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Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions

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ABSTRACT

Urban parks have complex surface structure that produces an environment with specific microclimatic qualities. These qualities affect the balance of energy of the human body and are applicable to an individual's thermal perception. They have impacts on using outdoor spaces especially in hot and arid regions. This study investigates users' thermal comfort in an urban park in Cairo, Egypt. The investigation was carried out during the hot and cold months using subjective surveys and field measurements. The campaign consisted of a subjective survey using questions on the perception of the thermal environmental applying seven-point ASHRAE 55 thermal sensation votes (TSV) in nine different zones in the urban park. At each zone, the thermal environment parameters – air temperature, solar radiation, air relative humidity and wind speed were measured. Through these data, the values of the Physiologically Equivalent Temperature (PET) were calculated in each zone using the RayMan model. The current people clothing and metabolic rate were recorded. The results of the field measurements were compared with judgements about the thermal environment. Results demonstrate that differences in the PET index among these zones due to different sky view factors (SVF) and wind speed. Results revealed an alteration in human comfort sensation between different landscape zones. This paper suggests that the thermal requirements of visitors and qualities of the local climate should be carefully considered when designing landscapes for the future urban parks in the hot and arid regions.

1. Introduction

Comfortable and healthy microclimate conditions are necessary for any type of environments. People are exposed to varying types of stress in the urban environment. The most influential one is the microclimatic conditions, which vary significantly from rural areas [1]. The reasons include the adjustment of the surface structure in terms of proportion of the built up area, 3D geometry of the buildings and vegetation [2,3]. These properties affect urban climate phenomena such as the urban heat island (UHI) and the variation in the radiation fluxes. Recent studies revealed that outdoor thermal environment factors, including air temperature, wind speed, relative humidity and solar radiation, affect assessment of thermal comfort, e.g., thermal perception and satisfaction [4].

People are frequently exposed to weather during recreation and leisure in the outdoor spaces. Hence, a comfortable thermal environment is particularly significant to the satisfaction of such spaces. A number of investigations revealed that people thermal assessments of an environment may extensively impact their usage of that place [5–7]. There is evidence that thermal comfort in the outdoor spaces and acceptable thermal range vary from the indoor thermal comfort due to psychological and behavioural factors [6,8–10].

Climatologists and designers have tackled urban climate in different ways, including scaling, relevant variables and objects of study [11]. Several researches reported that the integration of the climate and thermal comfort dimensions from one hand and the design process from the other hand is inadequate because of poor interdisciplinary work. Climatologists are more concerned with the causality of the urban climate, while designers are more interested in the effects of environmental forces on buildings and their impacts on thermal comfort of their users. The urban climatology concentrated first on the urban heat island (UHI) and moved progressively to micro-scales as the urban geometry was found to be decisive in the UHI [12,13]. By contrast, designers focus initially on indoor climate of individual buildings, on design strategies, and on the resulting energy needs for maintaining internal comfort

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[14,15]. Recently, the environmental quality of urban open spaces has become a fundamental subject for both disciplines [9,10,13]. The topic of thermal comfort in outdoor spaces will positively promote more collaboration between both fields. It will link between the complicated results of the urban climatology on one hand, and the more design-oriented outcomes of urban design and landscape architecture on the other hand.

The built environment components influence the outdoor thermal environment. For example, there is evidence that ground surface covering [16], evapotranspiration of vegetation [17] and shading by man-made objects and trees [4] significantly affects the thermal environment. The green areas in cities enhance the urban landscape and control the urban climate by reducing the air temperature and increasing the amount of moisture of the air [17]. Previous studies showed parks have a cooling effect because of the combined impact of shade and evapotranspiration [18]. The cooling effect largely depends on the park size and the distance to the park. Several studies investigated the effects of trees and water in urban settings in temperate climates [17,19], in hot humid climates [10], and in hot arid climates [20–23]. These urban settings comprise a considerable number of "obstacles" such as built structures. Few studies investigated the effects of such landscape elements in open spaces without built structures. No studies investigated the assessment of thermal comfort in public parks in Egypt. This study aims to assess microclimatic and human comfort conditions in various zones within an urban park.

2. Background

2.1. Urban parks and the urban climate

Recent studies of thermal comfort of urban spaces have been reviewed by Bruse [24]. Shashua-Bar and Hoffman [25] investigated urban streets and courtyards with trees. Their results indicated cooling effects of around 4.5 °C by the CTTC model. Bourbia and Awbi [26] found that conditions' variation of the street from East-West orientation may often be a desirable criterion in urban design under low latitudes. Thermal perception and attendance in a public square in a hot and humid region was studied by Lin [10] using both field measurements and a subjective thermal sensation vote (TSV) questionnaire survey. The results showed a considerable effect of psychological and behavioural factors perform significant roles besides the human energy balance model in outdoor thermal comfort. Kruger et al. [27] reported the significance of Sky View Factor (SVF) in urban climate. The SVF is an indicator of the amount of visible sky at a given point. The value of SVF ranges from 0 (zero) to 1, with a value of 1 representing an area without any obstacle between the selected position and the sky. Lin et al. [4] investigated shading effect on long-term thermal comfort in outdoor spaces of a university campus in a hot and humid environment using Physiologically Equivalent Temperature (PET) thermal index. They found that the SVF created by buildings and vegetation had a significant impact on users' perception of thermal comfort.

2.1.1. The effect of trees

Urban planning theories state that every urban planning neighbourhood should have a public green and vegetated area [22], since they play important role in enhancing the quality of air in the urban environments. Previous research established that urban trees integrated with the fabric act as cooling elements [28]. Matsuoka and Kaplan investigated people's requirements in the urban landscape. They showed that people tend to request connection with nature, aesthetic experience, entertainment and play, green colours in terms of green areas of trees [29]. In this respect, the vegetation is a modifying factor in the local climate. It is considered a significant element of design in enhancing urban microclimate and outdoor thermal comfort in urban spaces [30]. However, vegetation is typically used in the urban spaces for aesthetic, utility and recreational purposes.

The use of the green as a strategy to moderate the urban heat island (UHI) and improve the microclimate has been widely emphasized [31,32]. For the hot and arid climates, the best use of the vegetation should take advantage from its shading aspect to reduce the intense solar radiation in the summer as the overheating is mainly due to the heat storage by the sunlit surfaces. Unless regular irrigation is supplied, the evapotranspiration is often weak owing to the lacking water in the soil. Sparser vegetation well mixed within the urban structure to produce a sufficient shadow should be recommended in hot and dry climates [33].

Individual trees arranged in large intervals, as the typical case on an urban street, do not have a significant cooling effect. Therefore, some studies suggested that employing smaller groups of trees is more efficient for urban sites [20,34]. Trees can be placed in various zones such as in rows along the sidewalks, in parking areas, at street intersections and in urban parks in a compact urban environment.

Trees make visual amenities and stimulate the environment by increasing the green colour within the built environment [6]. Urban parks are usually spaces with high concentration of vegetation elements consisting primarily of trees. These parks could enhance outdoor spaces in terms of place making, scale, proportions, variety to urban arrangements and its geometric features [35]. Additionally, several studies reported the benefits of urban parks and their contribution on urban microclimate [13,22,36,37]. Despite the significant impact of urban parks on urban microclimate, few studies investigated the climatic impact on the design of urban parks in hot and arid regions.

The effect of street vegetation and urban parks on climatic conditions in hot arid environment received substantial attention in the last two decades. Shashua-Bar and Hoffman [2] investigated the street geometry and orientation aspects in passive cooling of canyon streets in hot arid climate. They found that the geometry and orientation affect ground shading and SVF. The effect of trees on microclimate in daytime is an outcome of the reduced penetration of solar radiation at the ground and walls due to the partial shaded areas. Thermal effects of trees on the urban canopy layer (UCL) microclimate in hot environments were further investigated by Shashua-Bar et al. [20]. They found that the impact of trees on the thermal effect can be explained by linear relationship. They provided a general design tool to thermal effects of vegetation in streets and courtyards.

Bourbia and Boucheriba [23] studied the effect of design of streets and vegetation on urban microclimate in an arid region in Constantine, Algeria. They showed that SVF and orientation of streets influence the absorption and emission of the incoming solar and the outgoing long wave radiation. This factor has a major effect on the variation of temperature within the street and the adjacent environment. Lin et al. [4] investigated the effect of shading on long-term outdoor comfort in hot climate in Taiwan. They found that adequate shading should be provided by trees and structures to enhance thermal comfort in summer in hot climate. Fahmy and Sharples [22] investigated the impact of urban fabric form and its urban green structure on the passive thermal comfort system in hot and arid urban environments in Cairo, Egypt. They revealed that there is a cooling capacity for some orientations and levels of urban density. This is due to the compact form and green cool islands and flow of wind through main street canyons. In a later study, Fahmy et al. [33] investigated the "leaf area index" (LAI) based thermal performance in Cairo, Egypt. Their results revealed that using some