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Is urban albedo or urban green covering more effective for urban microclimate improvement?: A simulation for Osaka

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ABSTRACT

Urban planning, building design and landscaping can all provide strategies for urban heat island mitigation, urban microclimate improvement and directly affect people's living environment and thermal comfort. This study aims to contribute to urban design for a new residential area of 10,000 m^2 area and urban aspect ratio (UAR) of 1.8, which is planned to be built in Osaka, Japan. In order to explore an appropriate design for the planned new residential area via rational building envelope and landscaping designs to better improve the urban microclimate, the effect of urban albedo (UA) and urban green covering (UGC) on the urban microclimate of the planned new residential area in terms of affecting outdoor air temperature and mean radiant temperature was analyzed using the environmental analysis model, ENVI-met. A total of six scenarios with UA of 0.3 and 0.7, UGC of 0%, 20% and 40%, were simulated. It showed that the scenario simulated with low UA of 0.3 and UGC of 20% has the greatest potential in improving urban microclimate of the planned new residential area in Osaka among the six simulated scenarios.

1. Introduction

1.1. The urban heat island phenomenon

The urban heat island (UHI) effect is a well-documented climatic change phenomenon and is becoming very serious especially in the summer period (Santamouris, 2001). The UHI is simply the characteristic warmth of a town or city and is defined on the basis of temperature differences between urban and rural stations. It is due to human modifications of the surface and atmospheric properties which accompany urban development and is probably the best example of inadvertent climatic change (Oke, 1995). UHI intensity in hot climates may raise temperatures by 10 °C (Livada, Santamouris, Niachou, Papanikolaou, & Mihalakakou, 2002), resulting in increased discomfort and higher pollution levels, while it has a serious impact on the cooling energy consumption of buildings (Hassid et al., 2000; Yuan, Emura, & Farnham, 2016).

1.2. Strategies for mitigation of the UHI

In order to mitigate the UHI effect, many studies have focused on defining the relationship between rising temperatures and different urban elements (Ahmed et al., 2014; Gray & Finster, 2000; Giridharan, Laua, Ganesan, & Givoni, 2006). Santamouris, Synnefa, and Karlessi (2011) reviewed many articles relating to the UHI mitigation strategies, and showed that the mitigation strategies such as highly reflective (HR) and emissive light colored materials, cool colored materials, phase change materials (PCMs) and dynamic cool materials used for building roofs or facades, increasing urban albedo (UA), green roofs, etc. can significantly contribute to UHI mitigation and the improvement of urban environmental quality. Also, other studies have focused on the micro-scale showing the influence of urban design on the climate (Idczak, Groleau, Mestayer, & Rosant, 2010; Oliveira Panão, Gonçalves, & Ferrão, 2009). Connors, Galletti, and Chow (2013) showed that the intra-urban variations in temperatures are a significant feature rising from the UHI and largely result from urban elements such as urban structure (e.g. urban aspect ratio (UAR)), urban green covering (UGC) and UA, etc. Doick and Hutchings (2013) showed that vegetation has a key role to play in contributing to the overall temperature regulation of cities. Informed selection and strategic placement of trees and green infrastructure can reduce the UHI and cool the air by

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between 2 °C and 8 °C, reducing heat-related stress and premature human deaths during high-temperature events.

Much research has shown that increasing the proportion of UGC or UA can decrease the urban temperatures, reduce energy consumption of buildings and improve outdoor thermal comfort. Among the strategies of mitigating UHI effect, HR coatings are being researched widely. Doulos, Santamouris, and Livada (2004) selected 93 pavement materials commonly used outdoors to increase the UA for UHI mitigation. Bretz and Akbari (1997) applied HR coatings to residential buildings in California and Florida, contributing to cooling energy savings of 10%–70%. Cozza, Alloisio, Comite, Tanna, and Vicini (2015) produced smart paints applied to building facades for UHI mitigation and energy conservation. A total of five different black colorants produced in laboratory have been mixed with commercial paints and have been compared to the standard black colorant usually used for building paints. It showed that the surface temperature on the back of a painted support is lower as the total solar reflectance is higher, thus can be used for building energy conservation.

HR roofs can reflect solar radiation to the sky if there are no high buildings around it. However, if there are high buildings nearby, part of the reflection will be absorbed by those neighboring buildings. In addition, HR materials applied to vertical surfaces can also reflect onto roads, causing them to become hotter, thus the total effect against the UHI is limited. To solve this problem of HR materials used for vertical outer walls, currently a variety of retro-reflective (RR) materials possibly applied to vertical outer walls which can reflect the incident solar radiation backward to the incoming direction of sunlight, are also being researched by scholars worldwide to mitigate the UHI effect and improve the urban microclimate (Yuan, Emura, Farnham, & Sakai, 2016). An experimental evaluation of RR pavement for UHI mitigation was implemented by Rossi et al. (2016). It showed that a cooling potential of the RR material with a maximum albedo increased of 4.6%. Meng et al. (2016) conducted a comparative experiment and numerical simulation to evaluate the influence of RR coatings on the heat flow, indoor air temperature, outer and inner surface temperature. It showed that the heat flow is reduced by more than 30%, the peak temperatures of both indoor air and inner surface can be reduced up to 8–10 °C and the peak temperature of outer surface can be reduced up to 20 °C, compared to the normal coatings. Strategies of arranging UGC to mitigate UHI effect are also being studied by many researchers. Wang and Akbari (2016) analyzed the environmental effect of street tree planting patterns in a central area in Montreal using a simulation model. It indicated that the correlation between tree cover and urban temperature is about 0.64 at summer mid-night. In the daytime, tree cover could reduce outdoor air temperature by 4 °C at the tree level of 20 m height and 2 °C at the tree level of 60 m height. In addition, Akbari (2002) demonstrated that urban shade trees could offer significant benefits in reducing building air-conditioning demand and improving urban air quality by reducing smog.

Georgescu, Morefield, Bierwagen, and Weaver (2014) showed that it is expected that the near-surface temperatures will be raised 1–2 °C not just at the scale of individual cities but over large regional swaths of the country, in the absence of any adaptive urban design, megapolitan expansion, alone and separate from greenhouse gas-induced forcing. Thus, it is essential to use an appropriate environmental analysis model to assess the influence of proposed strategies of urban design, such as HR building coatings or the other hybrid approaches, on the urban microclimate.

1.3. Background on urban planning in Japan

Japan is often held as the living example of a country at the forefront of problems many other nations expect to face in the future, such as the "aging society". The trend to urbanization is another such case. As the world's population continues to concentrate in cities, passing 54% in 2014 with projections to reach 66% by 2050 (United Nations, 2014), the proportion of the Japanese population living in urban areas has already passed 93% (The World Bank, 2017). Thus, the UHI is an issue that directly affects nearly the entire population of the country. Urban development plans have a direct impact on nearly everyone.

Japan's "aging society" has also seen the population decrease as of 2015 (Statistics Bureau of Japan, 2017), which is one factor in the trend to increasing numbers of vacant dwellings. There has been a shift from the post-World-War-II policy of building large numbers of residences for the increasing population, to a "quality over quantity" focus. Japanese national and city governments have enacted policies that encourage construction of large apartment blocks and complexes in urban centers (Ronald & Druta, 2016). Tall towers made of concrete replace masses of small wooden 1–2 story residences. Without proper planning on the aspect of effects on urban climate, this trend could worsen the UHI.

1.4. Research goal

The goal of the research is to aid in plans for improving the urban thermal environment at street level amongst existing buildings and already-planned developments. In such cases, the option to change the UAR, building locations, street orientation, etc. is restricted. The options of changing the amount of greenery and the albedo of building surfaces, such as by adding HR materials, may still be available. These "fixes" could also be implemented in a much shorter timescale and across an entire city's existing building stock rather than being restricted to only those city districts open to urban planning from scratch.

The subject of the study is a planned new residential area of 10,000 m^2 area in Osaka. Simulations of various levels of UA of building coatings and UGC for the planned new residential area are done with ENVI-met (Bruse, 2016). The resulting urban microclimate including outdoor air temperature (T_a) and mean radiant temperature (T_{mrt}), during a typical extreme hot summer day for Osaka are predicted.

2. Methodology

2.1. Target region

Osaka City (34.4°N; 135.3°E) is part of Japan's second largest metropolitan area, including the adjoining cities of Kyoto and Kobe. It has the lowest green coverage ratio of any city in Japan at under 9%, with the city center at about 2%. The daily high temperature is typically 2 °C higher than the surrounding suburbs. The hottest month in Osaka, as in much of Japan, is August. The average hourly temperature in Osaka for the first half of August over the past 10 years (2007–2016) is calculated; including maximum and minimum values, and the 25th and 75th percentile span (The graph of these values are included in the figure of simulation results in Section 3). The daily high temperature tends to occur at about 2PM, averaging about 33 °C with a record high of 38.4 °C (also occurring at 2PM) (Japan Meteorological Agency, 2017). The measurement site is a meteorological station on a small patch of grass near major roads and an elevated highway in the center of the city, thus it has a UGC of nearly zero.

The number of dangerously hot days is increasing. The Japan Meteorological Agency (JMA) tracks and announces days with a high temperature of 35 °C or greater, which it terms *moushobi*. In 2016, there were 26 *moushobi* in Osaka, the 3rd worst year since records began in the late 19th century. Of the top 10 years for