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DESIGN OF A NOVEL DEW POINT INDERECT EVAPORATVE COOLER: PRELIMINARY EXPERIMENTAL INVESTIGATIONS

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Abstract: *Evaporative coolers may represent a promising alternative to conventional cooling technologies based on vapor compression systems. Indeed, they present lower production and operative costs, as well as lower environmental impact. The present study aims to develop a novel Dew Point Indirect Evaporative Cooler (DPIEC), by combining simplicity, hence low production costs, and higher cooling performance. The design proposed has mixed flow configuration and is made of polycarbonate plate covered with cotton cloth as wicking material. Two prototypes with different length are experimentally tested for two different water distributors. The performance of the novel DPIEC is evaluated and compared in terms of temperature drop, dew-point effectiveness, cooling capacity and compactness. The results show that the long prototype performs better in terms of temperature drop and dew point effectiveness, but yields lower cooling capacity and is less compact. In addition, it is observed that the distributor that supplies water over the system performs better, independently on the prototype. These results can serve as reference for future designs of mixed-flow DPIEC.*

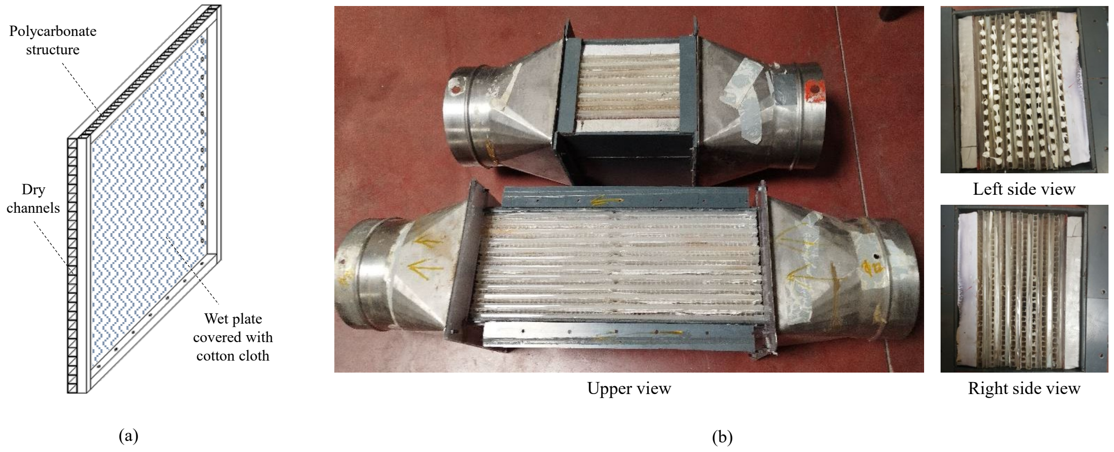


Figure 1. Schematic representation of the base element (a) and real photos of the assembled prototypes (b).

Keywords: Dew point, Indirect evaporative cooling, experimental investigation, cooling capacity, thermal effectiveness.

1. INTRODUCTION

Evaporative coolers may represent a promising alternative to conventional cooling technologies based on vapor compression systems. Indeed, they present lower production and operative costs, as well as lower environmental impact [1], [2], [3]. Evaporative coolers take advantage of water evaporation to cool down the ambient air. Among them, Dew Point Indirect Evaporative Cooler (DPIEC) represents the most advanced technology [4]. It is composed of coupled of adjacent dry and wet channels. First, the primary air stream flows in dry channels. Then, a part of this is diverted into the wet channel to form the secondary air. Here, the air comes in contact with the water and it is exhausted at the end of the process. Meanwhile, the resmaining flow of the primary air is supplied to the target space. With respect to other evaporative technologies, DPIEC has the advantage of high performance in terms of temperature drop. In fact, it can ideally achieve the dew point conditions of the inlet air. In addition, it ensures low electricity consumption and it does not increase the humidity of the indoor space. Despite undisputable advantages, this technology still finds hard to stand out in the european market [2]. To face that, the current study aims to develop and experimentally evaluate a novel mixed flow DPIEC, by combining simplicity, hence low production costs, and compactness. As a preliminary investigation, two prototypes with different length are tested for three different water distributor. The performance of the two novel DPIEC is evaluated and compared in terms of temperature drop, dew-point effectiveness, cooling capacity, and compactness.

2. METHODOLOGY

In this work, two mixed flow DPIECs with different length are developed and experimentally tested. Both prototypes are composed by overlapping modular elements made of polycarbonate sheets (Figure 1a). The base-element consists of 28 dry channels and a wet plate. In dry channels, some air paths are blocked and holes are drilled along the plate to drive part of the primary air through the wet plate. The wet plate is covered with cotton cloth on one side. The upper side is open, thus allowing the air to exhaust, and the water to be supplied. The bottom side, instead, is closed by a rib that is perforated to drain the excess water.

Once assembled (Figure 1b), the prototypes are composed of 8 base-elements. The water distributor is installed in the upper side and a water tank in the bottom side. A water pump permits the water to recirculate from the tank to the distributor. Air from alternate plates is driven to the secondary air side of the heat exchanger resulting in a mixed-flow configuration (Figure 2).

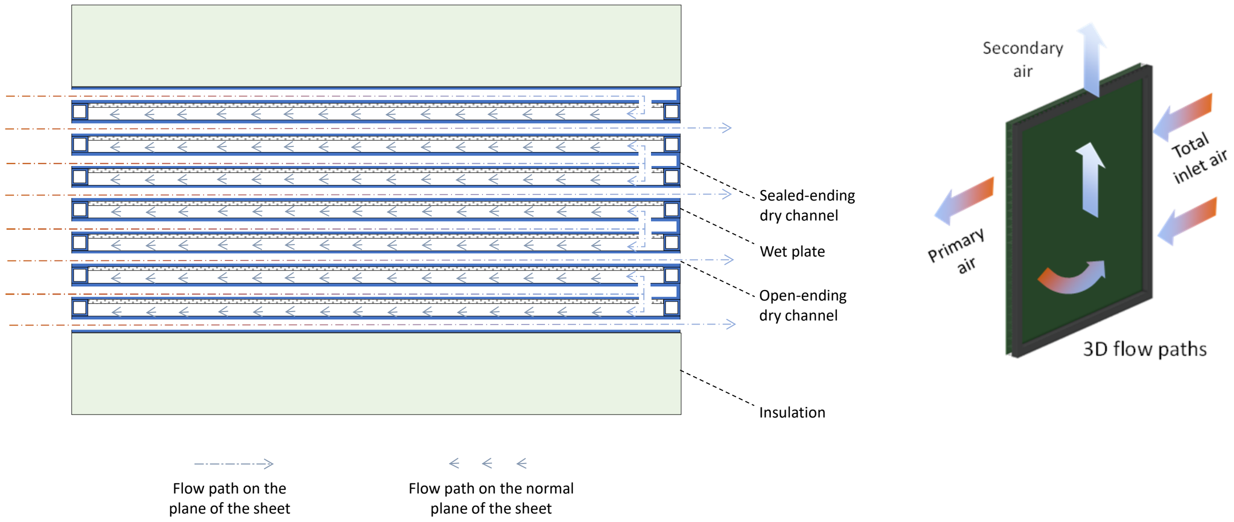


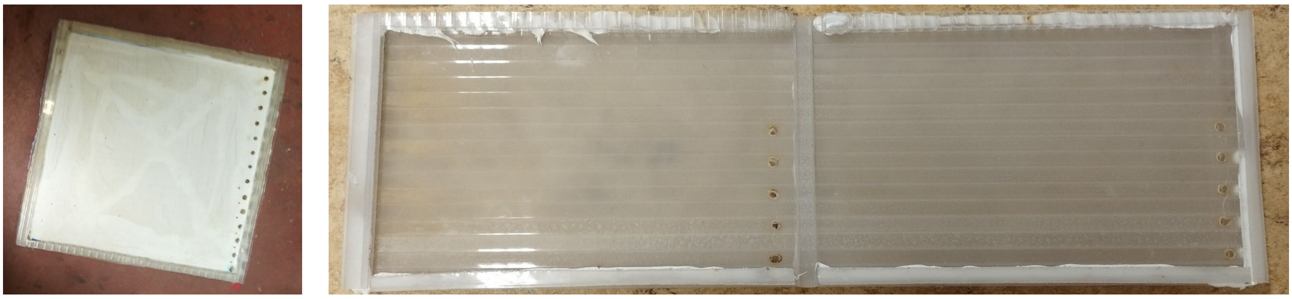
Figure 2. Schematic view of a section of the prototype and 3D view of the mixed-flow paths.

The difference between first and second prototype is the length of the dry channels and the distribution of the holes. In fact, the first prototype ("short" in the following) has dry channels 30 cm long, and the holes are drilled only at the end of the channel. Instead, the second one ("long" in the following) has dry channels 60 cm long, and the holes are drilled at the middle and at the end of the channel (Figure 2). This is to permit a better air distribution in the larger wet plate. The structural parameters of both prototypes are summarized in Table 1.

Table 1. Description of the structural parameters of the prototypes.

Parameters	Short prototype	Long prototype
Heat exchanger volume	31 x 25 x 30.5 cm	31 x 25 x 60.5 cm
Flow configuration	Mixed flow	Mixed flow
Dry channel length	30 cm	60 cm
Dry channel width	9 mm	9 mm
Dry channel height	9 mm	9 mm
Number of dry channels	8	8
Wet channel length	30 cm	60 cm
Wet channel height	30 cm	30 cm
Wet channel gap	9 mm	9 mm
Number of wet channels	8 x 28	8 x 28
Plate thickness	0.5 mm	0.5 mm
Channel material	polycarbonate	polycarbonate
Wicking material	cotton cloth	cotton cloth

Since many recent works [5] [6] highlighted the importance of studying the effect of the water spray on the performance of indirect evaporative coolers, both prototypes are tested by changing the type of water distributor. More in detail, two types of water distributor are investigated (Figure 2): the first one consists on a circular piping with further shorter pipes that penetrate inside the wet channels and distribute water through gravity ("inner distributor", in the following). Instead, the second type consists on a circular pipe equipped with nozzles that uniformly spray the water over the top of the wet channels ("outer distributor", in the following). The inner distributor has 16 outlets in the short prototype and 22 outlets in the long one. The outer distributor has five nozzles with 8 outlets in the short prototype, while has 7 nozzles with 8 outlets in the long prototype.



Short prototype

Long prototype

Figure 2. Holes distribution in the short prototype and in the long prototype.

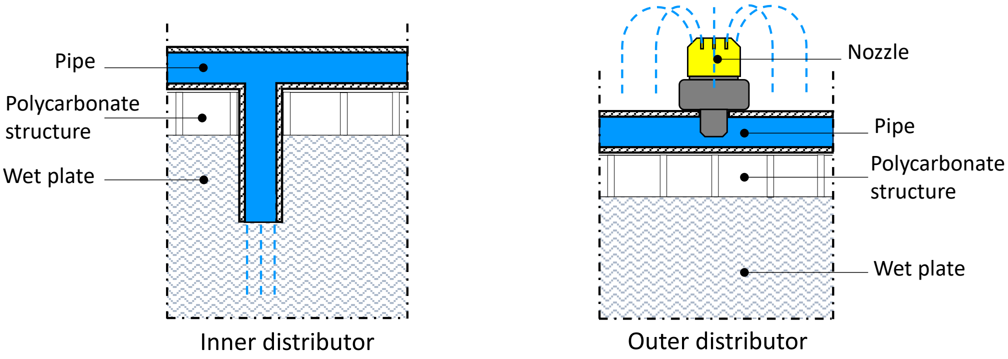


Figure 3. Schematic representation of the tested water distributors.

The experiments are performed by connecting the prototypes to an Air Handling Unit (AHU) to control the inlet air conditions. The sensors listed in Table 2 are used to measure the temperature and relative humidity of the total air, the primary air, and the secondary air. Furthermore, the total air mass flowrate and the primary air mass flowrate were calculated from the air volume flows measured indirectly from the pressure drops in two calibrated orifice plates located respectively before and after the prototype. Instead, the secondary air mass flow is calculated as difference between total and primary air mass flowrate. Also, the working-to-intake air ratio is calculated as the ratio between secondary and total air mass flowrate.

Table 2. Description of the sensors (accuracy, model, parameters measured)

Parameter	Instrument	Range	Accuracy
Static pressure	Data logger Testo 435-4	0/25 hPa	±0.02 hPa (from 0 to 2 hPa) ±1% of measured values (remaining range)
Air dry bulb temperature	Testo 175 H1 Temperature and relative humidity sensor	−20/+55°C	±0.4 °C
Air relative humidity	Testo 175 H1 Temperature and relative humidity sensor	0/100%	±2% RH (from 2 to 98% RH) at +25 °C

Tests are performed for inlet air temperature of 30, 35, and 40 °C. The resulting conditions are studied after 20 minutes from the start of each test, to ensure steady state. The humidity ratio is 13.16 ± 0.82 g/kg, the total air volume flow is 6.25 ± 0.27 m^3/min, the working-to-intake air ratio is about 0.5 for the short prototype, while it is about 0.7 for the long one. The performance is evaluated in terms of temperature drop ΔT (Equation 1), wet bulb effectiveness ε_{wb} (Equation 2), dew point effectiveness ε_{dp} (Equation 3), cooling capacity CC (Equation 4), and compactness C (Equation 5):

$$\Delta T = T_{tot} - T_{pr} \tag{1}$$

$$\varepsilon_{wb} = \frac{\Delta T}{T_{tot} - WBT} \tag{2}$$

$$\varepsilon_{dp} = \frac{\Delta T}{T_{tot} - DPT} \tag{3}$$

$$CC = \dot{m}_{pr}(c_a + x_{tot} c_v)\Delta T \tag{4}$$

$$C = CC/V_{hx} \tag{5}$$

Where T_{tot}, T_{pr}, and DPT are respectively the dry bulb temperature of the total air, the dry bulb temperature of the primary air, the dew point temperature of the total air, that is the same of the primary air. $\dot{m}_{pr}$ is the primary air mass flowrate, x_{tot} is the humidity ratio of the total air, c_a and c_v are the specific heat of the dry air and of the water vapor, respectively. Lastly, V_{hx} is the overall heat exchanger volume.

3. RESULTS AND DISCUSSION

Figure 4 compares the performance of both prototypes for different type of water distributor.

On one hand, the long prototype performs better than the short one in terms of temperature drop, wet bulb effectiveness, and dew point effectiveness. Depending on the inlet air conditions and water distributor, the temperature drops between 4.0 and 8.6 °C for the long prototype and between 2.0 and 4.9 °C for the short prototype. The wet bulb effectiveness varies within 0.41 and 0.54 for the long prototype, face to 0.23 to 0.30 for the short prototype. Taking as reference the ideal lowest temperature achievable in such systems, results are evaluated in terms of the dew point effectiveness, which is around 0.30 – 0.38 in the long case, while it is around 0.17 – 0.22 in the short one. This is due to the two regenerative stages implemented in the long prototype, which enables the system to reach closer to the ideal dew point limit.

On the other hand, the long prototype shows comparable cooling capacity than the short prototype (125-256 W against 106-290 W). This is because, despite higher temperature drop achieved, the primary air mass flowrate in the long prototype is reduced due to the increased working airflow driven to the wet channels. In fact, the resulting working to intake air ratio is about 50% larger. As consequence, the compactness of the long prototype decreases notably. When the inlet air temperature is 35 °C, the long prototype is able to supply at most 4.6 kW/m^3 against 10.1 kW/m^3 supplied by the short prototype.

Looking at the water distributor, in both prototypes the distributor with external outlets performs better than the one with internal outlets. In any case, the outer distributor enhance supply temperatures around 1°C cooler than the inner distributor. This positively affects the dew point effectiveness, which increase up to 0.08 in the long prototype, as well as the cooling capacity and the compactness. In particular, the maximum increase in cooling capacity and compactness – that is more significant in the short prototype – reach 99 W and 4.4 kW/m^3, respectively. This means that the outer distributor guarantees a more uniform distribution of the water in the wet channels due to the presence of the spray nozzles. Furthermore, it does not obstruct the air passage, hence avoiding the channel blockage [7].

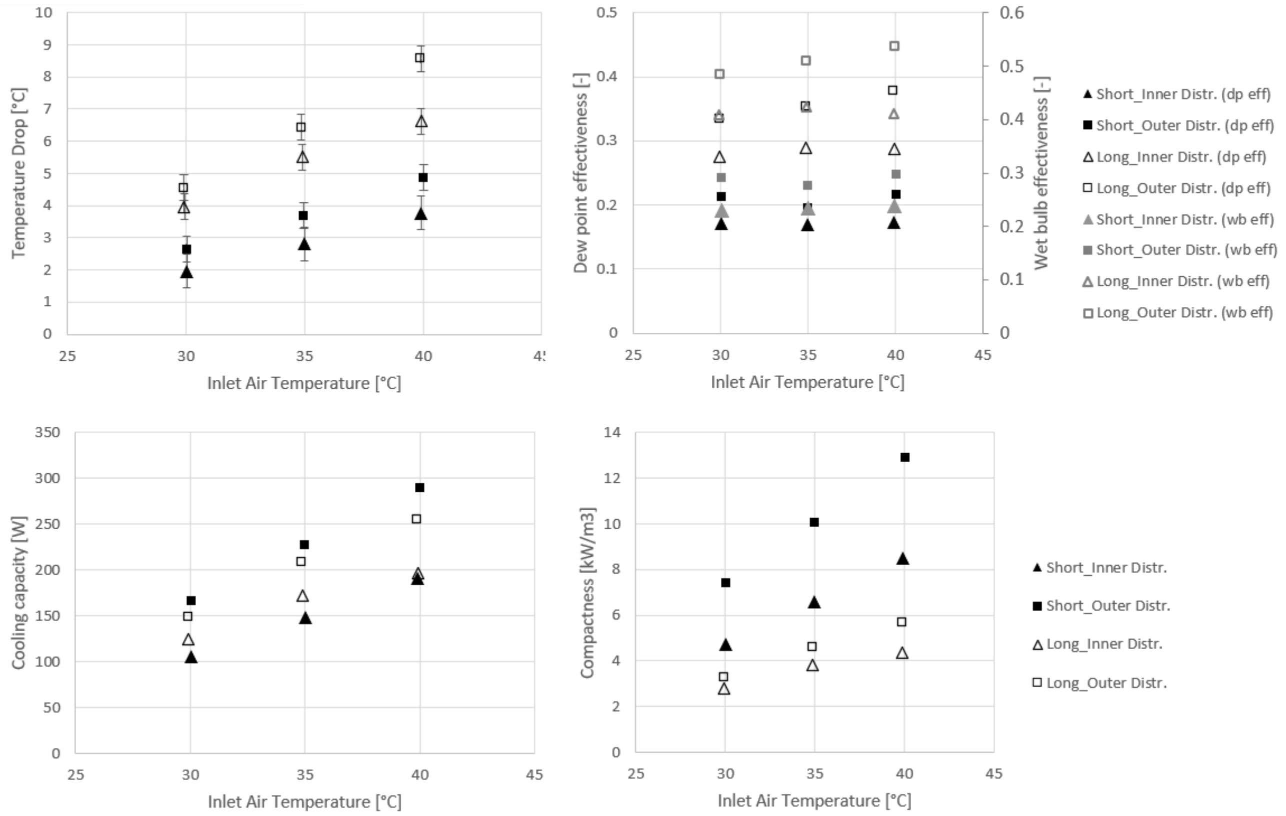


Figure 4: Performance evaluation of the short and long prototype with different water distributor

4. CONCLUSIONS

The current study presents a preliminary investigation on a novel dew point indirect evaporative cooler. It has mixed flow configuration and it is built by assembling plates within dry and wet channels , made of polycarbonate sheets covered with cotton cloth on the wet side. In particular, two prototypes with different length are experimentally tested. The dry channels in the short prototype are 30 cm long, while in the long prototype they are 60 cm long. The long prototype enhances the temperature drop almost double than the short one, yielding higher dew point effectiveness. However, its cooling capacity (208 W, intake air at 35°C) and compactness (4.6 kW/m^3, intake air at 35°C) are worse than the values obtained for the short prototype (227 W and 10.1 kW/m^3, respectively). This is due to the larger secondary airflow rate required, for a same inlet air flow. However, this determines a greater pressure drop in primary channels and – consequently – a lower supply air flowrate. Further studies should be address to optimize the air distribution inside the device, while limiting the primary air pressure drop.

Also, the effect of the water distributor is investigated. The distributor with extrenal outlets performs better then the one with inner outlets. More in detail, the temperature drop increase around 1°C, the dew point effectiveness may increase up to 0.08, and the increase in cooling capacity and compactness could achieve up to 99 W and 4.4 kW/m^3, respectively. This clearly demonstrates that an accurate design of the water distributor may improve the performace of indirect evaporative coolers.

5. NOMENCLATURE

Table 3 reports the acronyms and symbols used in the text

Table 3. Acronyms and symbols.

DPIEC	Dew Point Inderect Evaporative Cooler
ΔT	Temperature drop
ε_{wb}	Wet bulb effectiveness
ε_{dp}	Dew point effectiveness
CC	Cooling capacity
C	Compactness
T_{tot}	Dry bulb temperature of the total air
T_{pr}	Dry bulb temperature of the primary air
DPT	Dew point temperature of the total air
WBT	Wet Bulb temperature of the total air
$\dot{m}_{pr}$	Primary air mass flowrate
x_{tot}	Humidity ratio of the total air
c_a	Specific heat of the dry air
c_v	Specific heat of the water vapor
V_{hx}	Overall heat exchanger volume

6. ACKNOWLEDGMENTS

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