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Design, Development and Experimental Performance Evaluation of a 360° Automatic Evaporative Cooler–Heater

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Abstract

A 360° air cooler-cum-heater is a multifunctional thermal comfort system designed to provide cooling or heating according to user requirements and ambient conditions. The increasing demand for space conditioning has led to higher energy consumption, creating the need for energy-efficient alternatives to conventional air-conditioning systems. Evaporative cooling offers a low-energy solution, particularly in hot and dry climates, by cooling air through water evaporation, which reduces the dry-bulb temperature while increasing humidity. The proposed system distributes conditioned air uniformly in all directions, providing improved air circulation and wider coverage than conventional unidirectional air coolers. Compared with vapour-compression air-conditioning systems, evaporative cooling consumes significantly less electrical energy and reduces indirect greenhouse-gas emissions associated with electricity generation. The system integrates both cooling and heating functions in a single unit. During cooling, its performance depends on ambient relative humidity, with effectiveness decreasing under high-humidity conditions due to reduced evaporation. During cold weather, an electric heating element raises the air temperature to provide comfortable indoor conditions. The proposed 360° automatic air cooler-cum-heater combines evaporative cooling, electrically assisted heating, and multidirectional airflow in a compact design, enabling year-round operation. Its performance can be evaluated based on cooling and heating effectiveness, airflow distribution, relative humidity, power consumption, and overall thermal performance under varying ambient conditions.

1. Introduction

The evaporative cooling and forced convection heater are one of the earliest methods employed by men for conditioning their houses. Only in recent years, it has been put on sound footing thermodynamically. Evaporative cooling is a process of adiabatic saturation of air when a spray

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of water is made to 360° evaporative cooling pads without transfer of heat from or to the surroundings. Simple 360° evaporative cooling is achieved by direct contact of water particles and a moving air stream. If the water is circulated without a source of heat and cooling, dry air will become more humid and will drop in temperature. An evaporative cooler (also swamp cooler, desert cooler and wet air cooler) is a device that cools air through the evaporation of water. Evaporative cooling differs from typical air conditioning systems which use vapor compression or absorption refrigeration cycles. When a hot and dry air is allowed to pass through a wet cooling pad, the cooling pad is made up of wood wool the temperature of incoming air is reduced with an increase in specific humidity as some water from the pads is evaporated taking the latent heat of vaporization from the incoming air. The air may be sufficiently cooled by 360° evaporative process to results a considerable of summer comfort in climates of high dry-bulb temperatures associated with low relative humidity. The minimum outdoor temperature required for successful 360° evaporative cooling is above 32 ^{0}C. The comfort given by the 360° evaporative cooling always depends upon the outdoor temperature and RH. always gives more comfort with 360° evaporative cooling. Although the 360° evaporative cooling does not perform all the function of true air-conditioning but it provides comfort by filtering and circulating the cooled air. This system does not dehumidify the air but on the contrary, further humidify air. Before the advent of residential air-conditioning, it was the only mechanical means available to make home interiors livable in the hot, dry, desert summers. 360° evaporative coolers function well except for the few weeks of the summer "monsoon" season with its accompanying elevated humidity and thus decreased cooler efficiency. These cooling systems are economical in terms of energy usage. During the energy crunches of the last two decades, 360° evaporative cooler use was promoted as one means to control household utility bills. However, little thought was given to cooler water consumption. With rapidly increasing population, warm temperatures, and limited water supply, 360° evaporative cooler water usage can no longer be ignored. Heater is process of heating forced air with the help of heating coil. 360° heater, is forced convective heater that has an electric fan to speed up the airflow. They operate with considerable noise caused by the fan. In a convection heater, the heater made of stainless steel the heating element heats the air in contact with it by thermal conduction. Hot air is less dense than cool air, so it rises due to buoyancy, allowing more cool air to flow in to take its place. This sets up a convection current of hot air that rises from the heater, 360° heater is more use full temperature less than 30° Celsius, during the summer season the efficiency of the heater may decrees, the degree heater allowing the hot air to move in 360° manner and heats up the surrounding space. The initial investment cost of 360° cooler and heater is low and the operation is simple and cheap**.**

2. Literature Review

Evaporative cooling is one of the oldest methods of reducing temperature through the utilization of the latent heat of vaporization of water. The fundamental principle is based on the transfer of sensible heat from air or another medium to water, resulting in the evaporation of water and a corresponding reduction in temperature. Historical evidence indicates that the basic principles of evaporative cooling were used in ancient civilizations. Ancient Egyptians reportedly used porous water containers and wet mats to reduce the temperature of water and surrounding air. The movement of air across wet surfaces promoted evaporation and provided a simple form of passive cooling. These traditional practices represent the early development of technologies that later evolved into modern evaporative cooling systems. The use of porous ceramic containers for water cooling has been documented in several regions. In Spain and southern Italy, porous fired-clay vessels known as botijos were traditionally used to cool drinking water for agricultural workers. The cooling occurs as water migrates through the porous wall of the vessel and evaporates from the external surface. Similarly, traditional clay pots have been widely used in Egypt, Sudan, Nigeria and other regions for passive water cooling. When warm and relatively dry air flows over the wet external surface of a porous clay vessel, evaporation occurs, thereby reducing the temperature of the water stored inside the vessel. Such traditional systems demonstrate the effectiveness of low-cost evaporative cooling without the requirement of mechanical refrigeration. The evolution of evaporative cooling subsequently progressed from passive systems to mechanically assisted cooling devices. Mechanical fans were introduced to increase air movement and enhance the evaporation rate. During the nineteenth and twentieth centuries, evaporative cooling systems were progressively developed for industrial and domestic applications. Cooling towers, wetted surfaces, spray systems and later evaporative air coolers were developed to improve the contact between air and water. Modern evaporative coolers commonly employ a fan, water pump, reservoir and porous evaporative medium. The fan forces air through the wetted medium, where heat and mass transfer occur simultaneously. The resulting air temperature depends strongly on the inlet dry-bulb temperature, wet-bulb temperature, relative humidity, airflow rate, water distribution and characteristics of the evaporative medium. Traditional evaporative cooling principles have also been applied to agricultural storage. In India, the Zero Energy Cool Chamber and its improved versions were developed as low-cost systems for the preservation of fruits and vegetables. These systems use wetted porous walls and natural or forced airflow to reduce the temperature of the storage environment. Their low energy requirement and simple construction make them particularly useful in rural and low-income communities. The performance of such systems, however, depends significantly on ambient climatic conditions, particularly air temperature and relative humidity.

The development of portable evaporative coolers has received considerable attention because of their relatively low cost, simple construction and low electrical energy consumption compared with conventional vapour-compression air-conditioning systems. Talbot and Fletcher (2012) investigated the design and development of a portable forced-air cooler and highlighted the importance of parameters such as inlet air temperature, humidity and airflow conditions in determining cooler performance. Their work demonstrated that the design of a portable cooling system must consider both thermodynamic and practical design parameters to obtain effective cooling within a compact configuration. The performance of rotating and mechanically modified evaporative coolers has also been investigated. Kavle, Shahane and Garje (2014) studied a 360° rotational air cooler and examined the influence of parameters such as evaporative media thickness and atmospheric conditions on system performance. Their investigation indicated that the cooling effectiveness of a drip-type evaporative cooling system is strongly dependent on the interaction between the evaporative surface, water distribution and ambient conditions. The study also demonstrated the potential for improved cooling performance while maintaining comparatively low power consumption.

Govkar and Yadav (2016) reviewed the design and performance characteristics of modern evaporative coolers. Their study discussed the operating principle, material selection and performance parameters associated with evaporative cooling systems. The authors emphasized that evaporative coolers can provide an economical alternative to conventional air-conditioning systems, particularly in hot and dry climatic conditions. However, the effectiveness of direct evaporative cooling decreases as the moisture content of the incoming air increases because the air approaches its saturation condition. Recent research has focused on improving the heat and mass transfer characteristics of evaporative cooling systems through modifications in evaporative media, flow configuration and water distribution. Mehrabi et al. (2023) experimentally investigated the effect of pad angle on the thermal performance of a direct evaporative cooling system. Their study demonstrated that the geometric arrangement of the cooling pad influences airflow distribution, wetting characteristics and overall thermal performance. This confirms that the geometry and orientation of the evaporative medium are important design variables in the development of efficient air coolers.

The development of indirect evaporative cooling systems has further expanded the application of evaporative cooling. Unlike direct evaporative cooling, indirect systems cool the supply air through a heat-transfer surface without directly adding moisture to the conditioned air stream. Caruana et al. (2023) reviewed mathematical and numerical modelling approaches for indirect evaporative cooling systems. Their review highlighted the importance of airflow configuration, channel geometry, heat-transfer characteristics and operating conditions in determining the performance of indirect evaporative coolers. Indirect and dew-point evaporative cooling systems have attracted increasing research interest because they can achieve substantial cooling with lower energy consumption while maintaining better humidity control than conventional direct systems. Recent experimental research has also examined advanced configurations of indirect evaporative coolers. An experimental study published in 2024 investigated a baffled indirect evaporative cooler integrated with an air-conditioning unit. The results demonstrated that the use of indirect evaporative cooling can reduce the thermal load on conventional air-conditioning equipment while providing cooling with relatively low power consumption. Such hybrid arrangements are particularly important for reducing the energy consumption of conventional vapour-compression systems.

Zhou and Li (2024) experimentally investigated a vertical shell-and-tube indirect evaporative cooler incorporating internally grooved tubes. The study reported that the grooved tube configuration improved water-film characteristics and enhanced evaporative cooling performance. The investigation also demonstrated that inlet air enthalpy significantly affects the cooling capacity generated through evaporation. This work emphasizes the importance of improving water distribution and surface wetting in order to enhance heat and mass transfer in evaporative cooling devices. The integration of novel flow configurations and evaporative materials has also been investigated. Urso et al. (2024) developed and experimentally evaluated a mixed-flow dew-point indirect evaporative cooler. Their results indicated that the use of wicking materials can significantly improve cooling capacity, while optimized water distribution can increase the temperature reduction across the system. Such research indicates that the performance of evaporative cooling systems can be enhanced through the combined optimization of flow arrangement, surface wetting and evaporative material properties.

Similarly, semi-indirect evaporative cooling systems have recently been investigated for integration with conventional HVAC systems. Socci et al. (2024) and Mushan et al. (2025) experimentally studied a semi-indirect evaporative cooler capable of operating in dry and wet modes. The system was investigated as a pre-cooling device for an air-conditioning unit, demonstrating the potential of evaporative cooling to reduce the thermal load and energy consumption of conventional refrigeration-based systems. These studies demonstrate a clear shift in research from simple standalone evaporative coolers toward hybrid and high-performance cooling systems. A review of recent advances in indirect evaporative cooling technology has shown that system configuration, airflow arrangement, channel dimensions, evaporative material and operating conditions significantly influence cooling effectiveness. Counter-flow configurations, appropriate air-to-working-air ratios, lower channel height and optimized evaporative surfaces have been identified as important factors in achieving improved cooling performance. The research trend indicates that future evaporative cooling systems are likely to combine improved evaporative materials, optimized geometries, intelligent control and hybrid integration with conventional cooling technologies.

Although considerable research has been conducted on direct, indirect and hybrid evaporative cooling systems, several research gaps remain. A large number of commercially available portable air coolers continue to employ conventional wetted pads and relatively simple airflow arrangements. The performance of such systems is strongly influenced by ambient temperature and relative humidity. Furthermore, the simultaneous optimization of evaporative surface characteristics, water distribution, airflow arrangement, portability and energy consumption remains a challenge. Many previous studies have investigated individual parameters such as pad thickness, pad angle, airflow rate or water flow rate, but fewer studies have systematically investigated the combined influence of these parameters in a compact portable air-cooling system. Therefore, the present study focuses on the design, development and performance evaluation of a portable evaporative air-cooling system. The investigation is intended to evaluate the influence of important operating and design parameters on the cooling performance, including air temperature reduction, relative humidity, airflow conditions, water consumption, power consumption and cooling effectiveness. The study aims to contribute to the development of a compact, low-cost and energy-efficient evaporative cooling system suitable for applications where conventional air-conditioning systems may be economically or energetically unsuitable.

3. Materials and Methods

The objectives of the study are:

1. 360° design automatic cooler cum heater will allow person to sit in any direction, during winter it can be used for heating room.

2. To develop the Energy efficient, environment friendly direct evaporative air conditioning system having low operating cost suitable for hot and dry regions.

3. To manufacture advanced 360° rotating air cooler which rotates and provide air cooling and heating in all directions

360° evaporative cooling offers several advantages for indoor thermal comfort. It continuously introduces fresh outdoor air while helping to remove stale air, odors and airborne contaminants. The process also maintains a relatively natural level of humidity, thereby reducing excessive dryness and static electricity. Unlike conventional air-conditioning systems, evaporative cooling does not require a completely sealed building envelope for effective operation, allowing doors and windows to remain partially open when appropriate. Furthermore, the system does not require chlorofluorocarbon (CFC) refrigerants, thereby avoiding direct CFC-related ozone-depletion impacts. Consequently, 360° evaporative cooling provides a comparatively energy-efficient and environmentally friendly approach to localized space cooling.

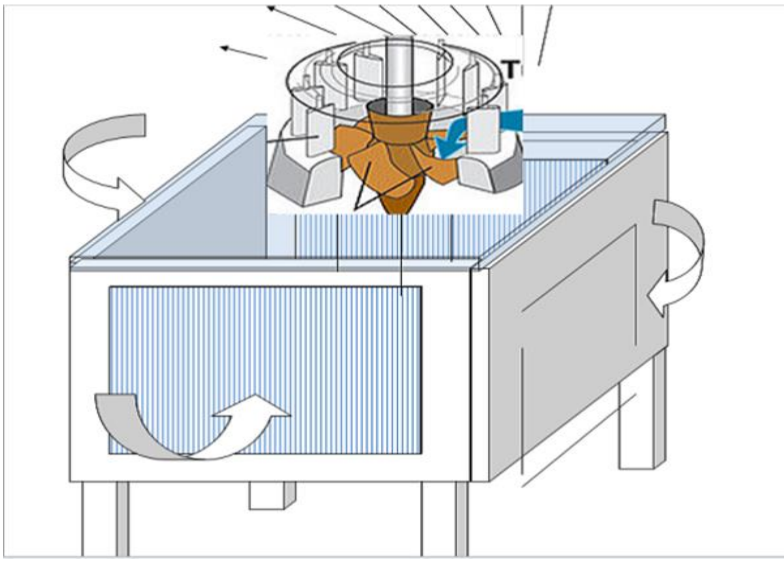

Figure 1: Working Principle of 360° Cooler cum Heater

As shown in Figure 1, the 360° air cooler-cum-heater operates in two modes: cooling mode and heating mode. In cooling mode, hot ambient air enters the unit through the four sides and is drawn through the wetted cellular cooling pads by the fan. Water supplied from the sump by a pump is distributed over the cooling pads. As the air passes through the wet pads, a portion of the water evaporates by absorbing the sensible heat of the air as latent heat of vaporization. Consequently, the air temperature decreases while its humidity increases. The cooled air then passes through the internal air passage and is distributed in multiple directions through the upper baffle arrangement, providing approximately 360° air distribution. During heating operation, the water pump is switched off and the heating coil is energized. The incoming air follows the same airflow path through the unit but, instead of undergoing evaporative cooling, passes over the energized heating coil. Heat is transferred from the coil to the air, resulting in an increase in air temperature. This process is primarily sensible heating, and the moisture content of the air remains approximately unchanged. Thus, the system provides cooling during warm conditions and heating during cold conditions, while the multidirectional outlet arrangement enables air distribution around the unit.

As illustrated in Figure 2, the evaporative cooling process begins by filling the bottom water tank with water. The pump draws water from the tank and delivers it through a distribution pipe to the stationary cellular cooling pads. The water is uniformly distributed over the pads, maintaining their wetted surfaces. Once the fan is switched on, warm and relatively dry atmospheric air is drawn into the system and forced through the wetted cooling pads. As the air comes into intimate contact with the water film on the pad surface, a portion of the water evaporates. The required latent heat of vaporization is absorbed from the sensible heat of the incoming air, resulting in a reduction in the dry-bulb temperature of the air. Consequently, the outlet air becomes cooler and more humid. Under ideal conditions, the air approaches the wet-bulb temperature of the entering air as the air–water contact becomes more effective. However, the actual cooling performance depends on factors such as ambient temperature, relative humidity, airflow rate, pad characteristics, water distribution and contact time. The cooling effect can be further enhanced by using chilled water in the reservoir; however, the use of ice should be considered an optional enhancement because it increases the cooling effect through sensible cooling in addition to evaporative cooling.

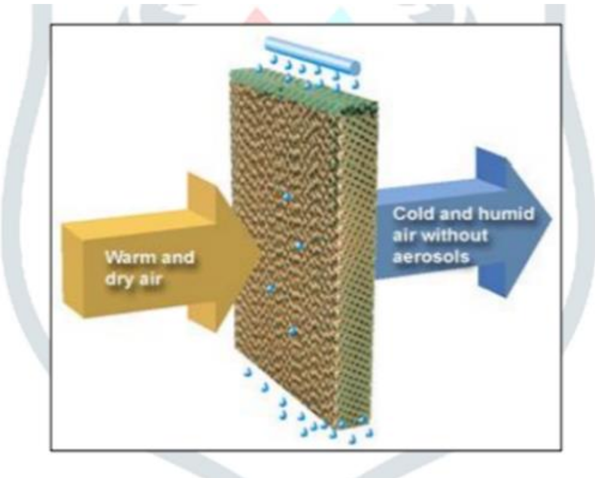

Figure 2. Working principle of direct evaporative cooling through a wetted cellular pad

3.1 Working Principle of the Heating Mode

The 360° air cooler-cum-heater can also operate in heating mode using an electrical heating coil, as shown in Figure 3. When heating is required, the water pump is switched off to stop the circulation of water through the evaporative cooling pads. The electrical heating coil is then energized. The fan draws ambient air into the system and forces it over the heated coil. Heat is transferred from the coil to the air, resulting in an increase in the air temperature. Since no water is circulated through the cooling pads during this operating mode, no significant evaporative humidification occurs. The process is therefore primarily sensible heating, in which the dry-bulb temperature of the air increases while its humidity ratio remains approximately constant. The desired outlet temperature can be controlled using a thermostat or temperature controller.

Figure 3. Electrical heating coil used in the heating mode of the 360° air cooler-cum-heater

When the measured air temperature reaches the preset value, the heating element can be switched off automatically, thereby preventing excessive heating and reducing unnecessary power consumption. This control arrangement enables the system to provide temperature-regulated heating during cold ambient conditions.

3.2 Components used in the system

i) Motor: The specifications of motor needed for the model is single phase induction motor as it less noisy. And its frame size is B42.Genral purpose FHP (fractional horse power) and air handling application motors are offered in B42.This motor is design for high efficiency and reliability considering the global customer requirement. This motor offered different mounting arrangements like open or closed enclosures. Power ranges from 75W to 370W. The features included as compact design, thermal protection available and corrosion resistance due to powder coated rolled sheet metal body.

ii) Fan: Fans are mainly classified into two types, namely centrifugal and axial. In a Centrifugal fan, air is pulled along the fan shaft and then blown radially outward from the shaft, where as in axial fan, air is pulled along the fan shaft and then blown along the axis of shaft. The fan used for the model is low pressure and high discharge. As the requirement for this model light weight (polycarbonate) material. And as centrifugal fan has greater weight axial fan is suitable for this model. For selecting fan knowledge of fan performance is of most useful like volume flow rate of air (mm), pressure and brake power (BP).

iii) Cellulose pads: It is used because it has high efficiency and cooling rate. The thickness of cellular pad 50 mm. Its type are khus grass, cellulose pads and coconut coir

iv) Pump: Electric pump is used. It has power 14W, having 1m head.

v) Heating Coil: The heating of air can be carried out in no of ways. The heating device can be a steam coil, hot water coil, an electric heater, fuel gas furnace. But as the requirement for this model is low cost with simplicity and efficient use of electric coil is convent. As air is directly exposed to heating element response is quick and its life is more. The Ni-chrome coil is used, it has high resistance and high stability to withstand high temp.

vi) Frame: The material used for frame is MS or cast iron. As it has to support the other parts It should be strong to withstand the force, stresses and vibration. And even as it is constantly in contact with wet environment it should also have high corrosive resistance.

vii) Water sump: The material used for the water sump is MS. As plastic materials has leakage problems.

viii) Baffles: Baffles is the component used for distributing the air in required direction in this case that is all direction. It is made of MS material as it has to absorb vibration, impact forces due to air and it should be corrosive resistance as it has to frequently operate in wet or moistures environment.

3.3 Design calculation of shaft: Mild steel C-45 is material is selected in our project. Easily available in all sections, welding ability, Machinability and Cutting ability. Cheapest in all other metals. Material = C 45 (mild steel) with factor of safety (FOS) as 2.

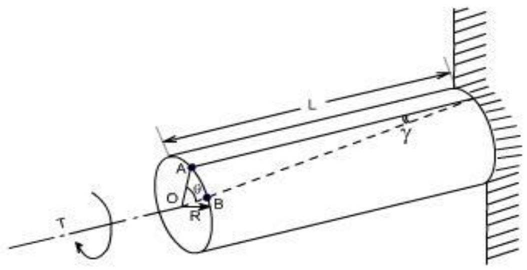

Figure 4. Shaft design

Considering, σt = σb = 540/fos = 270 N/mm^2, σs = 0.5 σt, = 0.5 x 270 = 135 N/mm2

Torque transmitted by shaft, T = F x L = 100 x 28= 2800 N-mm.

T = π/16 x σ s x d^3, Therefore, 2800 = π /16 x d3 x 80; d = 5.62 mm

As per the market availability, the shaft is used of 10 mm diameter.

3.4 Chamber stress calculation: The whole body of water cooler is kept on 4 box pipe. let the weight of whole flapper assembly including fans be 40 kg. so load on each pipe is 10 kg, 100N, Take FOS = 2 times so W =200 N, M = W L / 4 = 200 X 740/ 4 = 37000 N/mm

Z = B3 – b3 / 6 = 593 - 543 / 6 = 7985.8 mm3

σ b = M / Z, σ b = 37000 / 7985.8 = 4.63 N/mm2

Σ B Induced < Σ B Allowed, 4.63 N/mm2 < 160 N/mm2

3.5 Baffle Design calculation:

The link which we are using for rotating flappers may fail under bending F = maximum force applied = 100 N, For cantilever, M = F x L 11 cm, M = 100 x 160 = 117600 N-mm 18cm, And section modulus, Z = 1/6 bh; Z = 1/6 x11x18^2, Z = 1/6 x 3564; Z = 594 mm^2. Now using the relation, Fb = M / Z, Fb= 117600/ 594 = 197.97 N/mm^2, Induced stress is less then allowable 260 N/mm^2 so design is safe.

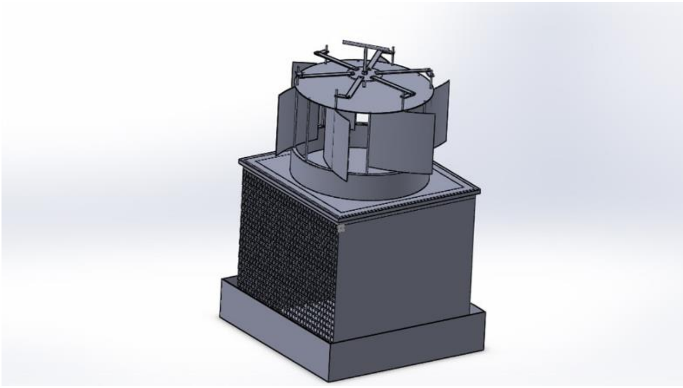

Figure 5. CAD model

3.6 Components Selected

Name of component	**Specifications**	**Figure**
Blower Motor	Company name: Radisson Power: 22W Speed: 2200rpm Voltage: 230V/50Hz	
Pump	Power: 40 W Output: 1200 L/Hr. Voltage: 230V/50Hz H-Max: 2.5 m	

Water Tank	Length: 65 cm Width: 65 cm Height: 15 cm Material: GI sheet Gauge: 20	
MS Sheets	Thickness: 5mm Class: Low Carbon Steel Density: 7.87g/cc	
Fan	Type: Exhaust fan No of blades: 5 Diameter: 250 mm Weight: 0.45 kg	
Heating coil	Brand: Electro mate Material: Nichrome Color: Silver Burnt type: Radiant Power: 2000W	
Temp PID Controller	Operator Interface type: Dual LED, 2 decimals Display: Both 10mm status beacons: OPI, OP2. MAN, Access Levels: Operator, Full access, Edit, Config Password protection Power Req. Supply voltage High voltage: 100 vac-15% to 240Vac + 10%, 48-62Hz.5W max, low voltage: 240Vdc or ac-15%, +20 DC to 62 Hz 5W max	
Temp Controller Dimmer	Resistance Materials: Metal and Plastic Input Voltage: AC 220 V Voltage Regulations: AC 50-220V Max power: 2000W Dimensions: 58×53×29 mm	

Pads	Length: 56.8 cm Height: 74 cm Width: 4 cm Material: Cellulose pads	

3.7 Trial on air cooler: Initial room temperature (DBT) = 32°C, Relative humidity = 45 %, Area of room = 255 sq. ft, Height = 7.5 ft.

Table 1. Trail on Air Cooler

Observation	Temp °C	Time Interval (Min)	Final Room Temp, °C
1	32	0	32
2	32	20	30.3
3	30.3	40	28.9
4	28.9	60	27.1
5	27.1	80	26.5

3.8 Trial on air heater: Initial room temperature (DBT) = 32°C, Relative humidity = 45%, Area of room = 255 sq. ft., Height = 7.5 ft.

Table 3. Trail on Air Heater

SN	Room Temp (°C)	Loads Watt	Temperature of Air at Exit of Heater(°C)	Final Room Temp (°C)
1	28	500	33.2	28.6
2	28	550	33.5	28.9
3	28	600	33.9	29.1
4	28	650	34.4	29.5
5	28	700	34.8	29.6

3.9 Advantages of 360° cooler cum heater

Today’s world, though air conditioners and heater are in most of the places, air cooler cum heater have their advantages and importance. It is a new concept also There are many advantages

1. **Easy to operate**: Any tube of cooler is composed of mainly two parts Fan and Pump. There are no complicated parts as in Air conditioners. Only 3 switches, one for fan and other for pump motor are to be operated and switch is for heater.
2. **Easy to clean**: Cooler cum heater are to be filled with water before operating. For this any one door is to be removes. Hence person can clean the base tank easily with any cloth. The pads do not need cleaning. They are to be replaced after every two years of frequent use.
3. **Less power consumption**: Power consumption in air coolers is many times lesser than air conditioners since no compressor or other complicated circuits are used.
4. **Cheaper**: Air coolers and heater do not have expensive components and hence are cheaper on cost.
5. **Maintenance**: Maintenance cost is nearly negligible. Only the cooling pads are to be replaced after every two years, which are very cheap. If the motor of the pump gets damaged, they can be repaired cheaply.
6. **Easy installation of different parts**: If the pump or fan or any other part is damaged, these can be easily replaced by any person.

Conclusions

The present investigation demonstrates that the performance of a drip-type 360° evaporative cooling system is influenced by several design and operating parameters, including the thickness and characteristics of the evaporative pad, water distribution and prevailing atmospheric conditions, particularly ambient temperature and relative humidity. The optimum values of these parameters are dependent on the operating environment and therefore should be selected according to the local climatic conditions. Appropriate optimization of the design parameters can improve cooling effectiveness while reducing the electrical power consumption of the system. Based on the developed prototype and the experimental investigation, the 360° air cooler-cum-heater demonstrated the potential to reduce the air temperature by approximately 10–12°C under suitable ambient conditions through the evaporative cooling process. In heating mode, the electrical heating coil was capable of increasing the air temperature by approximately 5–8°C, depending on the operating conditions and heating input. The combination of evaporative cooling and electrical heating enables the system to provide thermal conditioning during both warm and cold weather conditions. Compared with conventional vapour-compression air-conditioning systems, the proposed system has the potential to reduce initial cost and electrical energy consumption, particularly for localized cooling applications. The system also utilizes the natural process of water evaporation for cooling and does not require a conventional vapour-compression refrigeration cycle. Consequently, it provides a comparatively simple and energy-efficient approach to thermal comfort. However, the cooling performance of the evaporative mode is strongly dependent on ambient relative humidity; therefore, the reported temperature reduction should be interpreted in relation to the specific experimental conditions under which the measurements were obtained.

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