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Review on automatic vapour compression refrigeration indirect evaporative cooling-direct evaporative cooling hybrid air conditioner

Dhanish Shah[1,*], Ishan Thakkar[2], Manish Ramavat[3], Praharsh Sheth[4], Yash Patel[5], Digbijoy Sarkar[6]

[1,2,3,4,5]Students of Mechanical Engineering, ITM Universe, Vadodara 390510

[6]Lecturer, Department of Mechanical Engineering, ITM Universe, Vadodara 390510

*Corresponding Author: dhanishshah8@gmail.com

Abstract. The fully automatic hybrid air-conditioning system has verified as an technology which fully utilizes energy and works very efficiently for air-conditioning of the buildings. A rightly picked hybrid cooling arrangements provide huge cut in waste of energy and improves co-efficient of performance based on different climates. By providing sensors, which measures the temperature and relative humidity present in the atmosphere, we interface this sensors to the microcontroller and by programming these sensors, the system we got, is working automatically according to the change in temperature and relative humidity, which provides the best human comfort conditions. Usually people use Evaporative cooling system and Simple Air-conditioner (Vapour compression refrigeration system). All these systems have their merits and demerits. Basic study of all these Direct Evaporative Cooling–Indirect Evaporative Cooling–Vapour Compression Refrigeration is discussed in this paper. Our system will take their advantages for flexible uses. This is very frequently used system in domestic as well as industrial conditions. It will be very useful and affordable for the common people as well as small and medium scale industries. Integrated cooling unit can be used in various environmental conditions as an eco-friendly and power efficient system.

1. Introduction

Refrigeration is a process of maintain and reduce the temperature below atmospheric temperature of the different types of refrigeration systems. Generally in domestic application we used Vapour Compression Refrigeration System (VCRS).[1]VCR systems are generally used everywhere. It consumes a lot of power and releases harmful gases into atmosphere. IEC system is an alternative to overcome from this issue. It works same as other systems in hot and dry composite climates. By using this system we can save and use large amount of power consumption. [2] IEC is a system which declines the temperature by evaporating water. It's main aim is to drop the temperature of evaporative coolers. The energy for evaporation process is grabbed from atmospheric air. It is quite easy in construction and cheaper compared to VCR system. To cure the negatives of DEC system IEC system are used.[3] As the power consumption is more in VCR system the alternative systems were chosen individually. By doing this the efficiency and output was not achievable every time. So, hybrid system came into existence which consists of DEC and IEC system. Due to this the overall efficiency of product increased. Power consumption was less as compared to VCR system.[4]

2. Direct Evaporative Cooling

Evaporative cooling works on the fundamental methods of mass and heat transfer wherein air and water acts as working fluids. Direct Evaporative Cooling is the process in which the water dehydrates into the air which is to be chilled concurrently increases the humidity of it and the thermodynamic process acting is called Adiabatic Saturation. [5]

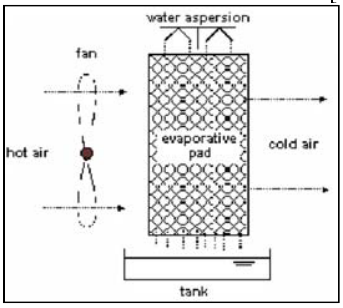

Figure 1. Direct Evaporative Cooling [5]

From the energy conservation equation for a fundamental control surface and analysis of the transfer of heat and mass in between the humid air and the water, we can obtain mathematical model for direct evaporative cooling air conditioning system. With the help of the convective transfer coefficient and mass air flow, we can obtain Eq. 1 where convective transfer co-efficient is determined from Eq. 2.[6]

$$\varepsilon = 1 - \exp\left(\frac{-h\ A}{ma\ Cpu}\right) \tag{1}$$

$$Nu = 0.10\left(\frac{le}{l}\right)^{0.12} Re^{0.8} Pr^{1/3} \tag{2}$$

Where,

ε = Cooling effectiveness	Nu = Nusselt number
h = Enthalpy	Re = Reynolds number
A=Area of heat transfer surface	l_e = Characteristic length
m_a = Mass flow	l = Pad thickness
C_{pu} = Specific heat of humid air	Pr = Prandtl number

We can get the reduction in outlet air temperature by increasing the width of the pad, which leads to increase in mass of the pad, which increases the time for achieving the steady state condition. In incremental front end velocity case, the outlet air gets cooled and rapid steady state condition is achieved with the drop in temperature. The cooling efficiency is propositional to the thickness of pad, which is the contact surface of water and air. So the increase in pad thickness leads to increase in efficiency. The contact of air and water in pad medium describes the increase in front end air velocity with decrease in cooling efficiency. [7] A test on different pad materials was carried out for the evaluation of their performance in evaporative coolers. For that the special system is made up, and the four materials, which are Wood wool, Coconut Coir, Stainless Steel Wire Mesh and Khus are tested. It was concluded that water consumption rate was highest in Wood wool pad and largest velocity of air was found in Coconut coir at same fan speed. Whereas least water consumption was observed in Stainless Steel Wire Mesh Pad.[8] Pads are bounded to have good thermal characteristics, satisfactory pressure and good water consumption. The reduction in air speed with the increase in pad thickness may become the optimum point.[9]

3. Indirect Evaporative Cooling

3.1 What is IDEC?

The main principle of IDEC is to provide cooling by the transfer of heat and mass in between the cooling water and air. In this system air is separated in two parts where one has dry surface and other is wet. So, the primary air stream has cooling without humidification and the secondary air stream has both cooled air and water.[10]

3.2 Classification of indirect evaporative cooling system: Based on cycle

3.2.1 Classic Indirect Evaporative Cooling(C-IEC)

Figure 1 shows the working principle of this type of system. The atmospheric air or primary air is moved to the dry channels and transfers heat towards wet channel through the surface. Therefore primary air coming out at outlet will have less temperature as compared to inlet, due to the heat that has been transferred. The secondary air stream flowing through the wet surface contains water, the heat transferred between the dry and wet channels is soaked by the water as latent heat and will get evaporated, increasing the humidity of this air at outlet.[11]

Merits: Primary air stream gets cooled without changing humidity.

Demerits: Cooling of primary air stream without change in humidity is depended on the secondary air stream's wet bulb temperature.

3.2.2 *Regenerative indirect evaporative cooling(R-IEC)*

In regenerative type cooling, the primary cooled air is utilized. Some portion of this primary cooled air is used to regenerate cooling so that the final cooled air gets so much cooler than the ordinary CIEC..[12]

Advantages: Primary air gets cooled below the wet bulb temperature of primary air.

Disadvantages: Rate of flow of primary air is lesser as compared to C-IEC.

3.2.3 *Dew point indirect evaporative cooling*

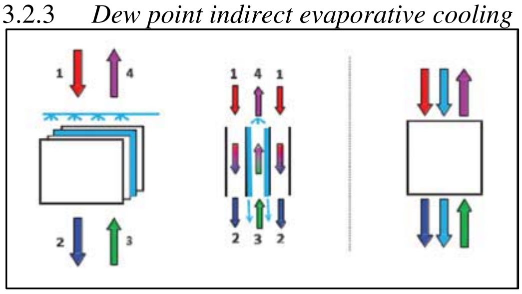

Figure 2. Classic Indirect Evaporative Cooling System[12]

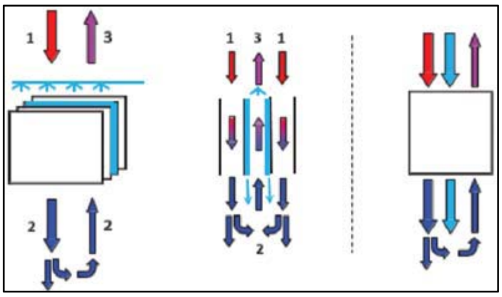

Figure 3. Regenerative Evaporative Cooling

This type of cycle consist of multiple stages as shown in figure The first stage is similar to the R-IEC but the remaining primary air is send to another stage as primary air as shown in figure for further cooling and is cooled by some portion of primary air released at outlet. The cooling process of primary air will last near the primary air's dew point temperature at the inlet therefore this is known as dew point indirect evaporative cooling.

Advantages: Primary air is cooled about near the dew point temperature.

Disadvantages: Primary air flow decreases with every stage.[11]

3.2.4 *Maisotsenko indirect evaporative cooling (M-IEC)*

Developed by Valeriji Maisotsenko, which describes the supplementary solution for the cooling of primary air along towards near to the inlet air's dew point temperature. The main singularity of this cycle is that has multiple passages from its dry channels into the wet channels. The primary air flows towards their own dedicated dry channels. As presented in figure, each dedicated dry channel contains the warm atmospheric air and transfers heat through heated surface to the wet channels. It can also be incurred from the figure that the outlet of primary air will be cooled to the temperature near the dew point temperature of inlet primary air. The secondary air is same atmospheric air flowing inside their dedicated dry channels, but having multifarious sections into the wet channels, where water gets evaporated and continues to add moisture in its path to the outlet. The final primary air's temperature at outlet can be near to the inlet primary air's dew point temperature.[13]
Merits: Primary air is cooled almost near to the dew point temperature without altering the moisture content.

Demerits: Complicated flow scheme inside the equipment and composite construction.

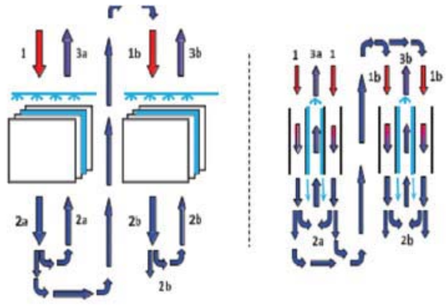

Figure 4. Dew Point IEC System[13]

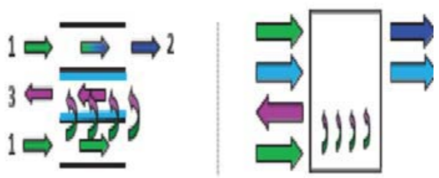

Figure 5. Maisotsenko Indirect Evaporative

It was found C-IEC is applicable for most of the region where the climate is dry. Consumption rate ranged from 2.1 to 3 KW/h Cooling output ranges from 3.1-4.3 $W/m^{3/h}$ air flow rate.[14]

From the performance of M-IEC at Greek climate conditions, when this cycle was applied to most of the Greek cities an impressive result of effectiveness ranging from 97% to 115% was found along with low energy consumption . [15]

4. Vapour Compression Refrigeration

Air-conditioning unit is a combination of four basic components, which are namely compressor, expansion valve, condenser, and evaporator. A refrigerant is a working medium in the refrigeration system which rejects the heat in condenser. The coefficient of performance increases and reduction in the mass flow of refrigerant takes place as the cycle is with sub-cooling and superheating hence finally the compressor work reduces. The main function of condenser is to cool down the vapour refrigerant from evaporator followed by the compression of the refrigerant by the compressor. To reduce the compressor work and to increase the coefficient of performance we need to increase in the sub cooling and superheating.[16]

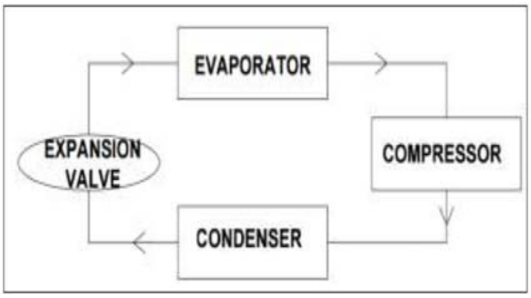

Figure 6. Simple Compression Cycle[17]

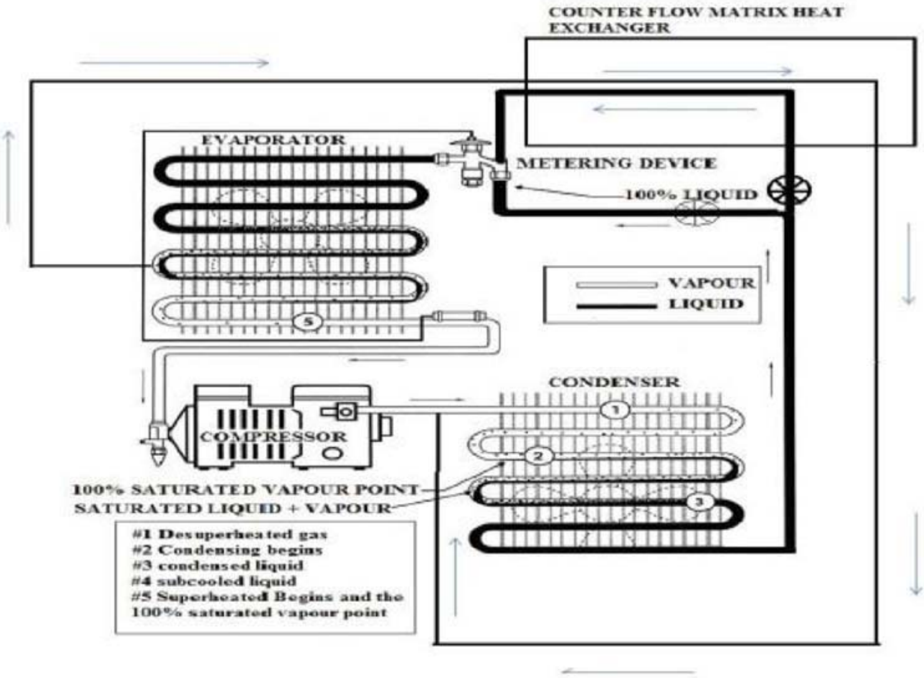

Figure 7. Cross Section Of Heat Exchanger[18]

The various eco-friendly refrigerants like HFC32, HFC152a, HC290, HC1270, HC600a and RE170 were used in ideal VCR system and their results were compared with R134a as possible substitute. By taking the consideration of various parameters of the substitute refrigerant, like Coefficient of performance, effect on ozone layer, effect on global warming, pressure ratio etc., the refrigerant RE170 was considered as the best replacement of the refrigerant R134a among all the other refrigerants. The COP of the system rises gradually with the evaporating temperature by taking the condensing temperature as constant.[17] The purpose of is to study the performance of VCRS by using a Matrix Heat Exchanger and also without it. A study has been done about the concept of analytical study of

VCRS using matrix heat exchanger in order to improvise coefficient of performance (COP) of a system. It states in order to increase COP, compressor work should be reduced and refrigerating effect should be increased. Most of the refrigeration system utilizes traditional VCR cycle which yields low COP but installing a heat exchanger would make it more efficient. Vapour refrigeration system requires huge amount of energy to operate. In order to compensate the electricity usage throughout the world we need to decrease the power consumption which can be done by decreasing energy consumption by using counter flow matrix heat exchanger and as a positive outcome coefficient performance of refrigeration system may increase. [18]

5. Hybrid VCR IEC DEC Cycles

5.1 Air Conditioner with Evaporatively cooled Condenser

A new invention in air conditioner is tested by placing the cooling pads on both sides of the system and pouring water over it to low the temperature of air in advance. After this, it passes through the condenser. So in conclusion, the thermodynamic feature of this device have amended significantly and has led to reduction of power consumption by nearly 16% and increase in COP by around 55%. [19]

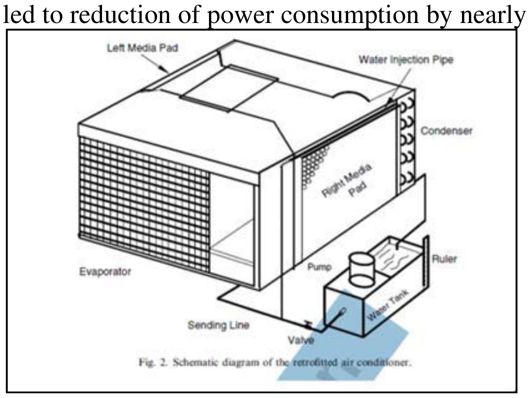

Figure 8. Typical Diagram of Window Air Conditioner[19]

5.2 Two Stage IDEC system with different shapes and cooling media

The saturation efficiency of direct evaporative cooling system ranges from 71.9% to 98.3% while the resultant efficiency of the system ranges from 74.3% to 119.5% and the outlet temperature of air ranges from 27.3 0 C and 32.4 0 C. The ability of cooling in direct cooling mode ranges from 3240 and 45427 kJ/h while for combined mode, it is in between 4679 and 43771kJ/h for alternative combinations. In direct stage of Evaporative cooling, the various cooling media and non identical shapes are manufactured, which are of rectangular, semi-cylindrical and semi-hexagonal types of shapes used in direct stage as cooling pads made up of different cooling materials like wood wool, rigid cellulose and aspen fiber. [20] Having various working environmental situations, it is concluded that IEC effectiveness changes from 55% to 61% and IDEC effectiveness ranges from 108-111%. From the analysis, it shows that the two stage IDEC system uses 55% more water than direct evaporative cooling system and consumes only 33% of power used by VCR systems. So this unit can be used in different environmental conditions as eco-friendly and energy saving system.[21]

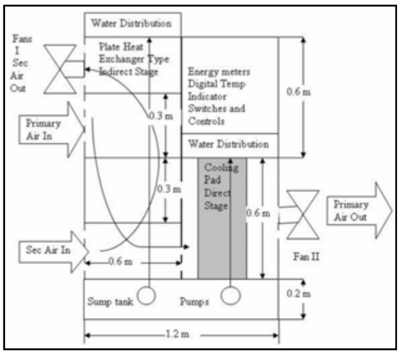

Figure 10. Experimental Setup Of Two Stage IDEC Cooler[20]

6. CONCLUSION

This hybrid system is environment friendly which does not release harmful gases and provides fresh air to the space. It also has overall high co-efficient of performance. By using above modification theories of VCR IEC DEC cycles, we can modify ordinary coolers and air conditioners to provide better output with minimum input. It is very comfortable to use as it works according to the comfort zone of human being, Here we are considering the temperature ranges of dry bulb temperature 19-25^{o} C, wet bulb temperature 11-19^{o} C, Relative Humidity 30% - 70% which is preferred from ASHARE Human comfort chart, and it is cost effective as it consumes overall less energy in comparison to different systems and provides better human comfort conditions.

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