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Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco

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Abstract

There are few studies on the microclimate and human comfort of urban areas in hot dry climates. This study investigates the influence of urban geometry on outdoor thermal comfort by comparing an extremely deep and a shallow street canyon in Fez, Morocco. Continuous measurements during the hot summer and cool winter seasons show that, by day, the deep canyon was considerably cooler than the shallow one. In summer, the maximum difference was on average 6 K and as great as 10 K during the hottest days. Assessment of thermal comfort using the PET index suggests that, in summer, the deep canyon is fairly comfortable whereas the shallow is extremely uncomfortable. However, during winter, the shallow canyon is the more comfortable as solar access is possible. The results indicate that, in hot dry climates a compact urban design with very deep canyons is preferable. However, if there is a cold season as in Fez, the urban design should include some wider streets or open spaces or both to provide solar access.

Keywords: Urban geometry; Thermal comfort; Microclimate; Urban cool island; Urban heat island; Urban design

1. Introduction

Due to rapid urbanization in developing countries, environmental issues have gained increased attention in cities with tropical climates. As a consequence, the interest in the microclimate around buildings in urban areas has increased because it affects, among other things, outdoor and indoor thermal comfort, energy use for heating and cooling, and the dispersion of air pollution. In the urban environment, a comfortable climate is important for well-being and to attract people to public spaces. The best known characteristic of urban climate is that air temperatures are higher than those in the surrounding rural areas at night. Nocturnal urban heat islands as high as 12 K have been found in dense centres of large cities [1,2]. By day, most studies show small urban–rural differences. Other typical characteristics of the urban climate include lower average wind speeds than outside the city [1].

Urban geometry and thermal properties of urban surfaces have been found to be the two main parameters influencing urban climate [1,3]. The ratio between the height of buildings (H) and the distance between them (W) influences the amount of both incoming and outgoing radiation and also affects wind speeds. The nocturnal heat island has been shown to increase with the H/W ratio since the net outgoing longwave radiation decreases due to reduced sky view factor (SVF). High thermal capacity of urban surface materials also contributes to the nocturnal heat island as a large part of the incoming radiation during the day is stored in such materials and not released until the night [2]. The effect of anthropogenic heat from the heating and cooling of buildings and motor vehicles on urban air temperatures is normally low, although some exceptions in city centres have been reported [3]. Air pollution affects both incoming and outgoing radiation but the

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net effect on air temperatures has usually proved to be small [1,3].

Since urban form and the properties of surface materials have a strong influence on the microclimate around buildings, urban design is a promising area for improving the thermal comfort of outdoor environments. However, urban climate and outdoor thermal comfort are generally given little importance in the planning and design processes [4,5]. Often the urban planning regulations used in hot dry countries, most of which are in the developing world, are imported from temperate climates and are thus poorly adapted to the local climate. Additionally, they may be very inflexible and thereby restrict the possibility of climate-conscious urban design, (e.g. [6–8]). As a consequence, urban areas often become unnecessarily uncomfortable.

In a hot and dry climate, where the diurnal temperature range is large with cool nights, the high daytime temperature during summer is the main problem rather than the nocturnal heat island (even though the latter may reduce the efficiency of night ventilation of buildings in summer). Compact urban forms in hot dry regions—typically found in old city centers—are known to be well adapted to the climate [7,9,10]. There are, however, few studies from hot dry climates on urban microclimate. In the desert city of El-Oued (33 °N) in Algeria, Bourbia and Awbi [11] reported only small daytime differences between urban and rural temperatures although the maximum temperature tended to decrease as the H/W ratio increased. In the hot, but humid, environment of Dhaka (24 °N), Bangladesh, Ahmed [12] found that on average the daily maximum temperatures decreased, by 4.5 K when the H/W ratio increased from 0.3 to 2.8. However, in these studies the H/W ratios were within a limited range and very deep street canyons were not included.

From a thermal comfort point of view, climatic and physical factors other than air temperature are important. In outdoor conditions the radiant exchange of the human body with the environment is of special importance due to exposure to solar radiation, the cold sky-vault, and warm and cool urban surfaces. The other factors influencing thermal comfort—air movements and humidity—vary much more outdoors than indoors. There are, however, few studies into the relationship between urban geometry and thermal comfort in hot dry cities. Pearlmutter et al. [6] compared the energy exchange of the human body within and above an urban canyon with $H/W = 1$ in Dimona (31 °N), Israel. However, this study was restricted to one type of canyon and no comfort index was calculated.

The aim of this paper is to investigate the influence of urban geometry on microclimate and thermal comfort at street level in a hot dry climate. This is done by comparing urban street canyons in two neighbourhoods, one with a compact and the other with a dispersed urban form. The comparison is made in Fez, Morocco, and includes both summer and winter. The study is based on field measurements of air and surface temperatures, air humidity and wind speed. Thermal comfort is assessed by calculating the physiologically equivalent temperature (PET), a comfort index which takes into account all the environmental parameters influencing thermal comfort – temperature, radiation, humidity and wind speed.

2. The city of Fez and the study areas

The city of Fez (33 °58′N, 4 °59′W) is located in the interior of Morocco in a valley situated between the Rif mountains to the north and the Atlas mountains to the south (Fig. 1). The climate (Fig. 2) is characterized by hot and dry summers and cold winters. Diurnal temperature swings are large; the mean range is 17–34 °C in July and 4–15 °C in January. The temperature can, however, rise above 40 °C in the summer, especially when the desert wind, *chergui*, is blowing from the Sahara, and fall below 0 °C in winter. The rainfall maximum is in the winter period whereas the summer period is almost completely dry. The daily hours of bright sunshine varies between about 6 h in December and 11 h in July [13].

Fez was chosen for this study because it consists of two sections with a completely different urban form: the medieval city—the *medina*, hereafter referred to as the old city—and the contemporary city which has its roots in the time of French colonization—*nouvelle ville* or the new city [13–15].

The old city of Fez is extremely compact. The buildings, normally two to four storeys high, are inward looking with a courtyard in the centre. The streets are narrow and cut deep canyons through the city. No

Fig. 1. The location of Fez in northern Morocco.