# Enhancing Split Air Conditioner Efficiency Through Evaporative Cooling: Improving COP, Reducing Compressor Load, and Lowering Energy Costs

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## Abstract

*This study explores the integration of evaporative cooling (EC) technology into split air conditioning (AC) systems to enhance their performance, reduce energy consumption, improve heat rejection capacity, and decrease compressor workload. A 1.5-ton split AC was retrofitted with an EC unit, which utilized cooling pads to lower the temperature of the air entering the condenser coil. The performance evaluation was carried out using R-410A refrigerant, and both thermodynamic analysis and empirical testing were employed to assess the impact of the evaporative cooling unit on system efficiency. The coefficient of performance (COP), compressor power consumption, and overall energy savings were measured before and after the retrofitting. The COP of the modified system increased from 3.026 to 3.16, which corresponds to a more efficient energy use for the same cooling output. Additionally, the compressor's power consumption decreased from 1.738 kW to 1.66 kW, indicating that less energy was required to achieve the desired cooling effect. On an annual basis, the modified air conditioning system saved 421 kWh of electricity, which translated into a reduction in energy costs from 15,225 BDT to 14,542 BDT per year. This study demonstrates the cost-effectiveness of retrofitting conventional air conditioners with evaporative cooling units and provides valuable insights into improving the energy efficiency of HVAC systems.*

Keywords: Air conditioning system; evaporative cooling; *COP*; Evaporative cooling (*EC*); Modified condenser

## 1.Introduction

Air conditioning systems are frequently utilized in residential and business settings to promote thermal comfort. Rising energy consumption has increased $CO_2$ emissions due to rising living standards and the growing desire for human comfort. About 30% of all energy use worldwide is attributed to air conditioning applications[1, 2]. Constant efforts to increase cooling systems' energy efficiency can make a big difference in the world's energy conservation efforts[3-6]. Three methods to reduce the energy consumption of air conditioners are to lower the pressure differential between the evaporator and condenser, increase the ability to reject heat and decrease the compressor's power consumption[7-9]. As the condensing temperature rises during the vapor compression cycle of split-type small-sized domestic air conditioners, the air condenser's performance drops. As a result, the pressure ratio across the compressor rises, increasing the work and power consumption of the compressor[10-12]. It is commonly known that the refrigeration system's coefficient of performance (*COP*) decreases by roughly 2-4% for every 1°C increase in condenser temperature[13]. Since water absorbs latent heat during evaporation, Evaporative cooling (*EC*) can efficiently chill the air surrounding the condenser by lowering the ambient air temperature before it travels through the condenser coil[14-17]. Empirical research has demonstrated that *EC* is a workable method for improving vapor compression systems' efficiency. Systems for *EC* fall into three categories: hybrid systems that include both techniques, indirect evaporative cooling (*IEC*), and direct evaporative cooling (*DEC*)[18]. Performance metrics significantly improve when an evaporative cooling unit is integrated into a split air conditioning system. The retrofitted system demonstrated a significant increase in efficiency which is consistent with the results by Harby et al[19]. This

improvement reduces the compressor's load, demonstrating that the system can provide better cooling output for the same energy input which is consistent with research by Ulpiani [20] and Yang et al[21]. They found that enhanced cooling techniques can significantly reduce energy consumption, extending the equipment's life and contributing to energy conservation. The annual energy costs dropped also dropped which is evidence of the financial advantages of the retrofitting process. The monetary repercussions were also noteworthy. The energy savings and performance improvements of AC system by incorporating *EC* were shown by Hajidavalloo [22] and Hajidavalloo and Eghtedari [23]. Particularly in settings with high ambient temperatures [24], the combined results of multiple studies, such as those by Wang et al.[25]and Pangsakorn and Thepa [26], support the feasibility of evaporative cooling systems as an environmentally friendly way to improve air conditioning performance.
Besides the above discussion, there is still need to study about the performance improvement of an existing AC system retrofitted with evaporative cooling pads. In this research work, a 1.5-ton split air conditioner modified with evaporative cooling unit have been selected and analyzed the performance and energy cost improvement. This retrofit lowers yearly energy usage and expenses, highlighting the substantial financial benefits of incorporating evaporative cooling into typical air conditioning systems.

## 2. Methodology

### 2.1 Experimental Method

The experimental setup is a split-type air conditioning system of capacity 1.5TR as shown in Figure 1, which is retrofitted with an evaporative cooling unit to enhance the system performance. Leak detection was examined, and the outside and inner units of the split air conditioner were installed. The apparatuses were linked to an electrical power source, and the system was activated after confirmation. The room temperature was taken every two minutes after the air conditioner was turned on. By measuring the system's temperature immediately upon turning it on and again after the room cooled, the temperature profile of the system was determined.

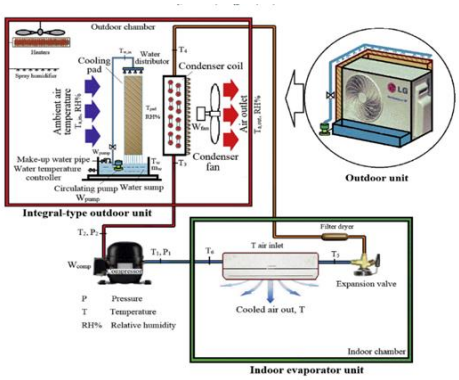



**Fig. 1.** Schematic split-type air- conditioner diagram with the proposed evaporative cooling unit[19].



**Fig. 2.** Experimental setup for Measuring the pressures and temperatures of various points.

Thermocouples and pressure gauges were set at various points of the air conditioning system (Figure 2) to determine the COP of the system. For example, the evaporator out/compressor in (point 1), where the refrigerant leaves and enters the compressor, was a critical place to measure since it provides information on the temperature and pressure of the refrigerant before compression. The compressor out (point 2) was another critical location because this is where the refrigerant is at its peak temperature and pressure. The condenser out (point 3) was watched to observe heat rejection. The evaporator input (point 4) was tracked to evaluate the state of the refrigerant as it started the chilling process. The copper tube used to install pressure gauges at different locations along the tube is attached to pressure regulators, hose pipes, t-joints, and non-return valves. The tubes are then brazed shut. After sufficiently insulating the sensor, thermocouples were installed at several locations. A thorough investigation of the system's functioning is ensured by these positions. This setup allows one to analyze the refrigeration cycle's behavior in great detail before and after retrofitting the evaporative cooling unit. The experimental setup was constructed precisely, using copper tubing to link pressure gauges to T-joints, hose pipes, pressure regulators, and non-return valves. These joints were firmly sealed through brazing, ensuring airtight connections. Thermocouples were fitted and suitably insulated at the crucial measurement sites further to improve the accuracy and dependability of the setup. A data logger accurately recorded the temperature values (T1 to T7), while pressure gauges measured the pressure at Points P1, P2, P3, and P4.

Thanks to this data collection technique, we could plot the pressure-enthalpy (*p-h*) diagram specific to R-410A refrigerant, which made it possible to calculate enthalpy values with accuracy. The system was charged with 1.1 kg of R-410A refrigerant to maintain an operating pressure of 58 psi. Once the system was started, we meticulously took pressure and temperature data throughout the preset places, leaving no stone unturned in confirming the absence of leaks.



**Fig. 3.** Cooling pad (a) Coconut & (b) Jute




**Fig. 4.** Experimental setup with an evaporative cooling pad.

We meticulously plotted the readings onto the *p-h* diagram using the gathered temperature and pressure data. The baseline coefficient of performance (*COP*) can be computed to understand the system's overall performance comprehensively. An evaporative cooling unit was subsequently added to the air conditioning system to improve condenser heat rejection. As illustrated in Figure 3, cooling pads intended for evaporative cooling often comprise a porous substance that permits water to pass through them. They are placed before a fan or an evaporative, which is an excellent unit. The cooling pad is designed to be saturated with water. The water evaporates when the fan or evaporative cooler air moves through the wet pad, removing heat and bringing the air's temperature down. The experimental setup with the evaporative cooling pad (Figure 4) was used to examine the effect on system efficiency. After the refit, the system was restarted, data on pressure, temperature, and room cooling were noted, and a temperature vs. time curve was used to evaluate the cooling performance improvement.

## 3. Results and discussion

### 3.1 Cooling Effect of Evaporative Unit

The split air conditioning system's capacity of 1.5 tons has been evaluated experimentally with and without an evaporative unit.

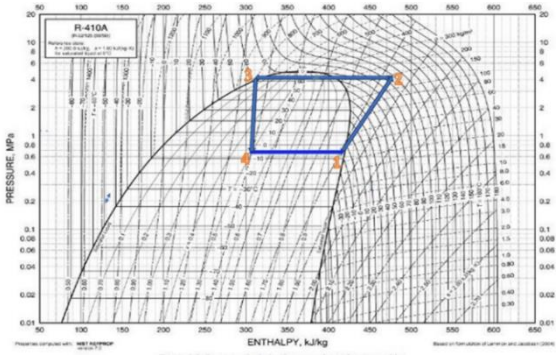



**Fig. 5.** *P-h* diagram of R-410A (without evaporative unit)

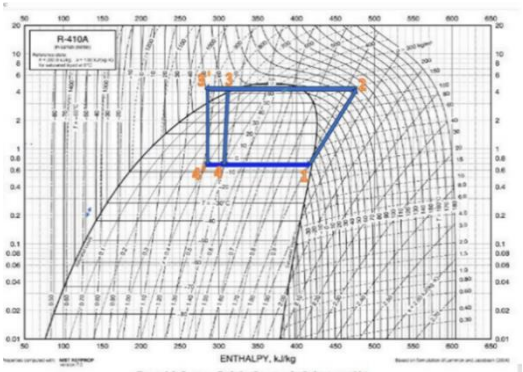



**Fig.6.** *P-h* diagram of R-410A (with evaporative unit)

This experimental test was conducted on a split air conditioning system in an actual condition that does not maintain the surrounding air conditioning. The various performance parameters like refrigeration effect, compressor work, and coefficient of performance were calculated for both systems (with and without an evaporative unit) by the *p-h* diagram shown in Figure 5 (without evaporative unit) and Figure 6 (with the evaporative unit).

### 3.2 Performance of *AC* system without and with evaporative unit

The performance of the split air conditioner with and without the evaporative cooling unit is clearly demonstrated in Figure 7. The retrofitted system showed a noticeable improvement in efficiency, with the coefficient of performance (COP) increasing from 3.026 to 3.16. A higher COP indicates superior cooling output for the same energy input, meaning the compressor operates under less strain and consumes less energy. As a result, the compressor's power consumption decreased from 1.738 kW to 1.66 kW. This reduction in compressor workload not only enhances the system's energy efficiency but also extends the equipment's lifespan. The decrease in energy demand led to significant financial savings, with annual energy costs dropping from 15,225 BDT to 14,542 BDT. These improvements, achieved through performance optimization and cost savings, demonstrate the effectiveness of incorporating evaporative cooling into the system. Bar charts comparing the performance parameters for the system with and without the evaporative unit are shown in Figure 7.

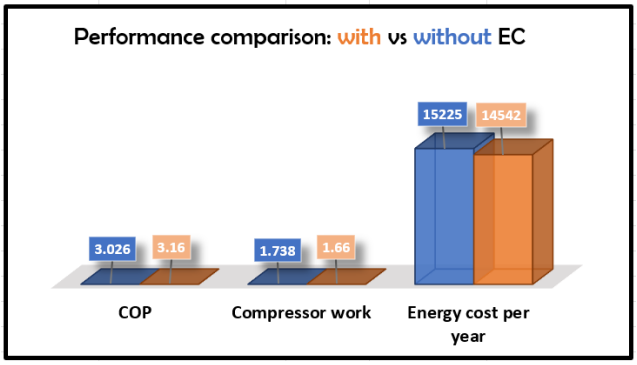



**Fig. 7.** Comparison of performance parameters without and with the evaporative unit.

### 3.3 Rate of change of temperature with and without evaporative unit

When evaporative cooling was not used, it took 53 minutes to reach the desired temperature of 20°C with steady airflow. However, with the same airflow and other conditions, the inclusion of the evaporative cooling unit reduced the time to 44 minutes to achieve the same temperature. This real-world example highlights the significant impact of using an evaporative cooling device on the speed at which the system reaches the desired temperature, which can have substantial implications for temperature control systems. Figures 8-9 and Tables 2-3 provide a clear visual representation of the temperature variation over time, illustrating the practical benefits of the evaporative cooling system.

**3.3.1 Without an evaporative unit:** The temperature of the split-type air conditioner was monitored for 58 minutes in the experimental setup without the evaporative cooling unit. Initially, the temperature dropped significantly, with rapid cooling occurring during the first 14 minutes, followed by a slower rate of cooling as the system approached equilibrium.

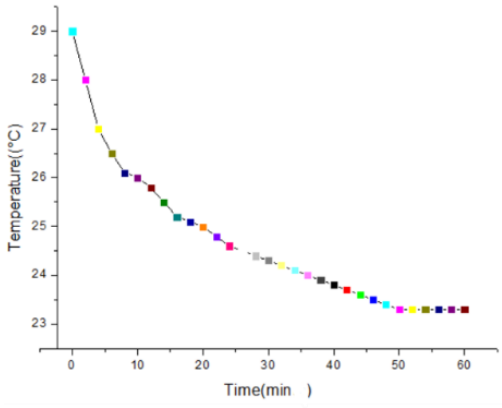



**Fig. 8.** Temperature variation inside AC room without evaporative unit.

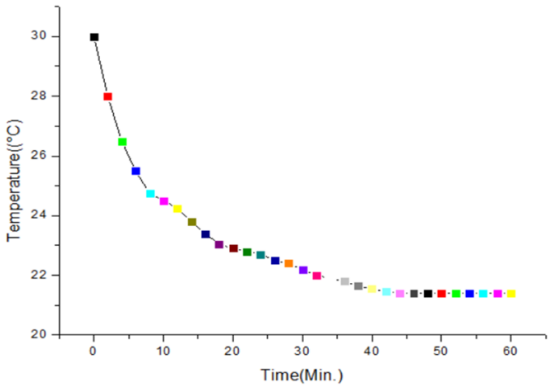



**Fig. 9.** Temperature variation inside AC room with evaporative unit.

The rate of temperature decreases stabilized after the 26th minute, with only slight variations thereafter. From the 54th minute onward, the temperature remained nearly constant at 23.32°C. This indicates that as the system approaches its cooling limit, its efficiency decreases. The table and bar chart clearly illustrate these temperature variations, highlighting the trend of steady cooling over time, as shown in Figure 8.

**3.3.3 With evaporative unit:** Using the concept of latent heat, adding an evaporative cooling unit to air conditioning systems is known to improve cooling efficiency. The data above shows how quickly the temperature changed over 58 minutes, indicating how successfully ambient temperatures can be lowered using evaporative cooling. The temperature gradually drops as the experiment goes on, demonstrating how well the evaporative unit removes heat from the air. The temperature drops dramatically in the first ten minutes and then more steadily as the system stabilizes. After 48 minutes, it steadily stabilizes at roughly 21.40°C, indicating the unit's ability to maintain perfect conditions for a prolonged time as shown in figure 9. Figures 8 and 9 show how the temperature drops over time inside the AC room and clearly shows how effective the evaporative cooling system.

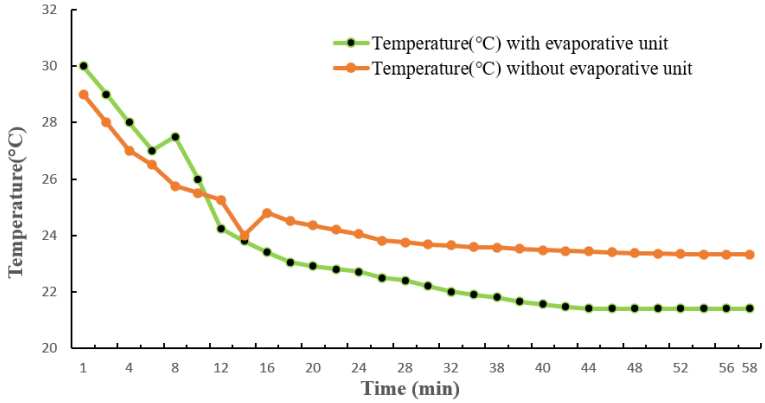



**Fig. 10.** Comparison between temperature variation inside AC room with and without evaporative unit.

Figure 10 shows the temperature change within an air-conditioned room with and without an evaporative cooling device. The graph shows that, over time, the temperature in the room with the evaporative unit is lower and more constant than in the setting without it. By lowering temperature swings, the evaporative unit's inclusion improves cooling efficiency. This demonstrates how well the evaporative unit contributes to the total cooling capacity of the air conditioning system.

## 4. Conclusion

This research demonstrates that integrating an evaporative cooling unit into a split air conditioning system significantly enhances energy efficiency. It highlights the potential of evaporative cooling as a practical solution for improving the performance of conventional air conditioners, which can benefit both the economy and the environment. Based on the findings, the following conclusions can be drawn:

(i) replacing conventional split air conditioners with those incorporating evaporative cooling units improves system efficiency, as evidenced by an increase in COP from 3.026 to 3.16.
(ii) the compressor's workload is reduced, leading to an annual energy savings of 421 kWh.
(iii) the system's improved performance results in lower operating costs, reducing annual energy expenses from 15,225 BDT to 14,542 BDT.
(iv) the evaporative cooling unit accelerates the temperature reduction process, enabling the system to reach the desired temperature 9 minutes faster than without it.
(v) this research presents an environmentally and economically viable approach for enhancing air conditioning systems, with the potential for significant cost and energy savings.

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