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The impact of vegetation on urban microclimate to counterbalance built density in a subtropical changing climate

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A B S T R A C T

The purpose of this research is to assess the microscale cooling effects of vegetation in urban environment, especially during daytime, to counterbalance urban warming effects resulting from an increase in built density in a subtropical climate. Considering that Brazil's climate will be warmer in the coming decades, the paper presents a brief review of planning with high-density and urban greening, having in mind that even low-density land use can contribute to urban heating, depending on the urban occupation pattern. In high-density cities, the most important vegetation effect is to prevent heating in urban canyons, decreasing solar radiation absorption by shading and evapotranspiration. Parametric studies exploring different scenarios of high-density urban blocks and greening have been carried out to investigate different distributions of dense trees to ameliorate urban microclimate using ENVI-met V4 Preview I, previously calibrated with field measurements of local climate and vegetation data. Aiming to benefit urban activities, air, surface and mean radiant temperatures at the pedestrian level are compared among different greening strategies and built densities' scenarios. Based on the results, two outdoor comfort indexes TEP –Temperature of Equivalent Perception and PET – Physiological Equivalent Temperature were applied to verify the contribution of vegetation to better comfort conditions.

1. Introduction

Brazil has recently constituted the Brazilian Panel on Climate Change (PBMC), compiling national studies related to climate change. According to PBMC, Brazil's climate will be warmer in the coming decades, with gradual and variable average temperature increase in all regions between 1 °C and 6 °C by 2100, compared to that recorded at the end of the 20th century (PBMC, 2013a, 2013b, 2013c). Brazil has its own voluntary commitments for emission reductions, as part of the National Politics for Climate Change, but adaptation measures for urban areas are still missing in many ways. Land use as climate change mitigation, especially in urban areas, is underexplored. We need more resilient cities and adaptation is crucial.

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1.1. The urban climate and the coupling of global and local effects

Concerning the coupling of global and local warming effects, cities do not cause heat waves, but they amplify them. Because of the greater prevalence of mineral-based building materials, cities absorb and retain substantially more heat than rural areas characterized by more vegetative cover. Because of that the main reason for city warming is not the global warming itself, but the replacement of the vegetation for hard surfaces and the anthropogenic emissions (Stone, 2012).

One of the climate related land use implications is the urban heat island (UHI), which is more diverse than originally suspected (Arnfield, 2003). On the surface UHI is easy to understand and to visualize the results of urbanization. However, UHI is a multi-faceted phenomenon whose proper definition and physical basis is more complex. Proper understanding of the definition and types, dynamics and underlying physical processes of the UHI, however, is key to formulating mitigation measures (Roth, 2013). Besides differences based on the medium sensed (air, surface, even subsurface) and the sensing system employed (Arnfield, 2003), there is growing evidence supporting the existence of phase and amplitude departures in the UHI in tropical cities, in comparison with mid-latitude cities (Marques et al., 2009; Chow and Roth, 2006). The UHI in tropical and subtropical cities is less intense than in higher latitude cities, and it is more pronounced during daytime and strongly regulated by the moisture content of the atmosphere and soil in adjacent rural regions (Roth, 2007). As well as in other tropical and subtropical climates, according to Ferreira et al. (2012), the UHI in the city of Sao Paulo has a daytime character, with a maximum intensity during afternoon (14:00–16:00 LT) and a minimum during morning time (07:00–08:00 LT) in almost all months monitored in 2004. The maximum UHI intensity varied from 2.6 °C in July (16:00 LT) to 5.5 °C in September (15:00 LT).

1.2. The role of density

Cities differ from their rural surroundings in a multitude of ways, many of them directly related to the surface energy balance and the formation of UHIs. Urban form is affected first and foremost by building dimensions and spacing, but also the characteristics of artificial surfaces and by the amount of green space (Erell et al., 2011).

For several reasons, one of the current needs of urban settlements is a higher urban density, a topic that still causes some debate, but from mobility and urban climate points of view, low-density areas can be even worse. According to Stone (2012) areas of low population density may still effect a significant influence on heat-island formation if they have extensive infrastructure development.

The presence of a dense matrix of buildings promotes the creation of UHIs through a variety of processes, for example, the trapping of solar energy due to multiple reflection and absorption within canyons, the restricted sky view factor of deep and/or narrow canyons and reduction of wind speeds near the ground (Erell et al., 2011). The urban climatic issues of heat, humidity, lack of daylight, solar access and urban ventilation is of topical concern to urban planners and governments; the need for appropriate designs for high-density cities is clear (Ng, 2010).

Urbanization and higher-density living is an irreversible path of human development. Higher-density living will continue to be developed and will soon be the norm. The environmental dimensions of high-density cities, especially in tropical and subtropical climatic zones, are decisive. Buildings are fighting each other for natural light and ventilation. For Ng (2010) the provision of light and air can be difficult; a paradigm shift is required, new tools are needed, but high-density living is a definite possibility, although it is not an easy path. To increase ventilation, height variation should be considered as much as possible; the stepped height concept can help to optimize the wind-capturing potential as well as the view of sky component for daylight availability. Designed properly, the strategy of tall and thin building forms has a better chance to capture daylight. Given the same building bulk, on average, daylight availability to windows can improve by some 40 per cent (Ng and Wong, 2005).

1.3. The role of green

Planted areas in a city tend to reduce daytime maximum temperatures, reducing radiant exchange at the ground surface. The effect of vegetation on the atmospheric heat island is manifested not only indirectly, in the form of a reduction of sensible heat flux from the cooler surface, but also directly in the form of evaporative cooling. Most field studies support the argument that a lack of vegetation in the city would tend to result in elevated daytime air temperature, and concomitantly, that a large-scale planting campaign may lead to a reduction of the daytime urban heat island (Erell et al., 2011).

According to Wong and Chen (2010), in a built environment the UHI effect can be described as a conflict between buildings and the urban climate, and considering the positive impact of plants upon the conflict, a conceptual model was posed by the authors to understand the interactions among the three critical components in the built environment: climate, buildings and plants. In order to uncover the benefits of greenery in a built environment, the microclimatic effects should be quantified. There are some possibilities to reduce ambient air temperature with plants: urban parks, road trees, landscape within the vicinity of buildings and rooftop gardens. In addition, the surface temperatures could be reduced with rooftop gardens or vertical landscaping.

In high-density cities, land is scarce and there is little provision of space for the incorporation of urban greenery such as urban parks and landscaping. The integration of greenery in buildings also faces many constrains (Wong and Chen, 2010), in spite of some cases of success, like in Singapore, with the adoption of Green Plot Ratio by the local legislation (Ong, 2002).