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Development and application of 'thermal radiative power' for urban environmental evaluation

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ABSTRACT

We have developed a new evaluation method of "thermal radiative power" (TRP) for investigating the impact of building surface material albedo on urban environment. The simulation system ENVI-met is used. This system is a 3D computer model which analyzes micro-scale thermal interactions within urban environments. It simulates urban-scale environmental conditions such as roofs, exterior wall, and ground surface temperatures. Focuses of this research are on the climate change in urban and community scale in cold climates. The urban environmental analysis is carried out in a typical residential area in the central city of Montreal. The model for simulation is based on the existing urban conditions (building layout, building volume and ground surface properties). The TRP with varied building roof materials is calculated and compared. The effect of building surface materials on local climate is analyzed. The selected simulation area in this research is 300 m by 300 m. Each urban surface (ground, walls, and roofs) is analyzed individually, in order to determine the urban environmental contribution. The interaction between reflective surfaces is discussed. Representing the environmental conditions by TRP could help to define the impact of urban surfaces on the macro-climate (urban level) and micro-climate (community level).

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1. Introduction

The urban heat island (UHI) effect is the phenomenon that a metropolis is usually significantly warmer than its rural surroundings. It occurs because city center buildings and street surface materials, which have high heat capacities, store heat during the day, and release heat slowly at night. The adverse energy and environmental effects of UHIs, and methods to alleviate them, has become a major research topic in sustainability programs. Decreasing the energy consumption of buildings is an important topic in environmental engineering.

Generally, three main types of UHI are measured and discussed to develop the solution for mitigation, which includes boundary layer heat island, canopy layer heat island, and surface urban heat island (SUHI) (Oke, 1997). In the community scale which is close to the urban surface, surface temperatures have an indirect, but significant influence on air temperatures and urban thermal comfort. Daytime solar energy absorption is the primary cause of the urban heat island effect in summer. Pavements and roofs comprise over 60% of urban surfaces. Dark materials, dark pavements and roofs, absorb 80–90% of sunlight. Lighter materials, white roofs and lighter colored pavements, absorb only 30–65% of sunlight. There is an interaction of thermal radiation between roof, wall and ground surfaces. The use of reflective building surface materials is a critical solution for UHI mitigation (Akbari, Bretz, Kurn, et al., 1997; Berdahl & Bretz, 1994; Bretz & Akbari, 1997; Bretz, Akbari, & Rosenfeld, 1998; Konopacki & Akbari, 2001; Synnefa, Santamouris, & Livada, 2006; Synnefa, Santamouris, & Apostolakis, 2007; Taha, Akbari, Rosenfeld, et al., 1988).

SUHI depending on the definition of surface, and it could be discussed by ground data, bird's-eye 2-D data, and true 3-D data. Currently, the research platforms for thermal remote sensing are based on satellite measurement (2-D data), aircraft scanner (2-D data), and ground based thermometer (ground data). Land surface temperature (LST) that derived from satellite data is the most commonly used index to demonstrate the extent of the SUHI effect in cities (Jin, 2012; Gupta, 2012; Peng, Piao, Ciais, et al., 2011). Advantage of using LST is the extensive spatial coverage could help to investigate SUHI in a macro-scale. However, as a 2-D data, LST has its limitations on spatial resolution and the expression of urban typologies. Observed LST depends on spatial resolution, because of the different land cover types. In most present studies, a spatial

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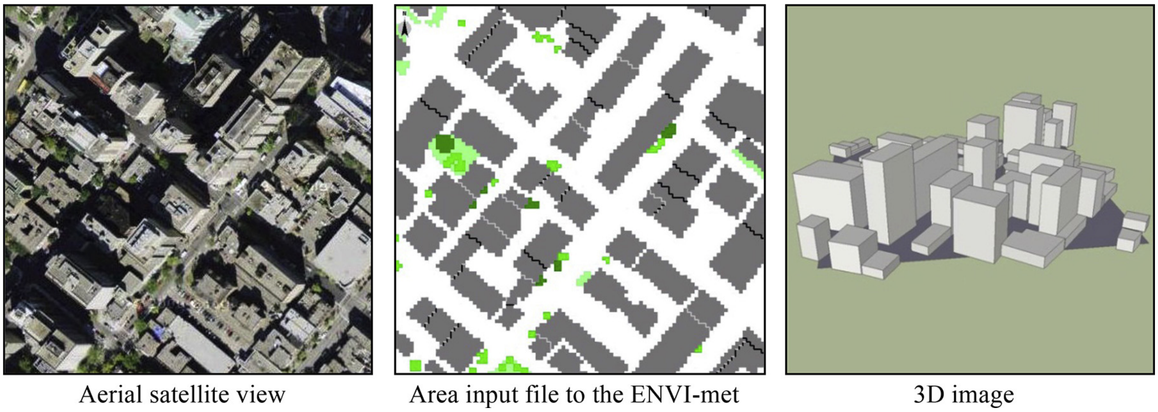

Fig. 1. Images of the selected area: (1) aerial satellite view pictures, (2) input file images for ENVI-met simulations, based on the aerial satellite view pictures, and (3) 3D images of the buildings volumes.

resolution of 1 km^2 is used. This ignores land cover characteristics on a community scale. Furthermore, LST derived from the satellite database ignores the contribution from the surface of exterior building walls. This is a serious deficiency for the consideration of urban solar heat absorption and reflection. This is especially relevant for metropolises that have a high density of high-rise buildings. This research will provide a new evaluation method for assessing the impact of building surface solar reflectance on the UHI effect in 3-D environment. The TRP, released from the urban surfaces, is not used in existing studies, even though it is a suitable indicator to represent the impact of solar heat absorption.

Many researchers have focused on the building surface materials, LST and urban heat island problem. Most studies have analyzed measured climatological data and demonstrated the correlations with urban development (Rao, 2012; Jin, 2012; Gupta, 2012; Peng et al., 2011). Very few have studied the UHI contribution from each environmental effector in micro scale that directly affects the outdoor thermal comfort. In this research, the thermal radiation from urban surfaces (such as building roofs, exterior walls and ground surfaces) will be simulated, using a micro-scale urban simulation model. Both an urban and a community scale will be analyzed. The simulation will be helpful to determine the contributions of each component, and to determine the optimal combination of urban surface properties.

In addition, most present studies are focused on the UHI effect in hot and dry cities. The UHI effect in cold climates, such as Canada cities, should be further investigated. In this research, a new UHI evaluation system is proposed and applied in the city of Montreal. The comparison of different albedo scenarios in terms of air temperature (T_a), human weighted mean radiant temperature ($MRT_{h\text{-}w}$), related humidity, and physiologically equivalent temperature (PET) is carried out to investigate the effect of TRP on ambient environment. The objectives of our study are to: (1) define the new UHI evaluation method TRP, and (2) demonstrate the qualification of the TRP to express the extent of UHI. This research will be an investigation of the methodology for UHI study, which contributes to environmental urban planning standards providing, that can be used in urban developments and redevelopments.

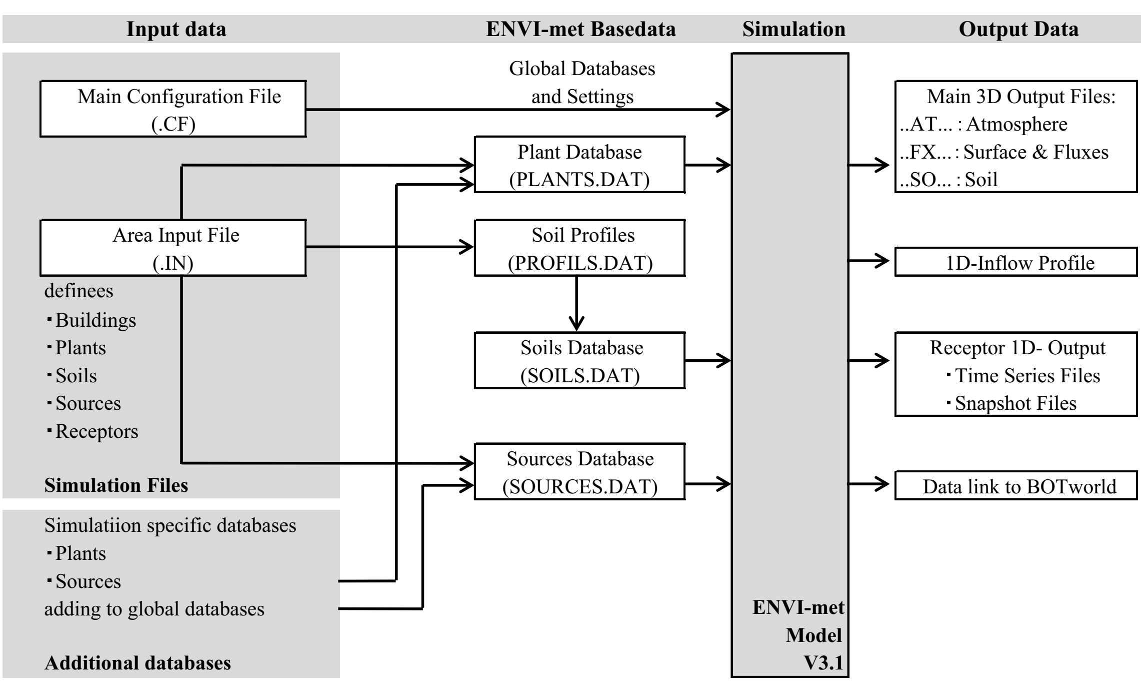

Fig. 2. Data flow in ENVI-met V3.1 (http://www.envi-met.com/).

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