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Review paper on Improvement of Heat transfer characteristics in AHU system using natural fibers, additives, and novel methods

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ABSTRACT

The air conditioner using an Air handling unit setup is modified for optimizing energy efficiency by improving Heat transfer characteristics of air and arriving at the thermal comfort zone range. Local Natural fiber material along with additive chemicals are used as cooling pads for testing. The setup utilizes a vapor compression cycle to precondition the air entering the air handling unit (AHU) by using R-22 as the refrigerant. The natural fibers that are used are Sisal, Bamboo, Coir Fibers, and Jute fibers. The additive proposed to be used is CMC 7H. The novel methods of improving the performance of the unit will be tried out by using a direct Evaporative cooler to cool the air-cooled condenser thereby obtaining an improved coefficient of Performance (COP) and decreasing the power consumption of the unit. Also, Cooling pads will be incorporated before the condenser cooling coil and evaporator coil to enhance the cooling capacity of the AHU. The setup will be analyzed for optimal heat transfer characteristics

Keywords *- Air handling unit, additives, Coefficient of Performance (COP), Heat transfer Characteristics, Natural fibers, Thermal Comfort.*

1. Introduction

Space heating and Cooling is the most important requirement in today's technically advanced world and it is of great concern to Engineers in the Heating, Ventilating, and Air conditioning (HVAC) industry. To address reliability and performance issues in buildings and offices of all air handling HVAC systems a detailed analysis of operational data from laboratory units can help in understanding the main variables that affect the performance and functioning of all-air distribution systems. This paper presents some results from operation data analysis of a VCRS-operated Air Handling Unit (AHU) serving a test enclosure reasonably insulated from the surroundings. The laboratory setup is located in the Coastal area of Panjim, and the humidity and purity of air are a major concern. The relative humidity in the location ranges from 60% to 90% throughout the year.

An experimental setup is utilized from the conventional Air conditioning test rig housed in the laboratory. It has a 1 TR rated capacity of cooling employing a vapor compression cycle system (VCRS) having an Air Handling unit (AHU) comprising of an inclined tube manometer, an evaporative coil with the drain pan, an air heater, evaporator cooling fan, and an insulated air duct. the setup can be used for a variety of experiments like capacity calculation, air handling unit heat transfer characteristics, and plotting thermal comfort zone on a psychrometric chart.

The experimental setup will be modified by providing a convergent flow straightener at the inlet an insulated air duct at the outlet and an extension duct running through the enclosed test cabin space.

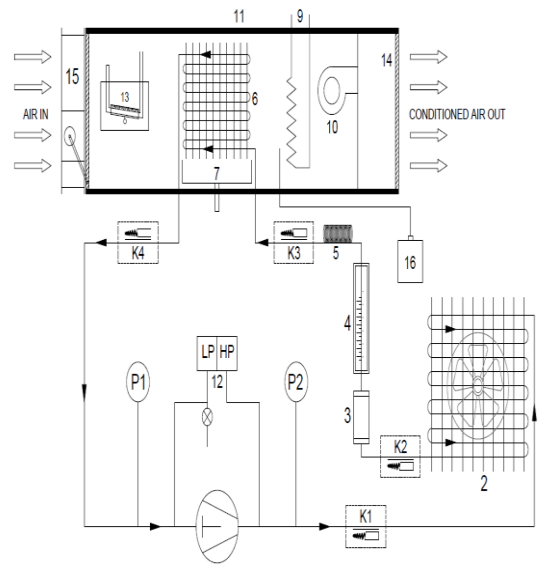
In the last decade, with the greater demand for human comfort Vapor compression air conditioners dominate the cooling sector due to their high efficiency, practicality, and technological maturity. Energy-efficient direct Evaporative cooler is used to decrease the temperature of the ambient air before it passes over the condenser coil, thereby decreasing the pressure and temperature of the condenser, the mass flow rate of the liquid refrigerant and its cooling capacity is also increased. Also, by using local natural fibers the air handling unit performance will be experimentally investigated and analyzed for enhanced indoor air quality and human comfort.

A Single duct setup for testing the shapes of natural fibers and cooling pads is proposed to be fabricated. The schematic of the proposed setup will be as follows:

Sr.No.	Component	Sr.No.	Component
1	COMPRESSOR	P1	SUCTION PRESSURE GAUGE
2	CONDENSER	P2	DISCHARGE PRESSURE GAUGE
3	DRIER/FILTER	K1	TEMPERATURE AFTER COMPRESSION
4	ROTAMETER	K2	TEMPERATURE AFTER CONDENSATION
5	CAPILLARY TUBE	K3	TEMPERATURE AFTER EXPANSION
6	EVAPORATOR COIL	K4	TEMPERATURE AFTER EVAPORATION
7	DRAIN PAN	17	FLOW STRAIGHTENER (as shown in Fig1
8	ACCUMULATOR	18	NATURAL FIBRE Pads (various materials)
9	AIR HEATER	19	SOLAR PANEL(4KW)
10	EVAPORATOR FAN	20	INVERTER BATTERY
11	INSULATED DUCT	21	ADDITIVES CMC H 7
12	HP/LP CUTOUT	22	Square Duct (32X32 cm) as shown in Fig 2
13	INCLINED TUBE MANOMETER	23	Sling Psycrometer
14	AIR OUTLET GRILLE	24	Anemometer
15	INLET AIR DAMPER	25	Digital Hygrometer
16	HUMIDIFIER	26	Digital Thermometers

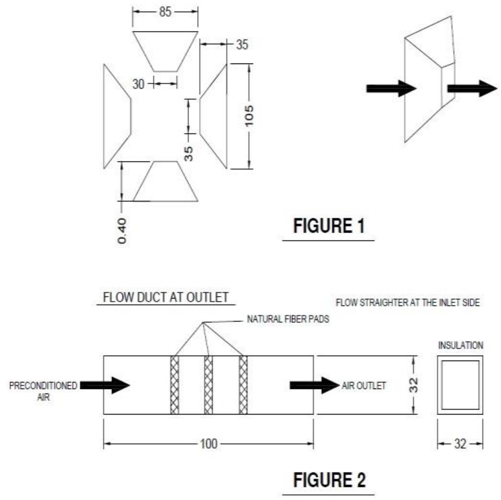
AIR CONDITIONING TEST RIG

PROCESS & INSTRUMENTATION DIAGRAM



2. EXPERIMENTAL SETUP

Experimental Air Conditioning tutor with AHU.



Modified Experimental Setup with insulated Duct & inlet flow straightener (Aspen Fiber cooling pads before condenser & Evaporator)

The Setup fabrication with calibration of equipment and Natural fibers & additives are available at Government Polytechnic Altinho- Panaji, Goa. The modifications at the inlet and outlet of AHU as proposed are fabricated.

To reduce the energy consumption and improve the performance of the system novel methods like using evaporative cooling to cool air over the condenser, local natural fiber cooling pads before the condenser, evaporator, and also in the outlet duct will be tried and performance will be analyzed.

Local natural fiber cooling pads made up of local coconut coir, cotton, Jute, Sugarcane and khus fiber pads will be tried and tested by adding additives like CMC H7 and other additives for various air velocities and temperatures of outdoor air. The experiment will be performed for all 4 seasons like Spring, summer, fall & winter and the effective cooling effect for comfort conditions will be deduced.

3. STANDARD VALUES AND FORMULAE

Parameter	Value	Unit
Standard Barometric pressure	1.013	Bar
Density of water	1000	Kg/m^3
Specific heat of water	4.18	KJ/kg
Gas constant for Air	288	KJ/kg K
The specific gravity of R-22 at 40^0c	1.2	
The specific gravity of the manometer liquid	0.8	
1 TR	3500	Watts
The density of Air at 25^0c	1.2	Kg/m^3
1 KWHr	3600	KJ
1 bar	14.5	Psig

3. ABBREVIATIONS AND ACRONYMS

A – Area

DBT – Dry Bulb Temperature

WBT – Wet Bulb Temperature

DPT – Dew Point Temperature

PSIG – Pounds per square Inch Gauge

KWHR – Kilowatt hour

LPH – Litres per Hour

MMWG – Millimeters of Water Gauge

H – Enthalpy

Q – Volume Flow Rate

M – Mass flow Rate

N – Refrigeration Effect

W – Compressor Work

H1 – Enthalpy before Compression

H2 – Enthalpy after Compression

H3 – Enthalpy after Condensation

H4 – Enthalpy after Evaporation

TR – Tonne of Refrigeration

COP – Coefficient of Performance

P-H Chart – Pressure Enthalpy Chart

ISHRAE – Indian Society of Heating Refrigerating and Air Conditioning

ASHRAE – American Society of Heating Refrigerating and Air Conditioning Engineers

RE – Refrigeration Effect

AHU – Air Handling Unit

HP – Heat Pump

VCRS – Vapor Compression Refrigeration System

4. SAMPLE CALIBRATING CALCULATIONS:

1. Tonnage Capacity of the AC System

VOLUME FLOW RATE OF AIR, Q = V X A m^3/sec

MASS FLOW RATE OF AIR, M = Q X Density of Air
Kg/sec
REFRIGERATION EFFECT, N = M X (H1-H2) KJ/sec
TONNAGE CAPACITY TR = N/3.5 TR

2. THEORETICAL C.O.P. OF THE AC SYSTEM:

From P - H CHART of R-22

REFRIGERATING EFFECT = N = H1 - H4 KJ/Kg

COMPRESSOR WORK = H2 – H1 KJ/Kg

COP = Q (useful heat)/W (input work)

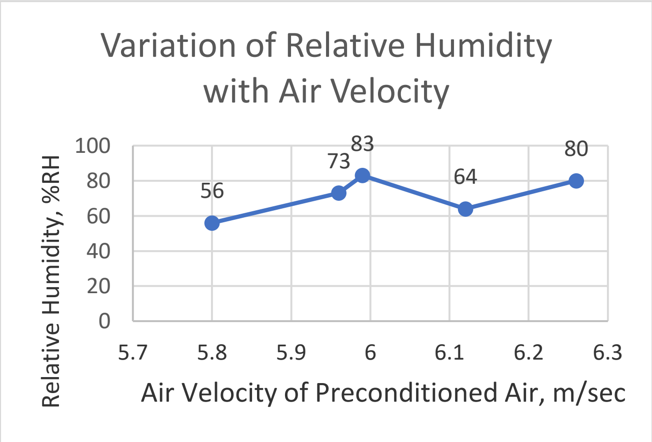
THEORETICAL C.O.P. = N/W
= (H1 - H4)/ (H2 - H1)

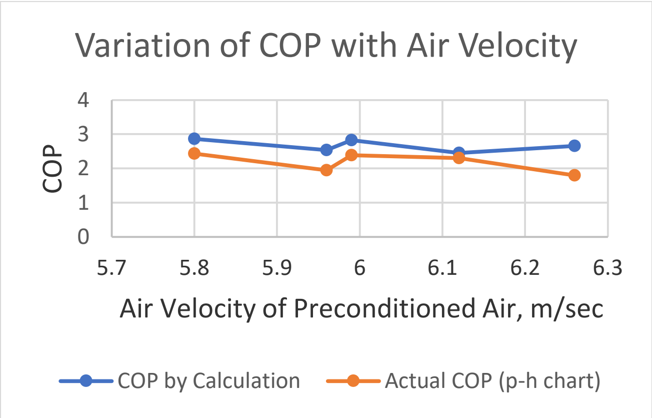
RESULTS OBTAINED: -

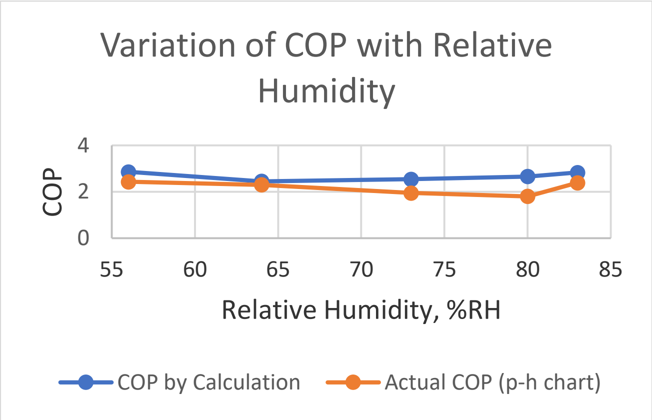
1. The Cooling Capacity of the system = 3.46 KW = 0.97 TR
2. The Actual C.O.P of the System = 2.66
3. The Theoretical C.O.P of the system = 3.09

A total of 5 sets of readings were taken at different times of the day and months and the results obtained were presented in the form of charts.

5. GRAPHS & VARIATIONS:







6. REVIEW OF LITERATURE

Air conditioners are necessary for every household today. The temperature of the atmosphere is increasing with global warming. In urban parts of Goa, it is not easy to stay indoors without a perfect cooling system. An air conditioner is a major home appliance today across the world to change the temperature and humidity level inside the room. But if not taken care of, it can cause serious health issues in people of all age groups. Studies have shown that extremely dry air or very humid air affects the human body in the following ways:

(1) Breathing improper air is a potential health hazard that can cause respiratory ailments such as asthma, bronchitis, nose bleeds, or general dehydration since body fluids are depleted during respiration.

(2) Skin moisture evaporation can cause skin irritations and eye itching.

(3) When the human body is exposed to improper air for many years then the synovial fluid of the joints which act as lubricant begins to dry up due to evaporation. This may allow the bones to rub against each other painfully.

(4) Arthritis joint pain inflammation is increased more due to the blowing of cold and dry air from the air conditioner. Researchers researched the effect of air conditioning air on arthritis patients. They detected that air conditioners cannot create a humid effect in the interior of the room during summer which makes the air dry and thus makes joints more painful overall.

A healthy humidity level measured from 30% to 50%. Humidity above 50% can be a breeding ground for mold, dust mites, bacteria, and other pests. Humidity below 30% increases the likelihood that cold and flu viruses will spread also leading to uncomfortable sinus and respiratory problems.

These problems can be reduced by maintaining indoor relative humidity. This can be increased by the direct evaporative cooler, but the direct evaporative cooler alone cannot reduce the temperature of the room to human comfort conditions in Goa due to prevailing high humidity air. Hence it is desirable to use a direct evaporative cooler in conjunction with a conventional vapor compression air conditioning system which brings the air temperature to the human comfort condition.

To increase the performance of the Air conditioner, the decrease in condenser temperature helps. Decreasing condenser temperature reduces the pressure ratio across the compressor resulting in lower power consumption. Also, the quality of the refrigerant is decreased after the capillary tube so that more liquid refrigerant will be available in the evaporator, resulting in more mass flow of the refrigerant and more cooling capacity.[1]

Prof. B.A. Shah [2] did an Experimental investigation on different Evaporative Cooling pads and found that there exists an optimum flow rate for which saturation efficiency is maximum. Also, for fixed water flow rate with variation in air flow rate saturation efficiency almost remains constant, with an increase in air flow rate Cooling capacity increases. It was found that cellulose fiber material gives the highest saturation efficiency of about 93%. The cooling capacity increases with the airflow rate.

Tara Sen & H. N. Reddy [3],[4] Demanded that researchers and Scientists apply appropriate technology to utilize locally available natural fibers such as Sisal fibers, Bamboo fibers, Coir fibers, and Jute fibers which have a lot of potentials. Also, various industrial applications of Hemp, Kenaf, flex, and Ramie natural fibers were discussed.

Wang et al. [5] investigated the Coefficient of Performance (COP)'s augmentation of an air conditioning system utilizing an evaporative cooling condenser. The experimental facility consisted of four major components, which are, the compressor, evaporator, thermal expansion valve, and condenser. An evaporative cooling unit was located upstream from the condenser. Thermal parameters, such as relative humidity, dry bulb temperature, and wet bulb temperature were measured to evaluate the effect of in-direct evaporative cooling on the system's COP.

Varun Jain et al. [6] studied the financial feasibility of a hybrid mode operation of a direct evaporative Cooler (DEC) with an air conditioning (AC) unit to reduce the annual expenditure on electricity usage (as against standalone AC unit to provide an almost similar level of comfort) are presented. Four different building applications located in four different cities in India have been considered in the study. The hybrid mode operation is found financially attractive for movie theatres and waiting for hall building applications for all the climatic conditions considered in the study.

Nada et al. [7] theoretically investigated the performance of proposed integrative air-conditioning (A/C) and humidification–dehumidification desalination (HDD) systems for energy saving of the air conditioning system and at the same time utilizing the system in freshwater production for the large capacity air conditioning systems.

Kim et al. [8] studied the energy performance of an indirect and direct evaporative cooler-assisted 100% outdoor air system (IDECOAS). It was concluded that the IDECOAS operating in the two-stage mode in the intermediate season shows a 51% energy saving over the conventional variable air valve (VAV) system. However, the proposed system may consume 36% more operating energy than the conventional VAV system during the cooling season. This may be caused by the limited cooling performance of the indirect evaporative cooler (IEC) in a hot and humid climate.

Fouda et al. [9] studied heat and mass transfer, the process in a direct evaporative cooler. A simple mathematical model is developed to describe the heat and mass transfer between air and water in a direct evaporative cooler. The study presents a comparison of the computed results with that of experimental results for the same evaporative cooler. The predicted results show the validity of a simple mathematical model to design the direct evaporative cooler, and that the direct evaporative cooler with high-performance pad material may be well applied to air conditioning systems.

E. Hajidavalloo et al. [10] investigated the increase in performance of Air conditioners by decreasing the condenser temperature. By reducing the condenser temperature, the pressure ratio across the compressor and condenser temperature reduces, resulting in reduced power consumption. It also decreases the refrigerant quality after the capillary tube and more refrigerant will be available in the evaporator, thereby increasing the mass flow rate of the refrigerant and the cooling capacity of the refrigerant gets increased. He used an evaporative cooler for this which is energy efficient, environment-friendly, and cost-effective. For large no of air conditioners used it caused considerable improvement in the performance of the cycle and a huge reduction in power consumption.

Cianfrini et al. [11] proposed an integrated energy-recovery system consisting of indirect evaporative cooling equipment combined with a cooling/reheating unit to reduce the energy demand of air-conditioning installations.

Delfani et al. [12] investigated the performance of indirect evaporative cooling (IEC) system to pre-cool air for a conventional mechanical cooling system for four cities in Iran. For this purpose, a combined experimental setup consisting of an IEC unit followed by a packaged unit air conditioner (PUA) was designed, constructed, and tested. Using experimental data and an appropriate analytical method, the combined system's performance and energy reduction capability has been evaluated through the cooling season. The results indicate IEC can reduce cooling load by up to 75% during the cooling season. Also, a 55% reduction in the electrical energy consumption of PUA can be obtained.

Kulkarni and Rajput [13] studied the theoretical performance analysis of cooling pads of different materials for evaporative coolers. The material has been considered, rigid cellulose, corrugated paper, corrugated high-density polythene, and aspen fiber. It has been observed that the saturation efficiency decreases with the increasing mass flow rate of air. It has also been seen that material with a higher wetted surface area gives higher saturation efficiency.

Sheng et al. [14] studied the empirical correlation of cooling efficiency and transport phenomena of direct evaporative cooler Effects of three system parameters (speed of frontal air, the dry-bulb temperature of frontal air, and the temperature of the incoming water) on cooling performance were evaluated. Each parameter was varied while holding all other variables constant, and data was collected using several different levels of each parameter. The general relationship between each parameter and efficiency was determined by graphing the data collected and observing trends.

Malli et al. [15] investigated the performance of cellulosic evaporative cooling pads. The thermal performance of two types of cellulosic pads which were made from corrugated papers has been studied experimentally. The results show the overall pressure drop and amount of water evaporated increases by increasing the inlet air velocity and thickness in both types of pads. On the other hand, effectiveness and humidity variation decrease by increasing inlet air velocity.

Wu et al. [15] studied the theoretical analysis of heat and mass transfer in a direct evaporative cooler. A simplified cooling efficiency correlation is proposed based on the energy balance analysis of air. The Influences of the air frontal velocity and the thickness of the pad module on the cooling efficiency of a direct evaporative cooler are discussed. An optimum frontal velocity of 2.5 m/s is recommended to decide the frontal area of the pad module in the given airflow. The simplified correlation of cooling efficiency is validated by the test results of a direct evaporative cooler.

Dai and Sumathy [16] studied a cross-flow direct evaporative cooler using honeycomb paper as packing material. A mathematical model, including the governing equations of liquid film and gas phases as well as the interface conditions, has been developed. Analysis results indicate that there exists an optimum length of the air channel, which results in the lowest temperature, and the system performance can be further improved by optimizing the operating parameters, such as the mass flow rates of feed water and process air, as well as the different dimensions of the honeycomb paper.

Bacchan et al [17] studied the properties of better alternative fibers and inferred that different natural fibers have different moisture absorption rates and different behavior after moisture absorption. The study was done to review the effect of moisture absorption on the properties of natural fiber reinforced polymer composites.

Zhang et al. [18] developed a mathematical model to describe the heat and moisture transfer between water and air in a direct evaporative cooler. The influences of the inlet frontal air velocity, pad thickness, inlet air dry-bulb, and wet-bulb temperatures on the cooling efficiency of the evaporative cooler are calculated and analyzed. The predicted results show that the direct evaporative cooler with high-performance pad material may be well applied for air conditioning with reasonable choices for the inlet frontal velocity and pad thickness.

Cui et al. [19] presented a hybrid system that combines an indirect evaporative cooler (IEC) system and a vapor compression system. In the IEC unit, the exhaust air from the conditioned room is used as the working air, and outdoor fresh air is used as the product air so that the IEC unit produces pre-cooled air for the vapor compression system. In this study, two types of IEC units, namely, a conventional counterflow IEC unit and a novel counterflow IEC unit based on Maisotsenko (M-cycle), have been numerically analyzed. Results have indicated that the 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.

J.K. Jain et al. [20] performed an experimental investigation by using two new evaporative cooling pad materials namely aspen and khus fibers. Also, coconut fibers and Palash fibers were tested in a laboratory setup. The airflow rate was maintained constant. Evaporative cooling effectiveness. The effectiveness of Palash fiber pads was found to be 13,2% and 26.31% more than that of aspen and khus pads whereas coconut fiber effectiveness was found to be 8.15% more than that of khus and comparable to aspen pads. Khus pad offers the lowest pressure drop whereas aspen pads offer the higher pressure drop of the four materials tested.

Selamma et al [21] did experimental investigation of a direct evaporative cooler, DEC, designed and installed in the hot and arid region of Biskra, Algeria. Date palm tree fibers are used as a novel evaporative cooling material. Different performance parameters are experimentally tested to assess the thermal performances of the DEC system. Results show that the cooling capacity, cooling efficiency and total cooling capacity of the pad improve by increasing the pad thickness and air mass flow rate in extreme ambient conditions.

Faleh Al-Sulaiman [22] made a special test setup to evaluate the performance of three natural fibers to be used as wetted pads in evaporative cooling. The chosen fibers are date palm fibers (stem), jute and luffa. As a reference, a widely used commercial wetted pad is chosen. The performance criteria include cooling efficiency, material performance and cooling efficiency degradation. The results show that the average cooling efficiency is highest for jute at 62.1%, compared to 55.1% for luffa fibers, 49.9% for the reference commercial pad and 38.9% for date palm fiber.

Kumar & Mathur et al [23] conducted a field study of thermal comfort in 32 naturally ventilated buildings, collecting a total of 2610 samples spread over a total period of four years, covering all seasons, wide age groups, clothing types, and building types. ASHRAE comfort boundaries at three different air speeds - still air (up to 0.2 m/s), natural air flow (0.2 m/s–0.5 m/s) and forced air flow with ceiling fan assist (0.5 m/s–1.5 m/s) were investigated. The proposed comfort zones show that subjects are comfortable up to 32 °C at still air condition (0 m/s–0.2 m/s) and up to 35 °C at higher speed (up to 1.5 m/s) in naturally ventilated buildings in the composite climate of India.

Taley Hussain [24] deduced that enormous amount of energy is consumed particularly in the areas having hot and humid weather conditions. He studied the effectiveness of an air conditioner unit using air cooled condenser and evaporative cooled condenser by varying three different flow rates resulting in COP improvement.

7. CONCLUSION

After the deep literature review, no work has been found like the work proposed in this paper to determine the performance of the combined system for the small-scale application under a tropical humid coastal climate for fresh air in Goa. Therefore, the objective of this combined system is necessary and important, especially when implementing this system into the real application under wet & humid conditions. However, some researchers have tried to reduce the power consumption of mechanical cooling coils by incorporating the direct and indirect evaporative cooler along with the mechanical cooling coil as revealed in the literature review.

Looking at the above problems a system is proposed in this paper as shown in the pictures above, which is the combination of a direct evaporative cooler and conventional vapor compression air conditioner, which on operating together under tropical humid conditions can produce cold and reasonably humid air to the human comfort condition at a reasonably low cost. An objective of making the system energy efficient is also thought by making the air conditioning system solar energy driven.

8. Acknowledgments

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Min-Hwi Kim, Jae-Weon Jeong* Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea

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A.Fouda[a]Z.Melikyan[b]

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E. Hajidavalloo*, H. Eghtedari Mechanical Engineering Department, Shahid Chamran University, Golestan St., Ahvaz, Iran

[11**] Energy performance of air-conditioning systems using indirect evaporative cooling combined with a cooling/reheating treatment**
Claudio Cianfrini, Massimo Corcione*, Emanuele Habib, Alessandro Quintino

[12] **Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions** Ghassem Heidarinejad a,*, Mojtaba Bozorgmehr a, Shahram Delfani b, Jafar Esmaeelian b aDepartment of Mechanical Engineering, Tarbiat Modares University, PO Box 14115-143, Tehran, Iran bDepartment of Installation, Building and Housing Research Center (BHRC), PO Box 13145-1696, Tehran, Iran

[13] **comparative performance analysis of evaporative cooling pads of alternative configurations and materials**

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[14] **Empirical Correlation of Cooling Efficiency and Transport Phenomena of Direct Evaporative Cooler**

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[14] **Experimental Investigation on Energy-Saving Potential in AHU of an Air-Conditioning System with BLDC Fan**

Madhab Chandra Jena,Sarat Kumar Mishra, Himanshu Sekhar Moharana

[15] **Investigating the performance of cellulosic evaporative cooling pads**

Abdollah Malli, Hamid Reza Seyf , Mohammad Layeghi , Seyedmehdi Sharifian , Hamid Behravesh.

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[19] **PERFORMANCE EVALUATION OF AN INDIRECT PRE-COOLING EVAPORATIVE HEAT EXCHANGER OPERATING IN HOT AND HUMID CLIMATE**

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[23**] An adaptive approach to defining thermal comfort zones on a psychrometric chart for naturally ventilated buildings in a composite climate of India**

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[24] **Experimental investigation of an air conditioner unit by varying different air flow rates using air and evaporatively cooled condenser**

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