Numerical Analysis of dew point Indirect Evaporative Cooler

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Abstract. An indirect evaporative cooler that uses a Maisotsenko (M) Cycle has the potential to be a green and sustainable solution for managing a building's cooling demand since it can attain sub-wet bulb temperature without humidification. This study presents the design and simulation analysis of a crossflow indirect evaporative cooler using the COMSOL Multiphysics software for various ambient conditions. The cooler's performance was evaluated by varying the inlet air temperatures. The analysis was conducted using numerical simulations, and the outcomes were compared with experimental data. The simulation results demonstrated that the cooler could achieve significant temperature reductions at a minor energy consumption as compared to traditional air conditioning systems. This study delivers that this system reduces the temperature of inlet air up to 22°C as well as cooling capacity and coefficient of performance values are 3.699 kW and 27.40. Overall, the results demonstrate the potential of crossflow indirect evaporative coolers as an energy-efficient alternative to conventional air conditioning systems.

1 Introduction

Indirect evaporative cooling is a technology that has gained popularity due to its energy efficiency and sustainable nature. The use of M-cycle technology in indirect evaporative coolers takes this technology a step further, allowing for even greater energy efficiency in HVAC systems [1]. The M-cycle technology utilizes an additional heat exchanger, allowing heat transfer between the exhaust air and incoming fresh air. This process allows for the cooling of the incoming air without adding moisture, making it ideal for use in areas with high humidity. The combination of indirect evaporative cooling and M-cycle technology provides an energy-efficient and cost-effective solution for cooling large commercial and industrial spaces while reducing the carbon footprint [2].

The demand for energy-efficient HVAC systems is increasing as businesses and industries seek to reduce energy consumption and their carbon footprint. Indirect evaporative cooling technology uses water evaporation to cool the air, and it has become a popular alternative to traditional refrigeration-based cooling systems. M-cycle technology takes indirect evaporative cooling to the next level by incorporating an additional heat exchanger, which allows for even greater energy efficiency [3]. The M-cycle technology allows heat transfer between the exhaust air and incoming fresh air, significantly reducing energy consumption. This technology is ideal for use in large commercial and industrial spaces, providing an environmentally friendly and cost-effective cooling solution while reducing environmental impact [4].

The design of the IEC system involves several parameters such as the flow rate of air and flow rate of water, heat exchanger geometry, and materials. Several researchers have investigated these parameters' impact on the IEC system's performance. The study by M. Ali et al. investigated the effect of different materials for the heat exchanger on the IEC system's cooling capacity and efficiency. The study found that using aluminum foam as the heat exchanger material resulted in higher cooling capacity and efficiency than using aluminum sheets [5].

Indirect evaporative cooling (IEC) is a promising technology for reducing energy consumption and carbon emissions in the HVAC sector. As a result, there has been a growing interest in designing and analyzing IEC systems using simulation and experimentation techniques. Simulation studies have been widely used to analyze the performance of indirect evaporative coolers. In a study by R. Tariq et al. a new type of IEC system was proposed, which was optimized using numerical simulation. The results presented that the optimized system achieved a cooling capacity of 0.38 kW with an energy efficiency ratio (EER) of 19, which was significantly higher than a traditional air conditioning system [6]. Another study by H. yang et al. studied the effect of different tube configurations on the performance of an IEC system. The numerical simulation showed that the IEC system with an S-shaped tube achieved the highest cooling capacity and EER [7].

In a study by Mohammed, et al., a designed and tested indirect evaporative cooling system for a domestic building was investigated in a hot and humid climate. The experimental effects presented that the IEC system was able to sustain the indoor temperature within the desired range while reducing energy consumption by up to 50% [8]. Another study by B. Zheng et al. analyzed the performance of an indirect evaporative system for data center cooling. The experimental data indicated that the indirect evaporative cooling (IEC) system achieved a temperature difference of 13 °C with a wet bulb effectiveness of 0.83, which was significantly higher than a traditional air conditioning system [9].

R. Tariq, et al. conducted a numerical simulation-based study to investigate the performance of an IEC system with a new heat exchanger design. The results showed that the optimized system achieved a cooling capacity of 0.45 kW with an energy efficiency ratio (EER) of 11.2, which was higher than a conventional air conditioning system. They studied the effect of different working parameters on the IEC system’s performance using a numerical simulation. The outcomes showed that increasing the inlet temperature of the water and reducing the airflow rate improved the cooling performance of the IEC system [10].

In a study by K. Rajski, et al., a hybrid air conditioning system that combines IEC was proposed and analyzed. The results exhibited that the hybrid system improved the coefficient of performance by 40% and reduced electricity consumption by 45%, which was higher than a traditional air conditioning system [11]. Another study by N. Nemati et al. proposed a hybrid IEC system that combines IEC with an earth air heat exchanger. The experimental results showed that the hybrid system achieved a 62% and 45% decrease in energy and water consumption, which was significantly higher than a traditional air conditioning system [12].

The analysis of the IEC system involves modeling and simulation to predict the system's performance under different conditions. Several studies have used simulation tools such as Fluent and EnergyPlus to analyze the IEC system's performance. For example, the study by B. Rasikh used Fluent to simulate the performance of a novel IEC system with a multi-stage heat exchanger. The simulation results showed that the proposed system had a higher cooling capacity and efficiency than a conventional IEC system [13].

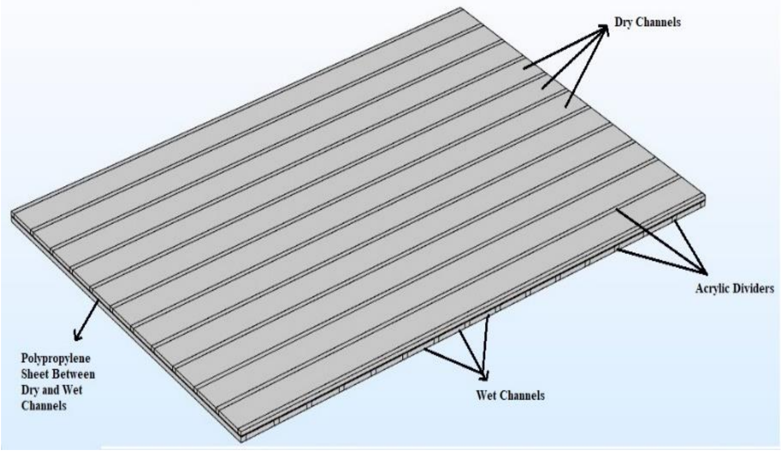
In this paper, we present the design and analysis of a crossflow indirect evaporative cooler using the simulation software, COMSOL Multiphysics. The goal of this study is to examine the performance of the cooler under different ambient conditions. The cooler is designed to provide effective cooling using the principle of indirect evaporative cooling, which involves the transfer of heat from the incoming air stream to the evaporative media without direct contact. The simulation is carried out by varying the ambient condition, and the results are analyzed in terms of cooling. The results of this study offer a valuable understanding of the performance of the cooler and its potential use in various applications.

2 Model Design

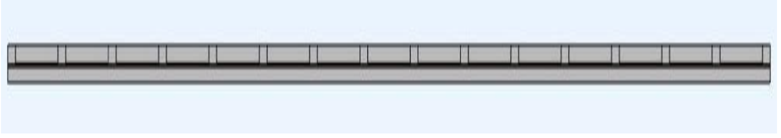
Indirect evaporative coolers consist of dry and wet channels. Ambient air flows in the dry channels and water flows in the wet channels. There are two wet channels and one dry channel in one stack. Both fluids flow in a crossflow direction. System geometry was designed in COMSOL Multiphysics as shown in Figure 1.

For the modeling, one dry channel is merged between two wet channels as a simulation unit. The polypropylene plastic sheet is placed between the dry and wet channels for heat transfer. The left and right sides of sub-channels are covered with acrylic plastic materials which are treated as impenetrable. The parameters of the system are given in Table 1. It is assumed that.

1. Fluid properties are kept uniform through channels.
2. The external surface of wet channels is symmetrical.
3. The physical properties of water are fixed.
4. Acrylic dividers are treated as solid. So, no heat is transferred through acrylic dividers.



(a)



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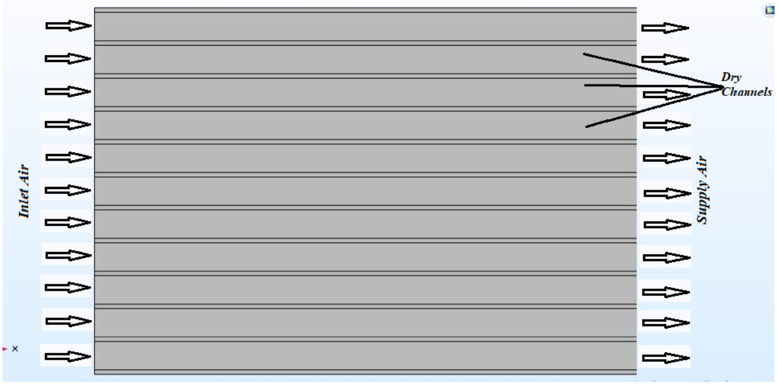


(c)

Figure 1: Design of indirect evaporative cooler (a) isometric view (b) side view (c) Top view

All the parameters and dimensions used to model the indirect evaporative cooler are given in Table 1.

Table 1*:* Parameters used for 3-D modeling of IEC

Parameter	**Symbol**	**Values**
Width of stack	W	0.410 m
Length of stack	L	0.590 m
Height of stack	H	0.01032 m
Height of channel	h-c	0.005 m
Width of Dry channel	W-dry	0.02615 m
Width of Wet channel	W-wet	0.0247 mm
Polypropylene sheet thickness	th	0.016 mm
Process air temperature	T_{in}	27-48 ^{0}C
Water temperature	T_W	15-27 ^{0}C
Air velocity	v_air	6.5 m/s
Water flow rate	$\dot{m}_W$	0.515/s

3 Material Selection

In dry and hot climates, low operational cost option for air-cooling is the indirect evaporative cooler. The selection of a polymeric material in wet channel for this cooler was based on its ability to hold water well and its light weight in relation to its volume. And other materials were selected based on low cost and locally available in the market, instead of importing expensive technology.

- Acrylic Plastic Sheet
- Polypropylene Sheet
- Water
- Air

Table 2: Properties of the materials

Sr No.	Properties	Propylene plastic	Acrylic Plastic	Air	Water
1	Thermal Conductivity (W/m.K)	0.11	0.2	0.024	0.598
2	Density (kg/m^3)	905	1200	1.225	997.77
3	Specific Heat (j/kg.K)	1920	1470	1005	4.191

4 Mathematical Calculations

Height of channel = a = 5 mm = 0.005 m
Width of channel = b = 26.15 mm 0.02615 m
Average velocity = v_{avg} = 6.5 m/s

$$\text{Hydraulic diameter} = D_h = \frac{4ab}{2(a=b)} = 0.008394 \text{ m} \quad (1)$$

$$\text{Reynold Number} = Re = \frac{\rho v D}{\mu} = 3117.36 \quad (2)$$

The Reynold number is less than 10,000 so it is a laminar flow [14]. Now, the thermal entry length can be found by using the equation 3.

$$L_{t,laminar} = 0.05 * Re * Pr * D_h \quad (3)$$

$$L_{t,laminar} = 0.9378 \text{ m} = 937.8 \text{ mm}$$

Which is greater than the length of the channel. So, the flow is developing laminar flow in the entire channel [14].
The Nusselt number (Nu) and convection heat transfer coefficients (h) are determined by the equations 4 and 5 [14],

$$Nu = 3.66 + \frac{0.065(^D/_L)RePr}{1+0.04[(^D/_L)RePr]^{2/3}} \quad (4)$$

$$h = \frac{Nu * k}{D_h} \quad (5)$$

Where k is thermal conductivity of material, $L_{t,laminar}$ is thermal entry length of the channel, L is length of channel, Pr is prantdl number and μ is dynamic viscosity.

5 Boundary Conditions

The boundaries assigned for the dry channels and wet channels of the model are given in Table 3. The behavior of heat transfer is analyzed in dry and wet channels. The ambient air flows in the dry channel while water flows in the wet channels. In wet channels, the temperature of the water is set as equal to the dew pointtemperature of incoming ambient air. Heat is transferred through dry to wet channels. So,the temperature of the process air is decreased. As assumed, the reduction of temperature in a single dry channel is considered the same as the temperature drop of the complete cooler stack.

Table 3: Boundary conditions

Wall			
Description	**Value**	**Description**	**Value**
Wall condition	No slip	Sliding wall	Off
Air inlet			
Velocity field	Normal inflow velocity	Normal inflow velocity	v_air
Water inlet			

Boundary condition	Mass flow	Normal mass flow rate	$\dot{m}_W$
Mass flow type	Mass flow rate		
Air and Water outlet			
Pressure	1[atm]	Suppress backflow	On
Normal flow	Off		

6 Meshing

Meshing plays a vital role in performing precise simulations in CFD. In the current system, predefined sizes of the fine element are selected, and its size is given in Table 4.

Table 4: Size of the mesh elements

Description	**Value**
Predefined size	Fine
Maximum size of the element	32.5
Minimum size of the element	4.06
Factor of Curvature	0.5
Resolution of the narrow regions	0.6
Maximum growth rate of element	1.45

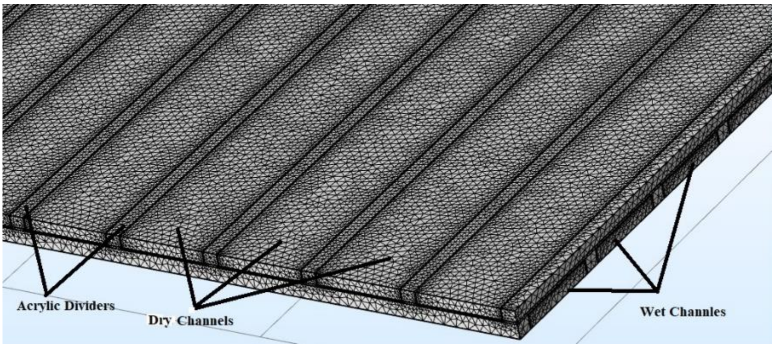


Figure 2: Meshing of Stack

7 Performance Parameters

Performance parameters can help in evaluating the suitability of a particular cooler for a given application and in comparing different cooler systems to make an informed decision.

7.1 Volume Flow Rate

This is the amount of air that a cooler can move through a given space in a specific time. It is presented in cubic feet per minute (CFM). The airflow of cooler was calculated by the following formula and its value is almost 340 CFM.

$$V = Av \tag{6}$$

7.2 Cooling Capacity

This is the amount of heat that can be removed from a given space by a cooler in a given amount of time. It is typically measured in British Thermal Units (BTUs) or Watts.

$$CC = \dot{m}\, C_p \Delta T \tag{7}$$

7.3 Coefficient Of Performance

This is the ratio of the cooling capacity (CC) of a cooler to the power input required to achieve that cooling capacity. A higher COP indicates that the cooler is more energy efficient.

$$COP = \frac{CC}{W_{ele}} \tag{8}$$

8 Results and Discussion

8.1 Temperature of Air in dry channels

The temperature contours in the following figure 3(a) show that the air entered in dry channels at 313 K and left from the outlet of the dry channels at 292.11 K. This shows that the air passing through the dry channels undergoes a temperature drop of 20.96 K at water temperature (Tin = 16°C), the velocity of air (V_{avg} = 6.5 m/s), $\dot{m}_w$ = 0.5 kg/s

8.2 Temperature of water in wet channels

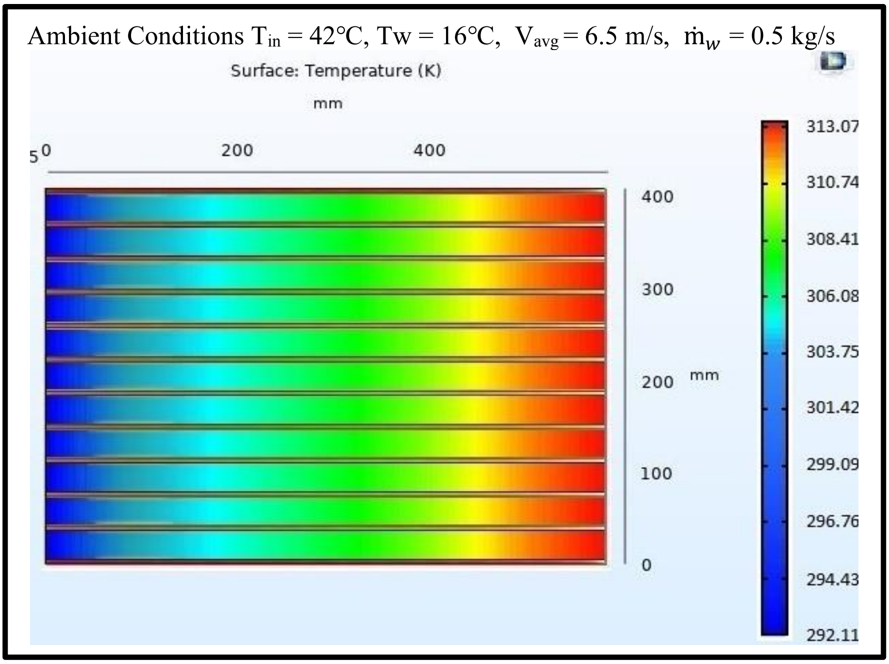
The temperature contours of water in the figure shows that the inlet temperature of wet channels is 294.43 K. The temperature at the outlet of the wet channels is 299.09 K. This shows that the water passing through the wet channels undergoes a temperature raise of 4.63 K because heat that transfer from water to the Polypropylene sheet. The air temperature, the velocity of air and the mass flow rate of the water are also given in Figure 3(b).

8.3 Temperature of Polypropylene Sheet

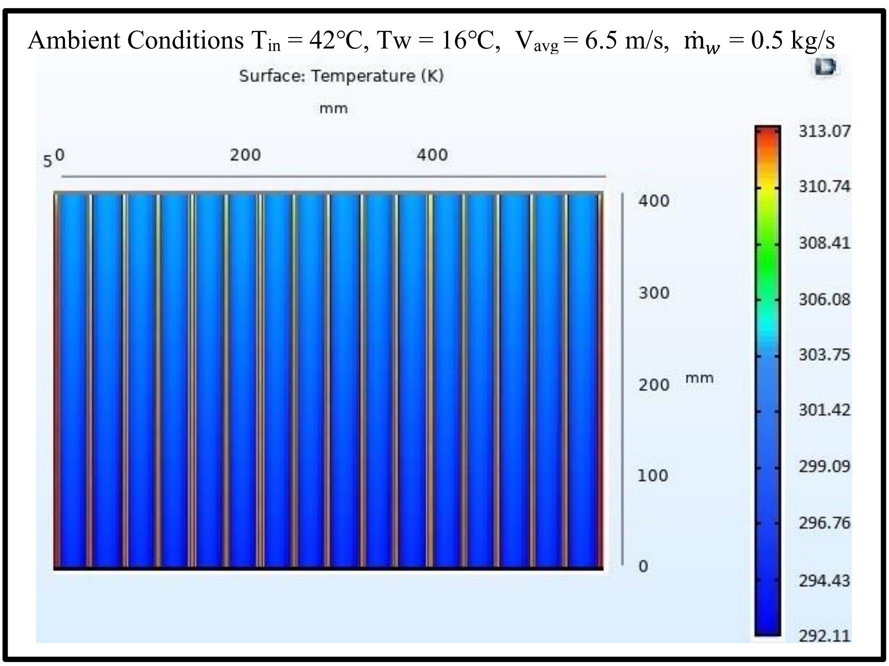
The Temperature Contour of polypropylene shows in Figure 3(c) that the temperature of the propylene sheet is 294.11 K and its almost constant on the whole PP sheet. This show that water channels on the top and bottom of the dry channel directly contact with the polypropylene sheet and this water cools down the sheet and blue color of the contour shows the temperature of polypropylene and the color changes from red to blue show the temperature of air from the inlet to outlet of the dry channel. The dry channel is covered with a polypropylene sheet on the top and bottom sides.

8.4 Velocity of air in dry channels

The Velocity contour dry channels Show at air velocity at the inlet of dry channels is the average velocity and 0 m/s at the surface of the acrylic plastic divider due to no-slip conditions and the maximum at the center of each dry channel which is 6.5 m/s. The ambient conditions and mass flow rate of water in wet channels are also shown in Figure 3(d).


Ambient Conditions T_{in} = 42°C, Tw = 16°C, V_{avg} = 6.5 m/s, $\dot{m}_w$ = 0.5 kg/s
Surface: Temperature (K)
mm
0
200
400
400
300
200
100
0
mm
313.07
310.74
308.41
306.08
303.75
301.42
299.09
296.76
294.43
292.11

(a)


Ambient Conditions T_{in} = 42°C, Tw = 16°C, V_{avg} = 6.5 m/s, $\dot{m}_w$ = 0.5 kg/s
Surface: Temperature (K)
mm
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200
100
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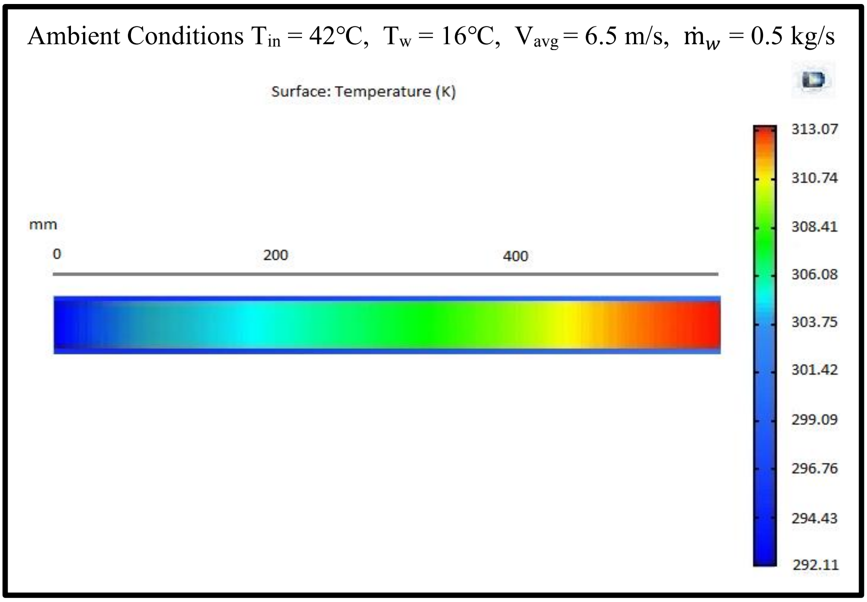
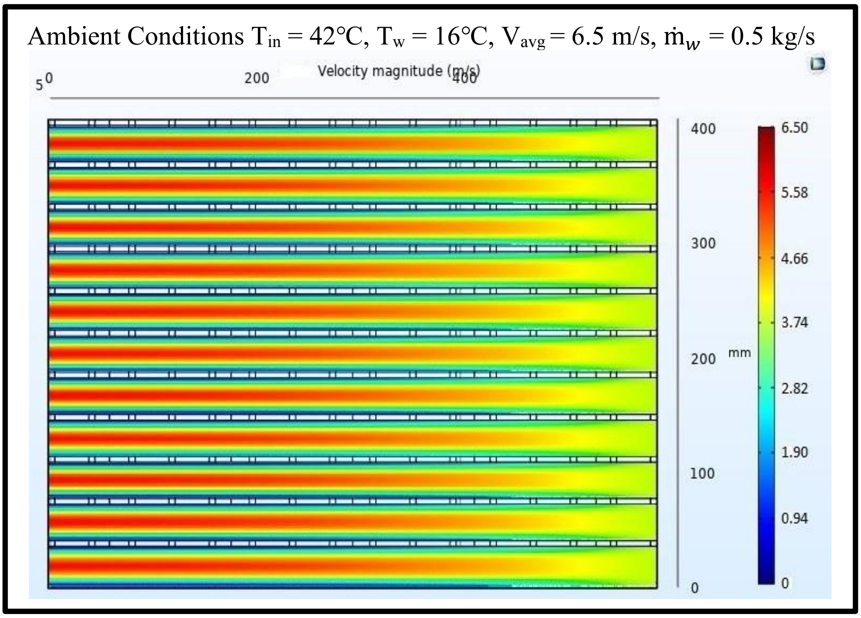
306.08
303.75
301.42
299.09
296.76
294.43
292.11

(b)



(c)



(d)

Figure 3: Temperature Profile of (a) dry channel (b) wet channel (c) of Polypropylene Sheet (d) Velocity Profile of dry channel

8.5 Temperature reduction of supply air

Several simulations have been run on different ambient conditions and the values temperature difference has been noted on each value of ambient and water temperature. Based on results, a graph has been generated as shown in figure 4. By maintaining the constant temperature of water and velocity of air, the increase of the temperature differential (T) is dependent on the temperature of process air and relative humidity. It is noted that when the dry bulb temperature at the input rises, the temperature on the process side falls even more. The maximum temperature difference is noted at 44°C and this described that higher inlet temperature favor the performance of indirect evaporative cooler.

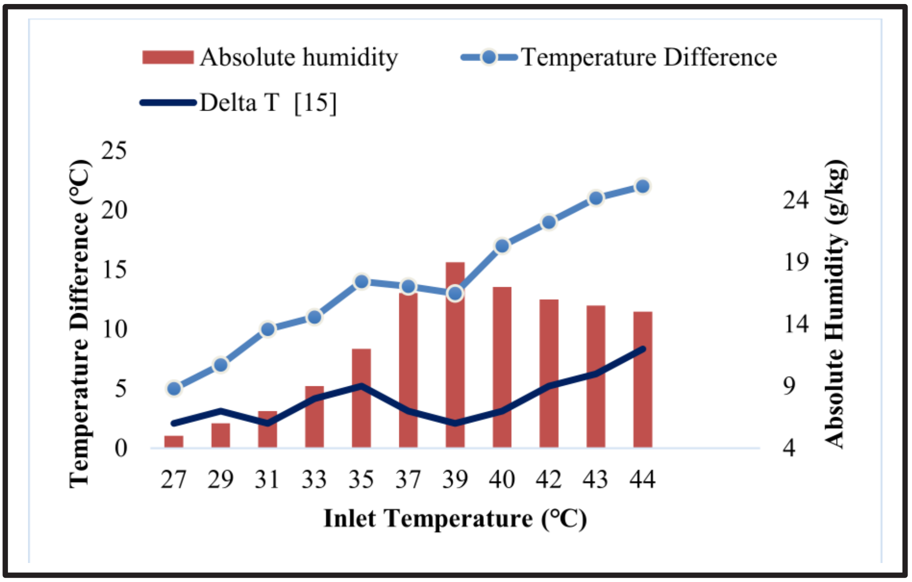


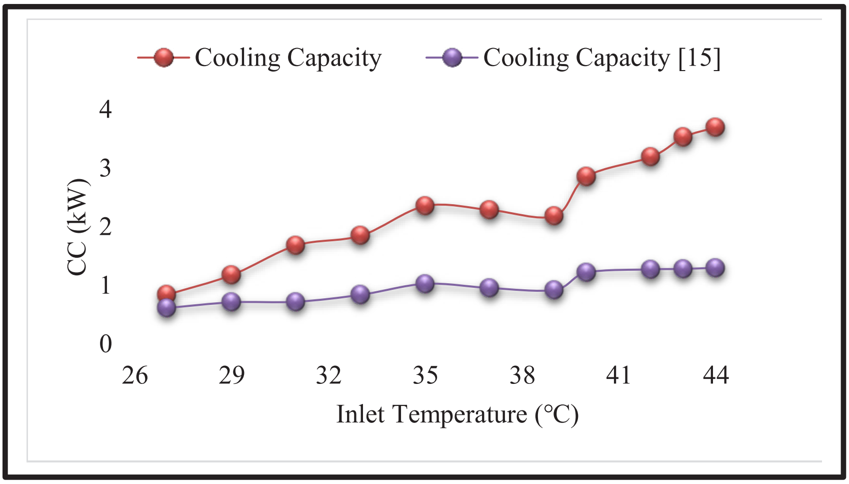
Figure 4:Temperature Profiles of Supply Air

8.6 Cooling Capacity

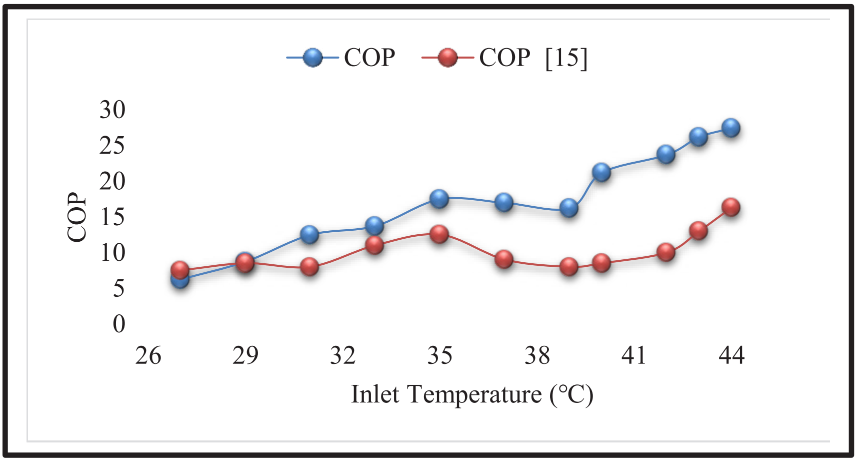
The cooling capacity of a cooler is affected by the ambient temperature and absolute humidity, as a higher ambient temperature and lower absolute humidity result in an increased temperature difference. The cooling capacity is directly proportional to this temperature difference, as shown in Figure 5(a), where the cooling capacity ranges from 0.84 KW to 3.699 KW. The maximum cooling capacity is achieved at an inlet temperature of 44°C and an average velocity of 6.5 m/s.

8.7 Coefficient of Performance

It is observed that coefficient of performance (COP) increases with increasing the cooling capacity and the maximum value of coefficient of performance is achieved at Tin = 4 °C, absolute humidity = 13 g/kg, Vavg = 6.5 m/s .it also depends on the absolute humidity as COP decreases with increasing the absolute humidity. The COP value varies between 6.22-27.40, as shown in figure 5(b).



(a)



(b)

Figure 5: (a) Cooling Capacity (b) Coefficient of Performance

8.8 Comparison of system

The system is compared with the international published study to show that this system is performed better or comparable in term of cooling capacity and COP. The key difference that is observed between the current study and Sabir et. al [15] is the size of system like width of channel, number of channels and air flow rate of the system. The difference of COP values between Sabir et. al [15] and current study are 68% to be noted.

Table 5: Comparison of System

Sr No	Parameter	Sabir et. al [15]	Current Study
1	Flow pattern	Cross flow	Cross flow
2	Width of channel	21.4 mm	26 mm
3	Height of channel	4 mm	5 mm
4	Total No. of channel	23	35
5	Length of stack	400 mm	590 mm

6	Channel geometry	rectangular	rectangular
7	Material in wet channel	polymeric	polymeric

9 Conclusion

The mathematical model that has been developed is run or solved using a COMSOL Multiphysics software. The different temperature profiles of the system dry channels in which the variation of ambient air temperature at fixed air velocity and water flow rates in the wet channels. The simulation analysis conducted in this study has demonstrated that the cooler can achieve significant temperature reductions at a minor energy consumption compared to conventional air conditioning systems. The system reduces the temperature of the inlet air up to 22°C, with cooling capacity and coefficient of performance values of 3.699 kW and 27.4, respectively at ambient conditions like inlet temperature Tin = 44°C, velocity = 6.5 m/s water temperature = 16°C. These outcomes indicate that the cooler has the potential to be an effective solution for managing a building's cooling demand while reducing energy consumption and greenhouse gas emissions. Therefore, this study's findings provide valuable insights for researchers and practitioners who seek to develop green and sustainable cooling solutions for buildings.

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