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## Performance Analysis of Direct Stage , In-Direct Stage and Two-Stage Evaporative Air Cooler

Thiri San<sup>1</sup>, Aung Ko Latt<sup>2</sup>, War War Min Swe<sup>3</sup>, Yin Yin Aye<sup>4</sup>

nwaythwin@gmail.com<sup>1</sup>, dr.aungkolat@gmail.com<sup>2</sup>, warswe05@gmail.com<sup>3</sup>,

dryinn2025@gmail.com<sup>4</sup>

<sup>1,2,3,4</sup> Department of Mechanical Engineering, Mandalay Technological University

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### Article Information

Received : 31 Mar 2026

Reviewed: 9 Apr 2026

Accepted : 13 Apr 2026

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### Keywords

Two-stage evaporative air cooler, Direct/In-Direct air cooler, Performance Analysis

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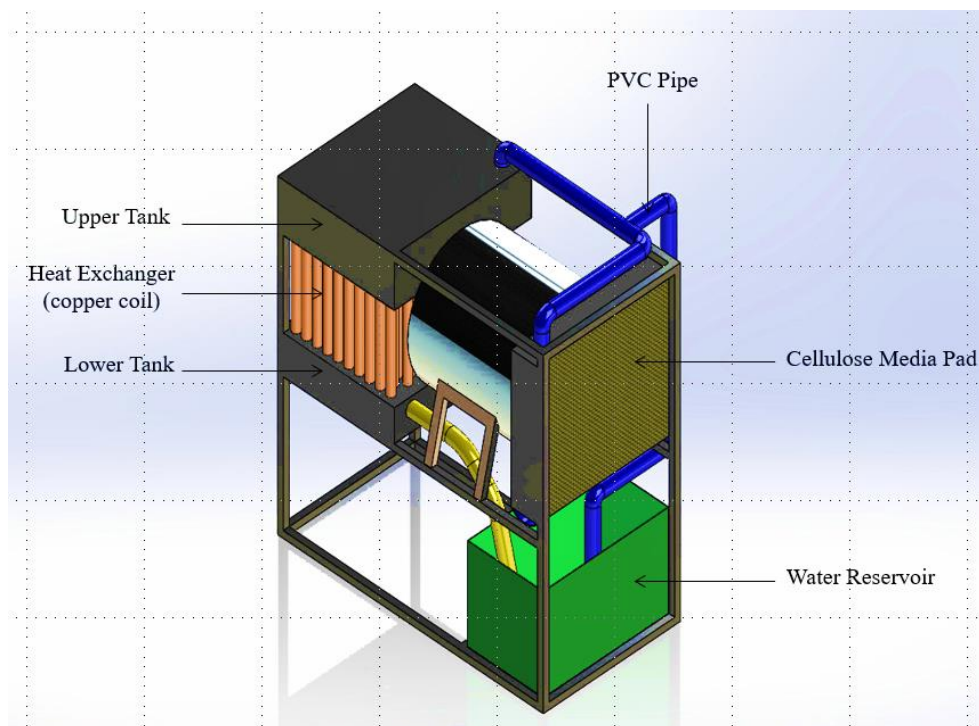
### Abstract

Evaporative coolers are used in various areas especially in dry, hot climates in weather. This research focus on the theoretical and experimental result of the evaporative air cooler. There are three types of evaporative air coolers. They are direct evaporative air cooler, indirect evaporative air cooler and two-stage evaporative air cooler. Evaporative air cooler can provide summer comfort conditions as an environmentally clean, fresh supply air and energy efficient cooling system for some regions of our country where direct system alone is not suitable. In this paper, the tube type heat exchanger was used and the tubes are made with copper and water is passed through the copper tube with 20°C. This model has been adapted for two-stage, indirect and direct stage. The cooling capacity of two-stage is 2.95 kW and direct stage and in-direct stage is 2.65 kW respectively. Therefore, the cooling efficiency of two-stage is 90% the direct stage is 85% and the in-direct stage is 80% of evaporative air cooler. So, two-stage evaporative air cooler performed more than direct and in-direct stage evaporative air cooler.

## A. Introduction

A natural evaporative cooling is also called as perspiration, it secretes from body to cool itself. The heat transfer from the body depends on the evaporation rate of water. The rate of evaporation depends on the temperature humidity of the air [1]. Evaporative cooling is a heat and mass transfer process that uses water evaporation for air cooling. Evaporative cooling is a physical phenomenon in which evaporation of a liquid into surrounding air [2].

Direct evaporative air-conditioning technologies is the simplest, the oldest and the most widespread form of air-conditioning. This system typically uses a fan to draw hot outside air into a dwelling through a porous wetted medium. Heat is absorbed by the water as it evaporates from the porous wetting medium and the air thus leaves the evaporative air-conditioning at a lower temperature [3].



**Figure 1.** Two-Stage Evaporative Air Cooler

In the direct method a wet surface heat exchanger is used where a nonadiabatic evaporation takes place. Two streams of air are used and there are alternative wet and dry passages which are separated from each other. Primary air which flows in dry passages is cooled sensibly without adding water, while the secondary air which flows in wet passages carries away the heat energy from the primary air [4]. The surface of wet passage is wetted by spray water, so that water film evaporates into the secondary air and decreases the temperature of the wall. Therefore, heat is transferred from primary to secondary air without the introduction of moisture into the primary air stream. The air leaving the dry side of the cooler has a lower wet bulb temperature than the ambient. Consequently, it would be advantageous to extract a fraction of this cooled air and pass it through the wet side of the heat exchanger instead of using ambient air [5].

## B. Research Method

The evaporative air cooler, dry air passes over water some of the water will be absorbed by the air. The hotter and drier the air, the more water that can be absorbed. Fresh outdoor air is drawn through the moist pads by a belt driven centrifugal fan. As the air passes through the pads, evaporation takes place liquid water molecules become gas in the dry air. Heat move from the higher temperature of the air to the lower temperature of the water. As a result, the air is cooled and its moisture content is elevated, while its wet bulb temperature remains constant.

## C. Design Consideration of Evaporative Air Cooler

In two-stage evaporative air cooling, cooling load must be calculated to design firstly. After design condition had selected, cooling load is calculated. Consideration of design condition is important. Design condition mean outside design temperature (ODT) and inside design temperature (IDT). Dry bulb temperature 41°C and daily range 13°C were chosen for ODT condition. Inside design condition is the condition under which the space should be maintained for human health and comfort. Effective temperature is chosen first to select inside design condition. The velocity of the air is 2.5 ms<sup>-1</sup>. Dry bulb temperature 30 °C, relative humidity 50% were chosen for IDT.

### Calculation of Cooling Efficiency for Air Cooler

In this journal, the specifications data of two-stage evaporative air cooler were shown in **Table 1**.

**Table 1.** Specifications data of two-stage evaporative air cooler

Parameter	Symbol	Value	Unit
Required load	Q	2.9	kW
Pad Area	A	0.36	m <sup>2</sup>
Pad Thickness	L	0.05	m
Inlet temp;	T <sub>1</sub>	41	°C
Outlet temp;	T <sub>2</sub>	30	°C
Velocity of air	V	2.5	ms <sup>-1</sup>
Density of air	ρ	1.15	kgm <sup>3</sup>
Gas constant	R	287	Jkg <sup>-1</sup> K <sup>-1</sup>
Pump-power	W	18	W
Fan power	P	100	W

For two-stage evaporative air-cooling system, saturation effectiveness, outlet air temperature, mass flow rate of the air and heat transfer surface area were calculated.

Cooling efficiency or saturation effectiveness ( $\varepsilon$ )

$$\varepsilon = 1 - \exp(-h_c / m'_{\text{air}} C_p) \quad (1)$$

$$\varepsilon = (T_1 - T_2) / (T_1 - T_w) \quad (2)$$

Where,  $\varepsilon$  is cooling efficiency or saturation effectiveness,  $h_c$  is heat transfer coefficient,  $m'_{\text{air}}$  is mass flow rate of air and  $C_p$  is specific heat capacity of air and  $T_1$  is inlet dry bulb temperature of air,  $T_2$  is outlet dry bulb temperature of air,  $T_w$  is inlet wet bulb temperature of air. Cooling efficiency of air depends not only

temperature but also velocity of air.

Mass flow rate of air ( $\dot{m}_{\text{air}}$ )

$$\dot{m}_{\text{air}} = \rho \times v \times N_T \times S_T \times L \quad (3)$$

Where,  $\dot{m}_{\text{air}}$  is mass flow rate of the air,  $\rho$  is density of air,  $v$  is velocity of air,  $N_T$  is number of tubes in transverse surface,  $S_T$  is transverse pitch and  $L$  is length of copper tube.

Area of cooling pad ( $A_w$ )

$$A_w = A_s \times V_p \quad (4)$$

Where,  $A_w$  is total wetted pad area,  $A_s$  is wetted surface area per unit volume of pad materials (can be changed in wetted materials such as  $A_s$  of cellulose pad is  $370 \text{ m}^2/\text{m}^3$ , coconuts coir is  $320 \text{ m}^2/\text{m}^3$  and so on.) and  $V_p$  is volume of pad.

Volume of Pad ( $V_p$ )

$$V_p = \text{Area of pad} \times t_h \quad (5)$$

Where,  $t_h$  is thickness of cooling pad.

Heat transfer coefficient ( $h_c$ )

$$h = \frac{Nu_D \times k}{D} \quad (6)$$

Where,  $h$  is heat transfer coefficient,  $Nu_D$  is Nusselt number,  $k$  is thermal conductivity of air and  $D$  is the diameter of the copper tube.

Characteristics Length ( $l_e$ )

$$l_e = V_p / A_w \quad (7)$$

Where,  $l_e$  is characteristic length.

Total Number of Tubes

$$N = N_T \times N_L \quad (8)$$

Where,  $N$  is the total number of tubes,  $N_T$  is transverse number of tubes and  $N_L$  is longitudinal number of tubes.

### Experimental Setup

Experimental apparatus for the performance testing of the evaporative air cooler is constructed at TTTC (Baelin), Auto Mechanics Department at Kyaukse. In this experiments, Type-K thermometer is used to measure the temperature of air and water, HTC-1 Clock/Humidity device is used to measure the relative humidity and UT363 Anemometer is used to measure the velocity of air and water. The capacity of pump is 18 W and flow rate is  $7.611 \times 10^{-5} \text{ L/min}$  in this experiment. The piping waters from the tank carries out the pump water. The fan speed is 1300 rpm. And then, the design of the tube heat exchanger is obtained as shown in **Fig.2**.



**Figure 2.** Tube Heat Exchanger for Air Cooler

**Calculation of Heat Transfer Rate for Tube Heat Exchanger**

The total number of tubes can be calculated by using equation (8). The design result of heat transfer rate of tube heat exchanger as shown in **Table 2**.

**Table 2.** Theoretical Results Data for Two-Stage Evaporative Air Cooler

Parameter	Tube Heat Exchanger	Units
Total Number of Tubes	150	-
Heat Transfer Surface Area	3	m <sup>2</sup>
Log Mean Temperature Difference	11.3	°C
Heat Transfer Rate	2900	W



**Figure 3.** Performance Test of Air Cooler

Required Equipment

1. Anemometer
2. IR Thermometer and
3. Thermometer

Figure 4 shows the equipment of an anemometer to measure the fan speed and outlet velocity of cooling pads.



**Figure 4.** Anemometer

Figure 5 shows the equipment of IR thermometer to measure the surface temperature of the room and inlet water temperature of the upper tank.



**Figure 5.** IR Thermometer

Figure 6 shows the equipment of thermometer used to measure the outlet temperature of cooling pads.



**Figure 6.** Thermometer

**Table 3.** Experimental Results Data of Two-Stage Evaporative Air Cooler with Water at 20°C

Time	Tdb <sub>1</sub>	Tw <sub>b</sub>	Tdb <sub>2</sub>	T <sub>diff</sub>	m' <sub>a</sub>	Efficiency
9:00 AM	32	32	32	0	0.2779	0.0
9:30 AM	32	27	29	3	0.2779	0.60

10:00 AM	32.1	27	29	3.1	0.2779	0.61
10:30 AM	32	27.1	28.4	3.6	0.2779	0.73
11:00 AM	32.2	27.2	28.5	3.7	0.2779	0.74
11:30 AM	32.4	27.5	28.3	4.1	0.2779	0.84
12:00 Noon	32.4	27.4	28.3	4.1	0.2779	0.82
12:30 PM	32.8	25.5	28.6	4.2	0.2779	0.58
1:00 PM	32.8	27.7	28.4	4.4	0.2779	0.86
1:30 PM	32.6	27.6	28.1	4.5	0.2779	0.90
2:00 PM	32.5	27.6	28.4	4.1	0.2779	0.84
2:30 PM	32.6	27.4	28.3	4.3	0.2779	0.83
3:00 PM	32.8	27.8	28.7	4.1	0.2779	0.82
3:30 PM	32.7	27.7	28.7	4	0.2779	0.80
4:00 PM	32.8	27.8	28.7	4.1	0.2779	0.82

Table 3 shows the experimental result of cooling efficiency for a two-stage evaporative cooling system. At 1:30 pm, the maximum cooling efficiency is 90% for two-stage evaporative air cooler.

**Table 4.** Experimental Results Data of Direct Stage Evaporative Air Cooler with Water at 20°C

Time	Tdb <sub>1</sub>	Tw <sub>b</sub>	Tdb <sub>2</sub>	T <sub>diff</sub>	m' <sub>a</sub>	Efficiency
9:00 AM	31	31	31	0	0.2779	0.00
9:30 AM	31	28	29	2	0.2779	0.67
10:00 AM	31.2	28.1	29.1	2.1	0.2779	0.68
10:30 AM	31.2	28.1	29	2.2	0.2779	0.71
11:00 AM	31.3	28.2	29	2.3	0.2779	0.74
11:30 AM	31.4	28.3	29	2.4	0.2779	0.77
12:00 Noon	31.6	28.5	29.1	2.5	0.2779	0.81
12:30 PM	31.6	28.5	29	2.6	0.2779	0.84
1:00 PM	31.8	28	28.7	3.1	0.2779	0.82
1:30 PM	31.9	28	28.6	3.3	0.2779	0.85
2:00 PM	31.7	27.5	28.6	3.1	0.2779	0.74
2:30 PM	31.7	27.5	28.5	3.2	0.2779	0.76
3:00 PM	31.7	27.5	28.3	3.4	0.2779	0.81
3:30 PM	31.6	28.5	29.4	2.2	0.2779	0.71
4:00 PM	31.6	28.5	29.6	2	0.2779	0.65

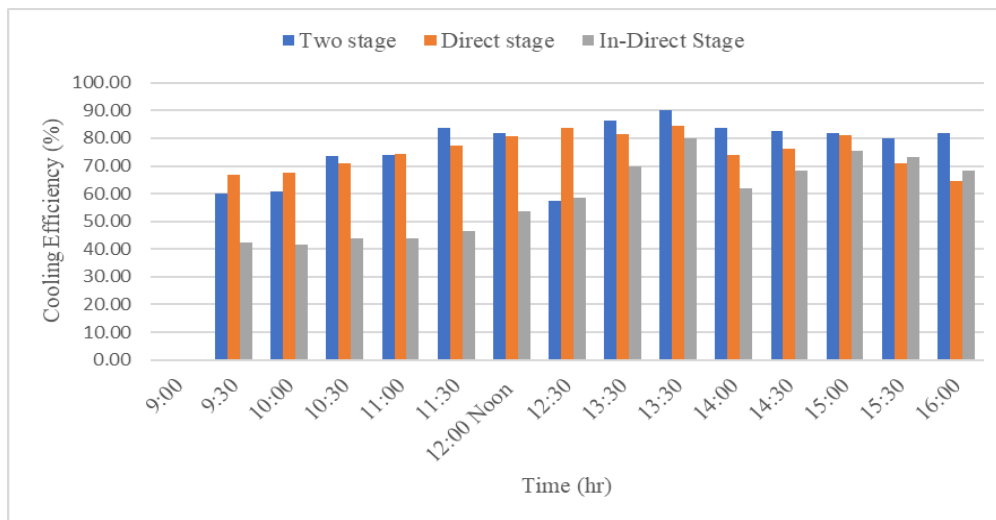
Table 4 shows the experimental result of cooling efficiency for direct stage evaporative cooling system. At 1:30 pm, the maximum cooling efficiency is 85% for direct stage evaporative air cooler.

**Table 5.** Experimental Results Data of In-Direct Stage Evaporative Air Cooler with Water at 20°C

Time	Tdb <sub>1</sub>	Tw <sub>b</sub>	Tdb <sub>2</sub>	T <sub>diff</sub>	m' <sub>a</sub>	Efficiency
9:00 AM	31	31	31	0	0.2779	0
9:30 AM	31	27	29.3	1.7	0.2779	0.43
10:00 AM	31.2	27.1	29.5	1.7	0.2779	0.41
10:30 AM	31.2	27.1	29.4	1.8	0.2779	0.44
11:00 AM	31.4	27.3	29.6	1.8	0.2779	0.44
11:30 AM	31.4	27.3	29.5	1.9	0.2779	0.46
12:00 Noon	31.6	27.5	29.4	2.2	0.2779	0.54

12:30 PM	31.6	27.5	29.2	2.4	0.2779	0.59
1:00 PM	31.8	27.8	29	2.8	0.2779	0.70
1:30 PM	31.8	27.8	28.6	3.2	0.2779	0.80
2:00 PM	31.6	27.4	29	2.6	0.2779	0.62
2:30 PM	31.6	27.5	28.8	2.8	0.2779	0.68
3:00 PM	31.4	27.3	28.3	3.1	0.2779	0.76
3:30 PM	31.4	27.3	28.4	3	0.2779	0.73
4:00 PM	31.2	27.1	28.4	2.8	0.2779	0.68

Table 5 shows the experimental result of cooling efficiency for in-direct stage evaporative cooling system. At 1:30 pm, the maximum cooling efficiency is 80% for in-direct stage evaporative air cooler.



**Figure 7.** Comparison of Cooling Efficiency for Three Types of Air Cooler Tested with water at 20°C

Figure 7 shows the cooling efficiency of three types of evaporative air cooler. At 9:00 am, the cooling efficiency is zero for all three types of evaporative air cooler. And then, the cooling efficiency is a slightly increased to the maximum cooling efficiency at 1:30 pm. The cooling efficiency is a slightly fall down for all three types of evaporative air cooler at 3:00 pm.

#### D. Result and Discussion

In this research, the desired room of the cooling load is 2.9 kW. According to the research, the cooling capacity of two-stage evaporative air cooler is 24% more than direct stage evaporative air cooler. The cooling efficiency of two-stage is 4% more than the direct stage evaporative air cooler. Based on the results of the experiment, the obtained results on the speed dial of primary air flow fan of 2.5 m/s maximum tool effectiveness applies with 90% resulting in two-stage and then happens 85% in direct stage and 80% in in-direct stage of evaporative air cooler. Therefore, cooling efficiency of two-stage evaporative air cooler is more than direct stage and in-direct stage evaporative air cooler.

## E. Conclusion

In this paper, experimental analysis of two-stage evaporative air cooler were carried out. According to, the size of the media pad and the number of tubes are designed for two-stage evaporative air cooler. And then, constructed and performed the two-stage evaporative air cooler. The results confirm that evaporative cooling is most effective when incoming air is warm and relatively dry. Performance can be further optimized by adjusting fan speed and thickness of pad. According to the experimental analysis, the two stage evaporative air cooler was given more cooling capacity and efficiency than the direct stage and in-direct stage evaporative air cooler.

## F. Acknowledgment

The author is deeply gratitude to Dr. San Yu Khaing, Pro-Rector of Mandalay Technology University for throughout this research. The author also special thanks to her supervisor Dr. Aung Ko Latt for his valuable advice. The author wishes to give a great thank to all the teachers at the Department of Mechanical Engineering, Mandalay Technology University for their suggestion and guideline throughout this research. And the author is thankful to her friends who have directly or indirectly assisted in her endeavors.

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