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Wet Curtain Wall: A Novel Passive Radiant System for Hot and Dry Climates

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Abstract

This paper proposes a novel radiative passive system for hot and dry climates to improve outdoor thermal comfort. The solution consists in a curtain, characterized by two different finishing surfaces, one is waterproof and the other one is absorbent, immersed in a water tank by means of a mechanized system and subsequently used as a radiant surface with reduced temperature thanks to evaporative cooling effect. The effectiveness of the proposed system is verified by means of CFD simulations carried out on a sample application in outdoor space and supported by experimental measurements carried out on a small sample of curtain. The results showed that the proposed system can reduce the operative temperature up to 6°C with respect to the testing conditions (air temperature of 28.5°C and relative humidity of 50.5%) ensuring higher comfort levels and a limited water consumption to keep the curtain constantly wet (25 l/h for 130m^2 of wet curtain).

Keywords: Wet-curtain wall; evaporative cooling; thermal comfort; outdoor spaces

1. Introduction

Many human activities take place in bounded outdoor spaces such as courtyards, patios and courts. The duration and intensity of the use of an outdoor space may be affected by the comfort conditions existing in the area. In hot regions, during the summer the exposure to the sun and to high outdoor temperatures often causes thermal discomfort and stress. In such places the possibility of improving the comfort conditions by shading the area and lowering its air and radiant temperatures is typically considered. In fact, by reducing the surface temperature of a wide shaded area, it is possible to reduce the radiant temperature of the area where the people are exposed. In addition, in hot dry climates and in the hottest part of the day in Mediterranean climate, also the phenomenon of evaporative cooling can be used to further decrease the radiant temperature. Indeed evaporative cooling is a common process in nature and its applications for cooling the air are being used since the ancient years [1]. Since the Medieval ages, the Arab populations

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adopted passive cooling systems that exploited the effect of water evaporation [2-3]. Evaporative cooling is a process of heat and mass transfer based on the transformation of sensible heat into latent one. The non-saturated air reduces its temperature, providing the sensible heat that transforms into latent heat to evaporate the water [4]. However, the main drawback of the evaporative cooling is its high dependency on the ambient air conditions. Since the temperature difference between the dry and wet-bulb temperatures of the ambient air is the driving force of evaporative cooling, for mild and/or humid climates such difference is small and thus a limited cooling effect can be obtained [5]. On reverse, in a hot and dry climate, this technology is able to reduce greatly the air temperature [6-7].

Among several evaporative cooling systems, the so-called "wet curtain" concept used in direct evaporative coolers [8-9], can also be successfully applied for the cooling of bounded outdoor spaces through the periodic immersion of a curtain in the water. A wet curtain, besides protecting from solar radiation, decreases the radiant temperature, improving consequently also the thermal comfort levels during periods of extreme temperatures.

The use of evaporative cooling is now virtually lost due to the diffusion of modern air-conditioning systems and also due to technological and practical difficulties to maintain a constantly wet medium. However, there are some commercial products available on the markets, such as breathable panels in wood fiber, able to absorb a quantity of water, delivered by ducts placed in the upper edge of the panel itself [10]. These are generally combined with horizontal axis fans, which pass the air at room temperature through the panel, whereby absorbing a part of the heat, thus lowering the exit temperature. However, the literature review showed that there are no existing commercial products able to exploit just the radiant cooling effect.

In the present work, a novel radiative passive system based on wet curtain is proposed and studied. The effectiveness of the proposed solution is verified both with experimental measurements, carried out on a small sample of curtain, and also with CFD simulations carried out on the entire system in reference outdoor conditions.

2. Design configuration

The design of proposed system consists of a constantly wet curtain at the bottom of a highly reflective shading element, in order to decrease the surface temperature of the curtain and consequently to reduce the mean radiant temperature. The supply of water flow to the curtain may be carried out in three different modes, illustrated in Fig. 1. In the first (a) the water channels are placed in contact with the curtain to be humidified: this system allows to reduce the amount of vaporized water in the air, while in the second case (b) the curtain is wetted by water atomization. In this case, the curtain would be wet more uniformly, but at the same time the required water flow and the relative air humidity would increase. The third system, shown in Fig. 1 (c), instead is based on the total immersion of the curtain in the water by means of a mechanized system that allow to move the curtain on a specific path thanks to different rotating cylinders. In this case, the same curtain acts as a radiant element in the bottom layer and as a shading element in the upper layer. The rotating speed has to be set according to the evaporation rate of the water contained in the tissue, as explained in next sections.

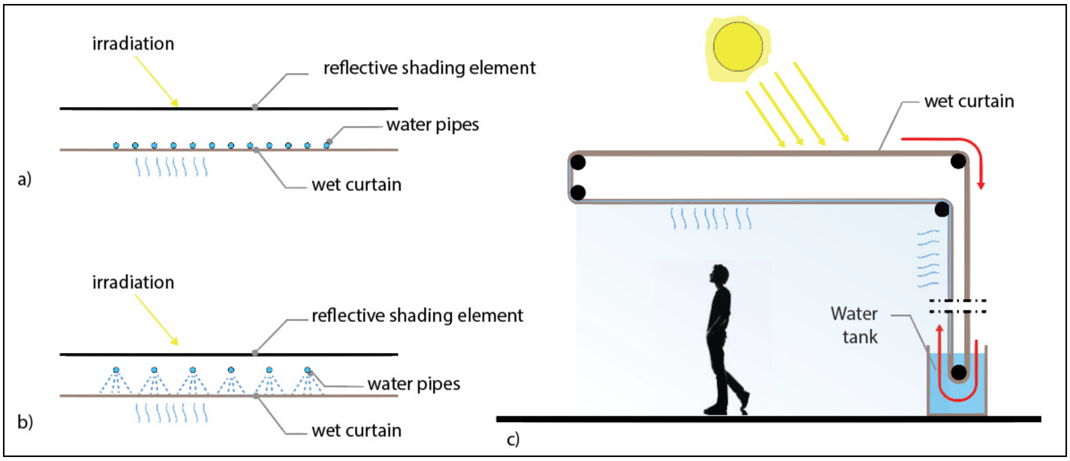

Fig. 1. Different wet curtain configurations

In this paper, only the last solution (c) is studied since it is considered technically the most feasible and effective option. In order to assess the performance of the wet curtain in a full-scale system, the related thermal comfort and hence the air temperature and the mean radiant temperature distribution, a CFD analysis is necessary. As a first step, an experimental campaign was carried out on a small curtain sample to assess its behavior, with particular reference to surface temperature and evaporation rate, in reference boundary conditions. Subsequently a CDF simulation was carried out on a computer model of a shelter realized with two wet curtains in a hot climate. The main results of the analysis are described in section 3.

3. Experimental analysis

In order to verify the performance of the wet curtain in real operating conditions and to support the CFD simulations, an experimental analysis was carried out on a sample of fabric whose two surfaces, the front and rear, are characterized by different treatments, and therefore, also different performances. In particular, while first surface is made of a highly absorbent material, capable of retaining water about 1 l/m2, the other has the opposite characteristics, resulting in fact waterproof. The sample used has a size of 210 × 300 mm, weight 52 g and is able to absorb about 62 g of water.

The experimental analysis was performed on the sample placed in horizontal position, with the aim of measuring the water evaporation rate and to verify the surface temperature of both sides as a function of water evaporation rate. The measurements were carried out respectively with the aid of a high-precision scale and an infrared thermometer with an accuracy equal to ±1 °C.

The experimental test is carried out in reference operating conditions, which are the following:

- average environmental temperature equal to 28.5°C (varying from 28°C to of 28.6°C);
- average relative humidity equal to 50.5% (varying from 50% and 51%);
- air speed on the curtain (air flow parallel to the curtain): 1 m/s;
- no incident solar radiation.

Such condition was preliminary considered representative of a typical operating condition of the wet curtain system in outdoor conditions.

It should be stated that, in presence of a wet surface as one of the proposed curtain, the evaporation continues unless the surrounding air is saturated. Evaporation keeps the temperature of the curtain and that of the film of surrounding moistened air below air temperature registered by a dry bulb thermometer.

The ventilation is needed to avoid the formation of a thick layer of saturated air around the wet surface, which decreases the evaporation rate. Literature works suggest that with an air speed higher than 1 m/s the temperature of the wet surface can be considered equal to the wet-bulb temperature [11-13].

The obtained results are reported in the following figure.

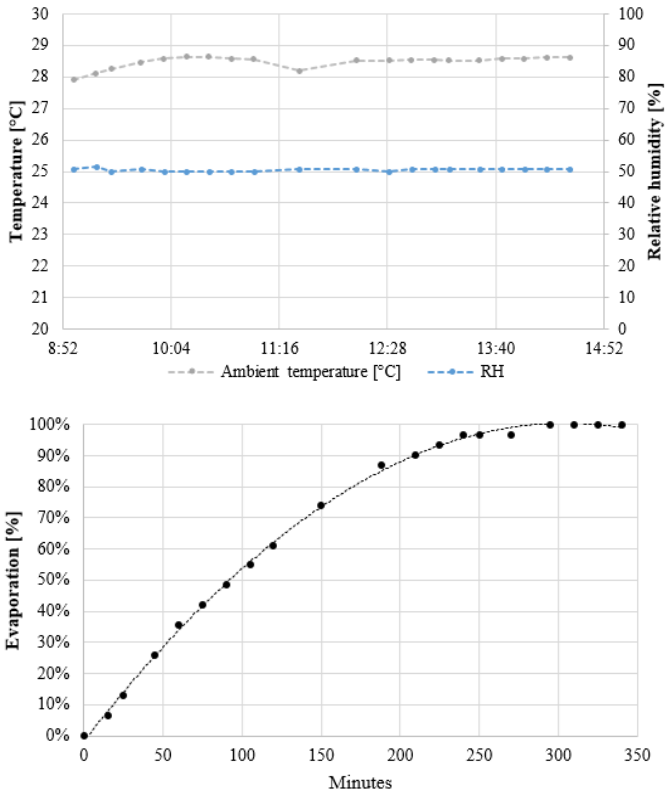

Fig. 2. Environmental temperature and relative humidity recorded during the test (up) - Water evaporation rate in percentage (down)

After the complete immersion of the curtain into the water at ambient temperature, the sample was placed on the high-precision scale and was weighed at the intervals of 15 minutes to assess the evaporation rate of water (Fig. 2 – right). To facilitate the reading of the results, the data and the graphs are shown as a function of elapsed minutes from the immersion of the curtain into the water.

From the experimental measurements conducted, it is evident that the sample has employed 295 minutes to pass from the saturation state to the dry state. Therefore, it was possible to calculate the water flow rate necessary to maintain the constantly wet curtain, under indicated environmental conditions, which is approximately 0.2 l/m^{2}h.

The sample fabric used in the experimental analysis is shown in Fig. 3

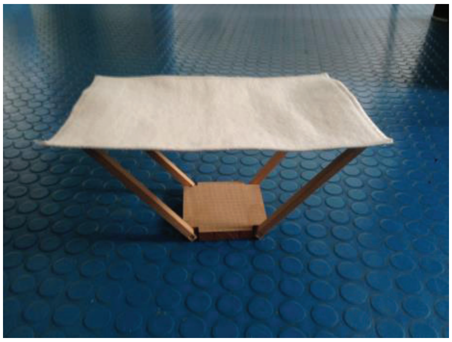

Fig. 3. The sample fabric used for experimental analysis

The results shown in Fig. 4, related to the temperatures measured in the central point on both sides on the absorbent and waterproof, clearly show following basic characteristics of the analyzed sample:

- the fabric is able to achieve surface temperatures, 3-6 °C lower than that of the environment;
- the absorbent side temperature reaches about 4 °C lower than the waterproof side;
- the surface temperature of the absorbent side of wet curtain can be considered close to the theoretical wet bulb temperature;
- the surface temperature of both sides, is almost constant during evaporation. However, when the evaporation is completed, the surface temperatures increase suddenly.

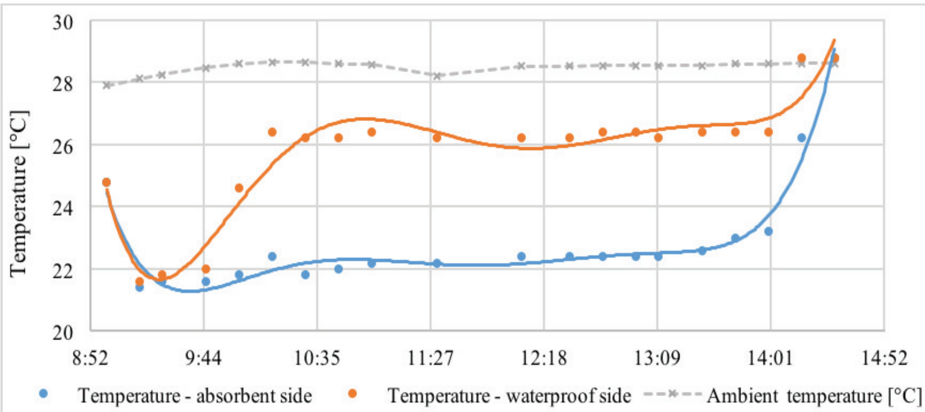

Fig. 4. Surface temperatures at the central point of the tested sample

It must be noted that the absorbent side should be facing towards the space to be cooled.

The behavior of the curtain will be subject to further analysis to be carried out on a larger curtain sample and in different boundary conditions, with the aim to validate a theoretical model which will be developed during the prosecution of the research to simulate the effectiveness of the system in various application contexts.

4. CFD simulations

In the following sections, the performances achievable with a full-scale system are described, according to the results obtained by mean of CFD simulations based on the experimental results summarized in Section 3.

In particular, in order to evaluate the benefits in terms of reduction of the mean operating temperature ensured by the proposed system, thermo-fluid dynamic simulations were carried out under steady state conditions considering the proposed sample application for outdoor spaces. This is represented by a shelter realized with 2 curtains: one with the dimension of 10 x 10 m, placed as a ceiling, at a height of 3 m above the floor, and the second one placed vertically on the east side, as shown in Fig.5-a. The simulations were carried out using the CFD module of Design Builder software, which is especially appropriate for such kind of evaluations [14]. In detail, the simulation domain is equal to the indoor air volume covered by curtain. The vertical surfaces of the model not covered with the curtain and the floor are set to the same temperature of the air, assumed at 28.5°C, while the surface temperature of the wet curtain was assumed equal to the wet bulb temperature (considering if necessary the application of a fan able to avoid, as already said, the formation of the thick layer of saturated air around the wet surface, which decreases the evaporation rate), at 20.9°C according to the reference levels of relative humidity, equal to 50.5%.

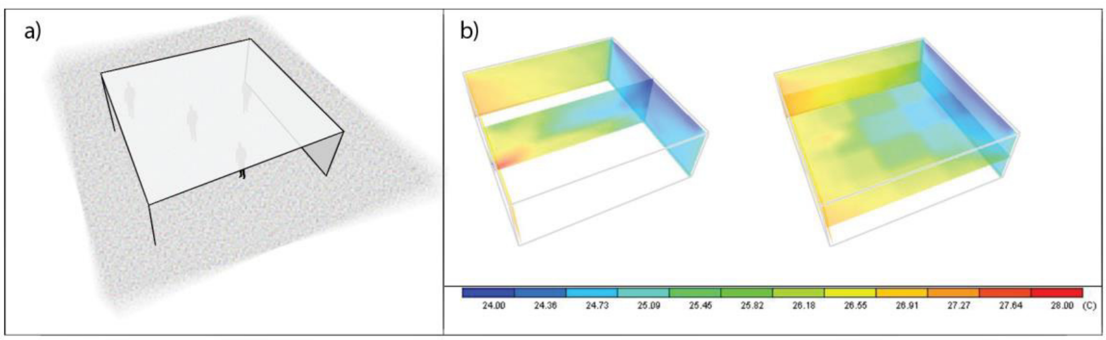

Fig. 5. View of the shelter defined as a sample application (a) and operating temperatures considering a surface temperature of the curtains 20.9°C

For this configuration, the operating temperature obtained in the center of the space covered by the shelter, at 1.5 meters from the floor level, is approximately 24.7°C. This value for the proposed solution can be considered a good contribution to improve the thermal comfort. Clearly, highest comfort is found near to the central part of the vertical curtain, while in the boundary zones of the shelter the operating temperatures are higher, but always lower than 28°C.

The water flow required to maintain the curtain constantly wet was carried out on the basis of experimental evaluations done on the sample of the curtain. In detail, for the entire shelter the water flow in the reference climatic condition is evaluated to be approximately 25 l/h. In this sense, the optimal rotation speed of curtain is calculated to be 2.6 m/h.

5. Conclusion

The studies presented in this paper show that the proposed system appears to be a viable alternative to improve comfort in outdoor spaces.

In particular, the simulation results showed that the proposed system can reduce the operative temperature up to 4°C with respect to the testing conditions (air temperature of 28.5°C and relative humidity of 50.5%) ensuring higher comfort levels and a limited water consumption to keep the curtain constantly wet (25 l/h for 130 m^2 of wet curtain).

In addition, experimental tests demonstrate that the wet curtain surface temperature achieve approximately the same values of theoretical wet-bulb temperature.

Further studies and experimental analysis, aimed at excluding potential errors due to edge effects, particularly relevant in the tested sample, will be conducted on larger component sample.

6. Copyright

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Biography

Claudio Del Pero is a researcher of the Architecture, Built Environment and Construction Engineering Department. He is actively involved in research and advisory activities related to energy efficiency of the built environment and to the exploitation of renewable energy sources, with particular reference to the topics of PV technology and distributed energy generation.