A Review on performance parameters and its evaluation of evaporative air cooler.

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Abstract - According to World Weather Information Service, Asia the maximum temperature recorded in India is 50°C on the plateau region. Thus, fresh air ventilation and efficient cooling has now become a necessity in both residential as well as industrial areas. Air conditioner provide insufficient cooling in drier regions, even they record higher power consumption upto 675kW/hr per month, under low relative humidity condition of about 40% at 35°C temperature. Hence in dry and hot regions like Vidarbha or central plateau region in India, mostly Air coolers are used for residential purposes. Even among coolers, Evaporative (Desert) Air cooler has proven to be efficient as compared to other cooler units. Desert coolers are highly efficient in dry, hot regions. Their power consumption is comparatively less than air conditioners about 54kW/hr per month under similar conditions, since pump and fan are the only two power driven components used.

The paper reviews the different factors to be considered while designing an evaporative air cooler to provide sufficient cooling and comfort through optimum use of pump and fan. The paper includes study and proper selection of the important parameters required in modification of cooler design in order to utilise minimum power consumption. Power saving can be achieved by controlling the actions of pump and fan, that is, by controlling switching operation of pump and varying the fan speeds as per the ambient conditions. The factors we consider for design of desert cooler are temperature,pressure, humidity, moisture, saturation effectiveness.

Key Words - Evaporative cooling, Desert cooler, Temperature, Relative Humidity, Cooling rate.

I. Introduction

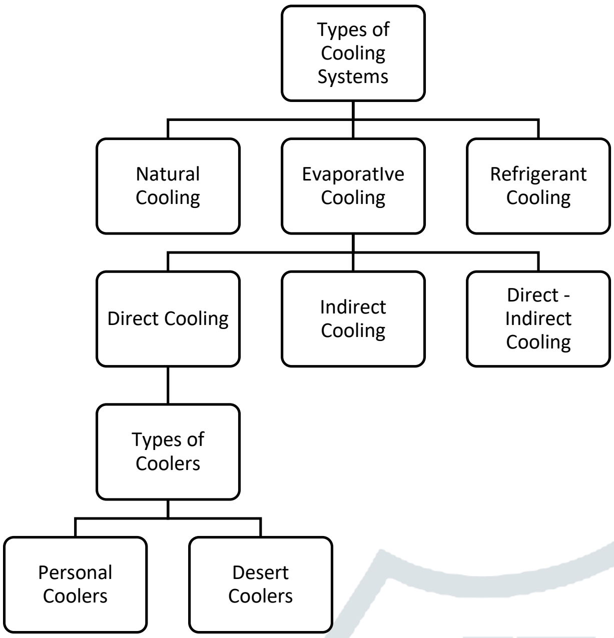
In the 21st century, energy demand worldwide for cooling in summers, has increased sharply in the last few decades because of urbanization modern industrialization. Over-usage of conventional as well as non-conventional energy sources of energy has already shown results in the form of depletion of energy resources and rise in the atmospheric temperature around the world i.e. global warming issue.

Nowadays, cooling systems have become the necessity for residential as well as commercial purposes. We have two medium cooling systems viz. air medium cooling and water medium cooling. Air medium cooling devices are used as they are user friendly. Types of air medium cooling devices are Air conditioners and Air coolers.

Air conditioner collects hot air from the surroundings and lowers the temperature and pressure by using compressor, condenser, expansion valve etc. due to more power- driven components, air conditioners consume around 675 units of electricity per month. On the other hand, air cooler is the device that cools surrounding air through evaporation of water.Thus, recently, use of air coolers, particularly, Evaporative air coolers are used widely in rural as well as urban regions, as they are financially cheaper and require no prerequisite installation setup.

Evaporative coolers are based on the simple principle that when unsaturated air comes in contact with water, the water evaporates. In this process, the moisture content of air increases, while itstemperature decreases. Evaporative cooling is a physical phenomenon in which the evaporation of cooling water into surrounding occurs, due to transfer of latent heat of surrounding air to the cooling water. This results in cooling of the room with increased moisture content of air leaving the cooler. Evaporative cooling is subdivided in two groups as direct evaporative cooling and indirect evaporative cooling. The factors we consider for design of desert cooler are temperature, pressure, humidity, moisture, saturation effectiveness.

II. TABLE I
CLASSIFICATION of COOLING SYSTEM



III. Evaporative Cooling-

According to various research paper, evaporative cooling is physical phenomenon, in which liquid gets converted into vapour using latent heat. Evaporative cooling depends upon the wet bulb depression, that is difference between the dry bulb temperature and wet bulb temperature. It is a natural process used for cooling purpose. In case of cooler, warm air outside the cooler enters through wet cooling pad, thus evaporating water into vapour form using latent heat of air which causes reduction in temperature of air.[3][5][12]

Farhan A. Khmamas[9] has stated the advantages of evaporative cooling like less energy (heat and power) consumption as compared to air conditioners, no use of refrigerants or gases, simple design and low cost.

There are two types of Evaporative cooling:

A. Indirect Evaporative Cooling-

In Indirect evaporative cooling, heat exchanger is used for cooling air in order to avoid direct contact between evaporated water and conditioned air. However, use of heat exchanger increases the initial setup cost. The regions having constantly high humidity, like the coastal areas are mostly suitable for indirect evaporative cooling systems. In this dry bulb temperature as well as wet bulb temperature both reduce.[1]

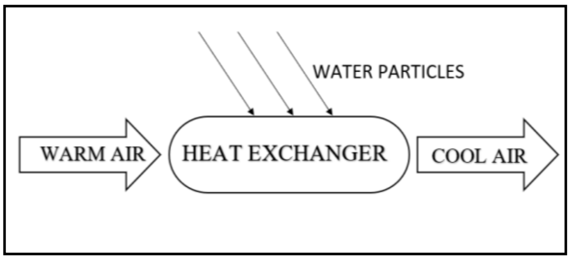


Fig. 1 Indirect Evapourative Cooling

B. Direct Evaporative Cooling-

In Direct evaporative cooling, the ambient air is cooled and humidified by evaporating the cold water due to latent heat transfer between air and water. This process reduces air's dry bulb temperature while moisture content in air increases at uniform rate. As the air saturates, the wet bulb depression value (*refer chapter 4*) decreases. In this process, the wet bulb temperature almost remains constant. Main benefits of direct evaporating cooling are that there is no heat transfer in this process resulting in less energy loss. Also, most of the impurities, dust and dirt in the surrounding air are washed out by the recirculating wet media, hence fresh, good quality air passes through the fan into the room. The latest ASHRAE Thermal Guidelines,2011 has specified a wide range of relative humidity (20% to 80% RH) for application of direct evaporative cooling at data centres, for misting purposes in hotels and for residential purposes.

Application of Direct Evaporative Cooling – In Air Coolers for residential as well as industrial applications.[1][4]

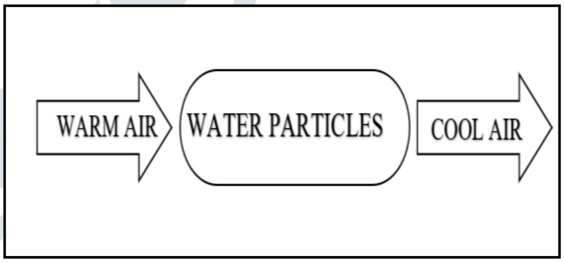


Fig. 2 Direct Evapourative Cooling

IV. AIR COOLERS-

The air coolers can be broadly classified as two types:

A. Personal air coolers or room air coolers
B. Desert air coolers

TABLE II
CLASSIFICATION of AIR COOLERS

Feature	Personal air cooler	Desert air cooler
Room type	Small to mid-size rooms	Medium to large size rooms
Water tank capacity	20 - 30 litres	30 - 60 litres
Air circulation	Huge fans	Blowers
Installation	Portable	Window installation
Efficient in Hot areas	Less	More
Price	Price starts from Rs. 5,000	Price starts from Rs. 8,000

Difference between the two coolers is summarized above for your reference.
Author Zhang Haitian in his paper [16] has evaluated the difference between four types of air coolers based on their water consumption and economic performance. His observations state that Evaporative cooler is the most optimum to use among all air coolers. Medium sized desert coolers provide more cooling coverage area (600 sq.ft) over a comparatively low water tank capacity (50L). Rate of evaporation of water is high as compared to personal coolers due to large value of wet bulb depression. Thus, Desert coolers are most suitable for both residential as well as industrial use.
The increasing demand for desert cooler due to its better cooling capacity and low power consumption has now become the major area of research all over the world.

Working of Desert Cooler-

- Usually dry regions having high temperature and low humidity are suitable for application of desert coolers.
- The desert coolers are made of metal box with sides vented for delivering air.
- Evaporative cooling pads used for holding cool water are mounted at the three sides of cooler and are wetted by means of a pump.
- A centrifugal fan draws surrounding air through side vents and then cooling pads to cool surrounding hot air.
- Heat in the ambient air gets absorbed by cool water in pads and it evaporates into the air. Then this moist cool air is delivered in the room.[2][5][17][11]

V. Comparative power consumption between Air Cooler and Air conditioner

B. Desert Cooler Specifications-
Pump power consumption = 18 Watt
Motor power consumption = 180 Watt

It consumes more electricity. So, to optimize it, we can reduce power consumption of pump by implanting a suitable controller device.

For example –

- Max. hrs. for which cooler is working in one house = 15 hrs.
  Power consumption by cooler = 120 W/hr.
  Power consumption per day = 120*15 = 1800 W/hr. = 1.8 kW/day
  1 unit of electricity = 1 kW/hr.
  Total = 1.8*30 = 54 units/month
  Total monthly charge = 54*5 = 270 Rs/month ………(1 unit = 5 Rs (rate for 100-300 unit/month))
- 1 house consumes additional 54 units/month electricity during summer.
  Consider 3.4 lakh houses in Pune using coolers.
  Total units of electricity consumed = 340000*54 = 18,360,000 units = 18,360 kW/hr
  Hence, 18360 kW/hr more power needs to be supplied by the government during summer.
- Assuming 30% power reduction by using controller device,
  Additional power consumption = 18,360,000*0.3 = 5,508,000 W ……. (for 3.4 lakh houses)
  Additional power consumption = 5508000/340000 = 16.2unit/house/month
  =16.2kW/hr/month
  = 0.54 kW/hr/day

*Similar calculations for Air conditioner.

TABLE III
COMPARATIVE STUDY of POWER CONSUMPTIONS

SR. NO.	PARAMETERS	COOLER	AC
1	Hours/day	15	15
2	Power consumption	120 w/hr	1500 w/hr
3	Power consumed/ day	1.8 kw/day	22.5 kw/day
4	Power consumed/ month	54 units/month	675 units/month
5	Monthly charges	270 rs	3375 rs
6	For a dist. (pune) 3.4 lakh houses	18360 kw/hr	229500 kw/hr
7	Power consumption	Less	More

VI. PARAMETERS-

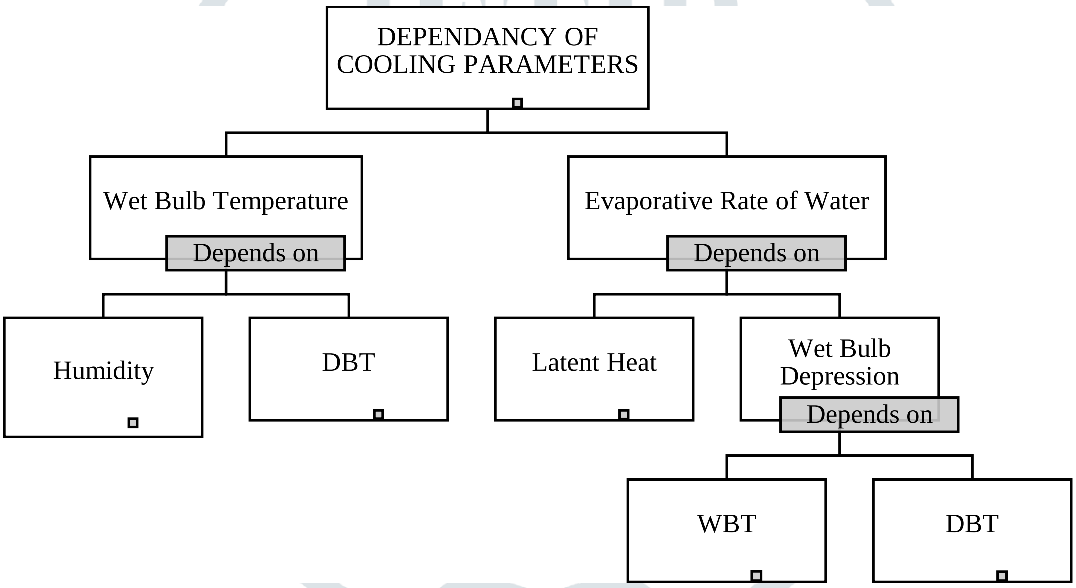


Fig. 3 Dependent and Independent Parameters

Some parameters are mention below [4] [5][8]:

Parameters has two classification:

A. Dependent parameters: Value of these parameters depends on some other parameters. They depend on Independent parameters. For example: Force, it depends on acceleration and mass.

B. Independent Parameters: These parameters don't depend on any other parameters. They have their own values. For example: Mass

In cooling System for Desert cooler there are also dependant and independent parameters as shown in tree diagram above.

Pumping action of cooler is dependent on water contain in pad. Water contain depends on evaporation rate which is depend on Difference between DBT and WBT.

- **Dry Bulb Temperature**: It is ambient temperature measured by thermometer. SI unit: Degree Celsius and Kelvin.

- **Wet Bulb Temperature** : Temperature of air cooled to 100% Relative Humidity by evaporation of water with the help of latent heat by air. If relative humidity is 100% then dry bulb temperature is equal to wet bulb temperature. It is temperature of adiabatic saturation that is 100% RH.
- **Wet Bulb Depression** : Difference between Wet bulb temperature and Dry bulb temperature is known as Wet bulb depression. It is used to calculate evaporative rate.

Unit : Degree Celsius and Kelvin

- **Latent Heat** : The heat required to convert a solid into a liquid or vapour, or a liquid into a vapour, without change of temperature.
  Unit : KJ
- **Dew bulb temperature**: At this temperature air is 100% saturated. After this temperature if we remove more heat from air then it will condense to liquid. It can measure easily with the help of saturation curves.
  Unit: Degree Celsius
- **Humidity**: It is amount of water present in air.
- **Relative Humidity**: It is unitless quantity as it is ratio of water vapour present in sample of air to that of saturated air. It is expressed in %.

VII. Design of Experiment –

TABLE IV
EFFECT of DIFFERENT PARAMETERS on COOLING RATE

Cases	Independent parameters		Depen-dent Para-meters (function)
	Constant	Variable	
1	Tempera-ture	Fan speed	Cooli-ng rate
2	Fan speed	Temper-ature	

TABLE V
CASE 1

Constant	Variable Fan Speed	Cooling Rate
Temp	High	
	Medium	
	Low	

TABLE VI
CASE 2

Constant	Temperature range *	Cooling rate
Fan Speed (High)	46-42	
Fan Speed (Medium)	46-42	
Fan Speed (Low)	46-42	

*Temperature will vary by 1 degree every time.

A. Cooling Capacity –

Author Ibrahim U. Haruna in his paper [6] established the following relation between coolness obtained and fan speed.

- Cooling capacity rate,

$$Q_c = m_a{*}C_p{*}(T1\text{-}T2) *3.6 \quad (kJ/hr)$$

where, Cp = Specific heat of air (kJ/kg*K)
T1 = ambient air temperature (K)
T2 = air temperature leaving the cooler (K)

- Above relation gives the cooling capacity provided by the cooler for a particular fan speed for the duration of one hour. So, using this relation we can determine the time for which pump can be turned off. Also, it gives the time for which fan speed can be maintained constant.

1) *Temperature Sensor:* According to the mentioned relation above, cooling rate is directly proportional to the temperature difference. In order to measure temperatures T1 and T2, DHT11 sensor is being used.
DHT11 – DHT11 is a temperature and humidity sensor with calibrated digital output. The sensor consists of resistive type humidity measuring sensor (Humidistat) and an NTC temperature measuring sensor (Thermostat). It is a 4-bit channel sensor with analog as well as digital output.

TABLE VII
SPECIFICATIONS

Sr. No.	Features	Specifications
1	Voltage	3 – 5 V
2	Current rating	2.5 mA
3	Humidity	20 – 80% with 5% accuracy
4	Temperature	0 - 50°C with +-2°C accuracy
5	Sampling rate	1 Hz
6	Body size	15.5mm*12mm * 5.5mm

B. Evaporative Cooling Pads:

- Saturation effectiveness, εsat, is the index used to determine the performance of a direct evaporative cooler. It is defined as:
  $\varepsilon sat = (T1\text{-}T2)/(T1\text{-}T3)$
- Saturation effectiveness tells the extent to which temperature can be lowered. [7][12]

- Author Ibrahim U. Haruna in his paper [1] states that, more the εsat of the cooling material, higher is the temperature drop between ambient temperature and temperature of air leaving the cooler.
- It means, higher the value of εsat, lower is the cooler's outlet temperature. Also, higher εsat of cooling pad increases the relative humidity of the ambient air.

1) *Experimental analysis:* Authors Shekhar Shashank, Santosh Suman, Dr. H S Moharana, D Sethy in their Paper [14] have carried out experiment on evaporative cooler, using stainless steel wire mesh pad, coconut coir pad, khus pad, wood wool pad, ceramic material tubes and galvanized sheet pads and comparison of results obtained was done on terms of cooling efficiency and water consumption rate. The experiment was conducted with varying fan speed and using different pad material for each working speed condition.

2) *Observations:*

- Maximum water consumption has been observed in wood wool pad, coconut coir and khus pads have shown less water consumption rate.
- Wood wool and coconut coir pads have shown higher air velocity providing proper air distribution in living place or work place.
- Wood wool has shown high cooling efficiency at moderate and high fan speeds.
- It reveals that resistance to air flow is higher at khus pad as comparing to wood wool and coconut coir pads.
- Stainless steel wire pad shows a poor cooling efficiency as comparing to other pads but can be used where relative humidity is higher.[10]

3) *Conclusion:* Although wood wool shows maximum water consumption, however water consumption mainly depends on the ambient wet bulb temperature, humidity in the surrounding and the air speed.
Hence wood wool is optimal choice to be used as an evaporative pad material.

4) *Moisture Sensor:* The moisture sensor is used to detect presence of water (moisture) around it. It is a resistive type sensor. It consists of two plate-like halves with small resistive pods embedded on its surface. Since water is a good conductor of electricity, more current flows through the sensor pods when sensor comes in contact with water. Whereas when the sensor is dry, less current flows through the pods. Hence percentage of water in a substance can be calculated using moisture sensor.
In order to measure the water consumption of evaporative cooling pads and to determine the amount of water required to achieve the required cooling effect in a room, moisture sensors can be used in evaporative coolers. As evaporative cooling is mainly dependant on the heat transfer between hot ambient air and cooling water, efficient usage of cooling water can be ensured by metered water content in a cooling pad.

TABLE VIII
MOISTURE SENSOR RATINGS

SPECIFICATION	RANGE
Voltage	3.3-5 V
Current	0-35 mA

For example,
For Wood wool, the saturation effectiveness range from 36.84 to 57.89 %, similar to coconut coir. If the ambient DBT for both wood wool as well as coconut coir pad is between 36-38 °C, then the air leaving the cooler varies from 26 to 31ºC for wood wool and from 27 to 30ºC for coconut coir respectively. This shows that the leaving temperature for aspen wood pad is lower than that of coconut coir pad. Thus the cooling efficiency is more for aspen wood pad than coconut coir pad.
The relative humidity for wood wool varies from 45.76 to 85.18%.
However, water consumption rate of wood wool is higher than other cooling pads since its εsat is higher.

Hence, we have used Wood wool as the evaporative cooling pad material because it has higher saturation effectiveness value, more cooling capacity and increases relative humidity.

B. Fan

We aim at varying the fan speed to achieve coolness in the room as per requirement and avoid unnecessary power wastage. In order to vary fan speed, rate at which required coolness is obtained has to be calculated. For this purpose, the *fan laws* are used.

- Volume flow rate or capacity of fan (Q) is directly proportional to fan speed (N)
- Power consumption of fan (P) is directly proportional to cube of fan speed (N^3).

According to above mentioned relations, speed of fan motor is the most crucial parameter to be measured. Since cooling provided by the evaporative cooler is directly dependent on the fan speed, motor speed measuring device like tachometer needs to be used during experimentation.

1) *Tachometer:*Tachometer is an instrument which measures number of revolutions per minute of the fan motor shaft and displays the result either on an analogue dial or digital display. Mechanical tachometer or DC tachometer are more suitable for use in measuring the speed of fan due to their ability to provide accurate readings per minute.

C. Pump

- Power consumption by a pump motor is given by,
  $Power = I*V$ kW
  where, I = Current, amperes
  V= Voltage, volts
- Considering average utilisation of cooler is 15 hrs per day in the month of April. However, according to the modifications to be made in the cooler, the pumping action will be switched ON only for particular period of time 't' hrs per day.
- Hence, power consumption by the pump motor will be given by,
  $$Power = I*V*t \quad ,kW/day$$
- Power consumption by cooler (pump motor) in April is given by,
  $$Power = I*V*t*30 \quad ,kW/month$$
- 1 unit of electricity = 1 kW/hr
- Total units of electricity consumed in April = $I*V*t*30$ units/month

Since, the pump is turned ON only for specific period of time (up to the cooling moisture reduces to a certain percentage), power consumption by the motor is reduced considerably.

VIII. Experimental setup –

We will validate the experiment to optimize water and power consumption of Desert cooler for residential application. The instruments required forcarrying out the experiment are mentioned below:

A. Basic components of desert cooler are-

1. Pump
2. Fan
3. Evaporative Pads
4. Sump Tank
5. Distributing Tank

B. Diagram -

The experimental setup diagram is shown below with the sensors mounted on the desert cooler model.

C. Working and Modifications:

1) Fan:

- According to the Authors Naseem M. A., Syed D. A., Khan T. H. and Syed M in their paper [13] state that,in most of the air conditioning system, centrifugal fans are used since they can provide large volume of air from very low to high operating pressures.
- Structure of centrifugal fan consists of scroll type housing mounted around an impeller, which is driven by a driving shaft or an electric motor or through belt and pulley arrangement.
- Rotating impeller produces a centrifugal force and pushes air outwards over the turbine blades.
- These blades are used to vary the amount of air to be delivered by the fan.
- Finally, air is directed outwards through the scroll housing into the room.

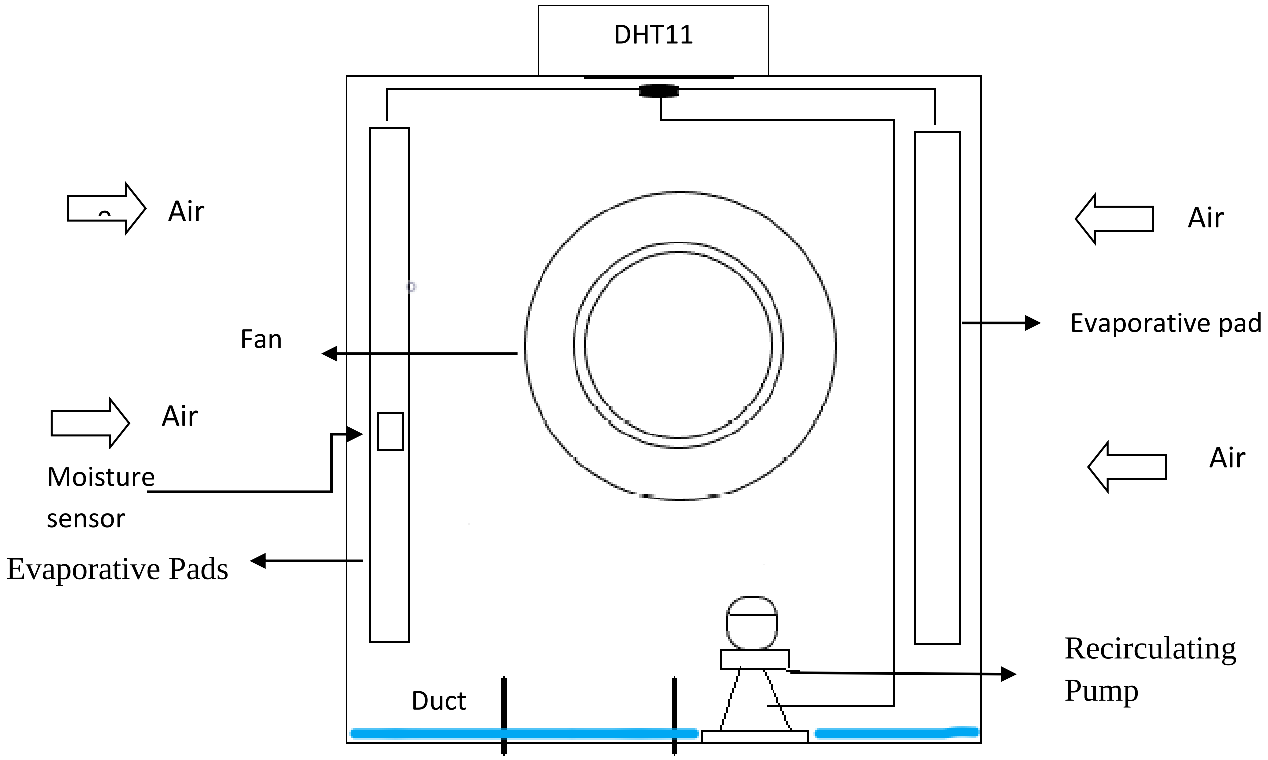


Fig. 4 EXPERIMENTAL SETUP of DESERT AIR COOLER

- The whirling action of air over the fan blades and through the housing cools the air to some extent as the air is delivered in the room.

1.1) Varying Fan Speed Principle :

- The fan stator revolves with synchronous speed N_{syn}
  N_{syn} = (120*Frequency)/ (no of poles in stator) rpm
- As electric supply is applied to the stator, a rotating flux is produced on it which induces an emf because of electromagnetic induction.
- The induced emf develops a torque on the stationary rotor which gradually increases the rotor speed. The rotor rotates in same direction as that of the rotating flux.
- Hence torque developed on rotor is equal to product of slip speed and square of supply voltage.
- **Speed proportional to Torque proportional to V^2**
- Thus, by controlling supply voltage, fan speed can be varied.

2) Pumps:

2.1) Purpose of Use :

1. Pumping cool water and circulating it to the wet evaporative pads for cooling ambient hot air by causing heat transfer.
2. Providing continuous water circulation to pads for efficient working of cooler.

2.2) Factors affecting performance of Pump:

1. Rate of evaporation of water
2. Surface area of wet pad media

2.3) Working:Centrifugal pump is used to lift the water at elevated height at increased pressure and flow rate. It consists of a rotating impeller connected to the impeller shaft. Due to presence of pressure difference at the eye of impeller, water is sucked upwards up to desired height with high velocity.

TABLE IX
DIFFERENT CAPACITIES of PUMP USED in COOLER:

COMPANY NAME	MODEL NO	WATER TANK CAPACITY	POWER CONSUMPTION (in WATT)	NO OF FAN SPEED	COOLING COVERAGE AREA	AIR DELIVERY (CU.M/HR)	MAX MOTOR SPEED rpm
HINDWARE	CS-176001HPP	60 L	AC 230V 50 Hz	3 (HIGH, MED, LOW)	969 sq ft	3800	1350
BLUESTAR	BS-ARD55 Hybrid	55 L	190 W	3	420	4000	1350

3) Evaporative pads:

- Evaporative pads are basically made of water absorbent material, located at the open faces of the cooler housing, to cool air by latent heat transfer between air and cool water.
- The latent heat transfer is directly proportional to the evaporation rate of water.
- This rate of evaporation of water purely depends on the ambient temperature, humidity of air and atmospheric pressure of the particular region.

3.1) Purpose of use:

1. Make large wet surface area available for air to pass through and get cooled
2. To hold maximum amount of water for evaporation
3. To offer resistance to air flow

3.2) Factors affected by evaporative pad material:

1. Water consumption by pad
2. Cooling efficiency

3.3) Different types of Evaporative Pad materials:

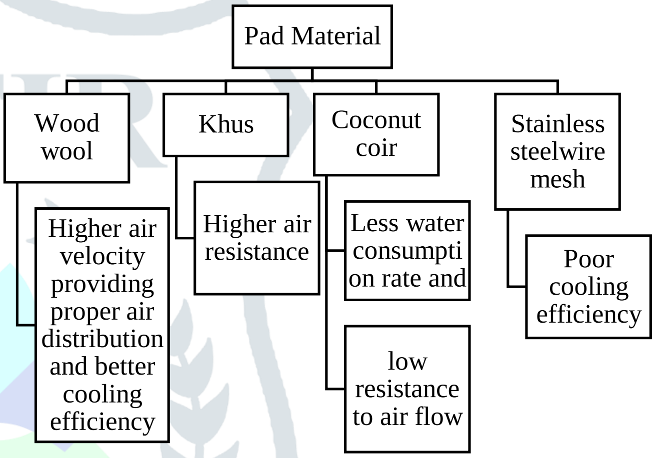


Fig. 5 Various Evaporative Pad Materials

- Wood wool cooler pads are generally made from fine aspen wood fibres which are interwoven in a randomly orientated square or rectangular pattern to form a highly porous, absorbent excelsior material netting that has been found to be very effective for evaporative cooler systems.
- The porous pad helps pumped cool water to penetrate downwards due to gravity, wetting the entire pad, thus providing a large wetted surface area for air to pass through and cool.
- Latent heat gets transferred from the hot incoming air to the cool water dripping down through the pads. The heated water evaporates which results in a large volume of cool, moist air passing over the fan blades into the room.[10][13][14][15]
- ***Evaporative pad material suitable for project– Wood wool (Wood Excelsior)***

4) *Sump tank:*It resembles a water reservoir, found in few coolers, usually located at the bottom of the cooler. It is used for storing large amount of cooling water (based on capacity of cooler), which is then pumped upwards and evenly distributed through pipes over the evaporating cooling pads.

5) *Distribution tank:*The cooling water pumped from the sump tank is collected in a distribution tank or a trough and then evenly distributed over the

evaporating cooling pads. This tank is mainly used for distributing cooling water rather than for storage. Since pumping action is continuous, the tank is never empty. Hence, by controlling the amount of water to be distributed, the pumping action can be controlled.

X. FUTURE SCOPE-

This project includes a controlled operation of pump and fan in the evaporative coolers through detail study of factors affecting evaporative cooling rate along with experimental analysis of the same. A controlled switching operation of pump depending on amount of water consumed and by running the fan at different speeds using a capacitive fan regulator reduces the power consumption in residential areas by a considerable amount.

Evaporative coolers provide a cooling effect of about 7 to 8 °C drop in the ambient temperature. Furthermore, evaporative cooling increases humidity of the air passing through the evaporative pad hence it proves beneficial for the surrounding dry weather.

As evaporative coolers provide less overall power consumption as compared to air conditioners, they are widely used in dry, arid regions with moderate humidity conditions.

In India, evaporative coolers are mainly used in Maharashtra, basically Vidarbha and Marathwada regions, Jammu and northern states.

Even in abroad, evaporative coolers are mainly used in Australia.

XI. INDUSTRIAL SCOPE –

The concept of evaporative cooling can be extended on industrial level to cooling towers. By controlling the operation of pump and fan, amount of power saved is in mega-watts. By running the fan at different speeds according to the surrounding conditions, and controlling the on-off condition of the pump, the overall power consumption of the cooling tower can be reduced dramatically

This experiment has been implemented by Cummins India Ltd. The used coolant from their lathe machines is recycled in the cooling tower by using the same concept of evaporative cooling. They have fitted a temperature sensor in the inlet pipe of the tower to terminate the operation of pump during night. Hence the fan is operated at slow speed in night to provide appropriate cooling required in the tower, which has successfully reduced their power consumption by almost 100MW per month.

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