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Design and Construction of a portable air cooler

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ABSTRACT

Human being wants to live in comfortable condition. Temperature is one of the most important factors for human comfort. When temperature of air is above the comfort limit then cooling of air is necessary. Air cooler is required to reduce the temperature of air for comfort. In this project a portable air cooler with evaporative cooling is designed and constructed. It consists of a fan, a water-wetted pad, a pump to recirculate the water and revolving wheels to move from one place to another. Room air is drawn through the water-wetted pad and is blown into the room. The cooling system slightly increases the humidity of the entering air. This type of system is very useful where the environment where temperature is high but the relative humidity is relatively low. Performance of the constructed air cooler is tested. Results showed that it can be reduced the temperature about $4^\circ C$ to $6^\circ C$.

Keywords: Evaporative air cooling, Temperature, Humidity, Human Comfort

1. Introduction

Human satisfaction is called human comfort. Human comfort is an integral part of human life. Human comfort depends on four factors. These are

- Temperature of air
- Humidity of air
- Purity of air
- Motion of air

Among the four factors, temperature and humidity of air are very essential for human comfort. We know that among six seasons, the summer portion is higher than others. So comfort cooling & dehumidification is necessary. But cooling & dehumidification is difficult to control simultaneously [1].

Portable air cooler is a mobile device which is used to cool air. There are several methods of air cooling.

Evaporative cooling is one of the most ancient and energy efficient methods because the energy consumption of energy is very low. Direct evaporative cooling adds moisture to the air. It is suitable for dry and acid climates .In wet climates; the results are not satisfactory, because of unacceptable indoor humidity. Indirect evaporative cooling, without added humidity, is less effective, costs more system [1].

Evaporative coolers are cooling devices that use the evaporation of water into the air to cool the air temperature. They are sometimes called air coolers, desert coolers or swamp coolers. Evaporative coolers use a quarter of the electricity of air conditioners and are relatively inexpensive. In addition, they do not use ozone-harming chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs).

This study also contains:

- ❖ Design a portable air cooler.
- ❖ Construction of a portable air cooler.

2. Thermodynamics of Evaporative Cooling

When a large quantity of water is constantly circulated through a spray chamber that is insulated from surroundings, the air-water vapor mixture is passed through the spray chamber and in doing so; it evaporates some of the circulating water. The air may leave at a certain humidity ratio or in a saturated state (Fig-2.1). The increase in specific humidity is equal to the quantity of water evaporated per unit mass of dry air. As the spray chamber is insulated from surroundings, no heat transfer takes place between the spray chamber and the surroundings. Therefore, the energy required for evaporation is supplied by the air, and consequently, the DBT is lowered. After the process has been in operation for a sufficient length of time, the circulating water approaches the WBT of air [1].

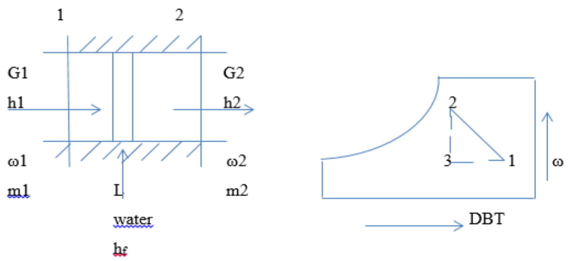

Fig 2.1 Adiabatic evaporative cooling.

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The energy balance and other relation may be expressed mathematically as follows:

$G1 = G2 = G$ ……………..(i)

$G1\omega1+L= G2\omega2$ ……………..(ii)

$L= G (\omega2-\omega1)$ ….…………(iii)

$G1h1+L\ h_f= G2\ h2$ ...…………….(iv)

$G (h1-h2) + G (\omega2-\omega1)\ h_f = 0$ ………………(v)

$h1 - \omega1\ h_f = h2 - \omega2\ h_f$ ………………(vi)

The process can be shown on psychometric chart by state 1 and 2 (Fig-). From this chart

Sensible heat transfer = G (h1 – h3)

Latent heat transfer = G (h2 – h3)

3. Design of the portable air cooler:

The schematic diagram of the evaporative cooling system is shown in figure 3.1. The major components of the evaporative cooling system are:

a)Water-wetted pad
b)Supply container
c)Receiver container
d)Frame
e)An Exhaust Fan
f)Water Pump
i)Connections Pipes

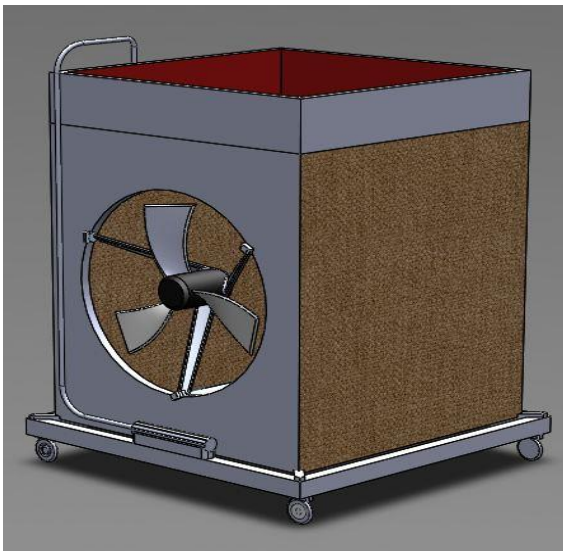

Fig- 3.1: Schematic diagram of a portable air cooler.

3.1 Selection of fan

The fan is a critical component of the portable air cooler. The cooling performance depends on fan size and speed. On the basis of this considerations the following specifications of fan was selected.

Diameter, D =10 inch= .25m

Power= 43 watt

Diameter of fan with casing, $D' = 0.3048\ m$

Velocity of air supplied by fan, V = 2.07 m/s (measured by anemometer)

Area through which air is supplied, $A = D'^2$

$= 0.3048 \times 0.3048$

$= 0.09290\ m^2$

3.2 Design of supply container

<u>Considering outside condition</u>

Let,

DBT = 33 ℃

WBT = 28 ℃

Relative humidity RH = 69%

Specific humidity at 33 degree Celsius, $\omega_0 = 0.0122$ kg/kg dry air

Density of air at $33℃, \rho = 1.156\ kg/m^3$

Specific heat of air at $33℃,\ c_p = 1.0061\ kJ/kg.k$

Mass flow rate of air $m_a = \rho AV$ ……………………(vii)

$= 1.156 \times 0.09290 \times 2.07$

$= 0.2223\ kg/s$

<u>Inside condition</u>

Let DBT $= 27℃$

Let total amount of water reserved $= 6\ litre$

$= 6\ kg$

And backup time $= 60\ min$

Total amount of water reserved

$= (2 \times \text{amount of water evaporated}) \times$ back up time

Or, amount of water evaporated $G = 6 \div 2 \div 3600$

$= 0.000833\ kg/sec$

Amount of moisture transferred $G = m_a\ (\omega_i - \omega_o)$ ………………..(viii)

$or,\ 0.000833 = 0.2223 \times 3600(\omega_i - 0.0122)$

$or, \omega_i = 0.015948$ kg/kg dry air

Amount of specific humidity increased $= 0.015948 - 0.0122$

$= 0.003748\ kg/kg\ dry\ air$

Latent heat transferred $, Q_L = m_a\ h_{fg} (\omega_i - \omega_o)$ ………………(ix)

$0.2223 \times 2440 \times (0.015948 - 0.0122)$

$= 2.033$ kJ/sec

Sensible heat transferred $Q_S = m_a\ c_p (t_o - t_i)$ ………………(x)

$= 1.3419$ kJ/sec

Length $= 40.64\ cm$

Width $= 40.64\ cm$

Height $= 7.62\ cm$

Total volume= $12585.26515\ cm^3$
So that it could contain 6 liter water
Water Height= $3.63\ cm$
Time required emptying the tank,

$$T = \frac{2A\sqrt{H}}{C_d\, a\sqrt{2g}} \qquad \text{……………………(xii)}$$

Where,
C_d = Discharge coefficient = 0.62
T=Back up time
H = Height of the water in the tank
$a = area\ of\ the\ orifice$

$$3600 = \frac{2 \times (40.64 \times 40.64) \times \sqrt{3.63}}{0.62 \times a \times \sqrt{2 \times 981}}$$

Or, $a = 0.063657\ cm^2$

Let diameter of each hole $d = 1\ mm$
Number of hole = n
So,

$$n \times \frac{\pi d^2}{4} = a \qquad \text{………………….(xiii)}$$

Or, $n = 9$

3.3 Design of frame

The frame is important component of a portable cooling system. It carries supply container on top, fan in one side, and pad in three sides. So the length and width of the frame would be equal to the supply container. And the height of the frame should be such that fan can be installed at the centroid of those side of the frame.

Considering above condition the following size of the frame was designed.
Length $= 40.64\ cm$
Width $= 40.64\ cm$
Height $= 45.72 cm$

3.4 Design of water reserve container

The size of the water reserve container would be such that it could contain the dropped water at the bottom of the box.

Rate of water evaporated, $G = 8.33 \times 10^{-4}$ kg/sec
Amount of water evaporated $= 8.33 \times 10^{-4} \times 3600$
$= 3\ kg$
Rest amount of water= $6 - 3 = 3\ kg$
Rest amount of water
= amount of water absorbed
+ amount of water dropped

Let,
water dropped $= \frac{1}{2} \times rest\ amount\ of\ water$ ………………..(xiv)
$= 1.5\ kg$

Considering above condition the following size of the reserve container was selected.
Length $= 45.72\ cm$
Width $= 45.72\ cm$
Height $= 1.27\ cm$

3.5 Design of water wetted pad

The function of water wetted pad is to absorb as much as water for a long period. And it must have the ability to pass air easily through the pad .It should be insured that no air will flow through the pad without wetted. For considering above reason the following size of the water wetted pad surrounding three sides of the frame was selected
Length $= 3.81\ cm$
Width $= 35.56\ cm$
Height= 30.48 cm

3.6 Selection of water pump

The following specification of water pump was selected
Voltage = 12 volt
Current = 6 amp
Power = 72 watt

3.7 Cost analysis of the project:

ITEMS	COST(TK)
1) Exhaust Fan	950/-
2) AC Pump	750/-
3) Metal sheet(5 kg)	750/-
4) Pipe	50/-
5) Power Supply	200/-
6) Wheels(4 pieces)	200/-
7) Wetted Pad	400/-
8) Manufacturing Cost	1000/-
Total	4300/-

4. Result and Discussion

4.1.1 Performance Test in open room:-

The cooling system was placed in a room of size 5.4m$\times 1.7m \times 3.5m$ at the door. The wet bulb and dry bulb temperatures were recorded at inlet and outlet of the cooling system by sling psychometer with different temperature water.

Table -4.1: Data Sheet For open room

Date	Duration	Water Temperature (℃)	Inlet Condition		outlet Condition	
			DBT (℃)	WBT (℃)	DBT (℃)	WBT (℃)
04-06-14	10.00-11.00 AM	27	35	31	31	30.5
	11.00 AM-12.00 PM	28	34	30	31.5	29.5
05-06-14	10.00-11.00 AM	26	37	31	33.5	31.5
	11.00 AM-12.00 PM	27	36	31	33	31.5
08-06-14	10.00-11.00 AM	26	38	30	34	29.5
	11.00 AM-12.00 PM	28	39	30.5	36.5	30
09-06-14	10.00-11.00 AM	18	34	29	28	27
	11.00 AM-12.00 PM	17	33	28	28	27
10-06-14	10.00-11.00 AM	16	35	30	29	27
	11.00 AM-12.00 PM	17	34.5	30	29	27

Table 4.2 Result Sheet For open room

Date	Duration	Relative Humidity, RH (%)		Latent Heat, Q_L (kj/kg)	Sensible Heat, Q_S (kj/kg)	Sensible Heat Factor, SHF	Mass Of Water Evaporated, G (kg/s)
		Inlet	Outlet				
04-06-14	10.00 AM - 11.00 AM	79.8	96.2	0.4339	0.8936	0.67	0.000178
	11.0b0 AM - 12.00 PM	83	92.6	0.0542	0.5585	0.91	0.000022
05-06-14	10.00 AM - 11.00 AM	64.9	86.6	1.4645	0.7819	0.35	0.0006
	11.00 AM-12.00 PM	69.7	89.8	1.3560	0.6702	0.33	0.000556
08-06-14	10.00 - 11.00 AM	55.6	71.6	0.4339	0.8936	0.67	0.000178
	11.00 AM-12.00 PM	54	62.1	0.0542	0.5585	0.91	0.000022
09-06-14	10.00 - 11.00 AM	68.8	92.5	0.5966	1.3405	0.69	0.000245
	11.00 AM-12.00 PM	68.2	92.5	0.2169	1.1171	0.84	0.000089
10-06-14	10.00 - 11.00 AM	69.3	85.5	1.6814	1.3405	0.44	0.000689
	11.00 AM-12.00 PM	71.8	85.5	1.7899	1.2288	0.41	0.000734

4.1.2 Performance Test in closed room:-

The cooling system was placed in a room of size at the door. The wet bulb and dry bulb temperatures were recorded at inlet and outlet of the cooling system by using psychometer with normal and cold water.

	AM						

Table -4.3: Data Sheet for closed room with normal tap water

Date	Duration	Water Temperature (℃)	Inlet Condition		outlet Condition	
			DBT (℃)	WBT (℃)	DBT (℃)	WBT (℃)
12-06-14	10.00 - 10.20 AM	27	36	31	33	30.5
	10.20 AM - 10.30 AM		35	30.5	32.8	30
	10.30 - 10.40 AM		34.5	30	32.5	29.5
	10.40 AM- 10.50 AM		33	29.8	32	29.2
	10.50 - 11.00 AM		32	29.5	31.5	29

Table -4.4: Data Sheet for closed room with cold water

Date	Duration	Water Temperature (℃)	Inlet Condition		outlet Condition	
			DBT (℃)	WBT (℃)	DBT (℃)	WBT (℃)
15-06-14	10.00 - 10.20 AM	17	35	31	30	29
	10.20 AM - 10.30 AM		32	29.5	30.5	28.5
	10.30 - 10.40 AM		31	29	30	28
	10.40 AM- 10.50 AM		30	29.3	29.5	27.5
	10.50 - 11.00		30.5	29	29	27

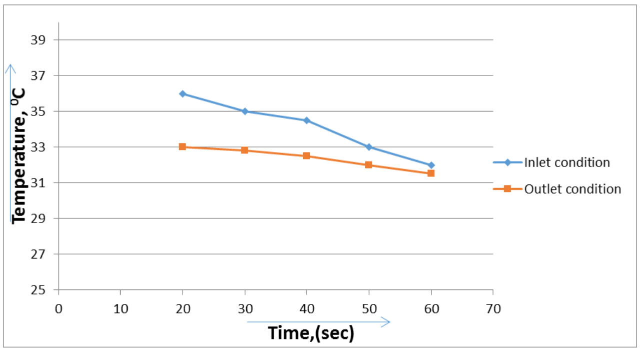

Figure-4.1: Time vs. Temperature diagram (27 ℃ Normal Tap water).

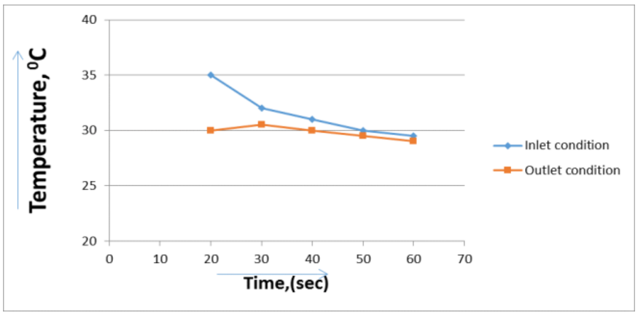

Figure-4.2: Time Vs. Temperature diagram (17 ℃ Cold water).

4.2 Discussion:

The cooling performance of portable cooling system mainly depends on the temperature and relative humidity of air and the contact surface between air and water. From Table 4.1 it was showed reduction of temperature depend on water temperature. When the temperature of water raised with ambient temperature reduction of temperature decreased. Besides with relative humidity increased with time. The constructed portable cooling system reduced the temperature of the room by an average of 4℃ with normal tap water and 6℃ with cold water from the atmosphere. This is a poor value .From fig 5.1 it was founded that after 20 minutes of installation of cooling system temperature reduced from 36 ℃ to 33℃ .And after 1 hour of installation of cooling system temperature reduction found 4.5 ℃. The difference between inlet and outlet temperature was also reduced with time because same air circulated through the system. At last difference was found about 1.5 In case of cold water temperature reduced from 35 ℃ to 30℃. And last temperature reduction found about 5 ℃ at outlet condition and difference between inlet and outlet temperature was found about 0.5℃. The main difficulties of the constructed portable air cooler was the long distance between the fan and water wetted pad . For this reason the fan was unable to circulate the air at desired speed. Another reason may be the jute water wetted pad that would be rotten in course of time. The system was unable to provide enough cooling effect because the relative humidity of the air was already at a higher value.

6.1 Conclusion:-

The portable air cooler was designed to port from one place to another place. Some values such as inlet dry bulb, wet bulb temperature, outlet dry bulb temperature, amount of reserved water and back up time were assumed primarily to complete the design. The system made portable by attaching four revolving wheels with the corner of the frame. A water pump was installed to recirculate the water and reduce human effort. Its performance was tested in both open and closed room with normal and cold water. It followed the evaporative cooling system. It reduced the temperature about 4℃ to 6℃ for using normal tap water and cold water respectively but increased humidity 16% to 20% for normal and cold water respectively. It showed better performance in closed room but relative humidity slightly increased than open room because the room was being saturated.

The following recommendation can be made to increase the performance of portable air cooler:

1. The pump was controlled manually. It may be made automatic using water sensor. Two water sensors can be set at the highest and lowest water level in supply tank. When the water level falls below the bottom sensor a signal will turn on the motor. And when the water level rises above the upper sensor the motor will be automatically turned off.
2. As the water was evaporating continuously, few times later the bottom reservoir will be blanked. So a system of supplying make up water may be attached with bottom reservoir. And it can be controlled automatically.
3. The main disadvantage of this system is increasing humidity. Humidity can be reduced by using humidity absorbing materials such as silica jell, glycol, etc.
4. The pad was made by jute fiber which will be rotten in course of time and has low permissibility. So synthetic pad can be used to recover this difficulty.

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