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Discovery

Development of economic & efficient air-cooler

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ABSTRACT

This research paper is on application of evaporative cooling for residential and small commercial buildings where compressor based air conditioners are not affordable. Its intended beneficiaries are manufacturers, hospitals, malls and various commercial buildings interested in employing technologies those reduce energy cost. This present work suggests a design which is a hybrid between the conventional Air-Cooler and Air-conditioners available in the market. It has less power consumption compared with available Air-conditioners and provides better cooling than Air-coolers. The major difficulty inherent in conventional air coolers regarding humidity is addressed in this work. Also in respect of energy consumption and cost, it has shown promising benefits.

Keywords: Comfort; humidity; cooler

1. INTRODUCTION

It is commonly accepted that power consumption is the number one challenge for future cooling systems (Radosław Januszewski, 2013). Global warming and energy efficiency are topical issues. With an amplified volume of carbon dioxide and greenhouse gases, temperatures are rising. If this rise in temperature continues, more cooling options will be required in the future. Much work is underway to ensure that disastrous and harmful effects caused by traditional refrigerants used in air conditioning units are limited and to develop safer alternatives (Duncan Pratt-Thompson). As a result, concerned heating & ventilation businesses are developing energy efficient products, such as portable evaporative coolers, with no refrigerant gases, which present a more environmental friendly solution to air conditioning (Khurmi and Gupta, 2011). Air coolers are electrical devices consisting of a fan, a water pump and cooling pads. It works on the principle of forced convection, by absorbing the air from the surrounding through the cooling pads. This air is forced from the cooling pads. Hence cooling it down and then delivering that cooled air to the surrounding (area). The process for cooling is “Evaporation” which gradually increases the humidity content of the delivered air and hence decreases its cooling efficiency. Owing to evaporation humidity rises in the air content and the cooling effect gets reduced. Expensive or insufficient water supplies are encountered or where cooling water pumping or treating costs are high, it is often found that air-cooled units are preferable for several services. The adverse conditions of high relative humidity or excessive space requirements occasionally create high costs or installation difficulties for Air coolers (Engineering Report, 1996; Larry Kinney).

Most air coolers are available in the market have lesser cooling effect and no provision of humidity control resulting in reduces comfort level. Hence to overcome these demerits, a new model of recirculation air cooler with humidity control mechanism is developed. It produces more cooling effect by thermoelectric module, pipe network and lower humidity through systematic recirculation of air. The two major problems faced during its development were rise in cost due to usage of copper pipes and an additional blower for air circulation.

2. EXPERIMENTAL METHODOLOGY

In an experimental air cooler, air from a partially closed room enters into a duct attached to a centrifugal blower cum compressor which compresses the air (a very nominal increase in pressure up to only 0.5bar) and then delivers it to a nozzle. The nozzle is further connected to copper pipes of ½ inch diameter which are installed in the evaporative cooling unit. The evaporative unit constitutes of cooler body (Poly Vinyl Chloride pipe structure), exhaust fan, cooling pads and water tank. The evaporative unit is placed in open space. This unit consists of cuboid frame with cooling pads and exhaust fan on one side the whole unit is completely closed except a hole at the rear side of the exhaust fan. The photographs of air cooler and experimental set up are shown in Figure 1 (a) and (b) respectively.

The experimental cooler works on the combination of various aspects such as ramming effect, evaporative cooling, counter flow heat exchanger, expansion of air and sensible cooling. Air with the help of blower, gaining high velocity pass through nozzles having isentropic compression ratio 1.2 to 1.3and is then through copper tubes which are at very low temperature of around 20°C due to evaporative cooling. The air cools down in these pipes and is then supplied to the room; this air further enters the room and expands. Air temperature drops down further due to expansion though this cooling effect is not obtained properly due to various losses.

All the units which are consuming electrical power i.e. exhaust fan, water pump, and air blower cum compressor are connected across a watt meter in order to determine the total power consumption. There are three inlets and three outlets for air in the evaporative unit consisting of copper pipes of different lengths i.e. of 2.5m, 6m, 1.8m which are used to check and validate the copper pipe length obtained by mathematical analysis and it is found that 2.5 m came out to be the most optimum length. These copper tubes are fitted between two layers of cooling pads. The cooling pads are kept wet by continuous water circulation from the tank below in the evaporative unit. The exhaust fan blows air towards one of the cooling pad, in order to trap moisture generated due to evaporation and conserve water. Also it increases the rate of evaporation at the cooling pads. Four Digital thermocouples are fitted at -

1) The inlet of the air (T_1)
2) The outlet of the air (T_2)
3) One Immersed in water available at the water tank (T_3)
4) Between two layers of cooling pads (T_4)

Relative Humidity (RH) Meter cum Thermometer is also used which is kept inside the enclosure made up of insulated cardboard from all four sides having gaps for the air inlets and outlets. Air is collected by the blower from the top portion of the box and the cool air is exhausted at the bottom of the box. All the other fittings are done with the help of Poly Vinyl Chloride pipes. Relative Humidity meter is kept at the centre of the box.

Thermodynamic Analysis

2.1. Length of pipe

The length of pipe is obtained by considering the system as a Heat Exchanger in which initial conditions are as follows:

Assumptions are:

1. Parallel flow heat exchanger.
2. Temperature of hot air at inlet = 36^0C
3. Temperature of air required at outlet = 25^0C
4. Rise in temperature of water in contact with the pipe =2^0C

Internal diameter of pipe = ½ inch = 0.012m

Outer diameter of pipe = 0.0137m

Mean temperature of air = $36 + 25/2$

$T(mean)_{air}$ =30.5° C

At,

$T\ (mean)_{air}$ =30.5° C

Data Obtained from data book

C_{p} = 1.00642 × 10^3 J/Kg^{0}C

ρ =1.1625 Kg/m^3

Therefore, Mass flow rate =density × volume/sec

Hence, m_h =1.1625×10^{-3} Kg/sec

μ=18.67 × 10^{-6} kg/ms K_f =0.02641 W/mc

Heat transfer rate $Q = m_h C_{ph}(T_{hi} - T_{ho})$

$=1.1625 \times 10^{-3} \times 1.00642 \times 10^3 (36 - 25)$

$Q = 12.8695\, watt$

(at Q=600 watt if v=2.8 m^3/kg)

Log mean temp difference (LMTD)

$$\Delta T_{lm} = \frac{\Delta T1 - \Delta T2}{ln(\frac{\Delta T1}{\Delta T2})}$$

ΔT_{lm} =5.279

Reynolds number = $\frac{\rho VD}{\mu}$

$= (1.1625 \times 6.78 \times 0.0137)/(18.673 \times 10^{-3})$

$= 5788.80$

Calculation for V = velocity of air in m/s

We know,

$m = \rho a V$

1.1625×((10) ^(-3) = 1.1625× (Π/4) × ((0.0137)^2) × V

$V = 6.78\, m/s$

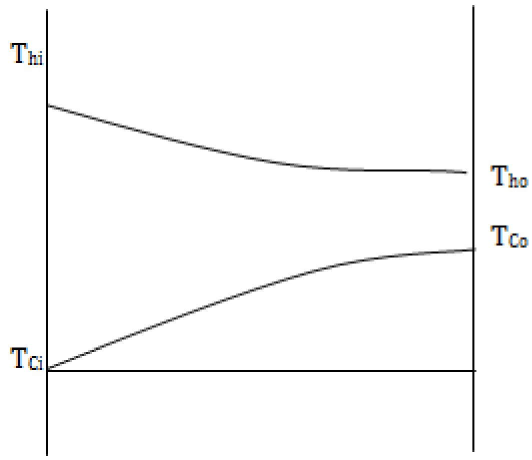
$Re > 2300 \quad therefore\ flow\ is\ turbulent\ using$

$Nu = 0.023 \times [(Re)]\ \hat{}0.8\ [(Pr)]\ \hat{}0.3$

=0.023 × (5788.80)^0.8 × (0.7119)^0.3=21.25 –Nusselt number

Heat transfer co-efficient on air side (h_i)

$$Nu = h_i . d_i \div K_f$$



21.95= (h_i × 0.0127)/0.02641

h_i=44.18w/m^2C

Heat transfer co-efficient on water side is neglected

Since, the velocity of water is very small, H_o=0

Overall heat transfer co-efficient based on outer diameter

$$Uo = 1 \div [(d_o / d_i h_i) + (d_o / 2k_f) \ ln (d_o / d_i)]$$

Outer heat transfer coefficient based on outer diameter(d_o)

$$Uo = 1/[(d_o / d_i h_i) + (d_o / 2k_f) \ ln (d_o / d_i)]$$

In above formula fouling is neglected in pipe

$$= \frac{1}{(0.0137/0.0127 \times 44.18) + (0.0137/2 \times 0.02641) \ ln(0.0137/0.0129)}$$

$$U_o = 22.696$$

$$Q = U_o A \Delta T ln$$

$$12.8695 = 22.696 \times A0 \times 5.279$$

$$A_0 = 0.1074 \, m^2$$

$$A = \Pi \, d_0 \, l$$

$$0.1074 = \Pi \times 0.0137 \times l$$

$$L = 2.495 \, m$$

This is approximately equal to 2.5 meter.
Therefore required length of pipe for proper cooling of air is only 2.5meter.

2.2. Power Consumption

Multiplication Factor

$$= \frac{I \times V}{No.of\ Units}$$

$$= \frac{(10 \times 600)}{150}$$

= 20

Constant Watt Metre Reading = 38

Power Consumption = 38×20

= 760 Watt

= 0.76 kWhr.

2.3. Heat Removal

Initial Dry Bulb Temperature = 28.8°C (at T_1 = 0)

Final Dry Bulb Temperature = 25.8°C (at T_2 =50 min)

Initial Relative Humidity = 44% (at T_1 = 0)

Final Relative Humidity = 44% (at T_2 = 50 min)

Enthalpy of air initially (H_1)=56.76 KJ/Kg

Enthalpy of air Final (H_2) = 49.17 KJ/Kg

Time = 50 min = 3000 sec

Volume of Room = 4 m^3

Volume flow rate (Vs_1) = 0.885 m^3/Kg

Mass flow rate (ma) = (V/Vs_1) = 4/0.885 = 4.52 Kg/ 50min

R.E. = $ma(H1 - H2)$ = 4.52 (56.76 – 49.17)

= 34.31 KJ/ 50 min

= 41.172 KJ/ hr

= 11.43 x 10^{-3} KJ/sec

Work done (W) = 760W = 760 x 10^{-3} kW

2.4. Consumption of water

Volume of water consumed (V_1) = $l \times b \times Height$

Tank dimensions = $82 \times 70 \times 9$ cm^3 Initially at t=0,

Volume of water consumed,V_2 = $82 \times 70 \times 8$ At t = 35min,

Volume of water consumed, $V1 - V2$ = 5740 cm^3

= 0.06 lit (approx.)

3. RESULTS AND DISCUSSION

From the above observations and thermodynamic analysis it is observed that this modified air cooler provides better cooling at lesser power consumption and a nominal length of 2.5 m of copper pipe. Air compressor cum blower can provide better cooling at lower price (24% less) compared to a one-tonne Air Conditioner. Also the water consumption is lower (45%) compared to normal air cooler as moisture gets trapped within the cooling pads. Hence a better cooling unit is obtained which can conserve water, gives more cooling effect with lesser humidity. It can replace power consuming compressor based air conditioners with low cost evaporation based Hybrid coolers. The cooler is able to deliver air and a temperature equal to that of cooling pads and hence the system is able to cool down the desired space. Proper design of the cooling system helps in reducing operational and maintenance problems as well as environmental impacts arising from system operation (Electrical and Mechanical Services Department, Hong Kong, 2006).

Figure1 (a)
Air cooler body

Figure1 (b)
Experimental setup

Table 1
Experimental Observations

Sr. No.	Time In minutes	Temperature in ^{0}C(T1)	Temperature in ^{0}C (T2)	Temperature in ^{0}C (T3)	Temperature in ^{0}C (T4)	Watt meter Reading	Water Level in cm	RH Meter Reading	
								Relative Humidity	Temperature in °C
1	0	28	28.8	25.1	28.8	38	9	RH=43%	27
2	10	27.3	24.5	24.2	24.3	40	9	RH=43%	26.8
3	20	27.1	23.6	23.3	23.2	40	9	RH=43%	26.4
4	30	26.9	22.6	21.6	21.4	38	9	RH=44%	26.2
5	40	26.6	22.4	21.5	21.4	38.5	8	RH=44%	25.9
6	50	26.5	22.4	21.5	21.4	38	8	RH=44%	25.8

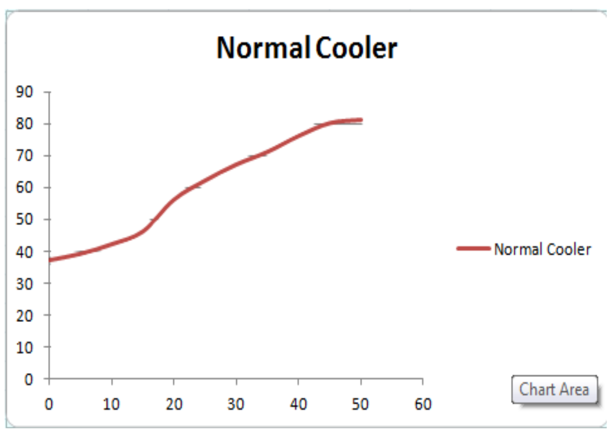


Figure 2
Relative Humidity v/s Time Graph(a)

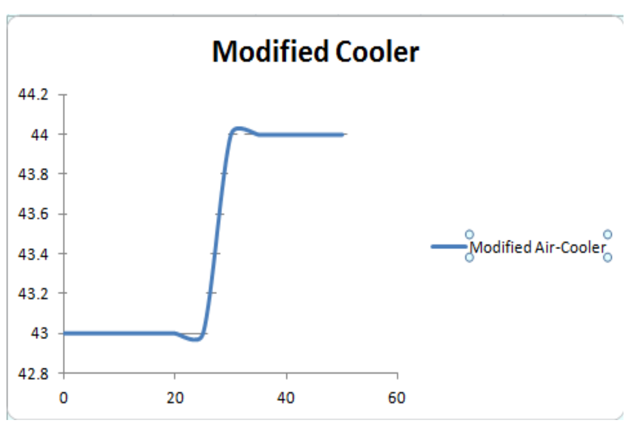


Figure 3
Relative Humidity v/s Time Graph(b)

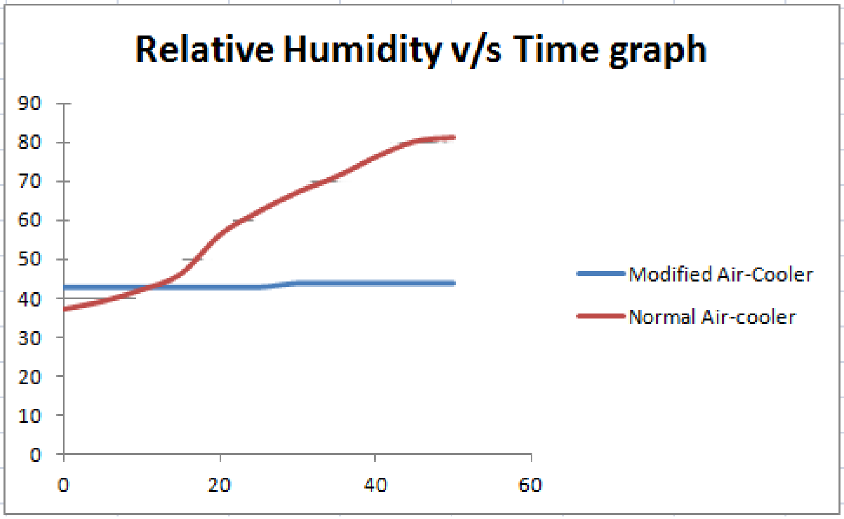


Figure 4

Relative Humidity v/s Time(in min) Graph(c)

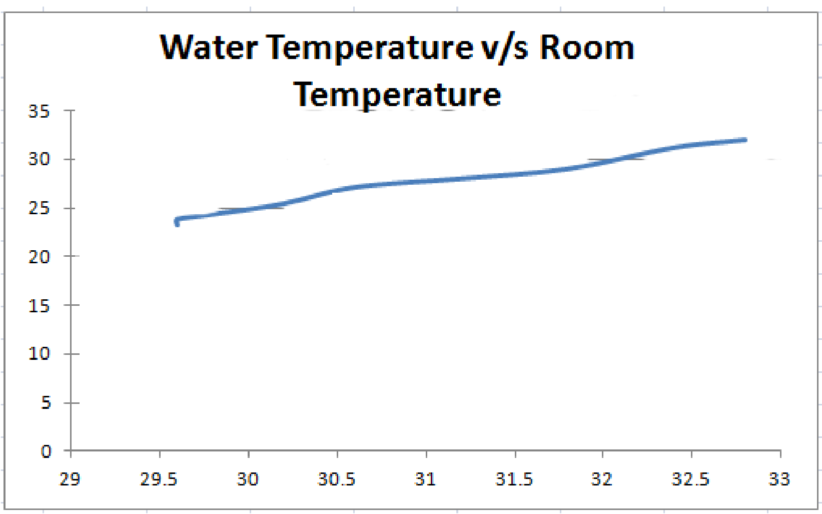


Figure 5

Water Temperature v/s Room Temperature (°C) (a)

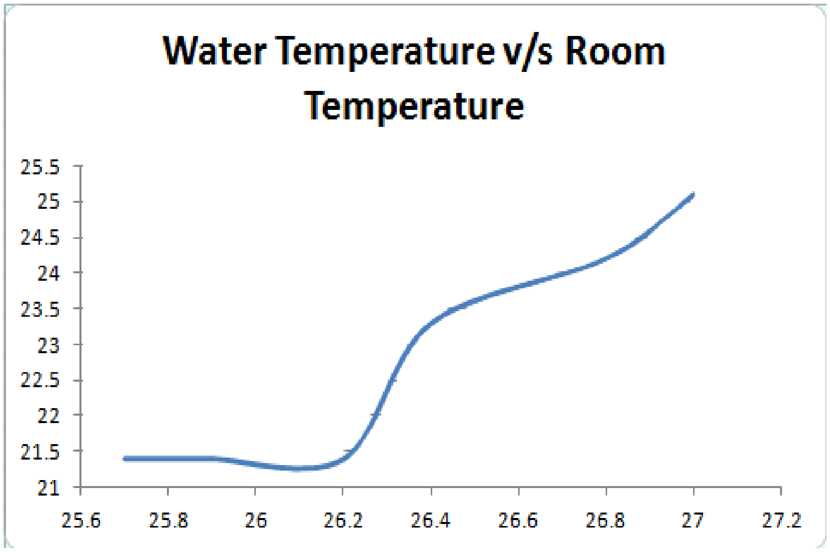


Figure 6
Water Temperature v/s Room Temperature (b)

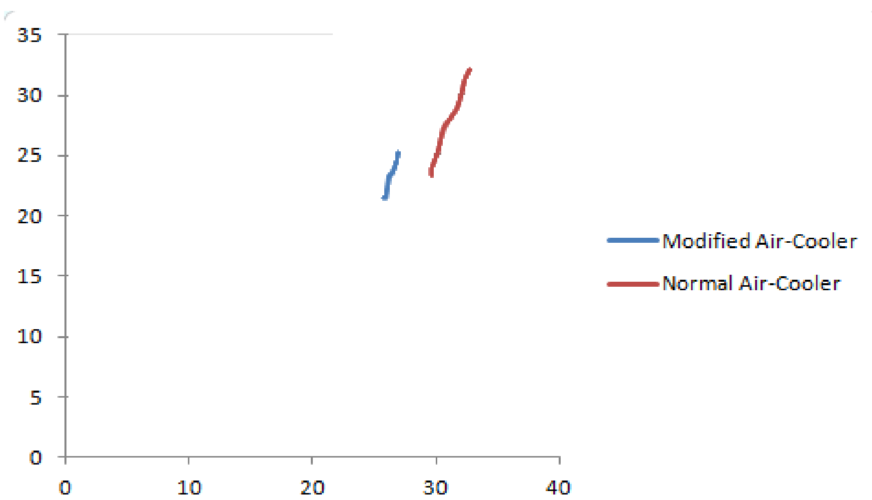


Figure 7
Water Temperature v/s Room Temperature(c)

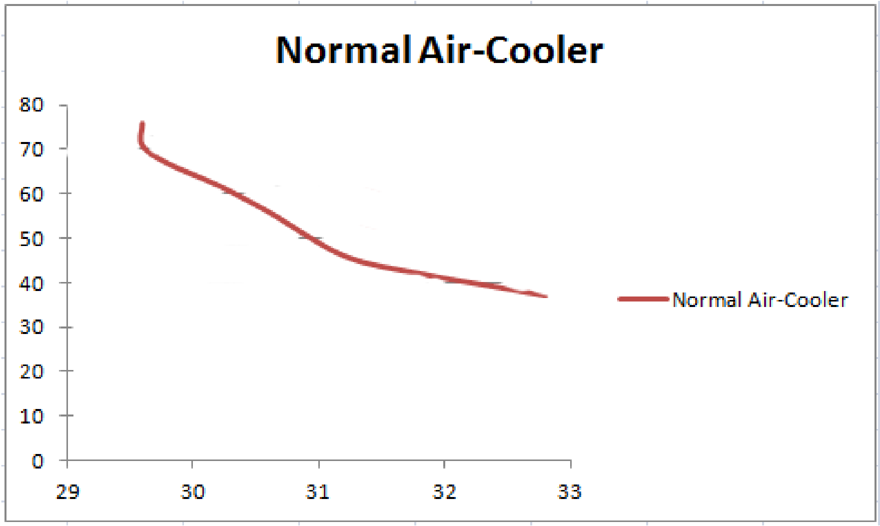


Figure 8
Relative Humidity v/s Room Temperature (a)

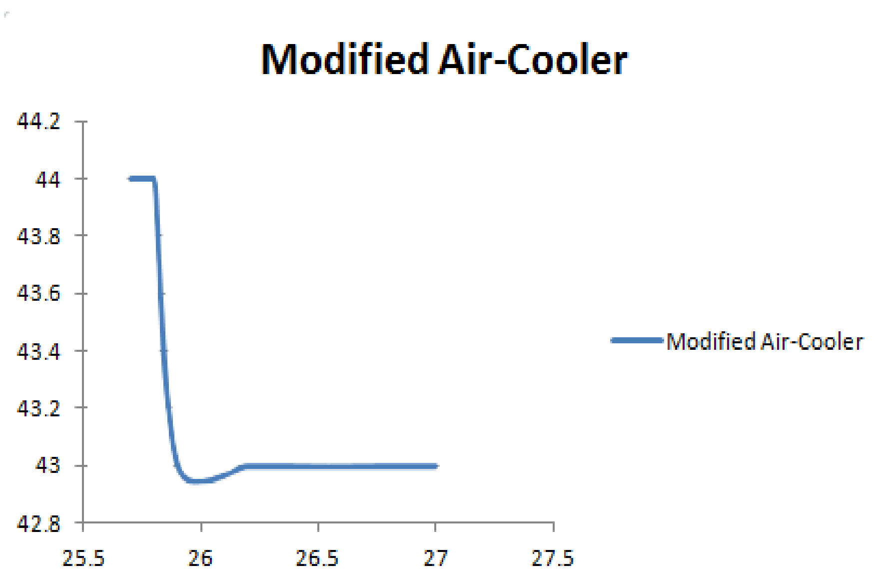


Figure 9
Relative Humidity v/s Room Temperature (b)

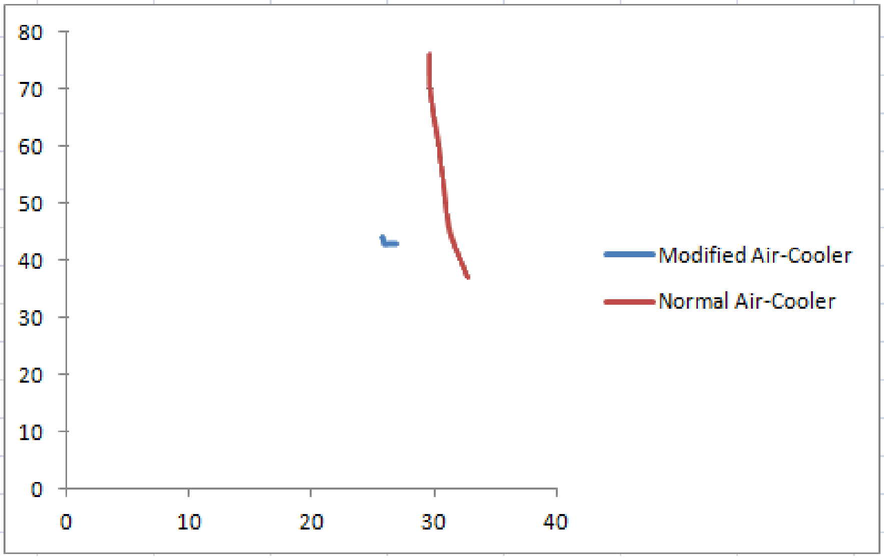


Figure 10
Relative Humidity v/s Room Temperature

4. CONCLUSION

This type of air coolers provide better cooling and consume less power. This work gives data base to find the nominal length of the pipe, air flow rate and the total power consumption. The purpose of the project was to develop a unit which can utilize the cooling effect at the cooling pads temperature, which is lower than room temperature, in the most efficient way at a lower cost than the air coolers available in market it is realized.

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NOMENCLATURE

a area of cross-section (in m^2)
C Specific heat of fluid at constant pressure ($JKg^{-1o}C^{-1}$)
D Diameter of pipe (in m)
d Diameter of Copper pipe (in m)
H Enthalpy of air in ($KJKg^{-1}$)
I Electrical current (in A)
k_f Thermal conductivity of fluid (in $wattm^{-2o}C^{-1}$)
L Length of copper pipe (in m)
l Length of water tank (in m)
m_h Mass flow rate of air in (kgm^{-3})
Nu Nusselt Number
Q Heat transfer rate (in watts)
Re Reynolds Number
t Time in second
T Temperature in °C
ΔT Change in Temperature in °C

U Overall heat transfer coefficient wattm^{-2}
v velocity of fluid
V Voltage in Volts
V_s Volume flow rate

GREEK SYMBOLS
μ Coefficient of dynamic viscosity in $Kgm^{-1}s^{-1}$
ϱ Density of air in Kgm^{-3}
κ Coefficient of heat conduction in $JK^{-1}m^{-1}s^{-1}$

SUBSCRIPT
h Hot Fluid or air
i inlet or at inlet
o outlet or at outlet
lm Logmean temperature difference

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