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The influence of height/width ratio on urban heat island in hot-arid climates

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Abstract

Urbanization has a substantial impact on the microclimate of cities. The urban form is composed of urban canyons that are defined by the building's height to street's width ration (H/W ratio) and the orientation of their long-axis. These two descriptors are controlling the absorption and reflection of the solar and emission of the thermal radiation that influence the ambient air temperature to be significantly higher than the rural surroundings (Urban Heat Island effect). Thus, the goal of this study is to investigate the thermal performance of two urban canyons, deep traditional (H/W=2.2) and shallow modern canyons (H/W=0.42) in a hot and arid city of Riyadh, Saudi Arabia. The objective is to determine if the H/W ratio is an influential factor that contributes to the formation of the Urban Heat Island (UHI) phenomenon, which in turn causes an outdoor thermal discomfort in hot-arid climatic zones. Both canyons are oriented approximately NE- SW and bordered by residential buildings. A series of field measurements were conducted over 18 summer days, 13th–30th of July, 2013, to measure the ambient air temperatures inside the canyon and at the roof level and surface temperature of walls, roofs and streets. Results show that the intensity of the UHI increases with the decrease of H/W ratio. The ambient air temperature in the deep and the shallow canyons are warmer than those in the rural surroundings by 5% and 15%, respectively. The significant temperature increase in the shallow canyon is attributed to the high exposure of the canyon's surfaces to the intense solar radiation.

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Keywords: urban form; urban canyon; H/W ratio; urban heat island; hot-arid climate

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1. Introduction

Urban microclimate is influenced by the urban form and its surfaces. Cities are featured with more impervious surfaces and a high concentration of anthropogenic activities, leading to significant increases in the ambient air (T_a) and surface temperatures (T_s) to be higher than the rural surroundings. This is recognized as “Urban Heat Island” phenomenon (UHI) [1], whose magnitude depends primarily upon the size of the city and the local climatic characteristics [2]. It is observed to be at its highest levels in hot-arid regions that are characterized by extreme solar radiation and heat during the summers as well as low relative humidity, contributing to an outdoor thermal discomfort. The urban microclimate is established in the urban canopy layer (UCL), extending from the ground to the buildings’ height, due to its high level of heterogeneity [3], and each urban form establishes its own microclimate [4]. An urban form consists of urban canyons, defined as linear spaces enclosed by buildings on both sides. They are characterized by three main descriptors that have been proven to have a substantial impact on the microclimate: building’s height to the street’s width ratio (H/W), the canyon’s axis orientation, and the Sky View Factor (SVF) [3]. The H/W ratio, or the aspect ratio, has been found to correlate significantly and directly with the UHI effect. With the orientation, it controls the amount of the direct and diffuse solar radiation to penetrate into the canyon.

In hot and arid regions, compact urban form- typically found in old parts of the city- represents a climate-sensitive approach that responds to the intensity of the local climate, contributing to the accomplishment of outdoor and indoor thermal comfort. However, modern urban forms in such climates have been developed based on urban planning regulations that have been imported from moderate and cold climates with no consideration to the extreme local climate. These regulations have led to the formation of dispersed urban forms that are characterized mainly by wide streets and low density of buildings in which the majority of the urban surfaces are vulnerable to the extreme incoming solar radiation and therefore causing outdoor and indoor thermal discomfort. In this regard, the impact of the urban canyon geometry, defined by the H/W ratio and orientation, on microclimate and the outdoor thermal comfort for pedestrians have been evaluated extensively. In a semi-arid city of Constantine, Algeria, seven urban canyons with H/W ratios that range from 1.0 to 6.7 were compared to assess their impact on T_a and ground T_s within urban streets [5]. They found that the T_a variations in the canyons could reach about 3-6 K compared to the surrounding rural environments. In Fez, Morocco, it was found that the compact urban form with very deep canyons has cooling effect during the daytime which enhances the thermal comfort for pedestrians; while the dispersed form creates an extremely uncomfortable environment [6]. In a desert city of EL-Oued, Algeria, it was concluded that the T_s variations between the compared urban canyons are larger compared to the T_a [7]. They reported that there is a significant correlation between the T_s and the street geometry. Additionally in Ghardaia, Algeria, it was stated that the duration of the sun exposure is a function of H/W ratio and orientation [8]. They found that a street in a shallow canyon (H/W ratio = 0.5) is irradiated longer than a street in a relatively deep canyon (H/W = 1.0) by almost 3 hours. Hence, as the H/W ratio increases, the access of the direct solar radiation to the ground surfaces decreases. Finally in Damascus, Syria, it was found that the influence of H/W ratio and orientation on the ground T_s is insignificant when the street is aligned with detached buildings; however, their influence is extremely substantial when the canyon is bordered with attached buildings.

Similar to the previous cases, modern urban form in Saudi Arabia have the same impact on the microclimate, yet there is a lack of investigation. It has been reported that the adoption of modern urban regulations in Saudi Arabia has led to an undesirable microclimate around buildings [9,10]. Hence, the goal of this study is to investigate how the traditional and modern urban geometries perform in terms of thermal quality in the city of Riyadh, Saudi Arabia. The objective is to determine if the H/W ratio is an influential factor that contributes to the formation of the UHI phenomenon, which in turn causes outdoor and indoor thermal discomfort in hot-arid regions.

2. Description of the study areas

Figure 1: Riyadh Location

The investigation was conducted in the city of Riyadh, Saudi Arabia (24.65° N; 46.71° E). Riyadh is situated in a desert region on a large plateau, in the heartland of the Arabian Peninsula (Fig. 1). Its climate is characterized as hot and arid with extremely high solar radiation intensities during the summer, an annual average precipitation rate of around four inches (10cm), and an annual average relative humidity of around 24%. The highest recorded