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Experimental Study of an Industrial Evaporative Cooler in a Closed Environment

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A B S T R A C T

It was studied cooling dynamics, of an industrial evaporative cooler in a closed environment, in this case the Fluid Laboratory of the Polytechnic Institute of Uerj, using different temperature measurement points. Local atmospheric conditions were obtained through the institutional meteorological station (CETEMA, IPRJ-UERJ). From two experiments it was observed that the rate of cooling is conditioned, mainly, to the higher incidence of the flow of water mist, or in other words, it depends on the position in relation to the height and distance from the evaporative cooler in the environment. Another fundamental factor is relative humidity, which has an inverse relationship with environmental cooling rate. The temperature experimental profiles were correlated with various mathematical models, with a better fit being observed from a second-order polynomial model.

Keywords: Industrial Cooler, Evaporative cooling, Psicrometry

Introduction

Evaporative cooling is a relatively simple cooling method, which is based on the simultaneous exchange of heat and mass between a moist air current (water mist) and the environment to be cooled, making the latter cooler and more humid.

Frescos from Ancient Egypt, dating back to 2500 BC, show slaves shaking air around containers with porous walls in order to cool their contents (ALMEIDA et al, 2009). Current water filters, made of clay, have similar characteristics, which reduce the temperature of the water inside them by evaporating the water on their surface.

We can mention some places that are more suitable for the use of evaporative coolers, such as: storage of fruit and vegetables, open spaces with large public, industries with heat dissipating machines, animal shelters, environments with controlled relative humidity, spaces intended for growing plants, among others (CAMARGO et al, 2000).

When compared to traditional cooling systems, evaporative cooling has some advantages such as: lower operating costs; cooling of large spaces; less impact on the environment; large air renewal in the environment, with better air quality and reduction of microorganisms; possible use as a pre-cooling system in conventional refrigeration systems, etc. (CAMARGO, 2003/2004). Several scientific studies have been carried out in the area in order to improve the performance of evaporative cooling systems (Yamada et al., 2008; Ulpiani et al., 2020; Farnham et al., 2017). Ulpiani et al., 2020, carried out studies on the effect of meteorological conditions on the cooling efficiency of an urban evaporative cooling system. They demonstrated that the cooling capacity was strongly a function of the depression of the local wet bulb temperature, with negative and positive influences, respectively, of solar irradiation and wind speed. Yamada et al., 2008, evaluated, through modeling and simulation, the effects of evaporative cooling in the context of the particle size distribution of water mist injected into the environment. The authors did not observe, from the numerical results, any difference in the reduction of the ambient temperature, due to the variation in the size of the mist particles. Farnham et al., 2017, studied the thermal effects of an oscillating evaporative cooler in a large work environment and observed a temperature drop in the range of 0.2-4.0K with a humidity increase of 5%.

In the present study, the cooling dynamics of an industrial evaporative cooler model (Ebone air conditioners – Fog V) in a closed environment were evaluated, in which the temperature was monitored at different points along its length. The experimental data were correlated with different mathematical models in order to obtain the best representation.

Methodology

Psychrometry is the branch of thermodynamics that studies mixtures of water vapor and dry gases. Atmospheric air is a mixture of various compounds, such as nitrogen, oxygen, argon, water vapor, carbon dioxide, and also contaminants such as dust, pollen, among others (ELIAS, 2012). When the air contains water vapor, it is called humid, and when it does not, it is called dry.

Evaporative cooling is based on reducing the temperature of the ambient air through the evaporation of a stream of water mist, which is formed by water droplets measuring micrometers. The contact of the stream of water mist with the ambient air, at a higher temperature, vaporizes part of the mist, removing latent heat of vaporization, making the ambient air cooler and more humid. Thus, devices that work using this principle are called evaporative coolers. Depending on atmospheric conditions, significant temperature reductions can be achieved, such as 11 ºC, achieved in the USA, and 6 ºC, in Brazil, the latter achieved in both hot and dry regions, such as Triângulo Mineiro, Mato Grosso and Goiás (WINGE, 2012).

$$\varepsilon = \frac{T_{bs1} - T_{bs2}}{T_{bs1} - T_{bu}} \quad (1)$$

The experiments were carried out in the Fluids Laboratory of the Polytechnic Institute of UERJ in Nova Friburgo-RJ (IPRJ), Brazil, which has the following dimensions: 17.0 x 6.8 x 3.9 m, corresponding to a volume of 450.16 m³. Fig. 1A below shows a 3D model of the laboratory, built in SolidWorks, with the respective top view (Fig. 1B), which indicates the positions of the thermometers used in the measurements, in relation to the evaporative cooler, the latter installed at the far left of the laboratory.

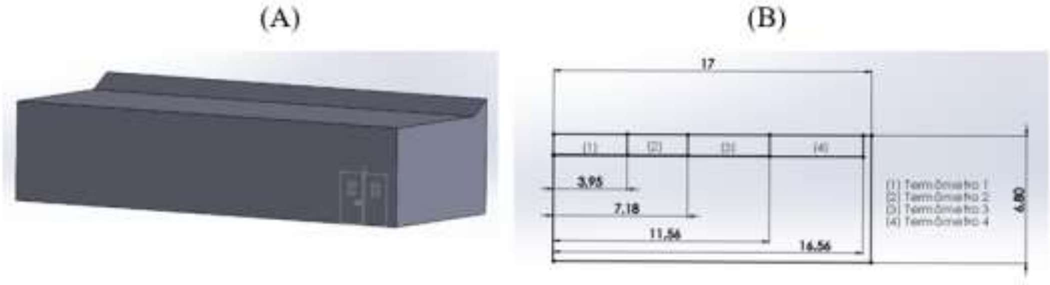

Fig. 1 – CAD project of the laboratory

In Fig. 2 below we have an image of the industrial evaporative cooler model used in the experiments, which is manufactured by the company Ebone Climatizadores - model Fog V (Brazil).

Fig. 2 – Image of the industrial evaporative cooler utilized, model Fog V

Below, in Table 1, we have the technical specifications of the evaporative cooler used.

Table 1 – Specifications of the industrial cooler (Fog V)

Model Fog V	Specification
Mist Sprinkler Motor	368W
Propeller rotation motor	150W
And another entry	518W
Weight	28,2 Kg

The water consumption of the evaporative cooler used depends directly on the flow of water mist injected into the environment. This flow can be regulated using an analog controller located on the side of the equipment. The cooler has a water reservoir at the bottom, which is pumped to the mist disperser, which consists of a circular disc located in the central part of the equipment.

Temperature measurements in the laboratory were performed using four bulb thermometers, with an error of ± 0.5ºC, which were arranged in a straight line along the length of the laboratory, starting from the position of the cooler, located on the wall to the left of the first thermometer (T1). In Fig. 1B you can see the locations of the 4 thermometers, in sequence, T1, T2, T3 and T4, from the cooler. Thermometers T1, T2, T3 and T4 were located at the following distances, respectively, 3.65, 7.18, 11.56 and 16.56 m, from the cooler, which was located on the left wall of the laboratory.

Results and Discussions

Experiments were carried out on two different days, under different environmental conditions, in order to study the effect of relative humidity variations on the experiments. On the first day, experiments were carried out with mild ambient temperature and relative humidity, while on the second day, relative humidity was in a higher range of value, with the ambient temperature practically stable in the same range as the previous day.

Tables 2 and 3 below are related to the experiments carried out on the first day (Day 1). The data in Table 2 were obtained from the meteorological station (CETEMA), which is installed at the Polytechnic Institute of UERJ in Nova Friburgo-RJ. Table 3 shows the thermodynamic data calculated from the properties presented in Table 2. The temperature of the water used in the cooler, measured on that day, was 24ºC.

Table 2 – CETEMA data (Day 1)

Atmospheric pressure	91,75 kPa
Air temperature	21,7 ºC
Relative humidity	51%

Table 3 – Thermodynamic data (Day 1)

Absolute humidity	0,011638
Vapor partial pressure	1,6852 kPa
Dry air partial pressure	90,0648 kPa
Saturation pressure	3,3044 kPa

Figure 3, below, presents the results of the temperature variation, in the IPRJ fluids laboratory, for the 4 measurement points (thermometers), as described in Fig. 1B. The experimental data, in Fig. 3, were correlated with second-order polynomial models (lines), which showed good correlation, with correlation coefficients greater than 97%. The temperature variations, at the end of the experiment, for the four measurement points, were equal to: $\Delta T1$ = 4.2 ºC, $\Delta T2$ = 5.6 ºC, $\Delta T3$ = 4.0ºC, and $\Delta T4$ = 2.6ºC. Therefore, it can be seen that, even over long periods of time, the temperatures do not equalize, showing, in this case, a strong dependence on the position of the cooler.

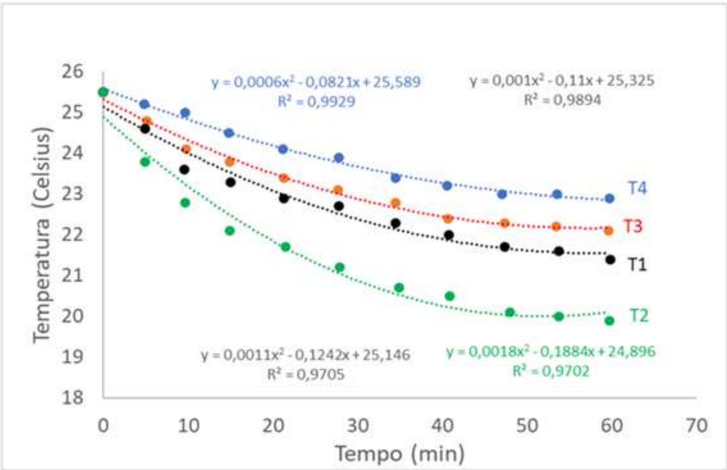

Fig. 3 – Cooling dynamics (Day1)

It can be seen, when analyzing the graph, that the smallest drop in temperature was observed in thermometer 2 (T2), with a temperature drop equal to 5.6 ºC, followed by thermometers T1, T3 and T4. Thermometer 1 (T1), even though it was at a shorter distance from the cooler, 4 meters, did not reach a temperature lower than T2, the latter at a distance of 7 meters from the evaporative cooler, as can be seen in Fig. 1B. These results show that the direction of the mist flow from the cooler is essential for local cooling of the environment, since, in the experiment carried out, the mist flow was in the directly of the position of thermometer 2. Thermometer 1, being closer to the cooler (4 m), was not subject to the direct flow of water mist, since the evaporative cooler was installed at a height of 3 m. Thermometers 3 and 4, being at greater distances from the cooler, 11 and 16 m, respectively, did not receive all the fog density of the previous thermometers, due to evaporative effects, which led to the loss of water mass through evaporation to the upper layers of the laboratory.

The cooling efficiency of the studied environment, in terms of location, can be better observed through the effectiveness calculations, which are in Table 4 below. Thermometer 2, due to the position of higher incidence of mist flow, obtained the greatest cooling effectiveness. Thermometer 1, as it does not receive a direct flow of mist, although at a shorter distance from the cooler (4 m), obtained an effectiveness value in the order of magnitude of thermometer 3, which was 11 m from the cooler.

Table 4 – Results of cooling effectiveness (Day 1)

Thermometer 1	58,6%
Thermometer 2	78,1%
Thermometer 3	52,2%
Thermometer 4	36,3%

Tables 5 and 6 below are related to the experiments performed on the second day (Day 2). The data in Table 5 were obtained from the meteorological station (CETEMA), which is installed at the Polytechnic Institute of UERJ in Nova Friburgo-RJ. Table 6 shows the thermodynamic data calculated from the properties presented in Table 5. The temperature of the water used in the cooler, measured on that day, was 24ºC.

From Table 5, we can see that the relative humidity value was much higher than on the first day, due to rain that occurred in the region the previous day.

Table 5 – CETEMA data (Day 2)

Atmospheric pressure	91,47 kPa
Air temperature	25,3 ºC
Relative humidity	67%

Table 6 – Thermodynamic data (Day 2)

Absolute humidity	0,01548
Vapor partial pressure	2,2212 kPa
Dry air partial pressure	89,2488 kPa
Saturation pressure	3,3152 kPa

Figure 4 below presents the results of the temperature variation for the second day in the IPRJ fluids laboratory for the four measurement points (thermometers), as described in Fig. 1B. The experimental data in Fig. 4 were correlated with second-order polynomial models (lines), which presented lower correlation coefficients than those of the first day, with correlation coefficients greater than 93%. The correlation coefficients between the models and the experimental data on the first day of experiments was 97%. The temperature variations at the end of the experiment for the four measurement points were equal to: ΔT1 = 2.5 ºC, ΔT2 = 2.9 ºC, ΔT3 = 2.2ºC, and ΔT4 = 1.0ºC. With this, it is clear, once again, that, even over long periods of time, the temperatures do not equalize, showing, also in this case, as on the first day of experiments (Day 1), a strong dependence on the position of the cooler. It can be seen, from Table 5, a relative humidity value much higher than on the first day, due to rain that occurred in the region the previous day.

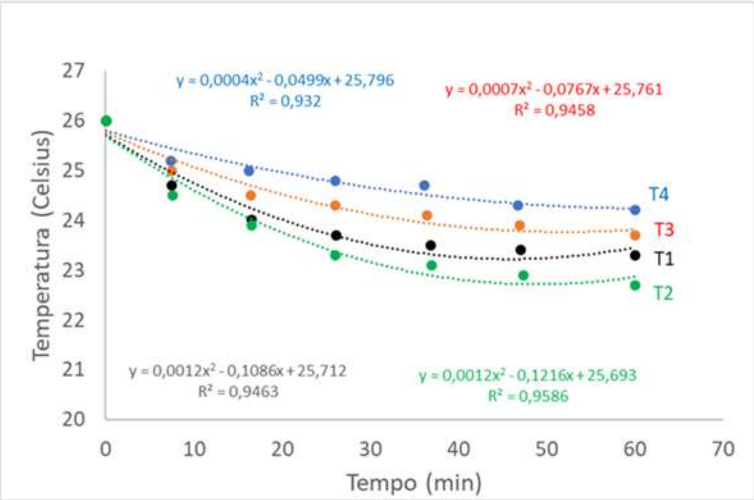

Fig. 4 – Cooling dynamics (Day2)

The cooling efficiency of the studied environment can be better observed by the effectiveness calculations, which are shown in Table 7 below. Thermometer 2, due to the position of greatest mist flow, obtained the greatest cooling effectiveness. Thermometer 1, because it does not receive direct mist flow, although at a shorter distance from the cooler (4 m), obtained an effectiveness value equal to 54%, a higher temperature value than thermometer 3, which was 11 m from the cooler.

Table 7 – Results of cooling effectiveness (Day 2)

Thermometer 1	54,1%
Thermometer 2	60,2%
Thermometer 3	44,7%
Thermometer 4	24,9%

Conclusions

The industrial cooler used proved to be effective in reducing the temperature of the environment studied, which has significant volume dimensions (17.0 x 6.8 x 3.9 m, which corresponds to a volume of 450.16 m³). It is worth noting that the windows in the upper part of the laboratory were left open in order to release the heated vapor generated by cooling the water droplets present in the mist flow. The maximum temperature reduction obtained was 6ºC, which is in accordance with the literature in the area.

The relative humidity of the environment has proven to be fundamental to the efficiency of cooling, in which the higher the relative humidity, the lower the cooling potential. The experiments of day 2 presented the lower cooling effect as they are closer to the saturation condition (relative humidity of 100%), which corresponds to the point of maximum cooling.

The experimental results showed that the direction of the mist flow from the cooler is fundamental for the local cooling of the environment, since, in the experiments carried out, the smallest temperature reduction was obtained in the position that received the higher mist flow. The positions further away from the cooler did not present such significant cooling, since they did not receive all the fog density of the closer positions, due to evaporative effects, which led to the loss of water mass through evaporation to the upper layers of the laboratory. In this case, the cooling rate is inversely proportional to the distance from the cooler.

The second-order polynomial models were able to represent the behavior of the experimental data, mainly those with lower relative humidity, which presented correlation coefficients greater than 97%.

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