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Relationship between land use variations and spatiotemporal changes in amounts of thermal infrared energy emitted from urban surfaces in downtown Tokyo on hot summer days

Nobumitsu Tsunematsu [a,*], Hitoshi Yokoyama [b], Tsuyoshi Honjo [c], Arata Ichihashi [a], Haruo Ando [a], Nobuhiko Shigyo [d]

[a] Urban Resources and Environmental Research Section, Tokyo Metropolitan Research Institute for Environmental Protection, 1-7-5, Shinsuna, Koto-ku, Tokyo, Japan

[b] Innovation Center for Meteorological Disaster Mitigation, National Research Institute for Earth Science and Disaster Prevention, 3-1, Tennodai, Tsukuba-shi, Ibaraki-ken, Japan

[c] Graduate School of Horticulture, Chiba University, 648, Matsudo, Matsudo-shi, Chiba, Japan

[d] Education and Research Center, The University of Tokyo Forests, Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, Japan

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ABSTRACT

This study investigated spatial and temporal changes in amounts of thermal infrared (TIR) energy emitted from urban surfaces in downtown Tokyo, using 2 m spatial resolution data obtained from airborne TIR measurements at midday on the three different hot summer days: August 7, 2007, August 19, 2013, and August 19, 2014. Detailed land use data were also used for analyses of relationship between amounts of TIR energy and land use variations. The results showed significantly large amounts of TIR energy in high density wooden residential areas, whereas amounts of TIR energy in areas with office and commercial buildings were relatively small. As for the areas with office and commercial buildings, we found that amounts of TIR energy in many parts of urban renewal areas had clearly decreased between 2007 and 2013. In the renewal areas, many green surfaces have been provided in public open spaces. This would be one of the main causes of the decreases in amounts of TIR energy. Creation of public open spaces has been promoted by an incentive-based policy that offers an increase in the floor area ratio as a reward for constructing public spaces. These results strongly indicate that some governmental measures like the incentive system enacted for the areas with office and

* Corresponding author at: 1-7-5, Shinsuna, Koto-ku, Tokyo, Japan.
E-mail addresses: tsunematsu-n@tokyokankyo.jp, nob.tsunematsu@gmail.com (N. Tsunematsu)

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commercial buildings are required to reduce radiant heat in the high density wooden residential areas, because the maximum occurrence frequency of heat strokes tends to be recorded in residential areas and at midday.

1. Introduction

In the Tokyo metropolitan area, heat wave and heat stroke frequencies tend to increase in recent years (e.g., Takaya et al., 2014; Takane et al., 2014). According to data from a surface observation network developed by Bureau of Environment of the Tokyo Metropolitan Government, air temperatures in downtown Tokyo exceeded 30 °C in 20–30% of the period between July 1 and September 30, 2013. In the same period, the total number of days with the minimum surface air temperatures exceeding 25 °C was over 40 days in downtown Tokyo. Also, annual mean air temperatures in downtown Tokyo have already increased about 3 degrees Celsius (°C) in the past 100 years due to the global warming and urban heat island (UHI), according to Japan Meteorological Agency. Kusaka et al. (2012) indicated that monthly mean August air temperatures in Tokyo in the 2070s will be 2.5 °C higher than those in the 2000s, using data from their regional climate model downscalings of multiple global climate model projections. These have promoted further implementation of UHI adaptation and mitigation strategies for summer heat in Tokyo. The improvement of thermal environment is one of the most urgent issues for the 2020 Summer Olympic and Paralympic Games, which will be held in Tokyo.

Effects of UHI adaptation and mitigation strategies for summer heat could be appreciated by reducing the corrected effective temperatures (CETs) that affect “feels like” temperatures. The effective temperatures (ETs) proposed by Houghton and Yaglou (1923) was a combination of the effects of dry air temperature and humidity. After that, Vernon and Warner (1932) substituted the dry-bulb temperature with the black-globe temperature to allow radiation to be taken into account (CETs) (Epstein and Moran, 2006). We can obtain the CET index using the CET nomograms (e.g., Auliciems and Szokolay, 2007). The CET index is determined by natural environmental factors: air temperature, humidity, wind speed, and radiant heat.

Table 1 shows characteristics of the natural environmental factors in terms of implementation of UHI adaptation and mitigation strategies. It is difficult to control air temperature and humidity in outdoor spaces because those factors are strongly influenced by advection of air masses originating from synoptic-scale weather systems such as the north pacific high. Outdoor wind speeds can be controlled by changing urban geometry. Surface wind speeds would be increased in the area where a ventilation path is created. However, this would lead to decreases in wind speeds in its neighboring areas, as indicated by previous studies (e.g., Masuda et al., 2005; Kagiya et al., 2010). Artificial changes in wind speeds, thus, have strong trade-off relations unsuitable for government environmental measures. Compared with air temperature, humidity, and wind speed, amounts of radiant heat at a specific location can be easily controlled by implementation of measures creating shade and lowering surface temperature with weak trade-off relations. Even if amounts of solar radiation and thermal infrared (TIR) energy radiated from land surfaces are decreased at a specific location, those in its surrounding areas will not be increased. Reducing radiant heat is therefore considered to be suitable for UHI adaptation and mitigation strategies. For instance, not only green and water spaces but also high-reflective and water-retentive pavements are capable of reducing surface temperatures and amounts of TIR energy, thereby improving outdoor thermal environment.

Outdoor thermal comfort associated with radiant heat is determined by downward shortwave solar radiation, reflected solar radiation, downward longwave radiation from the atmosphere, and upward longwave

Table 1
Characteristics of natural environmental factors for “feels like” temperatures in terms of implementation of UHI adaptation and mitigation strategies.

Environmental factors	Control in outdoor	Trade-off relation
Air temperature	Difficult	Weak
Humidity	Difficult	Weak
Wind speed	Possible	Strong
Radiant heat	Possible	Weak