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Radiative and heat storage properties of the urban fabric derived from analysis of surface forms

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A B S T R A C T

Radiative balance and heat storage capacity modifications play a major role in urban heat island formation. Urban shape determines the receipt and loss of radiation and consequently the heat storage potential, thus resulting in a higher air temperature.

In order to analyze the interactions between climate and urban shape, the territory is partitioned from the road network into elementary areas: the city blocks.

Nine geographical and two climatic indicators are computed at city block scale. The geographical ones are produced thanks to OrbisGIS platform from geographical data supplied by the French IGN. The first climatic indicator, the urban albedo, is computed from solar simulations with Solene model on 230 city blocks to characterize the radiative balance. The second one, the air temperature time shift, is calculated from three years of measurements between eight city blocks and a reference sites to characterize the heat storage properties of the urban fabric.

Relationships between those climatic and geographical indicators are investigated using linear regression analysis. Facade density is the geographical indicator which best explains both

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radiative and heat storage properties at city block scale. From the relationships identified previously and geographical data, climatic maps are produced to assess urban vulnerability to climate change.

1. Introduction

The combination of global warming and the Urban Heat Island (UHI) makes cities and the urban population particularly vulnerable to climate change and necessitates different adaptation measures. Usually, adaptation strategies assessment is based on a modeling approach of the interactions between local climate and urban environment (Masson et al., 2014). Several models are available and require a rather complete set of data: building geometry and their close surroundings, energy consumption practices and a large panel of climatic conditions. Consequently, it is a challenge to transfer climatic knowledge to institutional stakeholders and urban planners. A better understanding of interactions between urban environment and local climate conditions will provide city planning strategies for improving urban thermal environment.

Oke (1987) observed that the UHI spatial structure is strongly related to urban forms. Several others studies identified relationships between urban climate and local geographical indicators, for instance:

- The urban albedo (indicator of the solar radiation balance) of plot configurations decreases with increasing building height (Kondo et al., 2001). Moreover, Groleau and Mestayer (2013) showed that urban albedo values strongly depend on both building and facade density.
- The loss of longwave radiation to the sky as well as the turbulent heat transfers are reduced when the sky view factor decreases (Unger, 2004).
- The Bowen ratio (ratio between sensible heat and latent heat) increases when the percentage of land covered by vegetation decreases (Musy et al., 2012).
- Nighttime air temperature increases with increasing of building density during summer-time (Yan et al., 2014).
- There is a strong linear connection between the areal average of sky view factor and the annual mean UHI intensity (Gal et al., 2009).

Schwarz et al. (2012) showed that radiative balance (solar radiation trapping) and heat storage properties (thermal inertia) modifications play a major role on UHI formation. The net solar radiation give the amount of solar energy introduced into the urban thermodynamic system and partially transformed into sensible heat (Groleau and Mestayer, 2013). Arnfield and Grimmond (1998) demonstrated that the heat storage flux is a significant term in the energy disposition of an urban canyon.

The purpose of this study is to identify the main geographical indicators responsible for the radiative balance and heat storage properties of the urban fabric. Two ascertainments must be made from existing studies. (1) Morphology influence on the net solar radiation balance is mostly investigated on generic simplified geometries and the results are sometimes unobvious to transpose to urban planning. (2) The inertia phenomenon is often calculated as the result of a heat balance but is rarely highlighted through a direct measurement analysis.

In order to analyze the interactions between climate and urban shape, the territory is partitioned from the road network into elementary areas: the city blocks. Nine geographical and two climatic indicators are computed at city block scale. The geographical ones are produced thanks to OrbisGIS platform (Bocher and Petit, 2012) from geographical data supplied by the French IGN.

The first climatic indicator, the urban albedo, is computed from solar simulations with the Solene model on 230 city blocks to characterize the radiative balance. The second one, the air temperature time shift, is calculated from three years of measurements between eight city blocks and a reference