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Evaluation of effect of tree canopy on thermal environment, thermal sensation, and mental state

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ABSTRACT

Greenery is considered an important countermeasure technology that can be used to improve the thermal environment in urban areas. In this study, the effects of environmental factors relating to tree canopies on physiological response and human sensible temperatures were examined. Measurements were analyzed to determine the mutual relationship between the environmental elements of the tree canopy and the physiological response and psychological reaction. In five areas with tree canopies of different forms, located on the Osaka Prefecture University campus, measurements were performed during the hot summer season. The amount of solar radiation in the tree canopy was greatly attenuated in comparison to sunlit locations. In addition, it was determined that the air temperature in the tree canopy was about 1 °C lower in sunlit areas. Human thermal load under the tree canopies is closer to neutral than in sunlit places. The blocking of solar radiation greatly affected physiological response. Results of psychological testing confirm the effect of comfort was experienced under tree canopies. However, gloomy impressions were suffered in areas where the leaf area index was large. The fatigue value correlated best with physiological response. It was concluded that the thermal sensation of hot was causing mental fatigue.

1. Introduction

The heat island phenomenon is officially recognized in Japan as an environmental problem. Available countermeasures include the use of high solar reflection painting, water retentive material, and ventilation paths using sea breeze. Urban greenery is given more attention than any of the other countermeasures. For urban greenery, several effects are anticipated such as an increase in latent heat transfer through leaf transpiration, an improvement of the thermal environment, changes in thermal sensation under tree canopy cover, and psychological changes from healing and mental sedation. It is important to evaluate the improvements on the thermal environment and the psychological conditions quantitatively in order to examine the overall spatial design of greenery in terms of amount, form, and distribution.

Field studies to evaluate the thermal environment caused by greenery have been performed in various situations owing to the technological evolution and downsizing of measuring equipment. Summer daytime air temperatures under large green canopies are lower than in the surroundings. Moriyama et al. (2001) labeled these cooler areas the cool spot. Sets of

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meteorological elements were measured in and around urban parks to understand the thermal effects of green canopies. Thermal environments were examined at several locations with different tree species and layered structures; cool spot effect was evaluated using mean radiant temperature (MRT) (Hashida et al., 2005).

The field measurements on energy balance of a large-scale urban forest were carried out by Kanda et al. (1997). A ratio of latent heat transfer by the transpiration and evaporation for net radiation transfer was estimated, and the transpiration properties of the forest were clarified. The vertical structure of the park cool island was measured and discussed compared with the surrounding urban ground by Sugawara et al. (2011). The seasonal variation of the cool island intensity on urban green space was investigated by Sugawara et al. (2006). The cold-air seeping-out phenomena in a green space was found out by Narita and Sugawara (2011), Narita et al. (2011).

The effects of several types of small-scale plant communities on air temperature and relative humidity were investigated by Zhang et al. (2013). The outdoor thermal environment in street canyon units with different vegetation conditions installed in the scale model was measured to evaluate the quantitative effect of urban vegetation on the outdoor thermal comfort of pedestrians by Park et al. (2012). The tree canopy shade adjacent to the building wall was investigated by Berry et al. (2013).

The relation between the transmissivity of solar radiation through tree canopy and thermal comfort were discussed by Konarska et al. (2014). The radiation exchange through the tree canopy that affected greatly thermal comfort in outdoor was accomplished using Monte Carlo method by Wang (2014). The leaf area index of tree canopy is strongly required for modeling physiological processes. The estimation was performed by using digital photography by Chianucci et al. (2015).

Forest bathing, otherwise known as taking in the forest atmosphere, has been proposed as the term for the psychological action caused by green canopies (Takayama et al., 2005). Some studies have been conducted to scientifically review this psychological action. Oishi et al. (2003) carried out two kinds of tests, the profile of mood state (POMS) and semantic differential (SD) method, to check the psychological condition in five kinds of forest and reference districts outside the forest. The study examined changes after forest bathing. Kasetani et al. (2007) carried out experiments using the POMS and SD methods in various mountainous village landscapes, which included green trees. They concluded the psychological effects were influenced by the brightness and sacredness of the space. Fujii et al. (2006) inspected the effect of hortitherapy on patients suffering from distresses the mind and body. Healing was demonstrated scientifically by evaluating saliva cortisol density and blood flow to the brain. Takayama et al. (2001) evaluated using the SD method, natural landscape views and conducted the investigation with factor analysis relating to the image of greenery amount.

Some studies detailed the relationship between physical environmental factors in green areas, thermal sensation, and the psychological condition. Tada and Fujii (2006) evaluated the visual comfort of plant shades through their influence on the psychological state, excluding the thermal environment. Takayama et al. (2005) focused on the optical environment of forests and performed measurements in forest and urban areas, evaluating the influence of light on thermal sensation and the psychological condition. Park et al. (2011) examined the correlation between psychological responses and the physical environment in forests. Furthermore, Kuroko and Fujii (2002) measured electroencephalographic activity and heart rates in plant-dominant and concrete-dominant spaces. Noise stress and the recovery effect were proposed by studying the relationship between the physiological state and psychological reaction. The association among the thermal environment in green spaces, and thermal sensation and psychological state, has been well defined. However, some unidentified phenomena remain.

In this study, the simultaneous measurement of the thermal environment, thermal sensation, and the mental state of subjects was performed to examine the effects of urban greenery with various factors comprehensively. The environmental elements that express the effects of thermal sensation and mental state were examined based on their significance.

2. Measurement location and method

Five locations on the Nakamozu campus of the Osaka Prefecture University were selected for this study. These areas were chosen due to the varying conditions of ground material constitution, tree species, tree height, and leaf area index (LAI). A summary of the measurement locations is shown in Table 1. Images of the locations are shown in Fig. 1. Simultaneous measurement and comparisons of measured data were carried out for all conditions in the target tree canopy and the adjacent sunlit open spaces. In Osaka region, the summer climate is hot and is humid.

Thermal environment analysis included measurements for air temperature, surface temperature, relative humidity, wind speed, wind direction, solar radiation and infrared radiation. The measurement period extended over three days and lasted

Table 1
Outline of the measurement locations (area A–area E).

	Trunk around (cm)	LAI (–)	Tree height (m)	Branch height (m)	Ground (tree cover) (–)	Ground (open space) (–)	Period
A	84.6	3.02	9.0	1.8	Soil	Asphalt	08/02–08/04
B	101.3	2.84	13.0	2.3	Soil	Grass	08/09–08/11
C	88.8	2.97	9.2	1.9	Soil	Asphalt	08/12–08/14
D	109.4	4.80	6.8	1.6	Dry leaves	Tile	08/19–08/21
E	149.9	2.49	6.5	2.4	Soil	Grass	08/26–08/28

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