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Investigation of passive design strategies in a traditional urban neighborhood: A case study

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ABSTRACT

Traditional urban neighborhoods are studied to explore the architectural elements that could moderate outdoor thermal conditions. The current study evaluates the role of open spaces and alleys in an urban neighborhood quantitatively by the application of CFD simulation. The study selects a traditional context in Iran to find out how the design of urban context in the close proximity to the sea breeze leads the wind velocity through a city texture. Numerical analysis is established to analyze air velocity and air pressure in different heights and points within a neighborhood. The results show that the air ratio at the open spaces and alley's entrances and exits is higher than that in other locations. The cross-sectional analysis confirms that the air velocity at the exit points' increases up to 7.5 m/s at the height of 1.2 m from the ground. The figure increases up to 8.9 m/s at the height of 10 m from the ground where the surface roughness is in the minimum amount. Finally, the analysis of air pressure ascertains that wind velocity in the neighborhood is wind-driven where the high air pressure at the windward side near the sea shore causes wind velocity to flow in the neighborhood.

1. Introduction

The outdoor thermal comfort has been affected by the urban heat island phenomenon and global climate change. Wind speed, ambient air temperature, solar radiation, air quality, relative humidity, age, clothing levels are some important factors which, impact on the outdoor thermal comfort (Villadiego and Velay-Dabat, 2014). In particular, air movement is the most significant factor because it affects the outdoor thermal comfort and the residents' satisfaction in an urban area directly. Thus, the air flow pattern and speed should be analyzed concisely during an urban renewal to achieve a successful design. It can be declared that the urban development is not limited to the social, economic, and political issues, but also microclimate studies, including wind pattern and speed play an important role on design of new urban texture (Peng et al., 2015). Natural ventilation in an urban context could enhance comfort level and reduce energy consumption in a large scale. It has major impact on building energy whereas ventilation plays an important role in designing of building systems (Santamouris, 2005).

Various studies have been investigated to examine how wind velocity can be used effectively by the establishment of the architectural and urban elements. In the United Arab Emirates (UAE), Al-Sallal and Al-Rais (2012) studied passive cooling performance in the modern urban contexts with the hot humid climate using Computational Fluid Dynamics (CFD) simulation. The result showed

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that the wind flow funneled more rigorously between the building blocks and distributed in the street canyons effectively. The circulation of wind flow at the building corners creates some vortices that could affect the outdoor thermal comfort at the pedestrian level. Based on the results, increase or decrease of wind velocity rely on the street width and building geometry. Also, it is clear that in the wider street canyons, the wind flow pattern is laminar due to the less impact of obstacles and buildings. Finally, the study reveals that a street canyon with the aspect ratio of 1.75 could significantly improve thermal comfort conditions in the UAE.

In another study by Llaguno-Munitxa et al. (2017), the role of building geometry, including roof types on the mean wind flow in the street canyons is investigated. The study conducted a test under the neutral and stable conditions to evaluate the effect of various types of roofs such as flat roof, pitched roof and round roof on the air flow pattern. The results showed that architectural features play a decisive role on the airflow and turbulence statistics of the urban street canyon. Moreover, the results from the physical and numerical experiments show that geometric features of the buildings could affect in-canyon vortex dynamics and over-canopy flow conditions. Also, shear layer depth, roof types, including pitched and round roof geometries increase in-canyon mean and turbulent velocities.

A study by Liu et al. (2015) ascertains that ventilation and pollutant removal can be dominated by turbulent transport processes. Turbulent air exchange rate is proportional to the square root of the friction factor and aerodynamic resistance can serve as an estimate to urban ventilation efficiency. In another study, the effect of ventilation on pedestrians' thermal comfort in the coastal regions with the warm and humid climate is evaluated and According to the outcomes, wind speed is slower at the pedestrian level compared with the points on the high levels. Thus, it is significant that the urban control legislation be established at a level of a setback on all floors. This arrangement can promote the efficient ventilation levels, and consequently, it helps to mitigate local thermal discomfort (da Silva and de Alvarez, 2015). Apart from the building geometries and their influences on wind velocity and outdoor thermal comfort, there are some effective strategies that have been examined to provide thermal satisfaction. In a study in Australia, it is found that using irrigation is a good strategy for the temperature mitigation during summer. It can reduce air temperature during heat waves. However, over 20 $L\,m^{-2}\,d^{-1}$ cooling by the application of irrigation becomes less effective (Broadbent et al., 2017). In another study, outdoor thermal comfort in an urban street surrounded by high-rise commercial buildings is investigated in the central business district of Singapore. The study indicates that shading provided by the high aspect ratios can improve outdoor thermal comfort in urban streets. Finally, the study suggests that the ratio of height to width should be equal to 3 as a threshold in order to achieve comfortable outdoor environment (Yang et al., 2015).

Ground coverage ratio (λp) is the most important factor for sufficient ventilation in the urban scale. In a homogeneous building height, a power regression between velocity ratios and aspect ratios of parallel street canyons can be derived. In low-density urban area, inhomogeneous building heights give worse ventilation performance compared to homogeneous buildings. On the contrary, in high-density urban context, inhomogeneous building heights result in better ventilation performance than homogeneous buildings (Wang et al., 2017). Ikegaya et al. (2016) investigated turbulent flow generated by buildings and surrounding conditions affect the mean and fluctuating ventilation rates. The results showed that short-term ventilation rates are found to vary temporally and spatially. These values instantaneously become larger or smaller than the mean ventilation rates. Complex fluctuation patterns of a pressure coefficient distribution are found to be caused by air flow introduction from the block arrays into gaps between the blocks as well as by small-scale turbulence generated by surrounding buildings themselves.

The microclimate in urban street canyons is characterized by surface temperature difference, wind speed, pollutant concentration, high noise level (Ali-Toudert and Mayer, 2007; Anupriya, 2016). Insufficient ventilation rates and excessive penetration of outdoor pollutants are two important factors involved in naturally ventilated urban buildings (Ai and Mak, 2015). For canyons with a smaller sky view, the orientation is also decisive: E–W canyons provide the inconvenient environmental condition. Thus, it is suggested that to avoid this orientation for the provision of better outdoor thermal conditions. As an alternative, shading through overhanging facades or vegetation decreases the area of thermal discomfort when there is a need for the *E*-W urban canyons (Ali-Toudert and Mayer, 2007). Street canyons are also investigated by using simulation (ENVI-met software) through a study by Chatzidimitriou and Axarli (2017) in Thessaloniki. The results show that street canyon geometry affect microclimate and comfort conditions. Furthermore, comfortable conditions in summer occur in N-S oriented canyons of a medium or high aspect ratio while E-W oriented canyons need improvements such as additional shading on the exposed north side. Also, deepest streets are the most comfortable canyons. These streets were more comfortable than wide ones in summer, especially in the afternoon time. However, there is no differences are observed at nighttime when there are no solar radiation (Achour-Younsi and Kharrat, 2016).

Mean outdoor distance, site coverage, directionality and complexity are the most influential for the solar performance of open spaces. Urban layout is a key parameter in modifying solar availability in real urban forms and solar availability on ground and facades is importantly affected by urban layout. Also, urban layout and solar availability relationship varies with solar altitude angles (Chatzipoulka et al., 2016). Jamei et al. (2016) studied the effect of the most promising strategies on urban geometry and urban greenery on the pedestrian level thermal comfort. The results showed that the distribution and arrangement of the buildings in a city affect the formation of heat island and thermal comfort because it defines the level of exposure to the sun and wind flow intensity. Pedestrian level urban greening such as street trees and city parks cool the environments, especially at a local scale.

A study by Chatzidimitriou and Yannas (2015) indicated pavement with high albedo materials reduces surface temperatures and increases globe temperatures. Furthermore, the results showed that shadings provided by landscape and greenery have great impacts on microclimate and pedestrian thermal comfort. A study in Malaysia showed that high shading level in outdoor environments extends the continuity of the acceptable thermal condition during the day (Makaremi et al., 2012). Yang and Lin (2016) investigated outdoor spaces design procedure to relieve heat stress in hot and humid regions using ENVI-met software. Results revealed that planting trees is the most effective technique for reducing the physiological equivalent temperature (PET) by up to 15.2 °C. Moreover, proper design of outdoor spaces can reduce the frequency of heat stress from 79.7% to 40.5% compared with the original condition.