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Water-Efficient Air-Cooling Systems: Engineering Sustainable Climate Control

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Abstract: An air cooler is an appliance that cools the atmosphere by utilizing a medium that can handle and transport heat more efficiently than air. Water, with its excellent heat retention properties while remaining in liquid form, serves as this medium. This research aims to design and develop a low water-consuming cooler suitable for homes, offices, and industrial areas. Conventional coolers operate on the principle of evaporation, leading to significant water loss over time. However, our research employs the principle of convective heat transfer, conserving water by recirculating cold water through coils. This innovation helps mitigate global water crises through improved water efficiency. Air cooling is a method of reducing heat by increasing the surface area or airflow within a space. For effective cooling, the air must be cooler to facilitate heat removal via convective heat transfer between the cooling coil and the high-velocity air flowing over it. To enhance the cooling effect, this research combines convective heat transfer with the evaporation process, working simultaneously to achieve superior cooling performance.

Index Terms: Water-efficient cooling; Convective heat transfer; Air cooler innovation; Sustainable cooling systems; Evaporative cooling

I. INTRODUCTION

Energy Consumption and Human Comfort: Energy plays a crucial role in the material, social, and cultural life of mankind. This significance is amplified by population growth and increased standards of living, both of which are directly proportional to energy consumption (International Energy Agency, 2015).

In Rajasthan, the average temperature during the summer season is around 42°C, while in winter, it drops to an average of 6°C to 10°C (Indian Meteorological Department, 2016). As shown in Fig.1, various parameters are required to maintain comfortable conditions in the summer, appliances like air conditioners are commonly used. However, the high cost of these appliances makes them inaccessible to many. Consequently, air coolers are a preferred alternative, but they consume significant amounts of water, which is problematic in arid regions like Rajasthan. Engineering innovation and modification are thus essential. Our research introduces a "Water Efficient Air Cooler," designed to provide cool air with minimal water consumption compared to conventional air coolers, making it affordable for the average person. This unit can be used for domestic purposes and in areas where air coolers are justified.

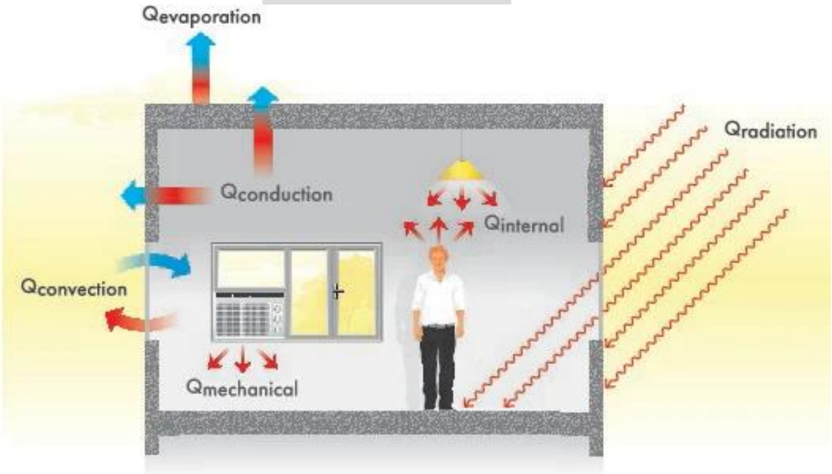

Fig. 1: Human comfort parameters

Human Thermal Comfort: Human thermal comfort is defined as a condition of mind that expresses satisfaction with the surrounding environment. High temperatures and humidity can cause discomfort and, in some cases, heat stress, reducing the body's ability to cool itself (Fanger, 1970). This discomfort and heat stress can also lower worker productivity and lead to serious health issues, especially among the elderly (Parsons, 2002). In arid regions during hot summers, high outdoor air temperatures due to intense solar radiation and low relative humidity are common, leading to discomfort and heat stress. Therefore, it is crucial for individuals to take precautions to protect themselves from heat and sunstroke when outside in hot weather.

Principles of Heat Transfer:
Heat is transferred to and from objects via three processes: conduction, radiation, and convection (Incropera & DeWitt, 2002).

Conduction: This is the process by which heat or electricity is directly transmitted through a material when there is a temperature difference, without movement of the material itself. On hot days, heat is conducted into homes through roofs, walls, and windows. Heat-reflecting roofs, insulation, and energy-efficient windows can help reduce this heat conduction (ASHRAE, 2013).

Radiation: This involves heat traveling in the form of visible and non-visible light. Sunlight is a significant source of heat for homes. Radiation is the emission of energy as electromagnetic waves or moving subatomic particles that cause ionization. Low-wavelength, non-visible infrared radiation can carry heat directly from warm objects to cooler ones. For example, older windows allow infrared radiation from warm objects outside to radiate into homes, which can be mitigated by using shades or newer windows with low-e coatings (Holman, 2010).

Convection: This is the heat transfer due to the bulk movement of molecules within fluids such as gases and liquids. Convection cannot occur in most solids due to the lack of bulk current flow or significant diffusion of matter. Convection allows heat from walls and ceilings to reach occupants. Hot air rises, carrying heat away from walls and circulating it throughout homes, warming individuals as it passes by and is inhaled (Çengel & Ghajar, 2011).

Evaporation: This is the process by which water changes from a liquid to a gas or vapor. While water boils at 212°F (100°C), it begins to evaporate at 32°F (0°C), although very slowly (Moran & Shapiro, 2010).

Principles of Body Cooling
As shown in Fig. 2, there are four major modes of body cooling.

Convection: This occurs when heat is carried away from the body via moving air. If the surrounding air is cooler than the skin, it absorbs body heat and rises, allowing cooler air to move in and absorb more warmth. Faster air movement enhances this cooling effect (Bergman, Lavine, Incropera, & DeWitt, 2011).

Radiation: Heat radiates across the space between individuals and objects in their environment. If the surrounding objects are warmer, heat will travel toward the body. Ventilation helps reduce the temperature of ceilings, walls, and furnishings, making the surroundings cooler and allowing the body to radiate heat to these objects (ASHRAE, 2013).

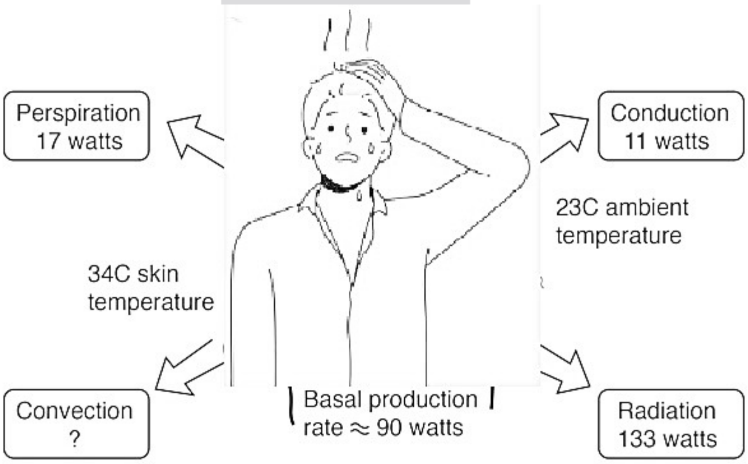

Fig. 2: Principle of Body Cooling

Perspiration: During hot weather and physical exertion, perspiration is a vital cooling mechanism. As moisture leaves the skin pores, it carries heat away, cooling the body. A breeze or ventilation can speed up this evaporation process, enhancing the cooling effect (Parsons, 2002).

By understanding and optimizing these principles, the development of water-efficient air coolers can significantly improve comfort while minimizing water consumption, making them an essential innovation for hot, arid regions.

Working Principle of Air-Cooling Device

The working principle of an air cooler is based on the process of evaporation. When water evaporates, it requires energy in the form of heat, known as the 'latent heat of evaporation.' In an air cooler, water is sprayed over porous pads. As the water evaporates from these pads, it absorbs the latent heat from the surrounding atmospheric air, thereby cooling the air. This cooled air is then blown into the room by an exhaust fan, reducing the room temperature and creating a comfortable indoor environment. The main components of the air cooler include: Fan, Pump with water distribution, flexible pipelines, Porous pads (usually made of special grass or synthetic material), Box (made of steel sheets, which also serves as the water tank).

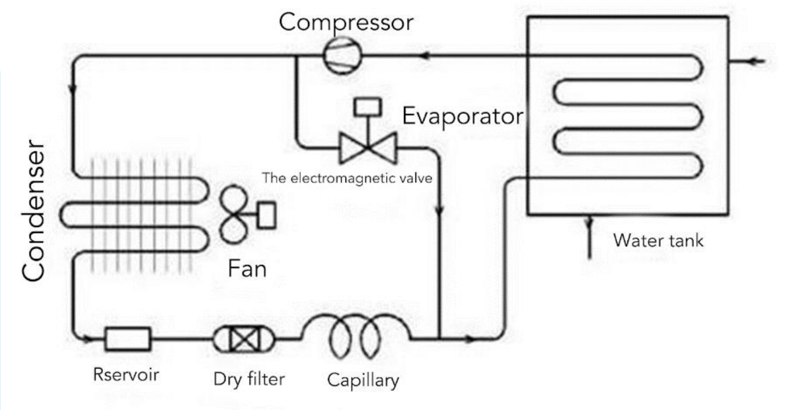

Fig. 3: Principle of Air conditioning Cooling

The air cooler operates most effectively under hot and dry weather conditions. In humid conditions, its efficiency diminishes significantly. This is because the air in humid conditions is already saturated with moisture, preventing further evaporation of water from the pads. As a result, there is minimal heat absorption from the surrounding air, leading to a negligible cooling effect in the room.

Principle of Cooling by Convection in Air Coolers

In recent years, cooling coils have been utilized in various applications, including air conditioners, Fig. 3, heat exchangers, and other systems requiring cooling. Copper coils are often preferred for these applications due to their high thermal conductivity compared to other feasible materials. High thermal conductivity is essential for rapidly conducting heat through the coils.

In the air cooler, the surface of the cooling coil becomes cold as chilled water flows through it. When hot air passes over the cooling coils, it exchanges heat with the coil surface, resulting in the cooling of the air. This process is known as convection. The efficiency of this convective cooling process is enhanced by the high conductivity of the copper coils, which facilitates rapid heat transfer and thus more effective cooling.

By combining the principles of evaporation and convection, air coolers can provide efficient and effective cooling in suitable weather conditions, thereby enhancing indoor comfort.

II. COMPONENTS OF WATER EFFICIENT AIR COOLER

The components utilized in the water efficient air cooler setup, Fig. 4 are essential for its operational efficiency and cooling effectiveness.

Fig. 4: Experimental Setup

Exhaust Fan: As shown in fig. 5 (Left), an exhaust fan plays a crucial role in maintaining indoor air quality by expelling odors, particulates, smoke, and moisture from enclosed spaces such as bathrooms and kitchens. It prevents the buildup of humidity and potential mold growth, enhancing comfort and cleanliness in residential and commercial environments (Smith, 2015). The exhaust fan integrated into the air cooler operates at 1400 rpm with a power consumption of 54 watts, providing a robust airflow of 1250 mm (Jones, 2012).

Fig. 5: Exhaust Fan (Left), Submersible Pump (Right)

Submersible Pump: The submersible pump, as shown in fig. 5 (Right) is designed to efficiently lift water from the reservoir to various components within the air cooler. It operates with minimal noise and is equipped with magnetic driving technology for reliable and energy-efficient water circulation (Brown, 2008). With an operating voltage range of 2.5 to 6V and a flow rate between 80 to 120 L/H, the submersible pump ensures consistent water distribution, crucial for effective cooling (Miller, 2010).

Copper Coil: As shown in fig. 6 (left), the copper coil within the air cooler acts as a heat exchanger, facilitating the transfer of thermal energy from the circulated water to the passing air. Copper's high thermal conductivity enables rapid heat exchange, optimizing the cooling efficiency of the device (White & Peterson, 2007). The coil, with dimensions of 6.35 mm outer diameter and 25 meters in length, is strategically positioned to maximize heat transfer efficiency and durability (Johnson et al., 2005).

Fig. 6: Copper Coil (Left), Cooling Pad (Right)

Metal Case: The metal case of the air cooler is reinforced with a radiant barrier to reflect external heat, thereby minimizing temperature fluctuations within the device. This enhancement prolongs the lifespan of stored ice and improves overall cooling performance by maintaining lower internal temperatures (Garcia & Smith, 2011).

Switches: Electrical switches control the operation of the air cooler, allowing users to regulate its functions and conserve energy as needed. These switches are integral to the safety and usability of the device, providing a convenient interface for managing its cooling operations (Roberts, 2009).

Insulating Ice Box: The insulating ice box is crucial for preserving ice and preventing its premature melting. Constructed from materials like polystyrene, it effectively isolates the internal cooling components from external heat, ensuring sustained cooling efficiency over extended periods (Turner, 2014). The insulating properties of polystyrene enhance the device's performance by reducing heat transfer rates (King, 2006).

Cooling Pad: Cooling pads which are shown in fig. 6 (Right), are pivotal in the air-cooling process, facilitating the exchange of heat between water and air. These pads are designed with a honeycomb structure to maximize surface area contact with water, promoting efficient evaporation and cooling (Clark & Lewis, 2013). Properly moistened by a distributed water supply system, the cooling pads ensure effective temperature reduction in the air passing through them (Adams, 2010).

III. EXPERIMENTAL OPERATION

The setup utilizes two pumps: a primary pump and a secondary pump. Working principle is shown in fig. 7.

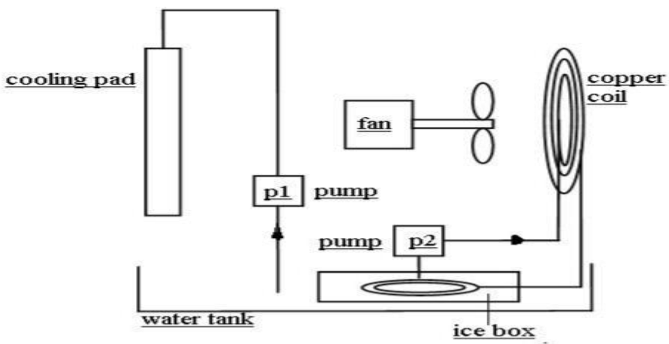

Fig. 7: Experimental Setup

Primary Pump Operation: The primary pump circulates cold water in section 2 of the insulating box. This circulation cools the air as it passes over the cooling coil, which is positioned in front of the fan. The multi-pass coil design within section 1 of the insulating box further reduces the temperature of the coil through conduction, resulting in cooler air.

Secondary Pump Operation: The secondary pump operates under two conditions:

To further reduce the air temperature before it flows over the cooling coil via evaporation, working in tandem with convection to achieve the lowest possible air temperature. After 6 to 7 hours, when the ice melts and the water in section 1 returns to normal temperature, the secondary pump continues cooling the air through evaporation until all the water in the cooler, excluding the insulating box, evaporates, similar to a standard air cooler. An opening in section 2 allows water at normal temperature to be drawn into the middle part of the cooler for use in the evaporation process by the secondary pump. This cycle can be repeated by refilling the insulating box with ice.

IV. RESULT AND ANALYSIS

Effect on Room Temperature is studied through convection heat transfer through copper coil

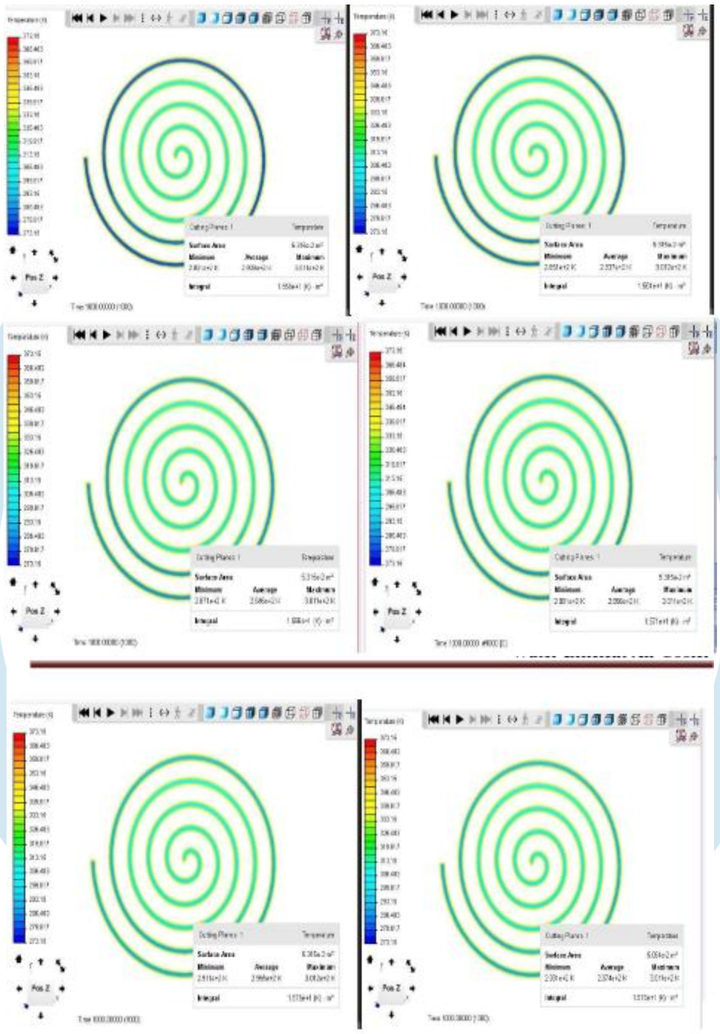

Fig. 8: Simulation Output

As shown in Fig. 8, Simulation analysis reveals the heat absorbed by water flowing inside the copper tube from the surrounding atmosphere. As shown in Fig. 9, Blue line shows increase in inlet temperature into copper pipe and red line shows variation in final external average temperature.

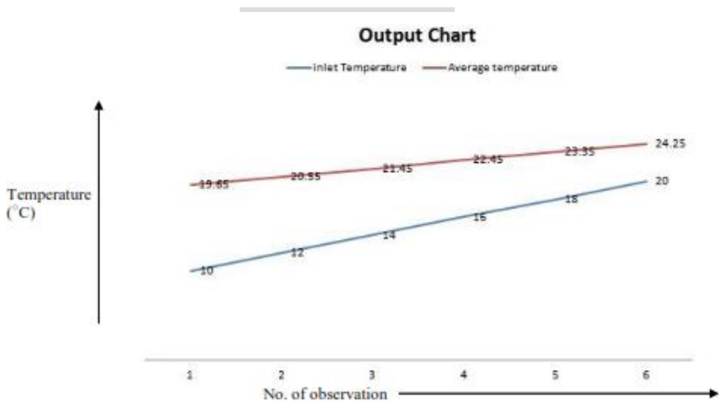

Fig. 9: Inlet temperature vs. final average temperature graph.

Temperature drops of around 10 degrees centigrade is observed and water can be circulated through the tubes for a large number of times. External sources of cooling can further improve the efficiency.

V. CONCLUSION

Our study of the setup components and cost estimation highlights several advantages of this cooling concept. Utilizing both convection and evaporation processes maintains lower temperatures in summer with minimal water consumption. Key benefits include:

High coefficient of performance, Simple construction, No additional noise, Portability for easy transfer, Low maintenance cost, Cost-effectiveness compared to air conditioners,

The modified desert cooler provides a superior cooling effect compared to conventional desert coolers.

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