A State Art Review of Combined System of Direct Evapo-Rative Cooler and Conventional Air Conditioner with Eco-Friendly Refrigerant

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Abstract. In this paper, a thorough review of performance investigation of combined system of direct evaporative cooler and conventional vapour compression air conditioner is presented. The performance of evaporative-vapour compression based air conditioning system also compared for different applicable climate such as hot and dry, hot and humid and moderate hot etc. Also discuss the new ecofriendly refrigerants which are used in conventional vapour compression air conditioning system. On the basis of study of literatures it is found that HCFC22 is going to be phase out due to its unfavorable impacts related to environment e.g. ODP and GWP. Vapor compression refrigeration systems are extensively used to provide cooling or freezing for different applications which expend 15% of globally electricity and contribute to approximately 10% of greenhouse gas emissions globally. It is reported that the need of cooling systems is expected to grow tenfold by 2050. Therefore, it is critical to make the system for human comfort and altered the R22 by new eco-friendly refrigerant. Introduced new ecofriendly refrigerant R1234ze(E) can be used as long-term alternative to R22 for residential air-conditioning applications.

Keywords: Evaporative cooler, conventional air conditioner, applicable climate, ecofriendly refrigerant.

1 Introduction

The temperature of the environment continuously increases with global warming over the years. It is not easy to stay inside deprived of a perfect cooling system. Thus the need and use of air conditioner has been increased since last few years. In hot climate, air conditioning can prevent heat stroke, dehydration from excessive sweating and other problems related to hyperthermia. Air conditioning (including filtration, humidification, cooling and disinfection) can be used to provide a clean and safe atmosphere in domestic, offices, shops cinema halls, hospitals, computer centers, libraries, restaurants, hotels, auditoriums, malls, museums, ships etc. It is also important to be aware of some of the possible issues they can create. The air condition ing system operating under hot and dry condition supplies cold and dry air. After the studies it has been observed that dry air has following effects on human body:

Nomenclature

h_s	specific enthalpy of air (in kJ/kg)
ε	effectiveness of the evaporative cooler
m_a	rate of mass flow of air (in kg/s)
Q	cooling load (in kW)
Q_r	rate of cooling in the conditioned space (in kW)
T	temperature (in ℃)
Φ	relative humidity (in %)
ω	humidity of air (in kg/kg of dry air)
BPF	bypass factor of cooling coil

Subscript

1	Proposed system
2	Conventional system
o	ambient condition
ec	evaporative cooler
c	cooling coil
s	supply
cs	conditioned space
scr	sensible cooling rate

Acronyms

COP	coefficient of performance
DEC	direct evaporative cooler
DPEC	dew point evaporative cooling
CCC	conventional cooling coil
ICE	indirect evaporative cooling
IEC	indirect evaporative cooler
TR	tons of refrigeration
VCRS	vapour compression refrigeration system
DBT	dry bulb temperature (in ℃)
DPT	dew point temperature (in ℃)
WBT	wet bulb temperature (in ℃)
ADP	apparatus dew point (in ℃)

i. Excessive air conditioning can have an adverse effect on skin, causing it to dry out i.e. skin moisture evaporation can cause skin irritation and eye itching.

ii. By breathing dry air human body may faces the respiratory ailments health issues such as asthma, bronchitis and nose bleeds or general dehydration since body fluid are depleted during respiration.

iii. When human body is exposed to dry air for many years causes serious health problem related to joint pain in the people of all age group. The synovial fluids of the joints which act as lubricant begin to dry up due to evaporation and this may allow the bones to rub against each other painfully.

iv. Researchers have research on the effect of cold and dry air of air conditioner on the arthritis patients. Researchers have found that air conditioner cannot create humid inside the room during hot and dry climate, which makes air dry and thus overall effects makes joint more painful.

The above problems can be reduced by increasing the inside relative humidity by using the direct evaporative cooler. It is noted that direct evaporative cooler alone cannot reduce the temperature of the room to human comfort condition for hot Indian climate. Hence it is desirable to use the conventional vapour compression refrigeration system along with the evaporative cooler which can reduce the air temperature to human comfort condition**.**

2 Literature Review

Baakeem et al. [2] presents the theoretical model for the study of a direct evaporative cooling in hot and dry climate conditions. It found that the role of the effectiveness of the cooler is not important issue to affect the exergy efficiency. The values between 0.7-0.8 are the most appropriate value of the effectiveness of the cooler when working under the summer climate conditions. ***Lin et al. [3]*** experimentally investigates the cooling capacity of a cross-flow dew point evaporative cooler under various conditions. It revealed that the cross-flow cooler is able to achieve good cooling capacity when the supply air humidity is suitable for indoor conditions but its performance degrades when it operates under the humid climate conditions due to the limited evaporation rate. ***Chauhan and Rajput [6]*** experimentally investigated the performance of an evaporative–vapour compression based combined air conditioning system for a different surrounding conditions in different modes of operations on the basis of climatic conditions in Bhopal, India. They revealed that proposed system can be replaced to simple air conditioning system for dry and humid weather with a payback period of 8.1 years. ***Chauhan and Rajput [9]*** theoretically investigated the performance of combined air condoning system of evaporative cooler and vapour compression system to provide the better human comfort conditions comparatively at low cost. It has found that combined system is applicable for dry and moderate humid conditions but not suitable for very humid conditions. ***Cuce and Riffat [10]*** represent a complete review of technologies based on evaporative cooling and their applications regarding buildings. The results indicate that the evaporative cooler have a great potential to save energy in hot and dry climate conditions. ***Chauhan and Rajput [13]*** has proposed an evaporative-vapour compression system based combined air condoning system to provide the good human comfort condition relatively at low cost when working under hot and dry weather condition. It was found that this combined system is more applicable for hot and dry condition and good worked for small capacity application with a net power saving of 646.8kWh from March to May. ***Pandelidis [14] et al.*** represents a theoretical modelling to analysis of the heat and mass transfer in the two different Maisotsenko Cycle of heat and mass exchangers which are used in different types of air-conditioning system for the indirect evaporative cooling. ***Nada et al. [15]*** investigate the performance of integrative air conditioning and humidification and dehumidification desalination system for hot and dry climate condition. In this paper comparison study has been presented to identify the system configuration that have highest fresh water production rate, highest power saving and highest total cost saving. ***Chui et al. [16]*** presents a combine systems of indirect evaporative cooler and vapour compression system i.e. hybrid system. Results have revealed that the use of

IEC reduces the cooling load of the vcrs system, as a result, the hybrid system has a large potential to reduce electricity demand and energy consumption. ***Anisimov et al. [17]*** investigated the performance of a novel cross-flow heat and mass exchanger-based on Maisotsenko cycle for dew point indirect evaporative cooling in terms of thermal effectiveness and specific cooling capacity under various ambient and operational conditions. The positive results of this validation indicated that the proposed model may be successfully used for prediction of operational performance of the investigated HMX. ***Anisimov et al. [18]*** developed a mathematical model based on the modified e-NTU method to make energy equations of the indirect evaporative cooling process, so that improve the overall performance of heat exchanger. ***Wang et al. [19]*** presented an experimental investigation of an air conditioning system with using an evaporative cooling condenser to improve the overall COP. The result showed the relation between water consumption and compressor energy saving regarding to their costs. ***Cianfrini et al. [20]*** numerically analyzed the performance of an integrated energy recovery system for air-conditioning applications. This system equipped with indirect evaporative cooling system and cooling/reheating unit. The result showed that in several cases the adoption of the proposed system may imply reductions of the energy consumption of the order of 40-60%. ***Wen et al. [21]*** experimentally studied the most effective spray cooling of an air cooled heat exchanger under wet conditions. The experimental results indicate that the cooling efficiency, the

of spraying water increases, but, the air-flow of the condenser is decreased at the same time. Furthermore, the cooling efficiency of the pads reduces with an increase of the inlet air velocity. ***Kim et al. [22]*** investigated the performance of an indirect and direct evaporative cooler with 100% outdoor air (IDECOAS) which was installed in a campus building, during its actual operation in cooling and intermediate seasons. It was concluded IDECOAS provides significant energy saving potential in the intermediate season. ***Kulkarni and Rajput [23]*** present a theoretical study of performance of evaporative cooler with different cooling pad shapes and materials. It was concluded that saturation efficiency varies with mass flow rate of air i.e. it is decreases with increase in mass flow rate of air and having highest value for hexagonal shaped pad with aspen material. ***Jain et al. [24]*** studied the financial feasibility of a proposed combined system of direct evaporative cooler with an air conditioning unit for reducing the annual expenditure on electricity usage. ***Sheng and Nnanna [26]*** experimentally determine the performance of direct evaporative cooler, uses evaporating water, combined with a wetted medium to reduce the temperature of air as it passes through it. ***Fouda and Melikyan [28]*** developed a simplified mathematical model to describe the heat and mass transfer between air and water in a direct evaporative cooler. The effects of the inlet frontal air velocity, pad thickness, inlet air dry-bulb temperature on the cooling efficiency of the evaporative cooler are calculated and examined. The results reveal that the direct evaporative cooler with high performance pad material may be well applied for air conditioning systems. ***Bruno [29]*** conducted an experiment to reduce the temperature of air without the addition of moisture by using the advantages of evaporative cooling. This paper reveal the result obtained from testing a prototype cooler installed in both a commercial and residential application in a wide range of ambient conditions. It is also reveal the performance characteristics of the indirect evaporative cooler in regard to its outlet temperatures and electrical energy efficiency. ***Riangvilaikul and Kumar [32]*** present theoretical performance analysis of a novel dew point evaporative cooling system operating under various inlet air conditions such as dry, moderate and humid conditions and also under the effect of major operating parameters such as velocity, system dimension and the ratio of working air to intake air. A model was developed and simulate to optimize the system parameter and to investigate the system effectiveness. ***heidarinejad et al. [33]*** *d*iscussed the hybrid system of nocturnal radiative cooling, cooling coil and direct evaporative cooling in Tehran. This hybrid system complements direct evaporative cooling as if it consumes low energy to provide cold water and it is also able to fulfill the comfort condition but the direct evaporative alone is not able to provide summer comfort condition. ***Delfani et al. [34]*** experimentally investigated the performance of IEC system to pre-cool air for a conventional mechanical cooling system for four cities of Iran. It found that IEC can reduce cooling load up to 75% during cooling seasons and also, 55% reduction in electrical energy consumption of packed unit air conditioner can be obtained. ***Riangvilaikul and Kumar [35]*** was constructed a novel dew point evaporative cooling system for sensible cooling of the ventilation air for air conditioning application and experiments were carried out to investigate the outlet air conditions and system effectiveness at different inlet air conditions covering dry, temperature and humid conditions. The result showed that wet bulb effectiveness spanned between 92 and 100% and dew point effectiveness between the 58% and 84%. ***Wu et al. [40]*** present the theoretically analysis of the heat and mass transfer between air and water film in the direct evaporative cooler. In this paper discussed the effects of air frontal velocity and the thickness of pad module on the cooling efficiency of a direct evaporative cooler. ***Wu et al. [41]*** developed a simplified mathematical model to explain the heat and mass transfer between water and air in a direct evaporative cooler. The calculated results reveal the direct evaporative cooler with high efficient pad material may be well applied for air conditioning with reasonable options for the inlet frontal velocity and pad thickness. ***heidarinejad et al. [42]*** experimentally investigated cooling performance of two-stage indirect/direct evaporative cooling system for the various simulated weather conditions. Results show that this system can fill the gap between DEC systems and conventional vapor compression systems as energy efficient and environmentally clean alternate. ***Mendell et al. [44]*** studied the causes due which human body faces the many problems such as skin irritation, eye itching, joint pain and health issues like asthma, bronchitis and nose bleeds or general dehydration etc. ***Camargo et al. [51]*** presents the basic principles of the evaporative cooling process for human comfort, the principles of operation for the DEC system and developed a mathematical model for thermal exchanges, which allow the determination of the effectiveness of saturation. It also presents experimental results are used to determinate the convective heat transfer co-efficient and compare with the mathematical model.

As numbers of literatures are available on vapour compression air conditioner and evaporative cooler, it is important to be aware of some of the possible issues they can create. In air conditioner temperature and specific humidity of air always decrease when it passes through the cooling coil. Since there is 100% recirculation in domestic air condoner, so this cold and dry air keep on reducing the moisture content every time while recirculating through the same cooling coil and drier.

After the studies it has been observed that dry air has adverse effects on human body such as skin irritation and eye itching, health issues like asthma, bronchitis and nose bleeds or general dehydration and joint pain because of synovial fluids of the joints which act as lubricant begin to dry up due to evaporation and this may allow the bones to rub against each other painfully. Therefore make a provision of adding the moisture to increase the specific humidity in the air which passes through the cooling coil of air conditioner. For this purpose proposed a hybrid system of direct evaporative cooler and conventional air conditioner as shown in fig.

3 Refrigerant

The working fluid used in conventional air conditioner for heat transfer is known as refrigerant which also influence the performance of it. There are various CFCs and HCFCs refrigerants used in various industrial and domestic applications causes increase in ozone layer depletion and global warming. According to Montreal Protocol (1987) the uses of CFCs refrigerants have been banned in developed countries since 1996 and in developing countries since 2010. The HCFC refrigerants will be banned on European countries in 2015 and practical use limit the year 2010.Generally, R12 was used as a refrigerant in refrigerator and R22 was used in air conditioning system which has higher COP as compared to other refrigerants. But both R12 and R22 was required to replace according to the Montreal Protocol because of high ODP and GWP.

O. O. Ajayi et al. [1] investigated the comparative thermal performance and energy saving abilities of refrigerants R22 and R290 in a residential air-conditioning system. The results showed that R290 can replace the R22 without any system retrofitting. When the system was reconfigured to contain the bio-based nanoparticles, result showed that the nanoparticles improved the overall thermodynamic performance and energy consumption of R290. ***She et al. [3]*** report the scenario of cooling demand is expected to grow tenfold by 2050. Therefore, it is critical to improve the efficiency of the vapour compression refrigeration system. A comprehensive review of advanced and hot technologies is conducted for the vapour compression refrigeration system. These technologies include radiative cooling, cold energy storage, defrosting and frost-free, temperature and THIC, GSHP, refrigerant sub cooling, and condensing heat recovery. ***Oruc and Deveciog˘lu [4]*** experimentally investigated the thermodynamic behavior of R1234yf and R1234ze(E) refrigerants in air conditioners having moderate and high evaporation temperatures applications. It was found that although the cooling capacity and power consumption of R1234yf amounts were higher than that of R1234ze(E) but COP value of the R1234ze(E) was seen to be greater. Thus air-conditioning systems may be alternatively charged with R1234ze(E) as a substitute for R22 as far as COP is considered. ***Shaik and Babu [7]*** theoretically investigate the thermodynamic performance of a 0.8 TR window air conditioner with ten binary refrigerant mixtures consists of propylene (R1270) and propane (R290) based on actual VCRS cycle. The results showed that overall the thermodynamic performance of a refrigerant mixture R1270/R290 (75/25 by mass %) was nearest to R22. Thus it is a suitable environmentally alternative refrigerant to replace R22 used in domestic air conditioning applications. ***Kasera and Bhaduri [8]*** reviewed the outcome of R407C as a drop in replacement of R22. The discussion is made about the experimental studies associated with the performance of R407C. It is found that R22 give better performance as compared to R407C in various aspects such as COP, Cooling Capacity, Energy Consumption, and Exergetic Analysis but retrofitting point of view, it is best suitable refrigerant and R410A is suitable for new design. ***Sun et al. [11]*** presents a comparative analysis of thermodynamic performance of CRSs for refrigerant couples R41/R404A and R23/R404A to discover whether R41 is a suitable substitute for R23. The theoretical investigation shows that R41/R404A is a more potential refrigerant couple than R23/R404A in CRS. ***Qv D et al. [12]*** presents an AC that uses R32 assisted with one-phase vapor injection shows high energy efficiency and low discharge temperature in the heat-pump cycle, but the performance is unsatisfactory in the refrigeration cycle. An improved injection cycle consisting of one-phase vapor injection mode and two-phase injection mode is proposed and integrated into an AC using R32, which is known as IAC. ***Padmanabhan and Palanisamy [25]*** presents an experimental comparison of exergy efficiency, irreversibility at the different processes and COP of R22, and its substitutes R134a, R290 and R407C in VCRS system of an air conditioner. The refrigerant R290 is the best performer among all refrigerants but it suffers from flammability. Thus, the refrigerant R407C can considerably be used to replace R22. ***Reddy et al. [27]*** theoretically deals with the exergetic analysis of a VCRS system with selected refrigerants. It was revealed that R134a has the better performance in all respect, whereas R407C refrigerant has poor performance. ***Qureshi and Zubair [30]*** theoretically investigate the performance degradation due to fouling in a VCRS cycle for various applications. Considering the first set of refrigerants i.e. R134a, R410A and R407C, from the first and second law point of view R134a performs best in all cases. Considering the second set of refrigerants i.e. R717, R404A and R290, from the first and second law point of view R717 performs best in all cases. ***Rocca and Panno [31]*** present the results of an experimental analysis comparing the performance of a vapour compression refrigerating unit operating with R22, and new HFC fluid: R417A, R422A and R422D. From this analysis it can be see that the performance with the new tested fluids did not result as efficient as when using R22. ***Llopis et al. [36]*** presents a performance comparison, based on experimental data, of the refrigerants R404A and R507A to replace R502 in medium and low evaporating temperatures using a facility which operates with two double-stage compression cycles: the double-stage without intermediate systems and the double-stage with subcooler. ***Padilla et al. [37]*** deals with an exergetic performance analysis of a domestic vapour-compression refrigeration system originally designed to work with R12, to impact of direct replacement of R12 with the zeotropic mixture R413A. The overall exergetic performance analysis of the system working with R413A is consistently better than that of R12. ***Bolaji [38]*** presents an experimental study of R152a and R32, environment-friendly refrigerants with zero ODP and low GWP, to replace R134a in domestic refrigerator. The refrigerant R152a give better performance as compared to both of R of R134a and R32 throughout all the operating conditions, which indicate that R152a can be used as replacement for R134a in domestic refrigerator. ***Dalkilic and Wongwises [39]*** presents the theoretical analysis of performance of traditional vapour-compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a for various ratios and their results are compared with R12, R22, and R134a as possible alternative replacements. Theoretical results showed that refrigerant blends of HC290/HC600a (40/60 by wt.%) instead of R12 and HC290/HC1270 (20/80 by wt.%) instead of R22 are found to be alternative refrigerants as a result of the analysis. ***Mohanraj et al. [43]*** reviews the various experimental and theoretical studies carried out around the world with environment friendly substitutes such as hydrocarbons (HC), hydroflurocarbons (HFC) and their mixtures, which are going to be the promising long-term replacements. ***Arora and Kaushik [45]*** presented exergetic analysis of an actual VCR cycle by developed computational model. The results reveal that R507A is a better alternative to R502 than R404A. ***Ge and Cropper [46]*** described the analysis and performance comparison of a display cabinet system using refrigerant R404A and its alternative refrigerant R22. The results obtained from the simulation significantly contribute to the optimal cabinet design and operating analysis. ***Park and Jung [47]*** tested the performance of two hydrocarbon refrigerants of R290 and R1270 in a heat pump bench tester of 1 ton capacity with a hermetic rotary compressor. The result shows that these refrigerants provide good performance with reasonable energy savings without any environmental problems then consequently can be used as long-term substitutes for residential air-conditioning and heat pumping applications. ***Mani and Selladurai [48]*** conducted an experimental performance analysis of a VCRS system with the new refrigerant mixture R290/R600a to substitute the CFC12 and HFC134a. From the two major environmental impacts i.e. ODP and GWP point of view this refrigerant mixture can be used as a replacement of CFC12 and HFC134a. ***Park et al. [49]*** measured the thermodynamic performance of R433A and R22 in a heat pump bench tester under air conditioning and heat pumping conditions. It found that R433A is a good long term eco-friendly substitute to replace R22 in domestic air-conditioners and heat pumps because of its excellent thermodynamic and environmental properties with minor alterations. ***Park et al. [50]*** compared the performances of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a, and dimethyl ether to replace the R22 in residential air-conditioners and heat pumps. It has concluded that, these refrigerants provide good performance with reasonable energy savings without any environmental problems thus can be used as long-term substitutes for domestic air-conditioning and heat pumping applications. ***Xuan et al. [52]*** are presented a ternary near-azeotropic mixture of HFC-161 to replace R502. Without any alteration to system components, drop in experimental tests are performed on a VCRS plant designed to use R404A, a major substitute for R502. The new refrigerant HFC-161 can achieve a high level of COP and can be considered as a promising retrofit refrigerant to R502. ***Aprea and Greco [53]*** are experimentally compared the performance of R22 and R407C. The investigation has revealed that R22 performs better as compared to R407C due to better compression process because of a number of factors, including the facts that the isentropic and volumetric efficiencies of the semi-hermetic compressor are better as compared to R407C. ***Yumrutas et al. [54]*** presented a computational model based on the exergy analysis for the performance investigation of a VCRS cycle. This theoretical investigation shows that the evaporating and condensing temperatures have strong effects on the exergy losses in the evaporator and condenser and on the second law of efficiency and COP of the cycle but little effects on the exergy losses in the compressor and the expansion valve. ***Aprea and Greco [55]*** are deals with the substitution of R22 in an experimental VCRS plant with the zeotropic mixture R407C. The overall exergetic performance of the VCRS plant working with R22 is consistently better than that its substitute.

This paper also presents the study of new ecofriendly refrigerants. There are the several theoretical and experimental investigation done to replace R22 can be seen in table2. The refrigerant R22 has been used mostly in residential air-conditioners and heat pumps for the past few year and its used has been maximum as compared to the other refrigerants. According to Regulation (EU) No. 517/2014 [58], the refrigerants having more than value of 750 GWP will be banned after January 01, 2025 to use in split-type air conditioning system in which 3 kg or less quantity of refrigerant is charged. The replacement process of R22 is still continuing. Although R407C and R410A having zero ODP but they have high GWP which are used in air-conditioning devices manufactured over the last years. The refrigerants having zero ODP and low GWP are restricted by some amount because of their flammability characteristic. The recent and future ecofriendly refrigerants to replace the R22 shown in table3.

Table1. Brief review of work done related to the proposed work in the literature

Author	Types of work	Cooling Technique	Applicable climate	Outcomes
Baakeem et al. [3]	Theoretical analysis	DEC	Hot and Dry	It found that the effect of the cooler effectiveness on the exergy efficiency is not major issue and the suitable value of the effectiveness of the evaporative cooler is to be between 0.7-0.8 when working under the summer climate conditions

Lin et al. [5]	Experimental analysis	Cross flow DPEC and de-humidification	1. moderate air humidity condition 2. Hot and Dry	It revealed that the cross-flow cooler is able to achieve good cooling capacity when the supply air humidity is suitable for indoor conditions but its performance degrades when it operates under the humid climate conditions due to the limited evaporation rate.
Chauhan and Rajput [9]	Theoretical investigation	DEPC+CCC	1.Hot and Dry 2. hot and moderate humid	1. Proposed system is applicable for dry and moderate humid conditions except very humid conditions. 2. The system is good working with an average net monthly power saving of 192.31kW h for hot and dry conditions and 124.38 kW h for hot and moderate humid conditions. 3. It has found that the saving of cooling load on the cooling coil is maximum with a value of 60.93% at 46ºC and 6g/kg specific humidity.
Chauhan and Rajput [6]	Theoretical investigation	DEC+CCC	Hot and Dry	1. It was found that the saving of cooling load on the coil is maximum in the month of March with a value of 64.19% due to lower outside temperature and minimum in the month of May with a value of 27.36% due to higher outside temperature. 2. This system is applicable for hot and dry condition and good worked for small capacity application with a net power saving of 646.8kWh from March to May.
Nada et al. [15]	Theoretical investigation	A/C and humidification-Dehumidification System	Hot and Dry	1. The main purpose of the proposed system was that to save energy of the air conditioning system and at the same utilizing the system in fresh water production for large capacity air conditioning system. 2. In this paper comparison study has been presented to identify the system configuration that have highest fresh water production rate, highest power saving and highest total cost saving.
Wang et al. [19]	Experimental research	DEC+CCC	-	1. The experiments compared the effect of DEC condenser with conventional air cooled condenser. 2. The result revealed that the saturation temperature drop through the condenser increased from 2.4ºC to 6.6ºC by using the evaporative cooling condenser. 3. There is increase of the mass flow rate of refrigerant that went into evaporator. Because of increase in liquid mass entering the evaporator, the result of increase in COP from 6.1% to 18% and power reduce up to 14.3% on the compres-

				sor was achieved.
Cui et al. [16]	Theoretical investigation	IEC+CCC	Hot and Humid	1. Presented combine systems of indirect evaporative cooler and vapour compression system. 2. The result shows that humid outdoor fresh air can be pre-cooled to a temperature below its dew point temperature when the wet bulb temperature of the exhaust air is lower than the dew point temperature of the outdoor air. 3. It is also shows that the use of indirect evaporative cooling reduces the cooling load of the vapour compressor system, as a result, the hybrid system has a large potential to save energy.
Cianfrini et al. [20]	Theoretical investigation	IEC + cooling/reheating treatment	-	1. The system has been proposed to reduce the energy demand of air conditioning installations. 2. The result showed that in several cases the adoption of the proposed system may imply reductions of the energy consumption of the order of 40-60%.
Jain et al. [24]	Theoretical investigation	DEC+CCC	All seasons	1. Studied the financial feasibility of a hybrid mode operation of direct evaporative cooler with an air conditioning unit to reduce the annual expenditure on electricity usage (as against an AC unit operating alone to provide almost similar level of comfort). 2. In this study four different building applications located in four different cities of India have been considered. The hybrid mode operation is found financially attractive for Movie Theater and waiting hall building applications for all the climate conditions considered in this study.
Frank Bruno [29]	Experimental investigation	IEC	-	1. This paper reveal the result obtained from testing a prototype cooler installed in both a commercial and residential application in a wide range of ambient conditions. 2. It is also reveal the performance characteristics of the indirect evaporative cooler in regard to its outlet temperatures and electrical energy efficiency.
Riangvilaikul and Kumar [32]	Theoretical investigation	IEC	-	1. To simulate the heat and mass transfer a model of dew point evaporative cooling system has developed. 2. This model was used to optimize the system parameter and to investigate the system effectiveness which have operating under various inlet air conditions.

Table2. Theoretical and experimental investigations to alternate R22

Authors	Analysis	Refrigerants	Outcomes	Comments
O. O. Ajayi et al. [1]	Experimental analysis	R22 and R290 refrigerants as well as with the nanorefrigerant (i.e. nanolubricant/R290 refrigerant) mixtures	The result showed that R290 can effectively replace R22 as A/C refrigerant without any system retrofitting.	It is noted that the peels of C. Lanatus (watermelon), which is an agriculture waste, can be valorized by employing it, at its nanoparticle size, to enhance the cooling capacity of R290 and also reduce the cooling system's energy consumption
Oruç and Devecioglu [4]	Experimentally Investigated	R22, R1234ze(E) and R1234yf	The outcome showed that the air-conditioning systems may be alternatively charged with R1234ze(E) as an alternate for R22 as far as COP is considered.	The oil of compressor of a Split-type air conditioning system was only changed and the experiment tests were performed under four different ambient temperatures.
Shaik and Babu [7]	Theoretical Analysis	R22 and ten binary refrigerant mixtures consists of propylene (R1270) and propane (R290) by mass % are as following- M1 (R1270/R290), 25/75 M2 (R1270/R290), 35/65 M3 (R1270/R290), 45/55 M4 (R1270/R290), 55/45 M5 (R1270/R290), 60/40 M6 (R1270/R290), 65/35 M7 (R1270/R290), 70/30 M8 (R1270/R290), 75/25 M9 (R1270/R290), 80/20 M10 (R1270/R290), 85/15	The results revealed that the Overall thermodynamic performance of a mixture R1270/R290 (75/25 by mass %) was closer to R22. Hence it is a suitable ecofriendly alternative refrigerant to replace R22 used in residential air conditioning applications.	The theoretical thermodynamic performance of a 0.8 TR window air conditioner with various refrigerant was investigated based on actual VCRS cycle.
Kasera and Bhaduri [8]	Theoretical Study	R22 and R407C	By studies regarding the performance of R407C it was found that performance of it is little low but it is the best substitute of R22 for retrofitting point of view	A detailed review of the experimental studies regarding performance of R407C is provided
Padmanabhan and Palanisamy [25]	Experimental analysis	R22, R134a, R290 and R407C	This experimental investigation represent that the R290 perform better than other refrigerants but it suffers from flammability. Thus, the refrigerant R407C can considerably	This investigation presents an experimental comparison of exergy efficiency, irreversibility at the evaporator exit to compressor inlet, compressor inlet to condenser inlet, condenser inlet to expansion valve inlet, expansion valve inlet to

			be used to replace R22	evaporator inlet and evaporator and COP of R22, and its substitutes R134a, R290 and R407C in an air conditioner.
Reddy et al. [27]	Theoretical Analysis	R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A	This theoretical study reveals that R134a has the better performance in all respect, whereas R407C has poor performance.	This study deals with the energy and exergy analysis of a VCRS system with selected refrigerants.
Rocca and Panno [31]	Experimental investigation	R22, R417A, R422A and R422D	The result revealed that R22 was energetically more efficient than the other fluids.	In the existing installations three new HFC fluids can easily replace R22 without having to change the lubricant, or renewing the refrigeration circuits and the accessories
Qureshi and Zubair [30]	Using EES Software	R-134a, R-410A,R-407C, R-717, R-404A and R-290	R-134a always performs better as compared to R-410A, R-407C &, R-717 always performs better as compared to R-404A and R-290	Performance of the vapour compression refrigeration system degrade due to fouling
Dalkilic and Wongwises [39]	Theoretical analysis	CFC12,CFC22,HFC134a & refrigerant mixture based on HFC134a, HFC152a, HFC 32, HC290, HC1270, HC 600 and HC 600a for various ratios	Refrigerant blends of HC290/HC600a instead of CFC12 and HC290/HC1270 instead of CFC22 can be replace	Better performance is obtained in superheating and sub cooling condition.
Park and Jung[47]	Experimental performance analysis	R22, R290 and R1270	The overall result shows that R290 and R1270 provide good performance with reasonable energy savings without any environmental problems. Therefore these hydrocarbons can be used as long-term alternatives for residential air-conditioning and heat pumping applications.	Experimental test were performed on a heat pump bench tester of 1 ton capacity with a hermetic rotary compressor.
Park et al. [49]	Experimental performance analysis	R22 and R433A	The result shows that R433A can be used as long term alternative to replace R22 in residential air-conditioners and heat pumps due to its excellent thermodynamic and environmental properties	Experimental test were performed on a heat pump bench tester under air-conditioning and heat pumping conditions.

			with minor alterations.	
Park et al. [50]	Experimental performance analysis	R22 R290(propane) R1270(propylene) 20%R1270/80%R290 50%R1270/50%R290 80%R1270/20%R290 60%R290/40%R152a 71%R290/29%R152a 75%R290/25%R152a 45%R1270/40%R290/15%DME	The overall result shows that these refrigerants provide good performance with reasonable energy savings without any environmental problems. Therefore these fluids can be used as long-term alternatives for residential air-conditioning and heat pumping applications.	The tests were performed in a breadboard-type laboratory heat pump/air-conditioner

Table3.Recent and future alternatives refrigerants to R22

Refrigerant	Name	Boiling Point (℃)	Critical Point(℃)	ODP	GWP	Safety group
R-404A	R-125/R-143a/R-134a (44/52/4)	-47	73	0	3800	A1/A1
R- 407C	R-32/R-125/R-134a (23/25/52)	-44	87	0	1700	A1/A1
R-410A	R-32/R-125 (50/50)	-51	72	0	2000	A1/A1
R-417A	R-125/R-134a/R-600 (46.6/50.0/3.4)	-43	90	0	2200	A1/A1
R-507A	R-125/R-143a (50/50)	-47	71	0	3900	A1
R-717	Ammonia	-33	133	0	0	B2L
R-32	Difluoromethane	-51.7	78.2	0	550	A2L
R-152a	1,1-Difluoroethane	-24.0	113.3	0	120	A2
R-417A	R-125/134a/600	-41.2	89.89	0	2346	A1
R-417B	R-125/134a/600	-44.9/-41.5	89.89	0	3027	A1
R-422A	R-125/134a/600a	-46.5	71.75	0	3,143	A1

R-422D	R-125/134a/600a	-45.8	79.56	0	2,729	A1
R-432A	R-1270/E170	-46.6	97.3	0	1.64	A3
R-433A	R-1270/290	-44.6	94.4	0	2.85	A3
R-438A	R-32/125/134a/600/601a	-42.33	85.27	0	2,265	A1
R-427A	R-32/125/143a/134a	-43.2	85.3	0	2,138	A1
R-290	Propane	-42	97	0	20	A3
R-1270	Propene (Propylene)	−47.6	92.42	0	1.8	A3
R1234yf (New)	2,3,3,3-Tetrafluoropropene	−29.45	94.7	0	4	A2L
R1234ze(E) (New)	trans-1,3,3,3-Tetrafluoroprop-1-ene	-18.97	109.36	0	6	A2L

4 Methodology

4.1 Assumptions

i. 100% fresh air is supplied to the room i.e. no circulation of air.
ii. Cooling load calculation is done after achieving the steady state of the
iii. Conditioned space.

4.2 Climate conditions

The experimental analysis of the proposed system is done for the different conditions as shown in table-2. The proposed system also compare with the conventional system.

4.3 Working Principle

The proposed system consists of two parts: a direct evaporative cooler (DEC) and a conventional vapour compression air conditioner system (VCC). The direct evaporative cooler and vapour compression air conditioner are used in series consider as a single unit as shown in fig.2. The cooling coil is arranged in front of the direct evaporative cooler but it is not easy task to use the direct evaporative cooler along with the vapour compression air conditioner due to its lower cooling coil temperature. Thus certain modifications needs to be done before it is used with the direct evaporative cooler such as increasing the cooling coil temperature to sufficient high value is one of them in order to reduce the dehumidification of air input to the cooling coil [2]. There two ducts are used; a carry the fresh cool- humidified air from evaporative cooler to cooling coil and to supply the cool-dehumidified air to conditioned room. A condenser fan is used to reduce the temperature of condenser by supply the room conditioned air over the condenser coil. The description of components and instruments used for the experimental work is shown in table3 and table4.

Table4. Climate Conditions

S. No.	Climate	Dry Bulb Temperature	Wet Bulb Temperature	Description
1	Moderate Hot and Dry	DBT<34°C	WBT<23°C	Only evaporative cooler (EC) is working with 100% fresh air ratio and this mode the pump is working along with the evaporative cooler fan (ECF). Compressor is not working.
2	Hot and Dry	DBT>34°C	20°C< WBT<23°C	Compressor is also working along with the EC. The surrounding fresh air cools & humidify in EC and then it mixes with recirculate air with 30% FAR. Condenser is cooled from the fan taking air from conditioned space
3	Humid condition	DBT>34°C	WBT>34°C	Compressor is working but fan and pump both of EC is not working. 100% air is recirculates to the cooling coil. The condenser is cooled from the external fan utilizing the surrounding air.

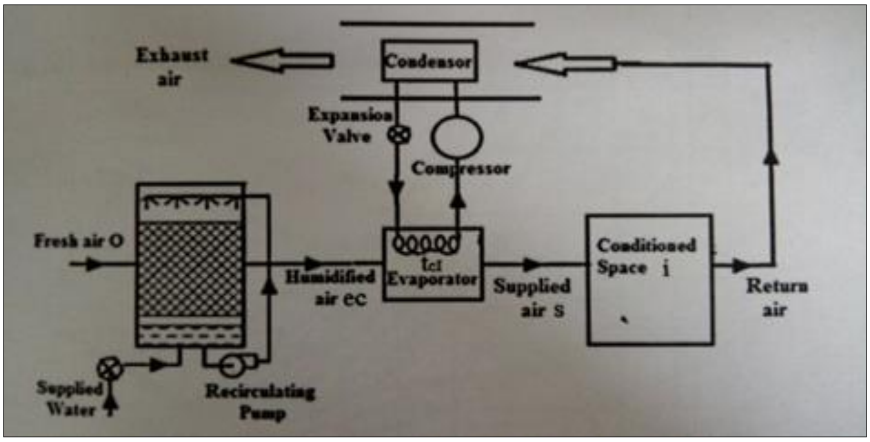

Fig. 1 Proposed system of conventional vapour compression air conditioner along with the evaporative cooler

4.4 Mathematical Modeling

Temperature of air after evaporative cooler is given by

$$T_{ec} = [T_0 - \{(\varepsilon/100) \times (T_0 - T_{w0})\}] \ldots (1)$$

Temperature of air supply to the conditioned space for proposed system is given by

$$T_{cs1} = [T_{c1} + \{BPF \times (T_{ec} - T_{c1})\}] \ldots (2)$$

Also specific enthalpy is constant across the evaporative cooler

$$h_0 = h_{ec} \ldots (3)$$

Specific enthalpy of air supply to the conditioned space in case of proposed system is given by

$$h_{s1} = [h_{c1} + \{BPF \times (h_{ec} - h_{c1})\}] \ldots (4)$$

Cooling load on the cooling coil in case of proposed system is given by

$$Q_{c1} = m_a \times (h_{ec} - h_{s1}) \ldots (5)$$

Sensible cooling rate to the conditioned space in case of proposed system is given by

$$Q_{scr1} = m_a \times (1.005 + \omega_{s1} \times 1.88) \times (T_{cs1} - T_i) \ldots (6)$$

Temperature of air supply to the conditioned space for conventional system is given by

$$T_{cs2} = [T_{c1} + \{BPF \times (T_{ec} - T_{c1})\}] \ldots (7)$$

Specific enthalpy of air supply to the conditioned space in case of conventional system is given by

$$h_{s2} = [h_{c2} + \{BPF \times (h_{ec} - h_{c2})\}] \ldots (8)$$

Cooling load on the cooling coil in case of conventional system is given by

$$Q_{c2} = m_a \times (h_{ec} - h_{s2}) \ldots (9)$$

Sensible cooling rate to the conditioned space in case of conventional system is given by

$$Q_{scr2} = m_a \times (1.005 + \omega_{s2} \times 1.88) \times (T_{cs2} - T_i) \ldots (10)$$

Saving of cooling load on the cooling coil for same sensible cooling rate

$$\text{Saving in } Q_c(\%) = [\{\frac{Q_{c2} - Q_{c1}}{Q_{c2}}\} \times 100 \ldots (11)$$

5 Conclusion

After study of literatures it concluded that the air conditioning system operating under hot and dry condition supplies cold and dry air which produces adverse effect on human body when they are exposed to dry air for many years. In air conditioning system temperature and specific humidity of air always decrease when it passes through the cooling coil. Since there is 100% recirculation in domestic air condoner, so this cold and dry air keep on reducing the moisture content every time while recirculating through the same cooling coil and drier. Hence it is important to be aware about possible health issues such as skin irritation and eye itching, health issues like asthma, bronchitis and nose bleeds or general dehydration and joint pain which they can create. This type of problem can be reduced by increasing the inside relative humidity with using the direct evaporative cooler but direct evaporative cooler alone cannot reduce the temperature of the room to human comfort condition for hot Indian climate. Therefore make a provision of adding the moisture to increase the specific humidity in the air which passes through the cooling coil of air conditioner. For this purpose proposed a hybrid system of direct evaporative cooler.

In this paper also focused on new ecofriendly refrigerants which are used as working fluid in conventional air conditioning system. There are the several investigations on new ecofriendly refrigerants done to replace R22 can be seen in table2. According to Regulation (EU) No. 517/2014 [58], if the refrigerants having Global Warming Potential more than the value of 750 will be banned after January 01, 2025 to use in split-type air conditioning system in which 3 kg or less quantity of refrigerant is charged. The R22 has been predominantly used in residential air-conditioning systems and heat pumps for the past few decades. The use of this refrigerant has been more than the other refrigerants. Table 3 presents the possible recent and future alternative refrigerants to R22. The phase out process of refrigerant R22 is still continuing. Air-conditioning devices manufactured over the last years uses the refrigerants having zero ODP but high GWP, it is necessary to phase out these refrigerants also. The refrigerants having zero ODP and low GWP are restricted by some amount because of their flammability characteristic.

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