Academic Article

Field Investigation on Thermal Environment and Human Thermal Sensation in Premises Woods in Urban Area

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ABSTRACT

The thermal environment parameters of premises woods in an urban area were measured in summer and winter. These measurements were used to calculate the human thermal load to evaluate thermal comfort in this region. The thermal environment parameters in the premises woods were compared with those in an adjacent open space, and the parameters were examined considering daily and seasonal fluctuations. The results indicate that premises woods effectively screen sunlight in both summer and winter and also clearly reduce wind speed during the day in summer. Thermal neutrality is maintained in the premises woods in summer during the day. The difference in thermal environment and thermal comfort inside versus outside the premises woods at night was significantly smaller than that during the day.

Key Words : Urban homestead tree canopy, Thermal environment, Thermal comfort, Field measurement, Daily and seasonal variation

1. Introduction

Trees planted around a house on a farm are referred to as "premises woods," and they are common all over Japan. They play numerous roles in mitigating environmental factors: they shelter buildings from the strong seasonal winds that blow from winter to the beginning of spring, create shade during summer to block the midday and evening sun, and help keep the air temperature beneath their canopy constant. They are also important in terms of safety, as they are believed to help prevent the spread of fire from neighboring structures. In flat areas with little woodland, the premises woods supply several resources: fallen branches can be used as firewood, wood is obtained from the trunks, and fallen leaves are composted. Thus, with their variety of functions, premises woods are well integrated into the lives of people living in the plains(1).

The premises woods that still exist in suburban areas have been attracting attention due to their rich ecology, supported by the protected, old-growth tree; their role in cleansing the air; and their contribution to environmental regulation by transmitting cool air to adjacent areas in summer. A number of premises woods once existed in the Musashino area, a suburb of Tokyo, but with the appreciation of land prices, it has become difficult to maintain them over generations. Thus, the number of premises woods is steadily decreasing, and it is feared that soon no premises woods will be left in Musashino(2). In addition to the role of the premises woods in environmental conservation, in suburban areas, they are expected to provide psychological comfort to the local residents and a place of rest and environmental education. There is an increasing need to conserve the premises woods by designating them as public property and protecting them through collaboration between residents and local authorities. Figure 1 shows protected trees in the premises woods, and Fig. 2 shows an example of the use of the premises woods by local residents. The neighboring elderly gather in the premises woods every morning and make an effort to promote their health through physical exercises.

The thermal comfort provided by premises woods has been demonstrated in several studies. In one study, air temperature measurements were made in the premises woods and in an adjacent residential area in summer and winter using a maximum and minimum thermometer. The study determined that whereas the temperature fluctuates greatly in the residential area, fluctuations in the premises woods are modest throughout the year. Therefore, it is more comfortable inside the premises woods(2). Apart from the physical thermal environment, i.e., the temperature, it is important to discuss the thermal mitigation effect of the premises wood from the viewpoint of human thermal sensation. The present study investigates the thermal comfort provide by the premises woods in a suburban area from the perspective of human thermal load. To calculate the thermal load, various aspects of the thermal environment in the premises woods and in the adjacent open space are measured, and the environmental thermal easing and the effects on thermal comfort are examined. On the basis of these measurements, the influence of seasons is also investigated. This study focuses on the premises woods that have survived in Nishi-Tokyo-shi (formerly known as Hoya-shi), which is located in the central region of the Musashino Plateau in the Tokyo area, an area known for its rapid loss of green space.

2. Measurement site and method

The studied premises woods are shown in Fig. 3. This woodland has an area of 1.1 ha and is located 300 m northwest of Hoya station in Nishi-Tokyo-shi. It is a mixed wood with both evergreen and deciduous trees. Figure 4 illustrates the layout of this woodland. It contains protected trees, including a 300-year-old Japanese zelkova and a 100-year-old camphor tree[(2)]. Moso bamboos are also cultivated. Four kinds of evergreen needle-leaved trees including cedars and Japanese cypress, fifteen kinds of evergreen broad-leaved trees including shira kasa oaks and ring-cupped oaks, and twenty-five kinds of deciduous broad-leaved trees such as Japanese zelkovas and sawtooth oaks are present here. The total number of trees in the premises woods is 336. Many are taller than 20 m, and their lowest branches may be at a height of 2 m or more. As Fig. 4 shows, the measurements were made at a site more than 20 m away from the edge of the wood and covered by the tree canopy. Its leaf area index was 5.47 in summer and 1.96 in winter. Most of the ground surface was covered by fallen leaves, and some was covered by undergrowth. The measurements of the adjacent open space were collected in an asphalt parking lot. The sky factor of the premises woods was 18.4% and 46.0% in summer and winter, respectively, whereas that of the adjacent parking lot was more than 90%. Figures 5 and 6 show the premises woods in summer and winter, respectively. Figures 7 and 8 show how the measurements were made in the premises woods and the parking lot, respectively.

A parking lot has one of the most severe thermal environments. The variation in the thermal environment and biometeorology within urban areas was made clear mostly by the comparison of the measured data between the premises woods and the parking lot. The overall thermal environment and biometeorology of the built-up area are assumed to have intermediate characteristics between those of the premises woods and the parking lot. Except

Fig. 1 Protected trees in the premises woods

Fig. 2 Use of the premises woods by the local residents

Fig. 3 Map of the premises woods and its neighborhood (retrieved from Google Maps)

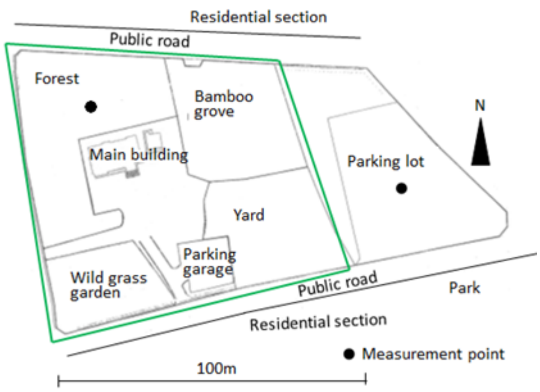

Fig. 4 Plan of the premises woods

around Hoya Station, the houses in the built-up area are low-rise buildings. There is a park with an area of 0.3 ha between the premises woods and Hoya Station. The major ground cover in the area is lawn.

Measurements were made in summer and winter. The summer measurements were made on August 10 and 11, 2013, which corresponded with the tropical and extremely hot weather. Winter measurements were made on February 6 and 7, 2014, when the minimum temperature did not exceed 0°C. The following quantities were measured: air temperature, relative humidity, wind speed, global irradiance, globe temperature, and surface temperature. With the exception of surface temperature, measurements were made at a height of 1.2 m above the ground. The temperature and humidity sensors were stored in a white radiation shield that permitted air passage. Measurements were made at 10-min intervals. An infrared camera captured images in six directions (north, south, east, west, above, and below) every 2 h during the day and every 4 h during the night in summer. The configuration factors of the representative material were obtained with fish-eye lenses (orthographic projection), and the radiation temperatures determined from the infrared camera images were used to calculate the average temperature of the infrared radiation. During nighttime in winter, the average temperature of the infrared radiation was obtained from the globe temperature, air temperature, and wind speed[(3)]. Surface solar reflectance was measured separately. The solar reflectances of the premises woods and the parking lot were 30.8% and 14.6% in summer and 23.5% and 8.5% in winter, respectively. The asphalt of the parking lot was repaired before the winter measurement period and that measurement was made when the asphalt was still in an unused state and free of dirt.

This study employs human thermal load as a thermal comfort index. Human thermal sensation has attracted attention as an evaluation criterion for the assessment of thermal environment. Thermal feeling is a mixed sensation, and in general it is determined by six dominant factors: air temperature, humidity, radiant temperature, wind speed, metabolism, and clothing. Therefore, it is advisable to include as many of these factors as possible for a thermal index. The human thermal load is in itself the heat flux under given condition based on the human energy balance equation. The human thermal load is considered to be an accurate indicator of thermal feeling because it contains all six of the above-mentioned factors. In fact, a previous study determined that human thermal sensation can be obtained using human thermal load in outdoor environments. Human thermal load refers to the thermal load on the human body and is calculated from the energy balance of the whole body in heat flux. Human thermal load and thermal comfort are sufficiently correlated[(4)]. In an experiment involving human subjects, human thermal load is calculated using environmental data (air

Fig. 5 The premises woods in summer

Fig. 6 The premises woods in winter

Fig. 7 Taking measurements in the premises woods

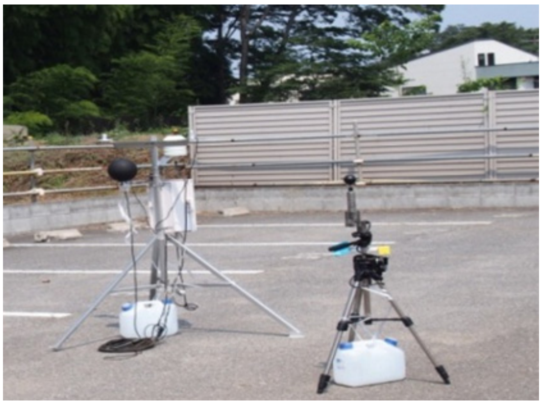

Fig. 8 Taking measurements in the parking lot

temperature, humidity, wind speed, global irradiation, solar reflectance, and the average temperature of the infrared radiation), representative skin temperatures from seven points on the body, metabolism, mechanical workload, and the amount of clothing worn. When only environmental data are obtained, as in this study, the skin temperature is calculated using a human body model that predicts physiological responses based on environmental data and conditions such as metabolism, mechanical workload, and the amount of clothing; this skin temperature is then used to calculate human thermal load. Here, skin temperature was calculated using the 65MN model[5]. This model considers the human body as a tube and evaluates four layers at 16 sites and central blood; it further evaluates heat conduction between the layers at each site, radiation from the external environment, convection heat transfer, and perspiration evaporation on the superficial skin layer. This study simulates an individual 172 cm tall, weighing 53 kg, and stationary in a standing position. The metabolism is set at 80 W/m2, and the mechanical workload at 0 W/m2; the amount of clothing was set at 0.3 clo in summer and 1.3 clo in winter; the surface infrared radiation was set at 1.0. Thermal comfort was predicted based on human thermal load[6].

3. Measured results and discussion

Figures 9 and 10 show the air temperature and globe temperature measurements in summer and winter, respectively. The results revealed that the premises woods had a significant cooling effect during the day in summer but were not very effective at night. The cooling effect of the premises woods during the day in winter was smaller than that in summer, and there was hardly any difference in air temperature at night. The globe temperature in the premises woods exhibited little discrepancy from the air temperatures during both day and night. The nighttime globe temperatures during both day and night. The nighttime globe temperature in the premises woods was higher than that in the adjacent space due to radiative cooling, especially in winter. In summer, an almost uniform temperature field was observed in the premises woods. The temperature difference between the ambient air and the green canopy formed by tree leaves was small throughout the day. The trunk surface temperature of the trees was lower than the other surface temperatures in the daytime as shown in Fig. 11. In winter, there were few differences among the air temperature and the surface temperatures of the green leaves, tree trunks and the ground covered with dead leaves in the premises woods.

Figure 12 displays the irradiation measurements for solar radiation. In both summer and winter, the premises woods exhibited a high sunlight screening effect, which was considered to have a significant influence on the premises woods globe temperature and daytime air temperature. The transmittance of

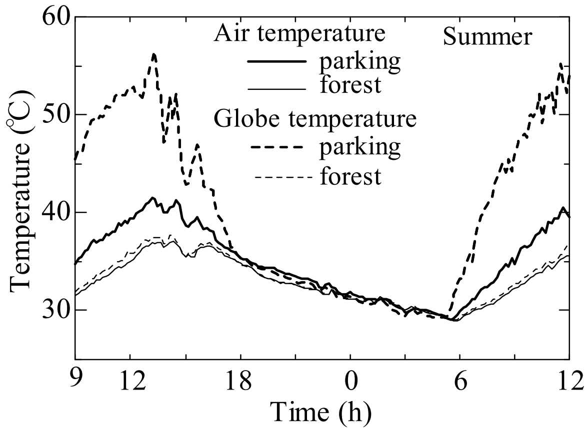

Fig. 9 Daily variations in air temperature and globe temperature in summer

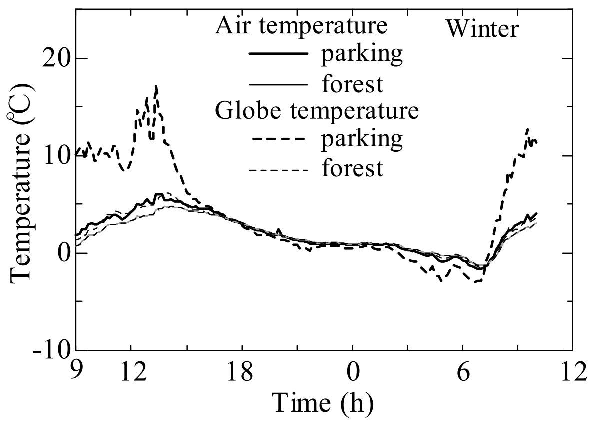

Fig. 10 Daily variations in air temperature and globe temperature in winter

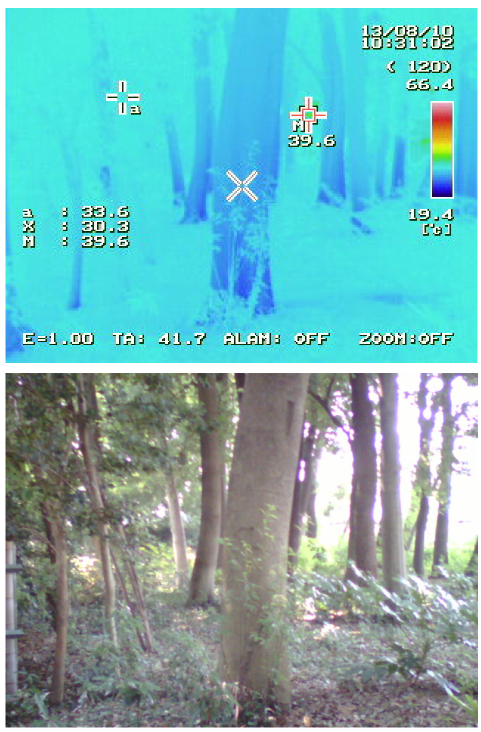

Fig. 11 Thermal image collected in the premises woods during daytime in summer

ultraviolet radiation in the premises woods was also less than 2% and 10% in summer and winter, respectively. Figure 13 shows the relative humidity measurements. The relative humidity in the premises woods was higher than in the parking lot during the day in summer, but there was hardly any difference between the two during the night. In winter, there was no difference between the two sites during either day or night. This was attributed to the amount of moisture on the surface and the wind speed, as discussed in the following paragraph. Figures 14 and 15 show the wind speed measurements for summer and winter, respectively. In summer, the wind speed during the day was lower in the premises woods than that in the parking lot, but there was hardly any difference between the two sites during the night in summer or at any time in winter. In summer, a southerly wind blew during the day and a northerly wind blew during the night according to AMeDAS (Automated Meteorological Data Acquisition System) data from Nerima, the station located nearest to this site. In winter, a northerly wind blew all day. When a northerly wind blows, it is suggested that the wind speed observed at the parking lot is lower because a wind blocking effect is observed for the premises woods. Furthermore in winter, the measurement of wind speed in the premises woods was thought to be affected by the fact that their measurement location was near the northern edge of the premises woods, which contained many deciduous trees with a lower leaf area index.

Figures 16 and 17 show the human thermal load and thermal comfort values calculated from the measurements for summer and winter, respectively. Thermal comfort in summer and winter was affected by a difference in thermal load; it was higher in the parking lot than in the premises woods during the day, and there were smaller daily fluctuations in the premises woods. Thermal comfort in the premises woods in summer was almost neutral. The difference in thermal load and thermal comfort between the two sites during the night was small. Thermal load and thermal comfort in the premises woods in winter did not indicate a windbreak effect of the woods and the reduction in the sunlight screening effect was small; thus, no environmental easing effects were observed in winter.

It is essential to consider the following factors in future studies. In this study, measurements were made at only one site in the premises woods. To examine how spatial representative this result is, it will necessary to obtain measurements from a few more sites there. Furthermore, in this study, measurements were

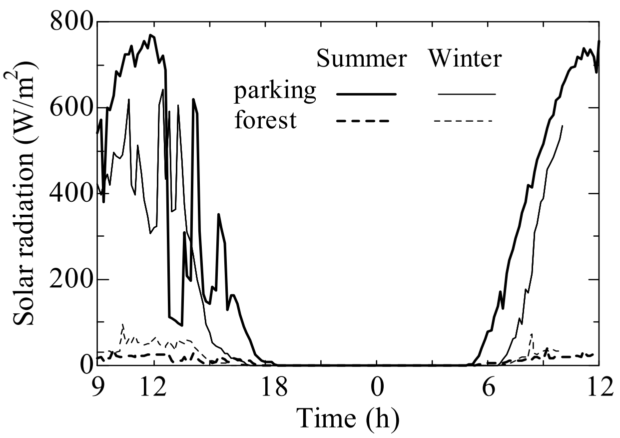

Fig. 12 Daily variations in global irradiation
in summer and winter

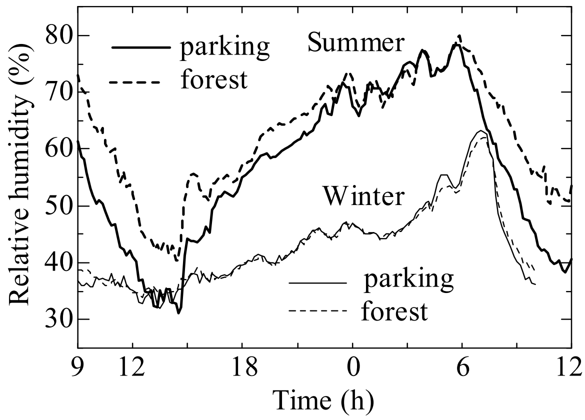

Fig. 13 Daily variations in relative humidity
in summer and winter

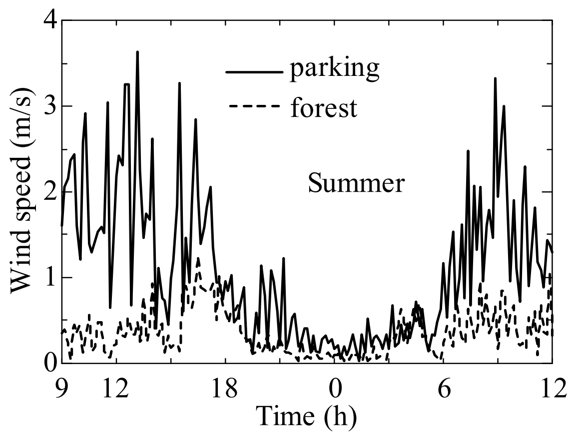

Fig. 14 Daily variations in wind speed in summer

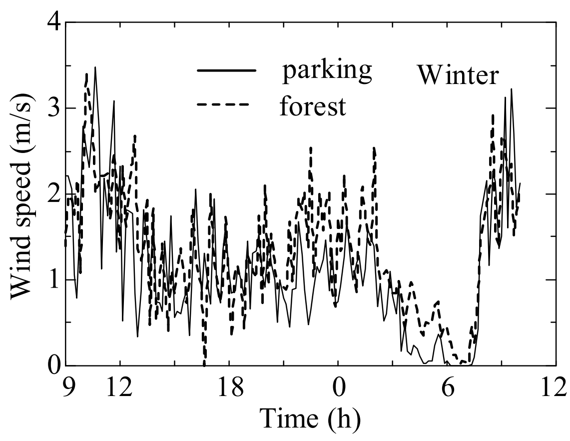

Fig. 15 Daily variations in wind speed in winter

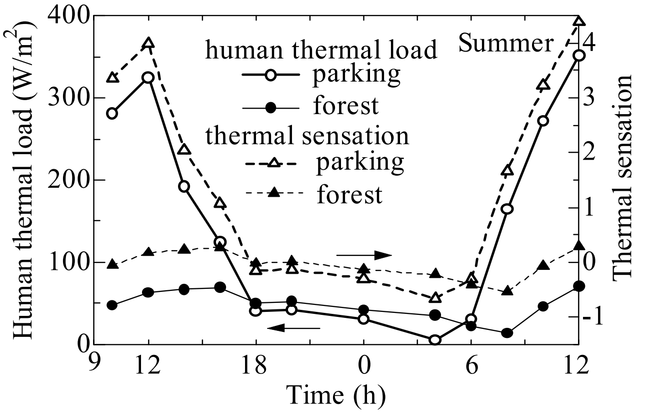

Fig. 16 Daily variations in human thermal load and thermal comfort in summer

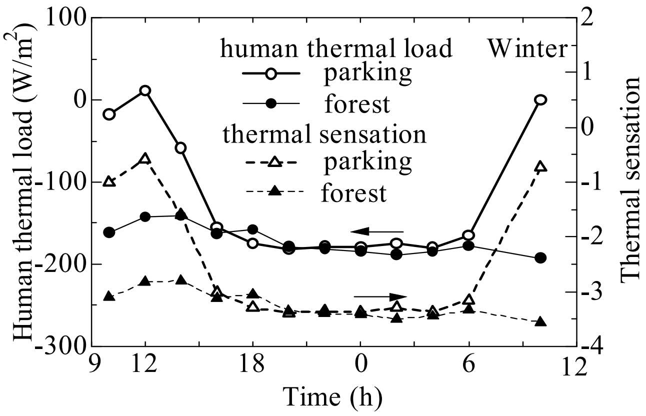

Fig. 17 Daily variations in human thermal load and thermal comfort in winter

made only over short periods of time, and therefore further efforts should include obtaining longer-term measurements spanning approximately a month and statistically analyzing them. It is also necessary to develop a questionnaire survey on premises woods focused on psychological factors such as mood and impression. Additionally, in future work we aim to propose a design for premises woods from the viewpoint of controlling the thermal environment based on this study.

4. Conclusion

Measurements of thermal environmental parameters under the tree canopy and in a nearby open space were made in summer and winter to investigate the thermal comfort generated by the premises woods in an urban area with reference to the human thermal load. The premises woods effectively filtered out sunlight in summer and winter, and the daytime temperature in the premises woods was lower than that in the adjacent open space. The premises woods consisted of almost homogeneous radiation fields, and the difference between the average infrared radiation temperature and the air temperature was small. The effect of the premises woods on wind speed reduction was significant during daytime in summer when the leaf area index was high. The difference between the thermal environments of the premises woods and the adjacent open space during the night was small. Human thermal load in the premises woods during the day in summer was significantly lower than that in the adjacent open space, and thermal neutrality was almost achieved.

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