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Using Evaporative Cooling to enhance thermal comfort conditions in Semi-open Areas.

Abstract:
The rising global temperatures and increased frequency of heat waves have made it crucial to address the need for effective cooling solutions in semi-open spaces, such as outdoor cafes, large atriums with open ends, stadiums, prayer areas and public transportation waiting areas. The combination of the pedestal fan and mist water spray was introduced to explore the potential of utilizing evaporative cooling as a sustainable and cost-effective method for reducing ambient temperatures within such environments. The experimental study is conducted in a real semi-open environment and the data collection involved air velocity, air temperature, and relative humidity. Two different nozzle configurations were used to define the appropriate arrangement of nozzles and their number to maximize the cooling efficiency. The results showed that the axial air velocity during the mist condition decreased compared to that of the dry condition. The eight-nozzle configuration resulted in a greater reduction in air temperature over the four-nozzle configuration. However, an undesirable increase in humidity ratio resulted. A comparative analysis of the mist plate and mist nozzle revealed that the water particles of comparatively considerable size generated by the mist plate tended to fall within a limited distance without undergoing thorough complete evaporation, thereby failing to provide a sufficient reduction in air temperature. In all cases a distance of three meters from the fan is to be avoided to escape the uncomfortable wetting effect in this region.

Keywords: Evaporative cooling; Thermal comfort; Water mist spray; Mist plate.

1. Introduction:

Outdoor spaces play a crucial role in developing sustainable cities as they provide a conducive environment for pedestrian movement and outdoor recreational activities and significantly enhance urban areas' overall quality and vibrancy [1]. Studying outdoor cooling is gaining importance as it holds the promise of enhancing outdoor availability. Attracting individuals to utilize outdoor and semi-outdoor spaces to provide a pleasant microclimate which provides the potential to enhance the physiological comfort of communities [2]. Spray cooling has recently gained significant global attention due to its beneficial economic and ecological characteristics, making it a widely adopted cooling technique. The objective of using it is to decrease the outdoors ambient temperature and provide a more pleasant climate in highly populated areas subjected to high temperatures [3].

Up to this point, mist cooling systems have encountered testing and implementation mostly in hot and arid regions, where the potential to increase the humidity level is not a major issue for attention. Research has shown the positive impact of these systems in enhancing occupant well-being and cooling outdoor and semi-outdoor environments,[4]. Mist cooling is appropriate for outdoor and semi-external situations since the presence of airflow enhances the rate of evaporation and avoids saturation [5]. A fine mist consists of tiny droplets that have a small size but vast surface area. This large surface area allows for a higher cooling rate. In a moist climate, the atomization efficiency is crucial as it decreases the quantity of water used for the same level of cooling, hence limiting the corresponding rise in relative humidity that may negatively impact comfort in the surrounding area [6].

The application of water mists is an effective method for enhancing thermal comfort during hot weather, that can be attributed to two primary factors [7]. Firstly, the temperature is reduced as the water mist droplets capture heat from the surrounding air before undergoing evaporation. Secondly, occupants experience a cooling sensation due to wetting their skin and subsequent evaporation effects due to air movement.

The assessment of the spray system's cooling efficiency has incorporated external as well as internal factors. The water supply pressure of the spray nozzle, the nozzle inclination angle and its type, number of nozzle and nozzle height are internal parameters. Conversely, external environmental factors encompass many elements such as wind speed, solar radiation, ambient temperature, and relative humidity within the designated location as mentioned in a review paper by Meng et al. [7].

According to a study conducted by Japanese researchers and validated during the summer Aichi Expo in 2005 [8] it was determined that the spray system has the capacity to effectively lower the ambient air temperature by a range of 1-2 ℃. This reduction in temperature was seen specifically when the initial air temperature exceeded 30℃ and the relative humidity was below 70%,[8-9].

Huang et al. [3] showed that the temperature decrease, and humidity rise rates vary depending on factors such as pressure, droplet diameter, airflow rate, temperature, and humidity level. Based on these findings, it is strongly suggested to use the spray cooling mechanism (Spray column provided by nozzle) when the nozzle pressure is around 3 MPa. It is suggested to use a suitable nozzle size and spray pressure to decrease droplet size, as it is preferable for the droplet size to remain below 40 μm.

Zheng et al. [10] conducted a study using double-flow pneumatic misting nozzles. The researchers observed that there exists an optimal distance downstream from the nozzle, at which maximum cooling occurs. This optimal distance was determined to be 2 meters downstream from the nozzle. Additionally, it proved that the water temperature has a limited impact on this system. Consequently, there is no need for extra energy to be used to decrease the water temperature before utilization.

Oh et al. [5] in their study, discovered that the addition of a mist system with a higher volume of spraying water resulted in a drop in the air temperature inside the mist-spraying environment, notably by -2.9 degrees. Furthermore, the presence of an air-blowing fan led to a further reduction in air temperature, with a decrease of -3.6 degrees while the mist water droplet size was adjusted to a range of 9–11 μm.

Zhang et al. [11] confirmed that the mist spray system in the urban transportation waiting areas caused a noticeable reduction in air temperature, but it also led to a quite increase in relative humidity. While the maximum and average relative humidity increased by 15.5% and 9.4%, respectively, the maximum and average air temperature declined by approximately 4.67℃ and 2.67℃, respectively. The mist spray system's acceptance rating was 74%, indicating that it might be extensively deployed to enhance summertime thermal comfort in urban transport waiting areas.

As well, Farnham et al. [12] combined sprays and fans to decrease the cooling load in outdoor spaces. The combination of the two was found to rapidly reduce air temperature by 1–2℃ , and the wet skin sensation caused by the spray seemed satisfying. Even in relatively humid environments, the mist fan system was able to effectively reduce thermal discomfort. Another study carried out by Farnham et al [13] compared between three hydraulic nozzles operating at two pressures. A nozzle was linked to a high-pressure water pump in each experiment, which supplied either 0.7MPa or 5.5MPa. The results showed that a spray nozzle with a sauter mean droplet diameter of 41 μm could effectively reduce the air temperature by 0.7K without causing wetting. Due to the wet bulb effect on the sensors, the cooling effects of mists with larger droplet diameters induced significant wetting resulting in inaccurate humidity measurements.

Wong and Chong [14] employed a spray system integrated with a fan within an environment characterized by elevated temperatures and humidity levels in Singapore. They proceeded to collect biological samples in containers with the aim of analyzing the development rate of legionella bacteria. The results of the study confirmed that this combination could decrease the air temperature by a range of 1.38 to 1.57℃ and simultaneously raise the relative humidity by a range of 8.61% to 10.38%. However, an elevation in relative humidity has the potential to allow for bacterial and fungal contamination.

The objective of this study is to perform an experimental investigation of the effects of evaporative cooling in semi-outdoor areas to gain more information and verify the effect of semi-outdoor evaporative cooling using a pedestal fan supported with different types of water spraying. It is also intended to map the frontal area of the fan to identify the suitable area for people to sit with a maximum decrease in temperature and achieve the best thermal comfort.

2. Methodology

2.1 Experimental Setup.

In this study, a large size pedestal fan was used to carry out experiments in a semi-open area. The field experiment was conducted in a large passage inside Benha Faculty of Engineering. The space is semi-enclosed, bounded by walls, a roof, and a floor. However, it is exposed to open ends and large windows as shown in Fig.1.

The 0.66 m diameter fan is used in this study. This fan was designed to use a rotating disc of 0.3 m diameter (called a misting plate) in its center. As the water supplied by a submergible pump fixed inside a water tank is delivered to the back of rotating plate, it is centrifugally pushed out radially through multi small passages. As a result, small water droplets are sprayed into the airstream. This action causes the droplets to evaporate as they are carried away by the airstream. The fan centerline was about 1.8 m above the floor.

The fan is capable of rotating at three different speeds, the highest speed of 1350 RPM was found to be the most suitable for producing a high-volume flow rate of air leading to further enhancement of the evaporation process.

The fan airflow was used to spread the effect of air cooling by pushing the water droplets away and enhancing the evaporation of water droplets. The fan could push air to 6 m downstream, but the value of velocity was decreased with increasing axial distance (x) and radial distance (r). The fan was fixed in position during the experiments.

The water spray cooling was carried out by two different methods, the first was by using the misting plate equipped with the fan which forces relatively large water droplets centrifugally into the airstream. The second method was a water mist spray system consisting of a medium-pressure