometric calculations
#define R 287.05          // Specific gas constant for dry air (J/kg·K)
#define Rv 461.495        // Specific gas constant for water vapor
(J/kg·K)
#define T0 273.15         // Reference temperature (K)

// Define temperature and humidity thresholds
#define TEMP_MIN 10.0     // Minimum temperature threshold (°C)
#define TEMP_MAX 30.0     // Maximum temperature threshold (°C)
#define HUMID_MIN 30.0    // Minimum humidity threshold (%)
#define HUMID_MAX 100.0    // Maximum humidity threshold (%)
```

```
// Volume flow rate
#define VOLUME_FLOW_RATE 1.5 // m³/s

// Mass flow rate of water
#define MASS_FLOW_RATE_H2O 4.616e-3 // kg/s

// Specific enthalpy of water
#define SPECIFIC_ENTHALPY_WATER 2260e3 // J/kg

// Specific heat capacity of air
#define SPECIFIC_HEAT_CAPACITY_AIR 1005 // J/kg·K

// Heat transfer coefficient in W/m²K
#define U 200    // W/m^2.K

// Area of coils in square meters
#define AREA_COILS 1.4  //m^2

// Powerinput
#define Pin 1000  //Watts

// LCD pins
const int rs = 12, en = 11, d4 = 6, d5 = 5, d6 = 4, d7 = 3, ct=9;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);


void setup() {
  Serial.begin(9600);  // Initialize serial communication
  pinMode(PUMP_PIN, OUTPUT); // Initialize pump pin as output

  // Initialize DHT sensor
  dht.begin();

  // Initialize LCD
  analogWrite(ct,100);
  lcd.begin(16, 2);

const int backlightPin = 8;
  pinMode(backlightPin, OUTPUT);
  digitalWrite(backlightPin, HIGH); // Turn on backlight
```

```
}

void loop() {
  lcd.clear();

  // Read temperature and humidity from DHT sensor
  float temperature = dht.readTemperature();  // Read temperature in
Celsius
  float humidity = dht.readHumidity();        // Read humidity as a
percentage

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

  // Perform psychrometric calculations
  // Calculate saturation vapor pressure (es) using temperature
  float es = 6.112 * exp((17.67 * temperature) / (temperature + 243.5));

  // Calculate actual vapor pressure (ea) using relative humidity
  float ea = (humidity / 100.0) * es;

  // Calculate partial pressure of dry air (Pa)
  float Pa = 101325 - ea; // Assuming total pressure is 101325 Pa
(atmospheric pressure)

  // Calculate air density (ρa)
  float density = Pa / (R * (temperature + T0));

  // Calculate mass flow rate of air (ṁ_air)
  float mass_flow_rate_air = density * VOLUME_FLOW_RATE;

  // Calculate heat transfer rate (ṁ_H2O * h_v)
  float heat_transfer_rate = MASS_FLOW_RATE_H2O * SPECIFIC_ENTHALPY_WATER;

  // Calculate temperature drop (ΔT = Q / (ṁ_air * c_p))
  float temperature_drop = heat_transfer_rate / (mass_flow_rate_air *
SPECIFIC_HEAT_CAPACITY_AIR);

  // Define input temperatures (in Celsius)
```

```
float Tcond_in = 60.0;    // Hot fluid inlet temperature
float Tcond_out = 50.0;   // Hot fluid outlet temperature
float Tair_in1 = 35.0;   // Cold fluid inlet temperature before evap
cooling
float Tair_out= Tair_in1 + 10; // Cold fluid outlet temperature

float Tair_in2 = temperature - temperature_drop  ;   // Cold fluid inlet
temperature after evap cooling

 // Calculate Delta Tlm1
 float Delta_t1= abs(Tcond_in-Tair_in1);
 float Delta_t2= abs(Tcond_out-Tair_out);
  float Delta_Tlm1 = (Delta_t1 - Delta_t2) / log((Delta_t1) / (Delta_t2));

 // Calculate Delta Tlm1
 float Delta_Temp1= abs(Tcond_in-Tair_in2);
 float Delta_Temp2= abs(Tcond_out-Tair_out);
  float Delta_Tlm2 = (Delta_Temp1 - Delta_Temp2) / log((Delta_Temp1) /
(Delta_Temp2));

// Calculate Q cond without cooling
float Qcond1= U*AREA_COILS* Delta_Tlm1;

// Calculate Q cond with cooling
float Qcond2= U*AREA_COILS* Delta_Tlm2;

  // Calculate COP 1 (Without avap cooling)
  float COP_1= Qcond1/Pin;

 // Calculate COP 2 (With avap cooling)
  float COP_2= Qcond2/Pin;

// Percentage increase in COP
float Percentage_COP= ((COP_2-COP_1)/COP_1)*100;


  // Print temperature, humidity, air density, mass flow rates of air and
water, heat transfer rate, and temperature drop readings to serial monitor
  Serial.print("Temperature: ");
  Serial.print(temperature);
  Serial.println(" °C");
  Serial.print("Humidity: ");
```

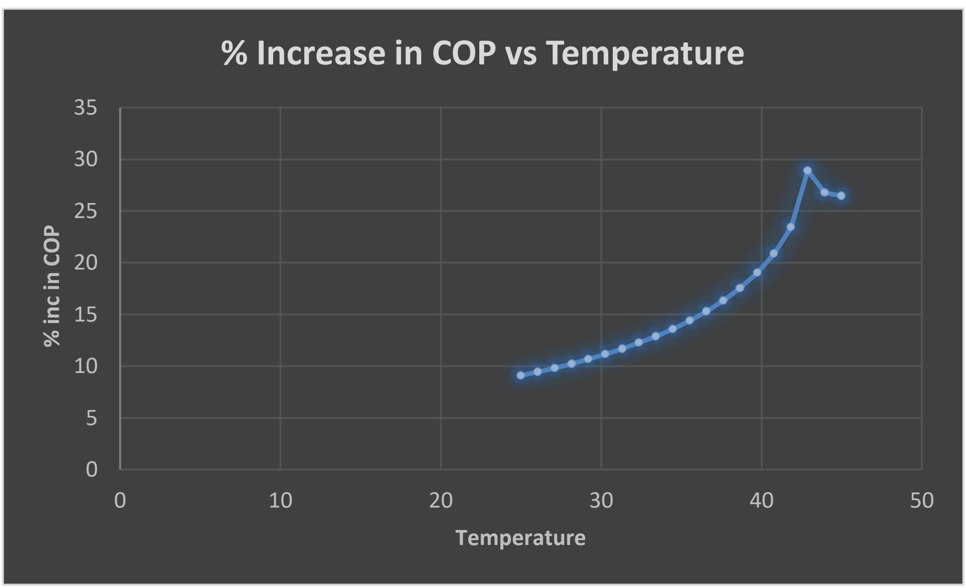
```
  Serial.print(humidity);
  Serial.println(" %");
  Serial.print("Air Density: ");
  Serial.print(density);
  Serial.println(" kg/m^3");
  Serial.print("Mass Flow Rate of Air: ");
  Serial.print(mass_flow_rate_air);
  Serial.println(" kg/s");
  Serial.print("Mass Flow Rate of Water: ");
  Serial.print(MASS_FLOW_RATE_H2O);
  Serial.println(" kg/s");
  Serial.print("Heat Transfer Rate: ");
  Serial.print(heat_transfer_rate);
  Serial.println(" W");
  Serial.print("Temperature Drop: ");
  Serial.print(temperature_drop);
  Serial.println(" °C");
    Serial.print("Delta Tlm1: ");
  Serial.print(Delta_Tlm1);
  Serial.println(" °C");
  Serial.print("Delta Tlm2: ");
  Serial.print(Delta_Tlm2);
  Serial.println(" °C");
  Serial.print("Qcond1: ");
  Serial.print(Qcond1);
  Serial.println(" W");
  Serial.print("Qcond2: ");
  Serial.print(Qcond2);
  Serial.println(" W");
  Serial.print("COP1: ");
  Serial.println(COP_1);
  Serial.print("COP2: ");
  Serial.println(COP_2);
  Serial.print("Percentage Increase: ");
Serial.print(Percentage_COP);
Serial.println("%");


   // Control the pump based on temperature and humidity thresholds
   if ((temperature < TEMP_MIN || temperature > TEMP_MAX) || (humidity <
HUMID_MIN || humidity > HUMID_MAX)) {
```

```
    // Conditions not met, turn off the pump
    digitalWrite(PUMP_PIN, HIGH);

    Serial.println("Pump turned Off");
  // Display "Pump Off" on the LCD
    lcd.print("Pump off");

  } else {
    // Conditions met, turn on the pump
    digitalWrite(PUMP_PIN, LOW);

    lcd.setCursor(0, 0);
    lcd.print("% Inc in COP:");
    lcd.setCursor(0, 1);
    lcd.print(Percentage_COP);
    delay(2000);
    lcd.clear();

  }


  Serial.println("----------------------------------");

  // Delay for a short interval
  delay(500);
      // Update readings every 0.5sec seconds (adjust as needed)
}
```

CHAPTER 4: CONCLUSION AND DISCUSSION

The addition of a water recycling system to the design is pending. Once implemented, this system will enable us to recycle and reuse the water that has been sprayed, thereby enhancing sustainability and resource efficiency. Additionally, the determination of the number of nozzles required may vary depending on the surface area covered by the mist from each nozzle spray. This consideration ensures optimal coverage and effectiveness of the evaporative cooling system.

Theoretical and numerical calculations have been instrumental in the design of this device, laying the groundwork for further refinement through experimental investigations in subsequent stages. We aim to validate the theoretical predictions, identify potential limitations, and iteratively enhance the design to ensure its effectiveness and efficiency in practical settings.



- Initial power input (before COP increase): $P_1 = 1000W$
- Increase in COP: 20% = 0.20
- Cost per unit of electricity: Rs.65 per kWh

First, let's find the final power input after the COP increase:

$$P_2 = 1.20 \times P_1$$

$$P_2 = 1.20 \times 1000\text{W}$$

$$P_2 = 1200\text{W}$$

Now, let's calculate the energy consumption:

$$E_1 = \text{P1}/1000\,\text{kWh}$$

$$E_1 = 1000/1000\,\text{kWh}$$

$$E_1 = 1\text{kWh}$$

$$E_2 = \text{P2}/1000\,\text{kWh}$$

$$E_2 = 1200/1000\,\text{kWh}$$

$$E_2 = 1.2\text{kWh}$$

The reduction in energy consumption is:

$$\Delta E = E_1 - E_2$$

$$\Delta E = 1\text{kWh} - 1.2\text{kWh}$$

$$\Delta E = -0.2 \text{kWh}$$

Since the energy consumption decreased, this means there's a saving.

Now, let's calculate the total saving on the electricity bill:

Total Saving=ΔE×Cost per unit of Electricity

If an AC runs 4 hours a day for a month

$$E_{month} = 4kWh/day \times 30days$$

$$E_{\text{month}} = 120\text{kWh}$$

The reduction in energy consumption as -0.2 kWh per hour.

$Energy\ saved\ per\ month = Energy\ saved\ per\ day \times days_{per_{month}}$
$Energy\ saved\ per\ month = -0.8\ \frac{kWh}{day} \times 30\ daysEnergy\ saved\ per\ month = -\frac{0.8kWh}{day} \times 30days$

$Energy\ saved\ per\ month = -24\ kWhEnergy\ saved\ per\ month = -24kWh$

Cost savings=Energy saved per month×Cost per unit of electricity

Cost savings=−24kWh×65 RS /kWh

Cost savings=−1560 RS

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