

Embracing the Evaporative System in Air Conditioning Technology for Efficient Cooling Solutions

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Abstract

The use of an air conditioning system requires large amounts of electrical energy to carry out repeated vapor compression cycles. The use of an evaporative cooling system in this research is by spraying condensate water on the condenser, which is one solution to absorb condenser heat. Another thing that can be done is to reset the fan speed on the condenser to cool it. Resetting the fan speed on the condenser can also help improve AC performance and reduce electrical energy use. The test was carried out by modifying the 1 Pk R-410a AC split condenser by installing 6 nozzles, 2 rows of 3 columns and a DC pump to spray water on the condenser. The independent variables of this research are spraying position and fan speed. The result obtained from the research is an increase in COP by 35% and a reduction in electrical power usage by 15% by using additional water spray with a nozzle behind the condenser both when blowing the full blower and when the blower blowing speed is reduced by 75%. The use of evaporative systems in air conditioning technology is a promising solution to achieve sustainable and efficient cooling solutions.

Keywords: Modified Condenser, Coefficient of Performance (COP), Nozzle, Fan Speed.

1. Introduction

Situated in the tropics, Indonesia experiences ample sunlight and high temperatures nearly year-round. This tropical climate lends itself to sultry air with elevated humidity. Seeking reprieve from the heat, Indonesia has witnessed a surge in air conditioning (AC) usage across sectors like hospitality, healthcare, transportation, industry, and households. Split AC systems prevail in homes, with the compressor, condenser and expansion valve placed externally while the evaporator lies inside. These vapor compression systems contain four vital components - compressor, condenser, expansion valve and evaporator - to regulate indoor air. The process has two key phases of heat transfer [1], [2]. First, the evaporator absorbs ambient heat. Next, the condenser ejects this heat outward using a blower and airflow. Condensed moisture from the evaporator gets drained via an exhaust pipe. However, high external temperatures can undermine this condensation process. In tropical weather, evaporative air coolers are an effective and energy-efficient option for cooling spaces. These coolers work by blasting warm air through a water-soaked pad to cool the moisture, resulting in cooler air. They are suitable for both hot and dry conditions and can be a cost-effective solution for controlling the temperature in tropical regions. The process of cooling in a tropical climate, such as evaporative cooling, may not be as efficient when the outside air temperature is high, requiring additional cooling systems to cool the condenser and reduce compressor work. In a direct evaporative system, water evaporates directly in the air stream, resulting in an adiabatic process of heat exchange. The air-dry bulb temperature decreases as its humidity increases, and the amount of heat transferred from the air to the water is the same as the one used in the evaporation of the water.

Researchers [3] aim to innovate and reduce energy consumption while maintaining comfort in tropical climates. They found that the addition of an evaporative system to a conventional AC cycle can reduce energy consumption for cooling fresh air by almost 80% and is environmentally friendly, because

it does not contribute to the problem of ozone layer depletion that previously occurred with non-environmentally friendly refrigerants [4]. Innovations in cooling systems for tropical climates can lead to more sustainable and energy efficient solutions. For example, passive design strategies, such as ventilation and windows can improve indoor air quality and reduce energy consumption. Electricity use for air conditioning has increased significantly, and air conditioning is driving higher global electricity demand. In air-cooled condensers, power consumption is a major concern, especially in areas with high ambient temperatures (between 50-60 °C). In search of more efficient alternatives to conventional air conditioning, scientists have explored the integration of evaporative cooling [5]. A study on existing blower systems found that although the basic coefficient of performance (COP) was 6.44, the addition of an evaporation stage increased the COP to 15.43 [6]. This significant improvement highlights the superior efficiency of utilizing water for cooling. In another experiment, the application of evaporative cooling to a 2 kW air conditioning system reduced electricity usage by 0.5 kW without cooling load and limited compressor work by 0.4 kW under load [7]. The results strengthen the potential of utilizing water evaporation, not just air, as a sustainable cooling technique [8]. Further research can continue to optimize this technology to maximize energy savings and thermal comfort.

Other research [9]–[11] shows that the use of condensate water can reduce the temperature of the refrigerant entering the condenser by 2.2 °C and reduce electrical power consumption by 0.5 kW with a cooling load of 2,000 Watts. Evaporative cooling systems work by flowing outside air over a water-saturated pad, causing the water to evaporate and lowering the air temperature. This system is energy efficient and sustainable as it uses 10% of the energy required by traditional air conditioning systems. Evaporative cooling is suitable for low humidity areas and can provide a comfortable environment in distribution centers, office buildings, and residential applications. The difference between this research and previous research is the use of a number of nozzles as water spray media and variations in fan rotation which produce different results from previous research.

2. Methodology

The design of this research is to modify the split AC condenser by adding an additional system consisting of a water reservoir, condensate water, pump and nozzle as in Figure 1 to see the effect of additional cooling on the performance of the split AC. The placement of this additional cooling system is above the condenser and in front of the cooling blower in the form of water spray through a nozzle [12], [13]. The water used is the result of air condensation from the AC itself, collected, pumped and reused to cool the condenser. This design combines water droplets above the condenser and water sprayed into the condenser.

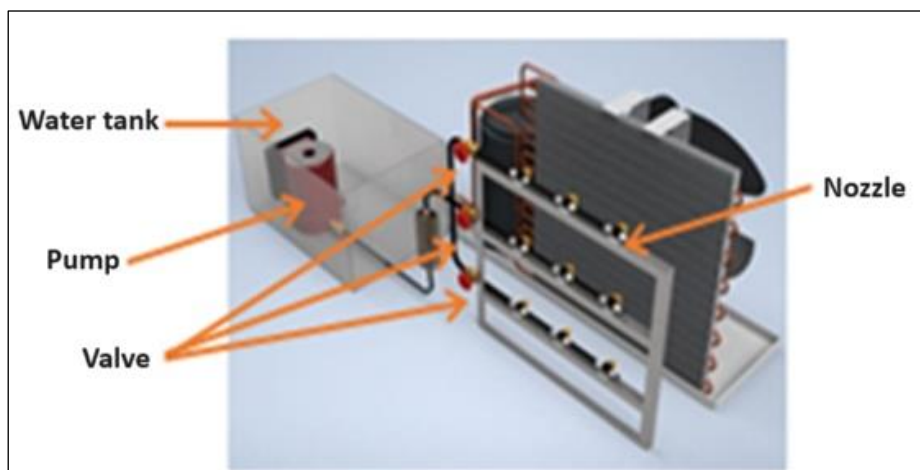


Figure 1. Design of Evaporating System

The system's air conditioning components are displayed in Figure 2, which includes a compressor (1), a condenser (2), a capillary tube (3), and another condenser (4). The high-pressure refrigerant flow (PH) and low-pressure refrigerant flow (PL) are also visible in Figure 2, along with temperature measurement points such as T₁, T₂, T₃, and T₄, where the flow will circulate through the compressor, condenser, expansion valve, and another condenser.

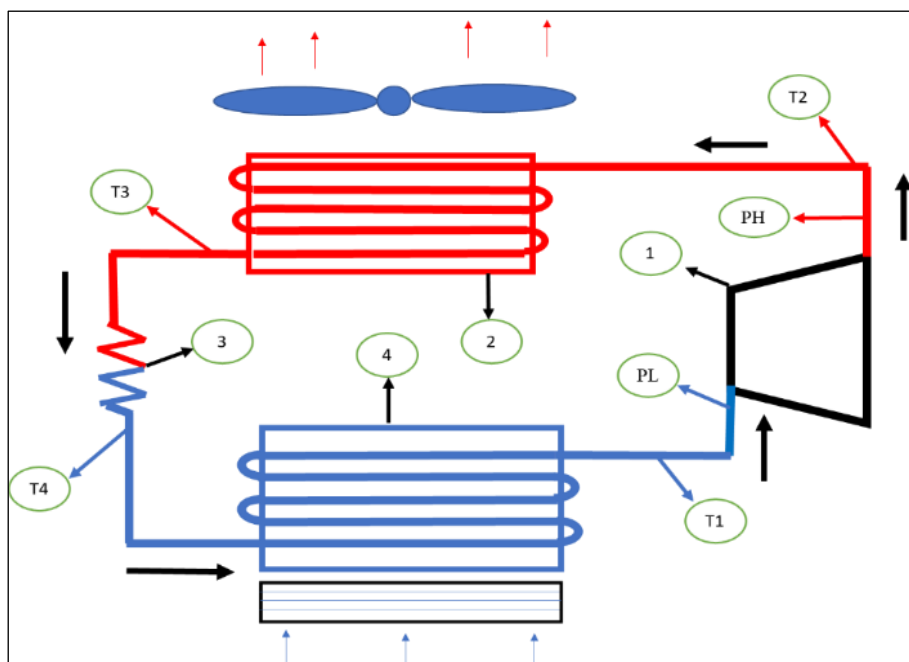


Figure 2. Measurement Position Design

For the data collection will use several instruments, such us thermocouple to take temperature data, Multimeter to take current and voltage data and pressure gauge which is directly added on the refrigeration machine to determine the low and high pressures that’s occur. That’s instrument will aid monitor performance of the system and next the data get it will use to analyze the performance of the system [14]. The test condition in this research are shown in Table 1 below:

Table 1. Test Condition of Research

No.	Parameters	Specification
1	Average environmental temperature	30 °C
2	Room use	Material Testing Laboratory Bali State Polytechnic
3	Air condition capacity	1 Pk
4	Refrigerant	410a
5	Power	735 watt
6	A/C set temperature	22 °C
7	Pump (direct current)	12 volt, 5 ampere
8	Nozzle (pressure, diameter)	1.5 bar, 0.5 mm
9	Room condition	<ul style="list-style-type: none"> ▪ Several cupboards with books and people in the room ▪ The room is limited by glass windows (4 pieces) which are equipped with curtains and half glass and wooden door

The test conditions carried out in this research are as follows:

CONDITION 1 : Without water, namely the condition without an evaporative cooling system as initial data from the COP system.

CONDITION 2 : The top row is the condition where the evaporative cooling system is sprayed through 3 top nozzles with normal condenser fan speed.

CONDITION 3 : Middle row, the condition where the evaporative cooling system is sprayed through 3 middle nozzles with normal condenser fan speed.

CONDITION 4 : The top row is the condition where the evaporative cooling system is sprayed through 3 top nozzles with a condenser fan speed of 75% of normal rotation.

CONDITION 5 : Middle row, the condition where the evaporative cooling system is sprayed through 3

top nozzles with a fan speed of 75% of normal rotation.

CONDITION 6 : Condition where the evaporative cooling system uses water droplets with a condenser cooling air speed of 100%.

CONDITION 7 : Condition where the evaporative cooling system uses water droplets with a condenser cooling air speed of 75% of normal rotation.

The layout of system in the Material Testing Laboratory of Bali State Polytechnic room is shown in Figure 3 below.

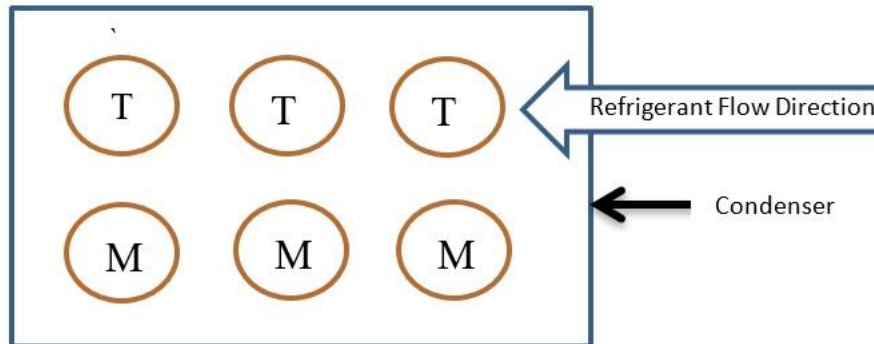


Figure 3. Lay-out of System

3. Result and Discussion

Evaporative cooling is based on the principle that as water evaporates, it absorbs heat from the surrounding air, resulting in a cooling effect. This process is governed by the psychrometric chart, illustrating how temperature, humidity, and pressure influence the air's thermodynamic properties. The study explores the mathematical models and equations describing the relationship between air and water vapor, enabling a comprehensive understanding of the cooling process. Effective design is crucial for the successful implementation of evaporative cooling systems. Factors such as air velocity, wet-bulb temperature, and water distribution play pivotal roles in optimizing system performance [15]. This section outlines the key considerations in designing evaporative cooling systems, including the selection of materials, control mechanisms, and integration with existing HVAC systems. The theoretical analysis includes an evaluation of the advantages and challenges associated with evaporative cooling. Advantages encompass energy efficiency, reduced environmental impact, and cost-effectiveness [16]. Challenges include humidity control, water quality maintenance, and system integration complexities. The study proposes potential solutions and strategies to mitigate these challenges, ensuring the practical viability of evaporative cooling systems. The theoretical study explores diverse applications of evaporative cooling systems, ranging from residential and commercial spaces to industrial settings. From the results of the tests that have been carried out, the data is shown in Table 2 and Table 3.

Table 2. The Average Value of Each Data

No.	Nozzles/ Water Drip	T ₁	T ₂	T ₃	T ₄	Electrical Consumption	High Pressure	Low Pressure	Wind Speed from Condenser
		°C	°C	°C	°C	Watt	Psi	Psi	m/s
1	Normal	20.56	62.46	41.96	18.29	1033.80	407.50	120.00	4.26
2	NOS 123	20.04	47.05	32.93	18.04	898.91	325.50	111.50	4.09
3	NOS 456	18.23	45.38	33.01	18.09	882.88	313.75	113.00	4.05
4	NOS 1231	21.44	48.17	32.30	17.45	900.54	335.00	113.75	3.85
5	NOS 4561	21.05	46.04	32.03	17.77	893.39	342.75	115.75	3.84
6	NOS 1232	22.73	50.03	35.15	18.36	947.72	348.75	119.00	2.34
7	NOS 4562	20.56	50.66	35.36	18.37	935.72	357.50	121.25	2.30
8	DRIP 1	19.33	47.41	35.59	18.50	943.96	341.25	121.75	4.18
9	DRIP 2	20.62	50.05	37.27	18.48	976.58	365.00	122.25	3.49

From Table 2, further processing is carried out using Coolpack software to obtain the Coefficient of Performance (COP) value for the 1-PK R410A split AC system. From the results of data processing, the results obtained are shown in Table 3.

Table 3. The Coefficient of Performance of Each Condition

No.	Nozzles/ Water Drip	Condenser	Evaporator	h ₁	h ₂	h ₃ and h ₄	COP	Electrical Consumption
		°C	°C	kJ/kg	kJ/kg	kJ/kg		Watt
1	Normal	49.28	8.26	427.806	464.182	290.456	3.78	1033.80
2	NOS 123	40.48	6.32	421.120	458.468	271.016	4.98	898.91
3	NOS 456	39.09	6.67	427.246	457.043	268.144	5.34	882.88
4	NOS 1231	41.57	6.84	427.307	458.990	273.302	4.86	900.54
5	NOS 4561	42.45	7.30	427.470	459.376	275.170	4.77	893.39
6	NOS 1232	43.07	8.03	427.726	459.343	276.499	4.78	947.72
7	NOS 4562	42.09	6.61	427.225	459.593	274.404	4.72	935.72
8	DRIP 1	42.28	8.65	427.940	458.233	274.808	5.05	943.96
9	DRIP 2	44.89	8.76	427.977	460.282	280.462	4.57	976.58
10	DRIP 3	46.45	9.90	428.360	460.756	284.141	4.45	1010.01

Based on the Figure 4, the coefficient of performance (COP) values of the 1 PK split air conditioning (AC) system are presented, where prior to activation of the evaporative cooling system on the condenser, the baseline COP was measured to be 3.78. Following activation of the evaporative cooling system through 3 upper nozzles with the standard condenser fan speed, the resulting COP increased to 4.98 and 5.34 for the upper and central nozzle positions, respectively. With a 25% reduction in condenser fan speed, the COP values were 4.86 and 4.77 for the top and middle nozzle locations. Additionally, reducing the fan speed further by 50% yielded COPs of 4.78 [15]–[17] and 4.72 for the same 3 upper and middle nozzle configurations. From these experimental results, it can be concluded that supplementing the condenser with 3 evaporative cooling nozzles leads to significant COP improvements, even when the condenser fan speed is reduced by up to 50%. This enhancement occurs due to a reduction in the compression work (Wk) required by the refrigeration cycle, a key component in calculating COP [18]. Further investigation is warranted to determine optimal condenser nozzle arrangements and cooling parameters to maximize energy efficiency gains.

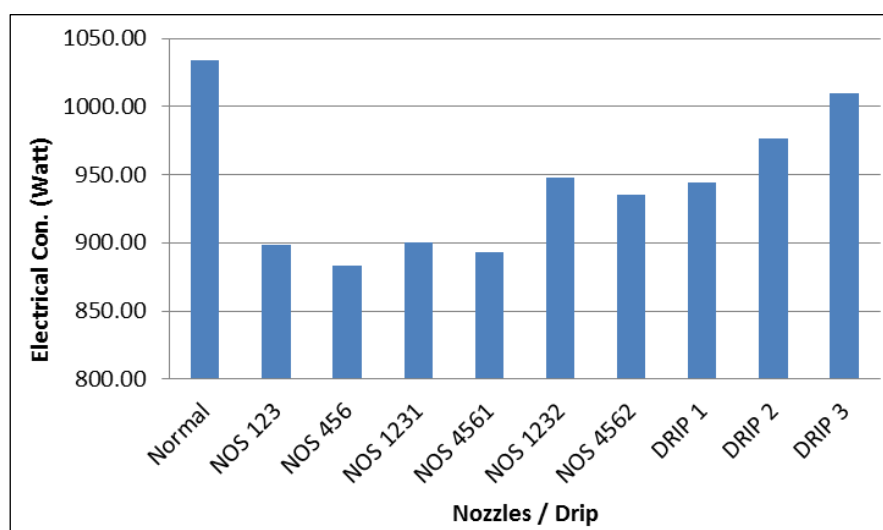


Figure 4. Electrical Consumption versus Nozzles/Drip

As depicted in Table 2 and Table 3, the total power consumption values (in watts) were quantified for the 1 PK split air conditioning (AC) system, both with and without activation of the evaporative cooling system on the condenser. Initially, without evaporative cooling, the baseline power consumption

was measured at 1,033.80 W. Following activation of the evaporative cooling through the 3 upper and middle nozzles at normal fan speed, the average power usage decreased to 899.135 W. At a reduced condenser fan speed of 25% of normal, the average electrical power consumption further dropped to 898.6 W. Additionally, reducing the fan to 50% of the standard speed yielded an average power usage of 943.56 W across the same 3 upper and middle nozzle configurations [19]. Similarly, supplemental evaporative cooling using a water hatch above the condenser led to reduce average power consumptions of 943.96 W and 976.58 W at the 25% and 50% lowered fan speeds, respectively. The utilization of a middle row nozzle demonstrated the most favorable outcome based on the investigation. The application of the middle row nozzle yielded the highest Coefficient of Performance (COP) results, approximately 5.34, in contrast to the utilization of the top row nozzle and water droplet. Furthermore, the middle row nozzle exhibited the lowest electrical consumption, specifically 882.88 watts during the investigation, in comparison to alternative models. These findings indicate that employing a middle row nozzle represents a viable selection for evaporative cooling systems [20].

In addition, when considering fan efficiency, it has been observed that utilizing a fan operating at 100% capacity yields the highest efficiency in comparison to fans operating at 75% and 50% capacity. The fan operating at 100% capacity achieves a coefficient of performance (COP) of 4.86. This heightened efficiency is attributed to the uninterrupted rotation of the fan at its maximum speed, leading to an overall increase in efficiency [21]. In summary, the experimental data demonstrates that total power consumption of the split AC system is consistently lower after implementing evaporative cooling on the condenser relative to the non-evaporative baseline condition. The reduction in electricity usage can be attributed to decreased compressor run times enabled by lower condensing temperatures and compression work from the added evaporative cooling [22]. Further studies could aim to identify optimal condenser cooling designs to maximize energy efficiency gains.

4. Conclusion

In conclusion, the present study demonstrated that the application of supplementary water cooling techniques, including a rear condenser water spray nozzle and direct top-surface water droplets, can substantially improve the performance and efficiency of the system. Specifically, these cooling methods resulted in increases to the coefficient of performance of 35% and decreases in electrical power usage of 15%, under both normal and reduced blower ventilation speeds. The significant enhancements in COP and energy consumption indicate that additional water cooling techniques could provide a viable approach for improving efficiency in comparable condenser systems. Further research is warranted to determine the optimal parameters for spray nozzle placement, droplet size, and amount of supplementary cooling water required.

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