

Comparative Study of the Humidification Efficiency of an Air Cooler with a Centrifugal Fan Versus an Axial Fan

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Abstract

This study presents a comparative analysis of the humidification efficiency and operational performance of evaporative coolers equipped with centrifugal versus axial fans. Employing experimental methods, the research evaluates key parameters such as cooling capacity, energy consumption, and moisture addition under controlled conditions. Results indicate that centrifugal fans achieve higher humidification efficiencies and heat transfer rates, making them suitable for applications demanding maximum cooling performance. Conversely, axial fans demonstrate lower energy consumption and operational costs, favoring energy-efficient cooling solutions. The findings provide insights into optimizing evaporative cooler designs for enhanced thermal comfort and sustainability in arid environments.

Keywords: Evaporative cooling; Centrifugal fan; Axial fan; Humidification efficiency; Energy performance.

1. Introduction

Evaporative cooling is a technique that has been employed since ancient civilizations such as the Greeks and Egyptians, who utilized the simple method of wetting fabrics to reduce air temperature and create a more comfortable environment. Over centuries, this natural cooling process has evolved into modern evaporative coolers, which are celebrated for being environmentally friendly alternatives to traditional refrigeration systems. Unlike conventional air conditioning units that rely on chemical refrigerants, contemporary evaporative coolers use water to facilitate cooling, making them a sustainable and energy-efficient choice. Due to their effectiveness and eco-friendly nature, these coolers are particularly popular in arid and dry regions such as the Middle East, Australia, and parts of Africa, where the low humidity levels amplify their cooling efficiency and practicality.

Despite their widespread use and advantages, a significant challenge persists within the industry: the absence of standardized protocols and benchmarks for the manufacturing and performance of evaporative coolers. This lack of industrial standards results in considerable variability in the thermal comfort provided by different units, thereby affecting user satisfaction and efficiency. Consumers often encounter inconsistencies in cooling performance, which can undermine trust and hinder broader adoption of these systems in commercial settings.

The primary goal of this study is to address these issues by conducting a comprehensive comparison between two common types of high-capacity evaporative coolers, each capable of delivering around 4000 CFM (Cubic Feet per Minute) of airflow. Specifically, the focus will be on evaluating centrifugal fan coolers versus axial fan coolers. The analysis aims to assess and contrast their performance in critical areas such as humidification efficiency, which directly impacts on user comfort and air quality; energy and water consumption, which are vital for assessing sustainability and operational costs; and overall thermal comfort, which determines the effectiveness of the cooling process in creating a pleasant indoor environment. Through this comparison, the study seeks to provide valuable insights that can inform better design practices, promote standardization, and enhance the thermal comfort outcomes of evaporative cooling systems in various applications, [1], [2], [3], and [4].

2. Theoretical Background

Understanding the fundamental principles and different configurations of evaporative coolers is essential for selecting the appropriate system for specific applications. This section provides an overview of the main types of evaporative coolers and the various fan technologies used to facilitate airflow within these systems, [1], [4], [5], and [6].

2.1 Evaporative Cooler Types

Evaporative coolers operate based on the principle of water evaporation to lower air temperature, but they differ significantly in design and operational methods. The two primary categories are direct and indirect evaporative coolers.

Direct evaporative coolers function by passing ambient air directly through wetted pads or media. As the air moves through these moist surfaces, water evaporates into the air, resulting in a cooling effect. This process not only reduces the air temperature but also increases the humidity level in space. These systems are particularly effective in dry, arid climates where the increase in humidity does not cause discomfort and can significantly lower energy consumption when compared to traditional air conditioning systems.

In contrast, indirect evaporative coolers utilize a heat exchanger to achieve cooling without adding moisture to the air that is eventually supplied to the interior space. In this configuration, warm outside air is first cooled indirectly through a heat exchanger by passing it adjacent to another airstream that has been cooled by evaporation. As a result, the cooled air delivered indoors has a lower temperature but maintains a lower humidity level. This method is advantageous in environments where maintaining low indoor humidity is essential, such as in data centers or certain industrial processes, although it typically provides less cooling compared to direct systems.

2.2 Fan Types

The efficiency and performance of evaporative coolers heavily depend on the type of fan employed to circulate air through the system. Two common types of fans used in these applications are centrifugal fans and axial fans, each offering distinct advantages based on the specific requirements of the cooling system. Centrifugal fans are characterized by their curved blades, which are designed to increase air pressure by imparting centrifugal force to the air as it moves radially outward from the center of rotation. These fans can generate higher pressure output, making them well-suited for systems with high-resistance airflow paths or extensive ductwork. Their design allows for efficient airflow control and is often preferred in larger or more complex evaporative cooling setups. The curved blades, which can be configured in forward or backward orientations, optimize the fan's performance for various operating conditions.

Axial fans, on the other hand, are simpler in construction and operate by moving air along the axis of the fan blades, like a propeller. They are typically used in applications requiring large volumes of airflow at relatively low pressures. Axial fans are known for their lower energy consumption and ease of maintenance, making them suitable for smaller or more straightforward evaporative cooling systems. Their design allows for high airflow rates, which can be beneficial in applications where volume is more critical than pressure.

In summary, the choice between centrifugal and axial fans depends on the specific airflow resistance and efficiency requirements of the evaporative cooling system.

Figure 1 illustrates two common configurations: (a) a centrifugal fan cooler, which employs a centrifugal fan to achieve higher pressure and efficiency in systems with complex airflow paths, and (b) an axial fan cooler, which relies on an axial fan for large-volume, low-pressure airflow suitable for simpler setups.

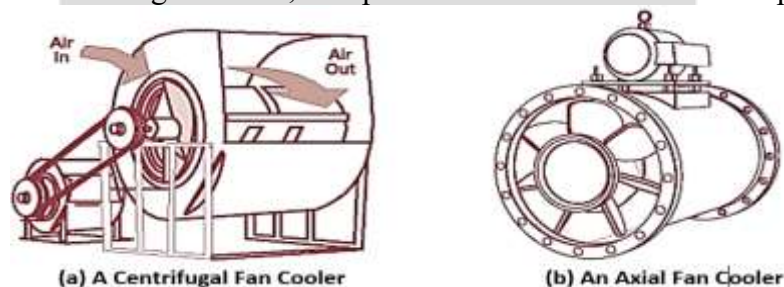


Figure 1: Two Common Configurations of Fan Coolers

And Table 1 concisely contrasts the two fan types across key characteristics. Centrifugal fans deliver higher pressure output but are less energy-efficient, featuring curved blades (forward or backward) and a more complex construction, making them ideal for high-resistance airflow systems. In contrast, axial fans prioritize lower energy consumption, use simpler propellers or tube axial blade designs, and excel in low-resistance applications. This side-by-side format helps users quickly evaluate which fan type best suits their needs based on pressure requirements, efficiency, design complexity, and intended use.

Table 1: Comparison of Centrifugal and Axial Fans

Feature	Centrifugal Fan	Axial Fan
Pressure Output	Higher pressure output	Lower pressure output
Energy Efficiency	Less energy-efficient	Lower energy use
Blade Design	Curved blades (forward/backward)	Propeller/tube axial designs
Construction Complexity	More complex	Simpler construction
Best Use Case	High-resistance airflow	Low-resistance airflow

2.3 Cooling Pads

Cooling pads play a vital role in enhancing the efficiency of evaporative cooling systems, particularly in applications such as poultry houses, greenhouse environments, and industrial cooling processes. Among the various types of cooling pads available, two prominent options are American Straw and Cellulose Pads, each with distinct characteristics and performance attributes.

American Straw pads (see Figure 2(a)) are constructed using Aspen wood fibers, which are renowned for their high-water absorption capacity. This property allows the straw pads to effectively facilitate the evaporation process by maintaining a moist surface, thus promoting efficient cooling. The high-water retention capability of Aspen wood fibers ensures that the pads remain saturated for longer periods, leading to consistent cooling performance even during periods of high ambient temperature.

On the other hand, Cellulose Pads (see Figure 2(b)) are made from layered paper materials that are treated with specific surface coatings. These treated surfaces enhance the durability of the pads, making them resistant to mold, bacteria, and other environmental factors that could degrade their performance over time. Furthermore, the layered structure of cellulose pads contributes to their overall efficiency, allowing for a more uniform airflow and water distribution across the surface, which results in higher cooling effectiveness.



Figure 2(a): Straw Pads

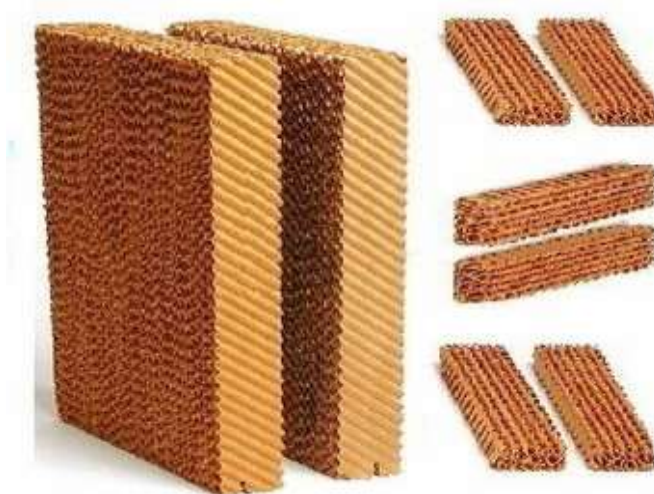


Figure 2(b): Cellulose Pads

To compare the performance of these two types of cooling pads, Table 1 provides a summary of their efficiency percentages and airflow resistance levels. The efficiency of American Straw pads ranges from approximately 48% to 54%, with airflow resistance categorized as moderate. This means that while they are quite effective at cooling, there may be some restriction to airflow, which could influence the overall system performance. Conversely, Cellulose Pads exhibit slightly higher efficiency, ranging from about 54% to 56.5%, with low airflow resistance. The lower resistance to airflow allows for better air circulation through the pads, potentially leading to more effective cooling with less energy consumption for air movement.

Table 1: Pad Performance Comparison

Pad Type	Efficiency (%)	Airflow Resistance
Straw	48–54	Moderate
Cellulose	54–56.5	Low

In summary, both American Straw and Cellulose cooling pads offer valuable benefits, with the choice between them depending on specific operational requirements such as desired cooling efficiency, airflow considerations, durability needs, and environmental conditions. Understanding these differences helps in selecting the most suitable cooling pad type to optimize system performance and energy efficiency.

3. Methodology

The study employed a comprehensive approach combining specialized equipment and controlled experimental procedures to evaluate the performance of different cooling units. The equipment used primarily consisted of high-capacity cooling systems and precise measurement instruments designed to capture key parameters relevant to the cooling process, [5], [7], [8], and [9].

3.1 Equipment

The cooling units tested included two types of air coolers: centrifugal and axial, each with a capacity of 4000 CFM (Cubic Feet per Minute). These units were selected to compare their efficiencies and operational characteristics under similar conditions. The centrifugal coolers are known for their high pressure and efficiency in certain applications, while axial coolers are typically favored for their simplicity and lower operational costs. To accurately measure the environmental conditions and airflow characteristics during experimentation, the following instruments were utilized:

A psychrometer, capable of measuring both dry bulb and wet bulb temperatures, was employed to determine the humidity ratio of the air before and after cooling. This information is essential for calculating the moisture content and understanding the psychrometric properties of the air.

An anemometer was used to measure the airflow velocity within the system. Accurate airflow measurements are critical for calculating mass flow rates and heat transfer quantities.

3.2 Experiments

The experimental procedure was designed to ensure consistency and comparability across different tests. Each experiment was conducted under strictly controlled conditions, with the ambient temperature and humidity maintained at constant values to isolate the effects of the cooling units themselves.

Test Conditions: All tests were performed in an environment where the ambient temperature and humidity levels remained identical throughout the experiments. This controlled setting ensured that variations in the results could be attributed solely to the differences between the centrifugal and axial coolers.

Measurements: During each test, key parameters were recorded at both the inlet and outlet points of the cooling units. These included:

The air temperatures measured using the psychrometer, to determine the temperature change imparted by the cooling process.

The humidity ratios, derived from psychrometric charts based on the dry and wet bulb temperature readings, to assess the moisture content of the air before and after cooling.

Calculations: The data collected enabled the calculation of several performance metrics:

Humidification Efficiency (η): This parameter indicates how effectively the cooling unit adds moisture to the air relative to the maximum possible humidification. It was calculated using the formula:

$$\eta = \frac{\omega_o - \omega_i}{\omega_s - \omega_i} \times 100\%$$

Where:

ω_i is the initial humidity ratio (before cooling),

ω_o is the final humidity ratio (after cooling),

ω_s is the saturation humidity ratio at the outlet temperature.

Heat Transfer (Q): The amount of heat removed by the cooling system was determined using the equation:

Where:

\dot{m} is the mass flow rate of air,

$(h_1 - h_2)$ are the specific enthalpies of the air at the inlet and outlet, respectively. These enthalpies were calculated based on the temperature and humidity data.

This methodology ensured a systematic and precise evaluation of the cooling units' performance, providing reliable data for further analysis and comparison.

4. Results and Performance Summary

The comprehensive analysis of the cooling systems is summarized in Table 2, which highlights key performance metrics for the different fan types evaluated. The study primarily compares centrifugal fans and axial fans, focusing on their average efficiency, heat transfer capabilities, and energy consumption.

The data indicates that centrifugal fans generally exhibit higher efficiency levels, with average efficiencies ranging from approximately 54.1% to 56.5%. Notably, when paired with cellulose pads, these fans can achieve efficiencies at the upper end of this spectrum, reaching around 56.5%. In terms of heat transfer, centrifugal fans demonstrate robust performance, with heat transfer rates measured at approximately 6.27 kW, indicating their superior capacity to dissipate heat effectively.

Conversely, axial fans operate at comparatively lower efficiencies, with averages spanning from 48% up to 54.1%. Their heat transfer rates are significantly reduced, varying between approximately 1.28 kW and 1.46 kW, which reflects their lower cooling capacity relative to centrifugal fans. However, this reduced heat transfer comes with notable energy savings; axial fans consume considerably less energy, resulting in an estimated 20–30% reduction in energy use compared to centrifugal counterparts. This makes axial fans a preferable choice in scenarios where energy conservation is prioritized over maximum cooling efficiency.

The key findings of this comparative analysis can be summarized as follows: centrifugal fans are more effective in achieving higher cooling efficiencies and heat transfer rates, making them suitable for applications requiring intensive cooling. On the other hand, axial fans offer substantial energy savings, making them advantageous in situations where operational costs and energy consumption are critical considerations, despite their comparatively lower cooling capacity.

Furthermore, Figure 2 illustrates the efficiency trends associated with different types of cooling pads used in conjunction with these fans. The graph clearly depicts how various pad materials influence the overall system efficiency, offering valuable insights into optimizing cooling performance through appropriate component selection, [3], [6], [8], and [9].

Table 2: Performance Summary

Cooler Type	Avg. Efficiency (%)	Heat Transfer (kW)	Energy Use
Centrifugal Fan	54.1–56.5	6.27	Higher
Axial Fan	48–54.1	1.28–1.46	Lower

5. Recommendations

Based on the current findings, several key recommendations can be proposed to improve the overall performance and reliability of the cooling systems. Firstly, material optimization plays a crucial role; it is advisable to conduct comprehensive testing of advanced pad materials, such as silica gel, which have the potential to significantly increase cooling efficiency due to their superior thermal properties. Incorporating these materials could lead to more effective heat absorption and retention, thereby enhancing the system's overall effectiveness.

Secondly, design improvements should be prioritized, particularly focusing on the airflow distribution within axial fan coolers. By refining the design to promote more uniform and efficient airflow, it is possible to maximize cooling performance and reduce energy consumption. Enhancing airflow management may involve optimizing blade angles, adjusting fan placement, or integrating innovative ducting solutions to ensure consistent and adequate air circulation throughout the system.

Finally, conducting seasonal studies through long-term testing across various climates is essential to understand the system's performance under different environmental conditions. Such studies will help identify seasonal variations in cooling efficiency, material durability, and operational stability. This comprehensive data collection will inform further modifications and enable the development of more resilient and adaptable cooling solutions capable of maintaining optimal performance year-round, regardless of climatic changes. Overall, implementing these recommendations will contribute to the advancement of more efficient, durable, and climate-responsive cooling systems, [1], [2], [5], and [10].

6. Conclusion

The comparative assessment reveals that centrifugal fans offer superior humidification and heat transfer capabilities, thereby delivering higher cooling efficiency in evaporative systems. However, their increased energy consumption positions axial fans as a more economical choice where reduced operational costs are prioritized. The study highlights the importance of selecting appropriate fan types based on specific application requirements and underscores the potential for further optimization through material and design enhancements. These insights contribute to advancing standardization and improving the effectiveness of evaporative cooling technologies in arid and semi-arid regions.

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