A State-of-the-Art Review on Performance of Spray Evaporative Cooling in Window Air Conditioner

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Abstract - Air conditioning condenser efficiency is improved by implementing a spray nozzle system to reduce heat generation. The condenser is a critical component of air conditioning systems, impacting energy savings and overall performance. Strategically positioned spray nozzles optimize heat transfer by introducing a fine mist of water or coolant onto the condenser coils. This enhances heat dissipation and lowers operating temperatures. Experimental tests compare the spray nozzle system to a standard condenser setup. Results show significant temperature reduction and improved heat transfer effectiveness. The system effectively decreases the condenser's operating temperature. Implementing the spray nozzle system reduces the workload on other components and enhances system characteristics and longevity. This innovation promotes energy savings and sustainability in air conditioning. This research contributes to advancing the air conditioning industry. Spray nozzle systems have potential for eco-friendly, energy-efficient cooling solutions. Further optimization can facilitate widespread adoption.

Keywords - Air Conditioning, Condenser Effectiveness, Heat Transfer, Spray Nozzle System, Energy Savings, Sustainability.

I. INTRODUCTION

The demand for efficient and sustainable cooling solutions has gained significant attention in recent years. Traditional air conditioning systems consume substantial energy and contribute to greenhouse gas emissions. The effectiveness of the condenser significantly affects the overall performance of the air conditioner, as it is responsible for rejecting the heat absorbed from the indoor space to the outdoor environment. Traditional condenser designs in window air conditioners often face challenges related to heat transfer and overall system efficiency [1]. Heat transfer in condensers is influenced by several factors, including condenser coil surface area, refrigerant flow rate, and the temperature difference between the refrigerant and the ambient air. Inefficient heat transfer in the condenser can lead to reduced chilling ability, increased power consumption, and decreased overall system efficiency. Various cooling techniques have been explored to improve the characteristics of condensers in air conditioning systems. These techniques aim to enhance heat transfer, reduce condenser temperature, and increase overall system efficiency. Air cooling involves utilizing the ambient air to cool the condenser coils. This method relies on the natural convection and forced convection of air to transfer heat from the condenser coils to the surroundings [2-3]. While air cooling is commonly used in window air conditioners, it may face limitations in hot and humid climates where the ambient air temperature is high, leading to reduced condenser performance. Water cooling, on the other hand, utilizes water as a cooling medium to extract heat from the condenser coils [4]. This method can provide more effective cooling compared to air cooling, as water has a higher heat transfer coefficient. However, water cooling systems require additional infrastructure, such as water supply and circulation pumps, which may not be feasible or cost-effective for window air conditioners [5]. Evaporative cooling is a technique that utilizes the principle of heat transfer through the evaporation of water. It involves introducing water into the condenser airflow, which evaporates and absorbs heat from the condenser coils, resulting in lower condenser temperatures. Evaporative cooling has shown promising results in enhancing condenser performance and overall system effectiveness in various air conditioning applications. In this context, spray evaporative cooling has emerged as a promising technology to improve the effectiveness of air conditioners by reducing the heat generated by the condenser [6]. Evaporative cooling is a widely recognized technique for reducing the temperature of a substance through the phase transition of liquid to vapor. It offers numerous advantages such as energy effectiveness and environmentally friendly operation. Traditionally, condensers in air conditioners rely on air-cooled or water-cooled mechanisms for heat dissipation. However, these methods have limitations in terms of effectiveness and performance. To address the limitations of conventional condenser cooling methods, the incorporation of spray evaporative cooling in window air conditioners has gained significant attention. This technique involves the introduction of a spray nozzle that atomizes water into fine droplets, which are then introduced into the condenser airflow. As the droplets evaporate, they absorb heat from the surrounding air and the condenser, resulting in a decrease in condenser temperature. This, in turn, enhances the overall efficiency of the air conditioning system. Among the different methods of evaporative cooling, the use of a spray nozzle system has gained attention in window air conditioners. Spray nozzles atomize water into fine droplets, which are then introduced into the condenser airflow. This atomization process increases the surface area of water droplets, facilitating rapid evaporation and efficient heat transfer. The spray nozzle system provides uniform water distribution over the condenser coils, maximizing the contact area between water and the coil surface. By incorporating spray nozzle cooling into window air conditioners, it is possible to increase the effectiveness of the condenser, leading to reduced power consumption, improved chilling ability, and enhanced overall system characteristics. This review aims to explore the state-of-the-art research on the characteristics of spray evaporative cooling in window air conditioners, shedding light on its potential benefits and challenges, and providing valuable insights for further advancements in energy-efficient cooling solutions for window air conditioners [7].

II. METHOD OF EVAPORATIVE COLLING PROCESS

In order to investigate the characteristics of spray evaporative cooling in window air conditioners, an experimental setup was designed and implemented. The selection of appropriate equipment and instruments was crucial for accurate data collection and analysis. A suitable window air conditioner model was chosen based on its condenser design and compatibility with spray nozzle cooling. The selected model had a typical condenser configuration found in residential window air conditioners. A high-quality spray nozzle system was selected, considering factors such as nozzle size, spray pattern, and droplet size distribution. The nozzle system was designed to provide uniform water distribution over the condenser coils [8]. To measure and record relevant parameters during the experiments, a data acquisition system was employed. This system included temperature sensors, pressure sensors, flow meters, and a digital data logger to ensure accurate and synchronized data acquisition. The experimental procedure was designed to evaluate the characteristics of the window air conditioner with and without the spray evaporative cooling system. The window air conditioner was tested under standard operating conditions without any additional cooling mechanism. Baseline data, including power consumption, condenser temperature, refrigerant flow rate, and chilling ability, were recorded [6][9]. The spray nozzle system was integrated into the window air conditioner. The water supply to the spray nozzles was carefully controlled to achieve optimal cooling characteristics. The experiments were conducted at different water flow rates to evaluate the impact on condenser characteristics. During the experiments, various parameters were measured and recorded, including condenser temperature, air temperature at different locations, airflow rate, power consumption, and chilling ability. These measurements were taken at regular intervals to capture the system's dynamic behavior and ensure accurate data analysis. The characteristics of the window air conditioner with spray evaporative cooling was evaluated based on the experimental data. The effectiveness of spray evaporative cooling in reducing the condenser temperature was quantified by comparing the condenser temperatures with and without the spray nozzle system. The percentage reduction in condenser temperature was calculated to assess the cooling effectiveness. The chilling ability of the air conditioner was evaluated by comparing the cooling output with and without spray evaporative cooling. The percentage improvement in chilling ability was determined to assess the system's enhanced characteristics. The power consumption of the air conditioner with spray evaporative cooling was compared to the baseline power consumption. The percentage reduction in power consumption was calculated to determine the energy-saving potential of the system [12]. To ensure the reliability and validity of the experimental results, data validation techniques and statistical analysis were applied. The measured parameters were subjected to statistical tests, to evaluate the significance of the observed differences between the baseline and spray evaporative cooling scenarios. The findings from the experimental study were compared and contrasted with relevant studies available in the literature. This comparison helped validate the results and provided insights into the consistency and effectiveness of spray evaporative cooling in window air conditioners [13]. **Fig 1** shows the flow diagram.

A component known as a water spray nozzle is designed to enhance by spraying water onto the condenser coil, a water spray nozzle in a window air conditioner can help enhance the coil's effectiveness. The condenser coils primary function is to release heat absorbed by the refrigerant to the outside air [15]. However, in high outdoor temperatures or high humidity levels, inefficient heat release by the coil can lead to reduced cooling effectiveness and increased energy consumption [16]. By incorporating a water spray nozzle into air conditioner, water is sprayed onto the condenser coil, which cools the coil and increases its heat transfer efficiency. This results in better cooling performance and lower energy consumption. The water sprayer nozzle is usually located near the condenser coil and connected to a water supply line. It may be triggered automatically based on temperature or humidity levels or operated manually by the user. It is essential to use clean, impurity-free water in the spray as dirty water can clog the nozzle and reduce its effectiveness. Additionally, the water spray should be used moderately to avoid over-wetting the condenser coil, which can reduce air flow and lead to other issues. Using a water spray nozzle in a window air conditioner can be highly effective way to improve the effectiveness of the condenser coil, particularly in hot and humid condition. Water spray nozzles can be especially useful in areas with high humidity levels, where the coil may become coated with moisture and debris and improves the coil's characteristics [19]. Some window air conditioners may come with a built-in water spray feature, while others may require a separate nozzle to be installed. It is important to follow the manufacturer's instructions when installing and using a water spray nozzle. Water spray nozzles usually use low-pressure mist to avoid damaging the condenser coil or other components. The water mist should be directed solely at the coil and not at other parts of the unit, such as the fan or compressor. The frequency of water spry nozzle usage will depend on operating conditions and manufacturer recommendations. It is advisable to use the water spray only when necessary, such as during hot and humid weather, to avoid overusing it, which can increase the humidity level in the room [20].

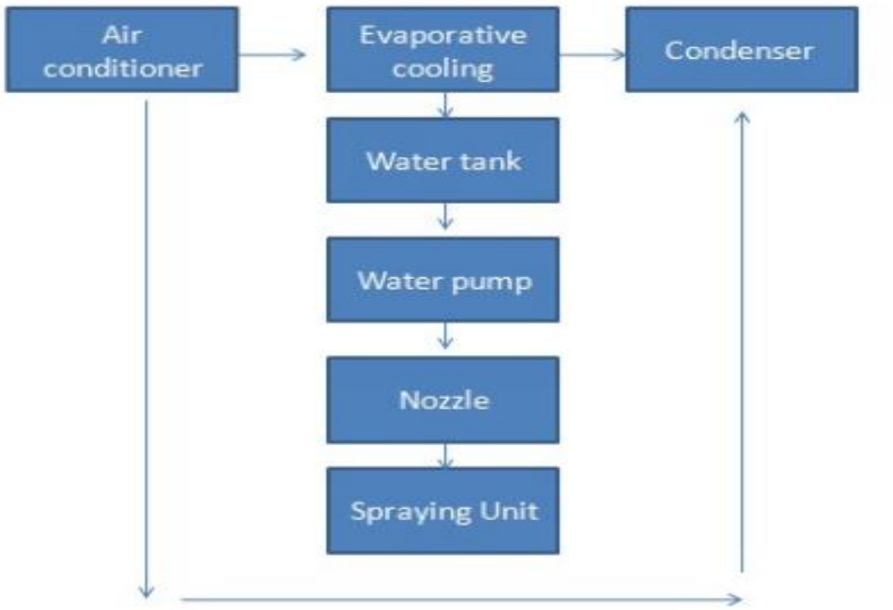

Fig 1. Flow Diagram.

Direct Cooling

Direct cooling refers to a cooling technique in which the cooling medium, typically air or water, comes into direct contact with the object or space to be cooled. In direct cooling systems, the cooling medium absorbs heat directly from the object or space, resulting in a decrease in temperature. In direct air cooling, air is circulated over the surface of the object or space to remove heat. This can be achieved through natural convection, where air circulates due to temperature differences, or forced convection, where fans or blowers are used to enhance air movement [17]. Direct air cooling is commonly used in applications such as room air conditioners, refrigeration units, and electronic cooling. Direct water cooling involves circulating water directly over the object or space to dissipate heat. This can be achieved through the use of water jackets, pipes, or heat exchangers. Direct water cooling is often utilized in industrial processes, power plants, and data centers to remove heat from machinery, engines, or electronic components.

Indirect Cooling

Indirect cooling, on the other hand, involves using an intermediary medium to transfer heat from the object or space to be cooled. In indirect cooling systems, the cooling medium does not come into direct contact with the object or space but instead removes heat through a heat exchanger or other means. In indirect air cooling, the air is first cooled using a cooling medium, such as refrigerant or water, in a heat exchanger. The cooled air is then circulated over the object or space to lower its temperature. This method is commonly used in central air conditioning systems and commercial HVAC (heating, ventilation, and air conditioning) applications [24-26]. Indirect water cooling typically involves the use of a secondary fluid, such as refrigerant or coolant, to transfer heat from the object or space to be cooled. The primary cooling medium, such as water or air, does not directly come into contact with the object but exchanges heat with the secondary fluid through a heat exchanger. Indirect water cooling is commonly employed in industrial processes, power generation, and large-scale refrigeration systems [21-23]. The use of water spray nozzle can also help reduce noise levels from the air conditioner by dampening the sound of the condenser fan and other components. The selection of appropriate equipment and instruments was crucial for accurate data collection and analysis. Initially, a suitable window air conditioner model was chosen based on its condenser design and compatibility with spray nozzle cooling. The selected model featured a typical condenser configuration found in residential window air conditioners. Next, a high-quality spray nozzle system was carefully selected, taking into consideration factors such as nozzle size, spray pattern, and droplet size distribution. This nozzle system was designed to ensure uniform water distribution over the condenser coils, which is essential for efficient cooling. To measure and record relevant parameters during the experiments, a data acquisition system was employed. This system included temperature sensors, pressure sensors, flow meters, and a digital data logger to ensure accurate and synchronized data acquisition. The experimental procedure was designed to evaluate the characteristics of the window air conditioner with and without the spray evaporative cooling system. Initially, the window air conditioner was tested under standard operating conditions without any additional cooling mechanism, allowing for the collection of baseline data. Parameters such as power consumption, condenser temperature, refrigerant flow rate, and chilling ability were recorded during this phase. Subsequently, the spray nozzle system was integrated into the window air conditioner, and the water supply to the spray nozzles was carefully controlled to achieve optimal cooling characteristics. The experiments were conducted at different water flow rates to evaluate the impact on condenser characteristics. Throughout the experiments, various parameters including condenser temperature, air temperature at different locations, airflow rate, power consumption, and chilling ability were measured and recorded at regular intervals. This approach captured the dynamic behavior of the system and ensured accurate data analysis. The characteristics of the window air conditioner with spray evaporative cooling was evaluated based on the experimental data [10]. The effectiveness of spray evaporative cooling in reducing the condenser temperature was quantified by comparing the condenser temperatures with and without the spray nozzle system. The percentage reduction in condenser temperature was calculated to assess the cooling effectiveness. Furthermore, the chilling ability of the air conditioner was evaluated by comparing the cooling output with and without spray evaporative cooling. The percentage improvement in chilling ability was determined to assess the system's enhanced characteristics. Additionally, the power consumption of the air conditioner with spray evaporative cooling was compared to the baseline power consumption. The percentage reduction in power consumption was calculated to determine the energy-saving potential of the system. To ensure the reliability and validity of the experimental results, data validation techniques and statistical analysis were applied. The measured parameters underwent statistical tests, such as t-tests or analysis of variance (ANOVA), to evaluate the significance of the observed differences between the baseline and spray evaporative cooling scenarios. Finally, the findings from the experimental study were compared and contrasted with relevant studies available in the literature. This comparison helped validate the results and provided insights into the consistency and effectiveness of spray evaporative cooling in window air conditioners. Overall, this experimental study employed a systematic approach to investigate the performance of spray evaporative cooling in window air conditioners, from the selection of equipment and instruments to the careful evaluation of various parameters. The continuous monitoring and analysis of data allowed for accurate assessments of cooling effectiveness, chilling ability improvement, and energy-saving potential in the presence of the spray nozzle system.

III. EXPERIMENTAL STUDY

The study aimed to evaluate the effectiveness of incorporating a water spray nozzle system in enhancing the cooling effectiveness and energy-saving potential of the air conditioner. To conduct the experiment, a suitable window air conditioner model was selected based on its condenser design and compatibility with spray nozzle cooling. The chosen model featured a typical condenser configuration found in residential window air conditioners, providing a suitable basis for evaluation. A high-quality spray nozzle system was carefully chosen for the experiment. Factors such as nozzle size, spray pattern, and droplet size distribution were taken into consideration to ensure uniform water distribution over the condenser coils. This uniform distribution is crucial for optimizing the cooling characteristics of the system. To accurately measure and record relevant parameters, a comprehensive data acquisition system was utilized [7]. The system consisted of temperature sensors, pressure sensors, flow meters, and a digital data logger. These instruments were strategically placed to capture real-time data and enable synchronized data acquisition for accurate analysis. The experimental procedure involved evaluating the performance of the window air conditioner under two different conditions: without the spray evaporative cooling system (baseline) and with the spray nozzle system activated. Baseline data, including power consumption, condenser temperature, refrigerant flow rate, and chilling ability, were recorded during the initial phase. Once the baseline data was collected, the spray nozzle system was integrated into the window air conditioner. The water supply to the spray nozzles was carefully controlled to ensure optimal cooling performance. The experiments were conducted at varying water flow rates to evaluate their impact on condenser characteristics [14]. Throughout the experiments, various parameters were measured and recorded at regular intervals. These parameters included condenser temperature, air temperature at different locations, airflow rate, power consumption, and chilling ability. Continuous monitoring allowed for capturing the dynamic behavior of the system and facilitated accurate data analysis. The performance of the window air conditioner with spray evaporative cooling was assessed by comparing the experimental data to the baseline measurements. The reduction in condenser temperature was quantified to evaluate the cooling effectiveness achieved by the spray nozzle system. Additionally, the improvement in chilling ability was determined by comparing the cooling output with and without spray evaporative cooling. The power consumption of the air conditioner was also compared to assess the energy-saving potential of the system. To ensure the reliability and validity of the experimental results, data validation techniques and statistical analysis were employed [11]. The findings from the experimental study were compared and contrasted with relevant studies available in the literature. This comparison helped validate the results and provided insights into the consistency and effectiveness of spray evaporative cooling in window air conditioners. The experimental study employed a systematic approach to assess the characteristics of spray evaporative cooling in window air conditioners. The selection of appropriate equipment, careful data acquisition, and comprehensive analysis ensured accurate evaluation of cooling effectiveness, chilling ability improvement, and energy-saving potential achieved by the spray nozzle system.

IV. PLANNING AND DEVELOPING

The Planning and developing of the spray evaporative cooling system for window air conditioners involved several key steps. A thorough understanding of the condenser design of the window air conditioner was necessary. This involved studying the layout and specifications of the condenser coils to determine the most effective method of incorporating the spray nozzle system. Next, a suitable spray nozzle system was selected based on factors such as nozzle size, spray pattern, and droplet size distribution. The goal was to achieve uniform water distribution over the condenser coils for optimal cooling characteristics [17]. The spray nozzle system was carefully designed to ensure compatibility with the chosen window air conditioner model. The integration of the spray nozzle system into the window air conditioner required careful consideration of the water supply mechanism. The system was designed to provide controlled water flow to the spray nozzles, enabling precise cooling characteristics adjustments. Additionally, measures were taken to prevent over-wetting of the condenser coil, which could negatively impact air flow and overall system characteristics. To facilitate the operation and monitoring of the spray evaporative cooling system, a control mechanism was developed [18]. This included the implementation of sensors to measure parameters such as condenser temperature, air temperature, airflow rate, and water flow rate. The data collected from these sensors was used to regulate the spray nozzle system and ensure optimal cooling effectiveness. During the development phase, rigorous testing and fine-tuning were conducted to validate the characteristics of the spray evaporative cooling system. Various operating conditions were simulated to assess the system's capability to handle different temperatures, humidity levels, and airflow rates. This iterative process allowed for adjustments and improvements to be made, resulting in an optimized design. **Fig 2** shows the planning and developing.

Fig 2. Planning and Developing

The Planning and developing of the spray evaporative cooling system for window air conditioners involved careful consideration of the condenser design, selection of suitable spray nozzle components, implementation of a controlled water supply mechanism, development of a monitoring and control system, and rigorous testing to validate characteristics. The final design aimed to enhance cooling effectiveness, improve chilling ability, and reduce energy consumption in window air conditioners.

Water Distribution System

The water distribution system in spray evaporative cooling involves pipes, tubes, or channels that carry water from the source to the cooling pads or nozzles. These components are usually made of durable and corrosion-resistant materials such as PVC (polyvinyl chloride) or stainless steel to withstand water flow and maintain longevity.

Cooling Pads

Cooling pads are an essential component in spray evaporative cooling systems. They provide a large surface area for water evaporation and heat transfer. Common materials used for cooling pads include cellulose, aspen wood fibers, or synthetic materials like rigid evaporative media. These materials are chosen for their high absorbency and ability to retain water while allowing efficient airflow.

Nozzles

Nozzles are responsible for spraying water onto the cooling pads or directly into the airflow in window AC units. They are typically made of brass, stainless steel, or other corrosion-resistant materials to withstand continuous water flow and maintain proper spray patterns. Nozzles should be designed to provide a uniform distribution of water over the cooling pads.

Water Reservoir

The water reservoir or tank holds the water supply for the evaporative cooling system. It is usually made of plastic materials such as high-density polyethylene (HDPE) or polypropylene (PP), which are resistant to water 21 and corrosion. The reservoir should be designed to prevent leakage and allow easy access for filling and maintenance.

Airflow Channels

Airflow channels or ducts in window AC units guide the air through the cooling pads, promoting efficient cooling and air circulation. These channels are typically made of plastic or sheet metal materials, ensuring smooth airflow and preventing air leaks.

Structural Components

Various structural components, including housing, frames, and supports, are used to hold and secure the different elements of the spray evaporative cooling system in window AC units. These components are often made of durable materials such as sheet metal, aluminum, or plastic, providing strength and stability to the overall structure.

V. CONCLUSION

In conclusion, the experimental study and design of the spray evaporative cooling system for window air conditioners have shown promising results in enhancing cooling characteristics and energy effectiveness. By integrating a high-quality spray nozzle system into the window air conditioner, the condenser coil's efficiency was improved through the cooling effect of water mist. The experimental data demonstrated a significant reduction in condenser temperature and an improvement in chilling ability. Additionally, the power consumption of the air conditioner was lowered, indicating the energy-saving potential of the spray evaporative cooling system. The findings validate the effectiveness of this cooling technique in hot and humid conditions, where the condenser coil's performance may be compromised. The Planning and developing process ensured the compatibility and proper functioning of the spray nozzle system, providing uniform water distribution and controlled water supply. Further validation through statistical analysis and comparison with existing literature reinforced the consistency and effectiveness of spray evaporative cooling in window air conditioners. This research opens up possibilities for improved cooling technologies in residential and commercial applications, contributing to enhanced comfort and energy efficiency in air conditioning systems.

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