Air Conditioner Coupled With Indirect Direct Evaporative Cooling System

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Abstract **-** *In this project we are going to analyze the coefficient of performance (COP) of a window air conditioner coupled with indirect-direct (two stage) evaporative cooling system using radiator and cooling pad. It has been seen that by coupling of indirect direct evaporative cooling with air conditioner, the input temperature in cooling coil is being reduced due to which the load on cooling coil in evaporator get reduced , work of compressor get reduced and hence COP of system increases. This type of installment can be very useful for commercial purpose on small and large scale. This type of system mainly reduces the consumption of water which is very important key factor for dry climate and places where there is scarcity of water. Using direct and indirect evaporative cooling system individually was not much beneficial as indirect direct evaporative cooling (IDEC) is. This project has been done in the summer season of Gwalior, India. Data used in this experiment are based on the climate of Gwalior. During calculation value of DBT (Dry Bulb Temperature) and RH (Relative Humidity) is taken in such a way that most frequently occurring.*

Key Words: ***Air conditioning, Relative humidity, Effectiveness, By pass factor, Cooling load, Dry bulb temperature, Wet bulb temperature, Dew point temperature***

1. INTRODUCTION

1.1 Conventional AC System - System controls the temperature, humidity, air movement and Freshness of air. It is based on the principle of vapor compression refrigeration System (VCRS). In VCRS cycle, liquid refrigerant in evaporator takes heat from cold storage by means of air and convert itself into vapor and get compressed into compressor with increased in temperature and pressure, from where it move into condenser where refrigerant release heat to the ambient air and condensed liquid get stored in the storage tank and refrigerant after passing through the expansion valve, get converted into liquid form.

1.2 Evaporative Cooling - When air pass through a water body, air cools itself after rejecting heat water and water evaporates.

Types of evaporative cooling-

1.2.1 Direct Evaporative Cooling (DEC) - Warm air passes through cooling pad where water perpendicular to air flow continuously passes through space and this warm air when come into direct contact with water, the air gets cooled and humidified.

1.2.2 Indirect Evaporative Cooling (IEC) - Water is allowed to pass through panel and from the opposite direction secondary air stream pass, by which water gets evaporate , secondary air get exhaust and surface of heat exchanger become cool, and when primary air stream passes through same heat exchanger the air gets cooled and supplied to desired location.

1.2.3 Indirect Direct Evaporative Cooling (IDEC) - It is the combination of DEC and IEC where air first get cooled and then further get cooled and humidified both and in this configuration , effectiveness found to be more than above two systems individually.

1.2.4 Novel Configuration of IEC - It is same as the 2 stage indirect direct evaporative cooling, the difference is that we use here concept of water spraying along heat exchanger and consider wall longitudinal heat conduction concept. It has been observed that it gives 60% more effectiveness than indirect evaporative cooling system [1]

1.2.5 Evaporative Cooling Condenser - It is same as the air cooled condenser, but we use water here but, the difference of mass transfer complexity due to evaporation on exterior surface of tube[2].

1.2.6 Regenerative Evaporative Cooling - In this system, some cooled air is taken and mixed with ambient air so that the efficiency of system increases. It is couples with liquid cooled water chiller system to accomplish energy conservation[3].

The objective of this study is to increase the efficiency of system so that we can reduce the energy consumption.

1.3 Literature Review -

Since the concept refrigeration has evolved there has been a lot of work that is done to enhance the refrigeration.

But here we are analyzing the 2 stage indirect direct evaporative cooling system, but before we analyze it, we should know about the drawbacks of direct and indirect evaporative cooling system that has forced us to combine them. Earlier, direct evaporative cooling system has been developed which cool and humidified the air but the humidification was not in our control in moist areas that's why indirect evaporative cooling is developed where air means to cool only. But when these above 2 systems is coupled then new system is arrived that is indirect direct evaporative cooling system (IDEC) which has high efficiency comparing to both type of cooling system.

There are many scholars who contributed a lot of effort in the field of IDEC system and did practical to enhance the effectiveness of system.

Kulkarni and Rajput (2011) theoretically investigated the performance of indirect-direct evaporative cooler in Bhopal, India during hot and dry climates. The study use plate type wet surface heat exchanger and rigid cellulose and aspen fiber in rectangular, semi cylindrical and semi hexagonal shapes as cooling pad. The outcome indicates that combined indirect -direct evaporative cooling system reduced the inlet temperature of air below its wet bulb temperature[4].

Fouda and Melikyan (2010) developed mathematical model for analysis of heat and mass transfer between air and water in direct evaporative cooler. The result shows that cooling efficiency increased with increasing of cooling pad thickness and decreased with increasing inlet air velocity[5].

Heidarinelad (2009) experimentally investigated the performance of two stage evaporative cooling system in Iran under wide variety of climate conditions and found that IEC and IEC/DEC effectiveness varies over a range of 55-61% and 108-111% respectively and water consumption 55% more than DEC[6].

Jain (2007) developed two stage evaporative cooler to improve cooling efficiency and tested in Ludhiana, India. The outcomes indicates that through two stage evaporative cooling, temperature drop ranged from 8 to 16°C and effectiveness ranged from 1.1 to 1.2 over single evaporation[7].

Camargo et al. (2005) investigated performance of a direct evaporative cooler in Brazilian city. The study uses rigid cellulose medium with wetted surface area of 370 m^2/m^3 for analyzing the performance of different pad materials. The outcome indicates that effectiveness is more at higher dry bulb temperature and lower air velocity[8].

EI-Dessouky et al. (2004) experimentally investigated the performance of two stage evaporative cooler in Kuwait. They set up indirect evaporative unit followed by direct evaporative unit. The result indicates that effectiveness of IDC/DEC system varies over a range of 90-105%[9].

2. SYSTEM DESCRIPTION

In this project we will couple some additional apparatus with conventional window air conditioner for indirect-direct evaporating cooling (two stage cooling) purpose so that coefficient of performance can be increase. Here, for indirect cooling purpose we will use radiator and for direct cooling we will use honeycomb pad.

This whole system comprises-

1. Radiator - The main purpose of radiator is for indirect cooling of air. Basically radiator is a heat exchanger in in which water is passed through the core of radiator. Cores of radiator are generally made of copper, bronze and aluminum. When ambient air ambient air forced into it with the help of air fan then air gets cool. In this project we are using aluminum cores radiator. We can take the radiator of size 365×348×16. Where, 365×348 represent the area of cross section and 16 represent the diameter of tube from which the water flows. The entire dimension is in mm.

2. Cooling Pad - The purpose of cooling pad of honeycomb structure is for direct cooling of air. We choose coconut fiber of dimension 91.44×60.96×5 because it is easily available and has effectiveness of 0.7 which is good enough[10]. The entire dimensions in cm. When hot air passes through one side then it comes in contact with water and heat transfer take place. In this way air becomes cool and humid.

3. Air fan - Air fan is used for forcing ambient air to the system.

4. Submersible pump - Submersible pump are used to circulate water over cooling pad and radiator. It is the normal submersible pump which we are using in desert cooler. We can use 50-100 watt pump which can sufficiently discharge the water at some height.

5. Water basin - An open cuboidal shape of dimension 60×40×20 of Stainless steel can be used as a water basin where Condensed liquid can be stored.

6. Pipes - Pipes are used to transport the water from one place to other. We can use rubber pipes because of its flexibility and durability. We can use pipe of .75 inch diameter and length according to need.

7. Conventional window air conditioner - Here we are using a whole set up of window air conditioning system. We will couple this whole set up with indirect-direct evaporative cooling system.

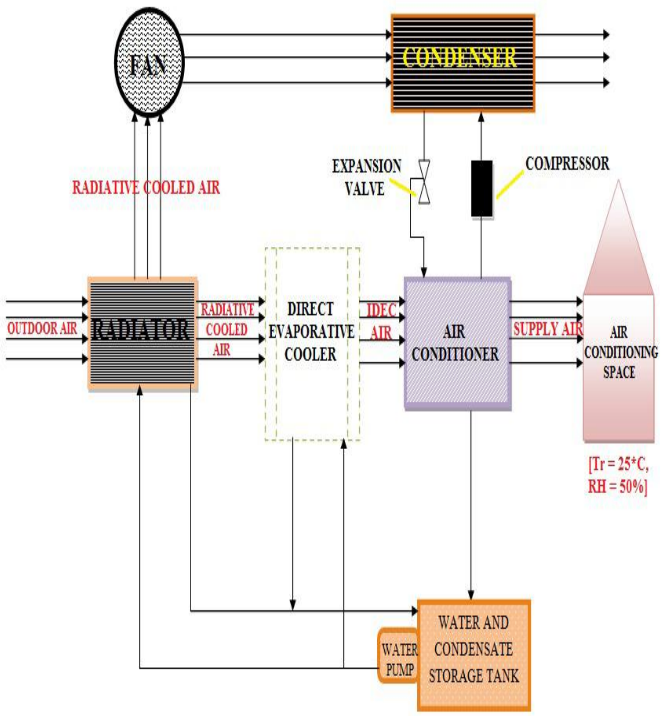


Fig-1: Air conditioner coupled with indirect direct evaporative cooling system

In an hot and dry climate, Process begins from when ambient air of high and low temperature and relative humidity respectively enters into a radiator where it gives heat to water passing in radiator tubes and become cool with no addition in moisture as per the effectiveness of radiator. Some of the radiative cooled air is bled off and used in place of ambient air, and this radiative cooled air is sent to the condenser where it takes all heat from the condenser and converts all moisture into condensed liquid of low temperature and store in tank. The remaining radiative cooled air moves to the cooling pad where it get both cooled and humidified using condensed chilled liquid and then it moves to the cooling coil where it reject remaining heat to refrigerant and cooled air is then supplied to the room. According to bypass factor of cooling coil, supplying air temperature is varied. And if inlet temperature in cooling coil is less, cooling load is less and hence inlet temperature of refrigerant that takes heat from air is less and work input of compressor is less hence, energy consumption is less. So our objective is to decrease the electricity consumption.

3. THERMODYNAMIC ANALYSIS

Here we are doing analysis for the summer season in Gwalior. Definitely, it would have average ambient condition. Properties of ambient air condition is taken after the observation and measured by thermodynamic devices. Medium that we are using is Water.

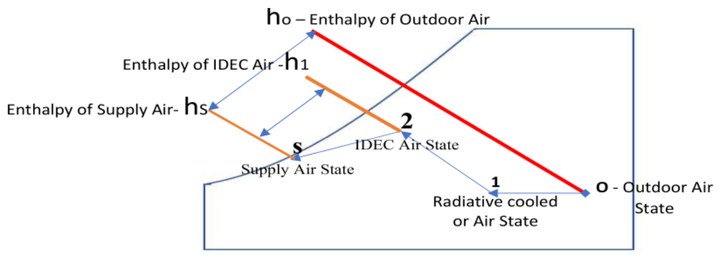


Fig-2: Psychometric representation

Ambient air condition

Dry bulb temperature $t_0 = 40^0c$

Relative humidity RH = 32%

Wet bulb temperature $t_{wbt} = 25^0c$

O-1 indirect evaporative cooling in radiator

Assuming radiator as a cross flow heat exchanger from where chilled water flows takes heat from ambient air. Air temperature coming out from radiator can be calculated by effectiveness formula

$$\varepsilon = \frac{t_0 - t_1}{t_0 - t_c}$$

Where, t_0 = inlet temperature of air in radiator,

t_1= outlet temperature of air in radiator

S.NO	$t_0(^oc)$	$t_s(^oc)$	Q (KW)
1.	36	23.2	6.43
2.	38	23.6	7.23
3.	40	24	8.04
4.	42	24.4	8.84
5.	44	24.8	9.64

t_c = temperature of condensed liquid

Normally the temperature of condensed liquid is about 20-22^{0}c and effectiveness of Radiator is about .6-.8, so we can take average value of 21^{0}c and 0.7, from where we can calculate value of t_1.We can say that value of t_1 would be about 26.7^{0}c.

1-2 direct evaporating cooling

As we are using coconut fiber as a cooling pad and we know its effectiveness value and its formula. Hence, using this we can calculate temperature of air coming out from coconut pad i.e., t_2

$$\mathcal{E} = \frac{t_1 - t_2}{t_1 - t_{wbc}}$$

And we take value of effectiveness as 0.7 and we know the value wet bulb temperature and t_1, from where we can calculate value of t_2 and that would be 25.51^{0}c. In this type of cooling humidity is constant WBT.

2-S cooling coil

Now we have the temperature at which air is entering into a cooling coil .Ideally air should come out from cooling coil at Apparatus Dew Point (ADP) but due to loss in enthalpy the temperature found to be less than the temperature at ADP. We can find the temperature of supply air with the help of by-pass factor (bpf).

$$\text{Bpf} = \frac{t_s - t_{adp}}{t_2 - t_{adp}}$$

Here we have the value of t_2 , t_{adp}, and bpf through which we can calculate value of t_s. The average temp at adp is nearly equal to 20^{0}c and bpf can be taken as .2 thus, we can calculate t_s that would be equal to 21.10^{0}c. Now air which is being supplied having a sufficient temperature to cool the room.

Refrigerant that take heat from the air moves to the compressor and since air was cooled before entering into cooling coil and gave less amount of heat to refrigerant will now require less volume in the compressor to get compressed and since entering temperature is less, then compressor work also get reduced by the relation

$$W = (n/n-1)\ mRT\ (r-1)$$

Where, n= polytropic index

R= gas constant

T= inlet temperature of gas

r= pressure ratio

And when this compressed refrigerant moves to the condenser get condensed in liquid form and this condensed liquid is collected in storage tank from where it can be utilized in radiator and cooling pad to cool the ambient air passing from them.

Here our main motive is to analyze the cooling load from which we can analyze the fluctuations in the COP.

We know that cooling load on cooling coil will be given by

$$Q_1 = \dot{m}c_p\ (t_2 - t_s)$$

Where c_p is specific heat capacity at constant pressure and its value for air is equal to 1.005 KJ/KgK. And $\dot{m}$ is the mass flow rate which can be taken in between .4 to .6 kg/s, but for our calculation purpose we can take it as .5kg/s. We can find the different value of t_2, t_s and t_1 at the different value of ambient temperature that is t_0.We know the effectiveness of radiator and cooling pad and by pass factor of cooling coil by which we can find different value at different ambient temperature.

S.NO	t_0 (^{0}c)	t_1(^{0}c)	t_2(^{0}c)	t_s(^{0}c)	Q(KW)
1.	36	25.5	25.15	21.03	2.07
2.	38	26.1	25.33	21.06	2.14
3.	40	26.7	25.51	21.10	2.21
4.	42	27.3	25.69	21.13	2.29
5.	44	27.9	25.87	21.17	2.36

Now we are going to calculate cooling load when we don't use IDEC system keeping same mass flow rate and by pass factor of cooling coil with modified formula of

$$Q_2 = \dot{m}c_p\ (t_0 - t_s)$$

From this formula we can calculate cooling load on cooling coil at different ambient temperature.

Now, we know the cooling load at different ambient temperature with or without IDEC system. Now we can compare the work compressor in both cases and can find the percentage of energy conservation.

$$\text{COP} = \frac{\text{Cooling load}}{\text{compressor work}} = \frac{Q}{W}$$

If we take COP of normal 5 star AC is 3. Then we can calculate the energy consumption through compressor with the help of above formula.

S.NO	t_0	Q_1(KW)	Q_2(KW)	W_1(KW)	W_2(KW)
1.	36	2.07	6.43	.69	2.14

2.	38	2.14	7.23	.71	2.41
3.	40	2.21	8.04	.73	2.68
4.	42	2.29	8.84	.76	2.94
5.	44	2.36	9.64	.78	3.21

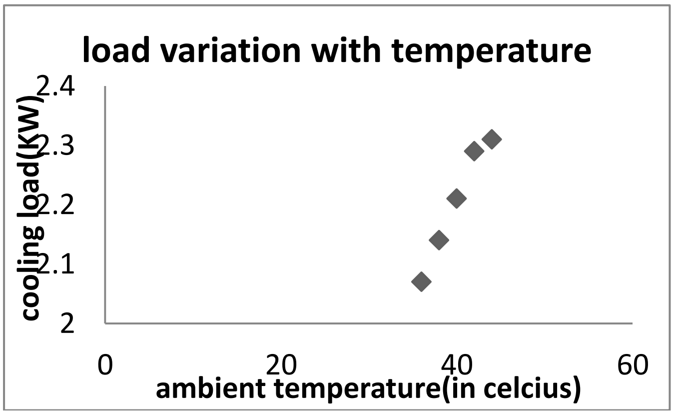
The average of work compressor are .734 and 2.676 KW in IDEC and non-IDEC system respectively

then energy conservation in % is $\frac{2.676-.734}{2.676}$ X 100 = 72.57% .

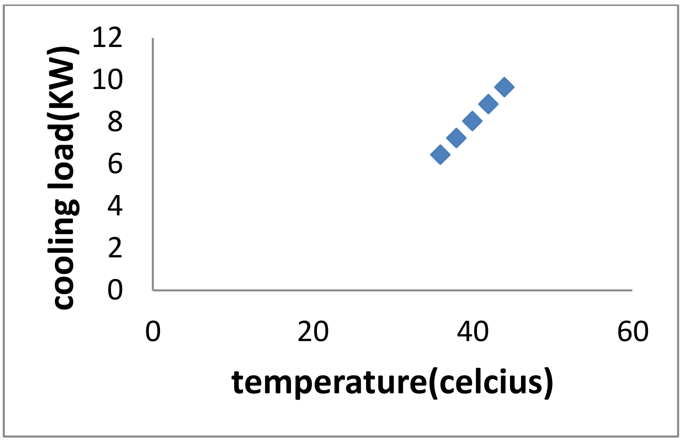
4. RESULT AND DISCUSSION

As we coupled radiator and cooling pad with our air conditioning system we have found the very low supplying temperature which is beneficial dry and hot climate. But if we use radiator only, the output temperature would be 26.7^{0}c and supplying temperature would be 21.34^{0}c without any addition in humidity which will increase the cooling load and hence more energy consumption. But if we use cooling pad alone, we get both cooled and humidified air and supplying temperature at 26^{0}c but not so cooled that we was obtaining from IDEC system, hence it will also increase the cooling load on cooling coil and again energy consumption is more. But when we uses IDEC system , the coefficient of performance (COP) of system found to be more comparing to both type direct and indirect evaporative cooling system. If we talk about condenser, the heat is taken away by the ambient air but in our experiment, some of radiative cooled air is drawn and used to pass it through condenser in place of ambient air. It will decrease the condenser pressure and hence input work decreases and ultimate energy consumption decreases.

There is a graph showing the result very clearly that how cooling load is varying with an ambient temperature.



Now the graph is made between the same but this time we are not using IDEC system.



From these two above graphs we are very clear about cooling load variation with ambient temperature using IDEC and non-IDEC system respectively. And we also analyzed that using IDEC system as compare to non-IDEC system gives us 70-75% energy conservation which is very significant in the field of air conditioning. Using IDEC system with our air conditioning system gives many advantages like one we have discussed before that electricity consumption reduces, another main advantage is that this system is health conscious because it is providing continuous fresh air so that no one suffer breathing problem due to lack of oxygen and no one gets headache and suffocation problem. Also by maintaining the desired relative humidity there cannot be skin dryness and eye irritation problem. Using condensed chilled water we have reduced water consumption and this condensed liquid may used in radiator and cooling pad to cool and humidify the air, this condensed water lower the air temperature to such extent when air gives heat to refrigerant , it doesn't have high specific volume so that the size of compressor reduces.

5. CONCLUSIONS

Using IDEC system comprising radiator made up of aluminum of tube and shell types and cooling pad made of coconut fibers which allows water to get humidified and cool gives us the better result and sufficient supplying temperature compare to DEC and IEC system. This both type of system individually had a limitations which was not sufficiently desirable for us and didn't give us a desirable result. Using IDEC system we come to conclude that in hot and dry climate such as in Gwalior we can reduce our energy consumption up to 70-75% and water consumption to some extent. IDEC system can be coupled with any type of AC system either it is central AC system, domestic AC system, medical, library AC. So by analyzing IDEC system we can conclude that this system would be beneficial for upcoming and current society in matter of saving energy, water and of course in matter of air conditioning too.

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