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Thermal environment assessment around bodies of water in urban canyons: A scale model study

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ABSTRACT

Bodies of water in urban areas are regarded as potential tools for urban thermal environment amelioration, but research interest and planning recommendations remain limited. In this experimental study, by using an outdoor scale model, the influence of various configurations of bodies of water (in the form of artificial ponds) on the urban thermal environment was assessed, with particular emphasis on pedestrian comfort. The results of the first experiment conducted in this study indicate that the thermal environment inside an urban canyon with a pond is better than that without a pond, particularly during the day. Lower air temperatures were also recorded downwind from the pond. However, this effect is accompanied by an increase in the absolute humidity, which may negatively influence pedestrian comfort. Thus, effective pond design is necessary. The results of the second experiment show that ponds in different configurations have different effects on the surrounding thermal environment. Generally, configurations with a larger surface area showed a greater cooling effect, and the mean radiant temperature and physiological equivalent temperature were found to be optimized with ponds oriented parallel to the prevailing winds.

1. Introduction

The microclimate in urban canyons is different from that in rural areas, mainly as a result of differences in the canyon surface properties. This shared space between buildings and the urban canopy can affect the nearby outdoor and indoor microclimates, pedestrian thermal comfort, and the energy consumption of urban buildings. A lack of surface moisture and vegetation for evaporative cooling in urban canyons may lead to many urban problems, such as urban heat islands (UHIs), and negatively impact the well-being of the urban population. Thus, to improve the quality of urban spaces, proper design is as important as understanding the microclimate benefits of urban elements.

Urban climate researchers have proposed various sustainable urban development methods and concepts that encourage the inclusion of energy-efficient buildings and pleasant outdoor spaces by designing for temperature, humidity, and solar radiation (Gaitani et al., 2014; Ren, Lau, Yiu, & Ng, 2013;Wong, Jusuf, & Tan, 2011). These quantitative climate indices provide valuable information to planners and designers, enabling them to propose designs geared toward better urban living and a healthier environment. Therefore, the arrangement and orientation of urban elements and landscaping are important considerations regarding the mitigation of the adverse effects of UHIs and the provision of better urban pedestrian comfort.

Given this context, UHI adaptation and mitigation strategies related to water show promise in improving the quality of the outdoor thermal environment and pedestrian comfort. Such strategies include pavement and vegetation watering (Daniel, Lemonsu, & Vigue, 2016), evaporative cooling by water spray systems (Montazeri, Toparlar, Blocken, & Hensen, 2017), and the introduction of bodies of water (Martins et al., 2016). Such water features have the ability to regulate the microclimate and assist in cooling down the air mainly through evaporation (Oke, 1987). Evaporation alters the energy balance; increases latent heat Q_h; and affects the partitioning of energy between sensible heat Q_e and stored energy Q_s, where the reduction of Q_e and the magnitude of Q_s result in an immediate decrease in the surrounding air temperature (Fritschen & van Bavel, 1963; Pearlmutter, Kruger, & Berliner, 2009). Furthermore, bodies of water (e.g., lakes, urban rivers, and ponds) are used for mitigation because of their high thermal capacity, which makes them efficient heat sinks. However, this process depends on the availability of thermal energy and other climate

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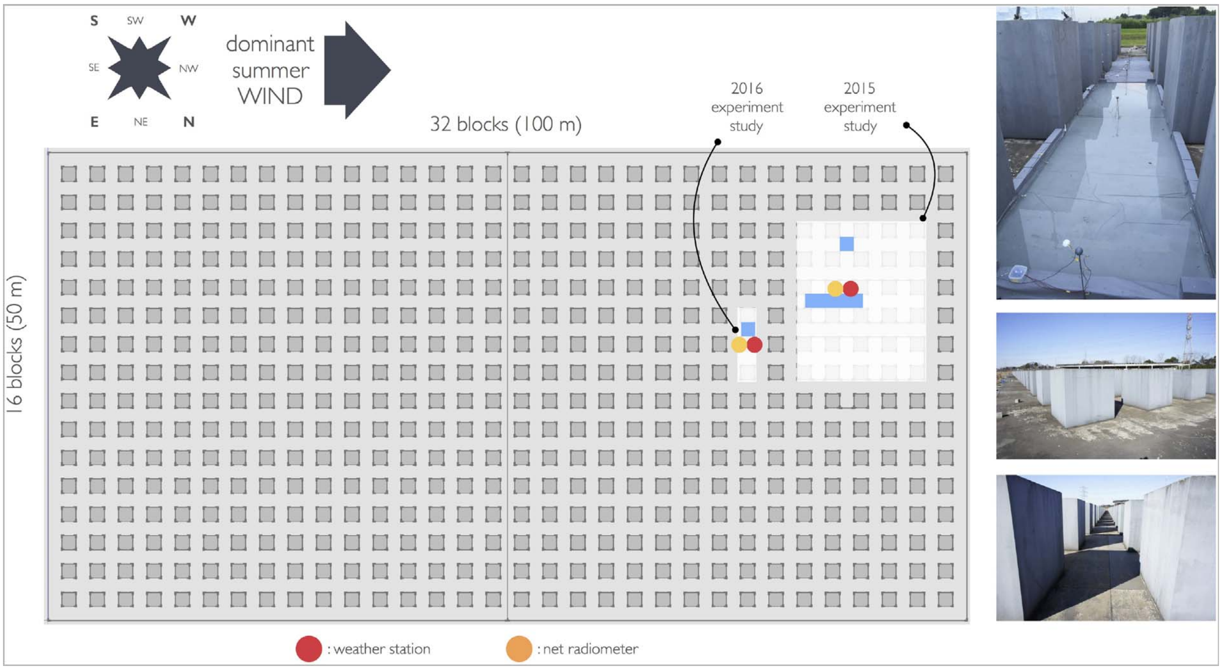

Fig. 1. COSMO and the footage of the measurement.

parameters (i.e., air temperature, wind speed, and humidity), as well as the physical properties of the bodies of water, (i.e., their surface area, shape, depth, and water quality) (Gianniou & Antonopoulos, 2008). These distinct characteristics make bodies of water optimal absorbers of radiation while having very little thermal response (Oke, 1987).

In a number of previous studies, the microclimates around bodies of water have been found to have lower air temperatures than the surrounding urbanized areas. Katayama et al. (1990–1991) have documented a 1–3 °C difference in air temperature between the river and the city during the warmer season in Japan. Similarly, observations made by Hathway and Sharples (2012) have demonstrated the cooling effect of a small river in the Sheffield, United Kingdom, with an average temperature difference of nearly 1 °C during hot weather conditions. In Fukuoka, Japan, Ishii et al. (1991) found that a large pond had a 3 °C cooling effect that extended up to 400 m from the pond. Furthermore, because of limited space in cities, even small bodies of water can have a horizontal cooling effect. Chen et al. (2006) have found an average air temperature reduction of 1.3 °C near a small lake in Guangzhou, China. Saaroni and Ziv (2003) have also found an air temperature reduction resulting from a pond within a park; with the addition of spray and waterfalls in the same location, Nishimura et al. (1998) have demonstrated further temperature reduction. Likewise, in the tropical climate of Singapore, Jusuf et al. (2009) have observed that bodies of water with added water walls are able to reduce the air temperature by up to 1.8 °C on a typical hot day. A study by Robitu et al. (2004) has also shown that even a 4 m^2 pond is able to reduce the surrounding air temperature. However, within urban areas, the climatic effectiveness of a body of water seems to depend on the speed and direction of the prevailing wind, as well as the surface area of the water. The wind carries cooler air from above the body of water and extends the temperature reduction downwind (Jusuf, Wong, & Syafii, 2009; Kim et al., 2008). Hathway and Sharples (2012), Murakawa et al. (1991), and Han et al. (2011) have argued the importance of open space close to a river for better distribution of the cooling effect, as compared with narrow streets or enclosed spaces. Furthermore, Theeuwes et al. (2013) have observed that a larger lake has a greater affect within the city with respect to the wind direction, whereas equally distributed smaller lakes influence larger portions of the city.

Although all of these studies have demonstrated the usefulness of bodies of water in the attenuation of air temperature, researchers have limited knowledge of how different parameters influence the cooling effect. Further investigation is needed to advance the current understanding of these parameters, which may be useful for planners and designers. However, conducting such studies in real urban settings comes with a number of challenges because of the heterogeneity and complexities of the relevant building and road surface materials, making it difficult to isolate the individual effects of each influential parameter (e.g., shape, surface area, position, and configuration).

In this study, an outdoor scale model was used to quantitatively demonstrate the spatial and temporal effects of evaporative cooling from a typical body of water in the form of a pond within an urban canyon. With the scale model, comprehensive measurements can be conducted through parametric measurement studies. Provided that the radiation, air flow, and thermal inertia conditions are sufficiently similar, this approach provides an effective alternative for studying urban microclimates and helps to bridge the gap between on-site field measurements and numerical studies (Kanda, Kawai, Narita, Hagishima, & Moriwaki, 2006; Park, Hagishima, Tanimoto, & Narita, 2012). Therefore, the main purpose of this study was to demonstrate the importance and potential of the quantitative analysis of bodies of water in urban canyons as a promising strategy of increasing pedestrian comfort. The present study uses two approaches while focusing on the same study area: (a) an experimental study on air temperature reduction through pond modification, and (b) a pedestrian comfort evaluation based on microclimate measurements. The results may provide information on the effect of urban bodies of water that would be of great value to designers and planners and provide beneficial guidance for future development.

2. Methodology

2.1. Outdoor scale model: COSMO

To clarify the mitigating effects of bodies of water on the thermal environment and evaluate the factors most affecting pedestrian comfort inside an urban canyon, an experimental study was conducted with various configurations of bodies of water installed inside an outdoor scale model called the Comprehensive Outdoor Scale Model (COSMO).

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