Academic Article

Thermal Environment and Mental State in Premises Woods in Urban Tokyo Area

Atsumasa Yoshida*[1], Shoko Hashida*[2], Shinichi Kinoshita*[3]

*[1]Department of Mechanical Engineering, Osaka Prefecture University
*[2]Graduate School of Frontier Sciences, The University of Tokyo
*[3]Department of Mechanical Engineering, Osaka Prefecture University

Corresponding author: Atsumasa Yoshida, ayoshida@me.osakafu-u.ac.jp

ABSTRACT

Thermal environment parameters within premises woods in an urban area were measured for one month during the summer. These data were compared to similar data from the top of an adjacent building. Premises woods effectively decrease daytime solar irradiation and reduce wind speed. The differences between air and black-bulb (globe) temperatures inside and outside the premises woods were significantly larger during the day than at night. Fifteen data collection locations within the different land-use types of the premises woods were selected for continuous data collection. There were small differences in air temperature throughout the premises woods. Humidity varied across land-use types within the premises woods. Study participants rated thermal comfort and mental state to be higher in the premises woods than in an adjacent park.

Key Words: Urban tree canopy, Woodland, Thermal environment, Thermal comfort, Field measurement, Thermal design, Spatial distribution, Psychological effect, Landscape impression

1. Introduction

In Japan, the group of trees surrounding a farmhouse are called ‘premises woods’ and this land-use type is found across the country. Premises woods were artificially created for disaster prevention, providing functions such as windbreaks, snow protection, and fire prevention. These areas also provide shade, firewood, a timber supply, and a familiar wooded area for people living nearby(1). Recent research has focused on the thermal environment mitigation function of premises woods, rather than on the woods’ disaster prevention functions.

In the premises woods remaining within urban areas, mature trees provide air purification, cool air during the summer, and a rich ecosystem. We conducted thermal environmental measurements in urban premises woods during summer and winter, calculated the human thermal load, and evaluated the thermal sensation(2). We compared thermal environmental data from premises woods and a neighboring open space to determine if there were diurnal and/or seasonal changes. However, the number of data collection days was insufficient, and the connection to meteorological conditions was unclear. Because there was only one data collection location within the premises woods, analysis of spatial distribution and factors contributing to the thermal environment was insufficient. Therefore, in the present study, we used an adequate number of data collection locations in the same premises woods, and conducted continuous measurements over approximately one summer month. To elucidate the psychological effects of premises woods, and the impressions people have of them, we also conducted a human-subject experiment(3). We aimed to comprehensively evaluate the thermal environment mitigation function of premises woods for thermal environment design.

2. Data collection locations and methods

The premises woods used in this study were a 1.1 ha area located 300 m northwest of the Hoya Station, Nishitokyo (Figures 1 and 2). They were classified into five land-use types: forest, wild plant, main house, bamboo grove, and yard (Figure 3). The leaf area index (LAI) was measured in the premises woods in the summer and winter. The LAI values in the winter were much lower than those in the summer, except in the main house and bamboo grove areas (Table 1). The forest is a mix of evergreen and deciduous trees. The total number of trees

growing in the forest area of the premises woods exceeded 300. Many trees were taller than 20 m, with branch heights exceeding 2 m. The crowns covered the sky, and the average LAI was 3.74–4.89. The ground was covered by dry leaves and undergrowth. A two-story Child Welfare Center is located adjacent to the premises woods; the roof of this building is concrete and partially covered by planted vegetation. The average sky view factor of these premises woods was 18.4%, and the sky view factor of the rooftop was greater than 90%.

For the investigation of human psychological impressions, we used a nearby park as a reference location for the yard area within the premises woods. A lawn was located at the center of the park where the sky view factor was 50% or greater, with the rate of visible greenery 60%.

Measurements were taken continuously from August 1 to 28, 2014. Weather stations installed in the forest area of the premises woods, and on the rooftop of the adjacent building (Figures 4 and 5), measured air temperature, relative humidity, wind direction, wind speed, global solar radiation, global infrared radiation, and black-bulb temperature (globe temperature). Measurements were taken at 1.2 m above the ground. Air temperature and humidity sensors were stored in a white radiation shield, and naturally ventilated. Wind direction and wind speed were measured using a wind vane and a three-cup anemometer, respectively. The starting wind speed for the anemometer was 0.4 $m \cdot s^{-1}$. Measurements of solar reflectance on the ground surface were made separately. The solar reflectance of the premises woods was 30.8%. Thermo-hydrometers and soil-temperature meters were installed in each area within the premises woods (ten in the forest area; one each in the wild plant, yard, and bamboo grove areas; two in the main house area) and on the rooftop of the adjacent building (one). The thermo-hydrometers were stored in birdhouses to block solar radiation, and were naturally ventilated at a height of 1.0 m in each location (Figure 6). Soil temperature meters were placed in the forest, the main house, and bamboo grove areas and on the rooftop of the adjacent building. Measurements from all instruments and locations were taken at 10- minute intervals.

Fig. 1 Premises woods and surrounding areas A: Premises woods, B: Adjacent building (child welfare center), C: Park (retrieved from Google Maps)

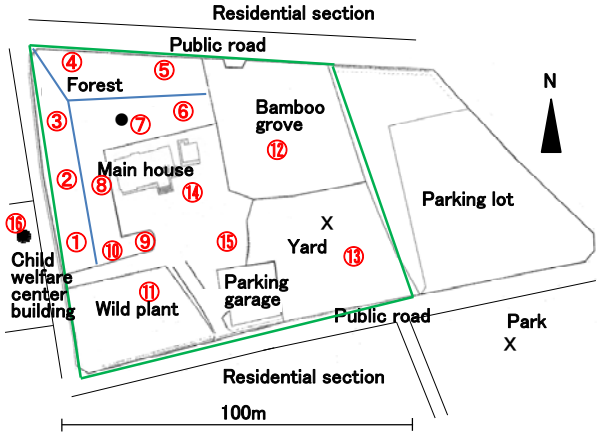


Fig. 2 Plan of the premises woods ●: Weather station, ×: Human subject experiment, ①-⑯: air temperature and relative humidity data collection points

Table 1 Leaf area index values for various areas within the premises woods

Area	Forest (center part)	Forest (west part)	Forest (north part)
summer	4.89±0.07	4.28±0.17	3.74±0.34
winter	2.69±0.12	1.85±0.20	2.06±0.07

Area	Wild plant	Main house	Bamboo grove
summer	2.36±0.10	1.94±0.11	5.35±0.17
winter	0.54±0.16	1.30±0.04	4.97±0.20

Area	Yard
summer	3.17±0.11
winter	0.84±0.29

(a) Forest area

(b) Wild plant area

(c) Main house area

(d) Bamboo grove area

(e) Yard area

Fig. 3. Land-use areas in premises woods

Fig. 4 Weather station inside the premises woods

Fig. 5 Rooftop of the building adjacent to the premises woods

Fig. 6 Sensors installed in birdhouses to measure air temperature and humidity in the premises woods

3. Human-subject experiment methods

Twenty-two healthy seniors (4 males and 18 females) ranging from 68 to 86 years old, and 4 healthy students (3 male and 1 female) ranging from 18 to 21 years old, participated in a human-subject experiment on August 18, 2014 within a nearby park and in the yard area of the premises woods (Figure 7). The data collected were thermal sensation, comfort, sense of healing, psychological self-reporting using the Profile of Mood States

(POMS) method developed by McNair et al.[4], and scenic impression according to the SD method[5].

Thermal sensation, comfort, and a sense of healing were all measured on relative scales (Figure 8). The right ends of the scales were labeled 'hot', 'comfortable', and 'there is a sense of healing', respectively, and the value of +3 was assigned. The left ends of the scales were labeled 'cold', 'uncomfortable', and 'there is no sense of healing', respectively, and a value of -3 was assigned. Using these scales, study participants were asked to indicate their experiences, and results were assigned numerical values within 0.1 increments.

The POMS method evaluates mood via a questionnaire composed of 65 items. This method allows quantification of a person's emotions and mood under given conditions. Evaluations are made based on six mood categories: 'Tension-Anxiety', 'Depression-Dejection', 'Anger-Hostility', 'Vigor', 'Fatigue', and 'Confusion'. To reduce the burden on the participants, a shortened version was developed by Yokoyama[6]. Although the questionnaire was reduced to 30 items instead of 65, it was able to provide the same results as longer version, with sufficient reliability and validity. Scores for each of the six mood categories were totaled, and the score for 'Vigor' was subtracted to obtain the Total Mood Disturbance (TMD) score. This allowed the expression of the mental state of a subject with a single numerical value. For all categories other than 'Vigor', the lower the score, the better the mental state.

The SD method is a psychological test developed by Osgood et al.[5]. In this research, we evaluated differences in the scenic impression of the data-collection locations. There were 13 questionnaire items, each item consisting of two antonymous adjectives, with a 7-step scale.

Participants were gathered in the yard area of the premises woods at 9:30 a.m. Details on how to respond to the questionnaire were provided before the participants were asked to record their responses. The participants then took 2 minutes to walk to the park next to the premises woods and recorded their responses again. The experiment was completed at 10:00 a.m. The senior participants exercised lightly for 15 minutes prior to gathering at the yard area as daily routine and rested 10 minutes at the same location before participating in the experiment. Within the yard area, many of the participants faced southwest in response to our request, toward the outside of the premises woods; at the park, they faced southeast toward the central lawn. The participants completed the response forms while standing. Meteorological data measured at 9 a.m. and 10 a.m. included the following mean values (for the premises woods and rooftop respectively): air temperature (27.4 °C, 31.0 °C), global solar radiation (15 $W \cdot m^2$, 411 $W \cdot m^2$), relative humidity (85%, 65%), wind speed (1.0 $m \cdot s^{-1}$, ≤ 0.4 $m \cdot s^{-1}$), and globe temperature (27.8 °C, 40.5 °C).

(a) Yard area of premises woods

(b) Park adjacent to premise woods

Fig. 7 Fisheye photographs of data collection sites for the human subject experiment

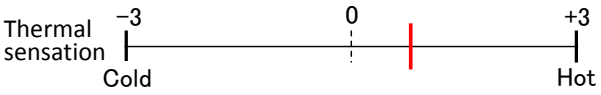


Fig. 8 Thermal sensation scale

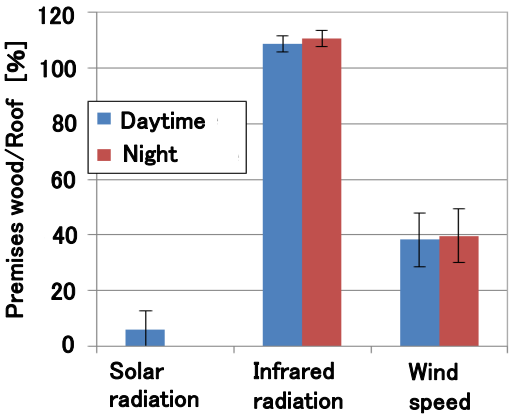
4. Results and discussion

Figure 9 shows the comparison of environmental elements on sunny days in the premises woods with those from the rooftop of the adjacent building (the reference area). Global solar radiation, infrared radiation, and wind speed were expressed as the ratio of premises woods/reference area. Air temperature, globe temperature, and relative humidity were expressed with the equation: premises woods – reference area. Daytime values for solar radiation, air temperature, and wind speed were lower in the premises woods than they were in the reference area (Figure 9). The relative humidity in the premises woods was higher than

that in the reference area (Figure 9) because of the ground-surface moisture and the transpiration of tree leaves. The absolute humidity was the same in both areas, based on air temperature and relative humidity data. The global infrared radiation in the premises woods was slightly higher than that in the reference area because of the greater tree canopy in the premises woods. Daytime globe temperature in the premises woods was closely related to the subjects' thermal sensation and was lower than that in the reference area. This is because the solar radiation decreased near the tree canopy and the surface temperature decreased according to the solar radiation. Except for wind speed, the differences between environmental variables in the premises woods and the reference area were smaller at nighttime than they were during the daytime. This finding was similar to the results of a previous study[(2)].

Figure 10 compares air temperatures and relative humidity within the different land-use types of the premises woods during the day and night. There were small differences in air temperature between each area of the premises wood; the mean values varied by only approximately 1 °C. The air temperatures in the wild plant area and the main house area were expected to be higher than those in other areas, based on the relationship between LAI values and solar radiation. In the wild plant area, the ground was primarily covered with grass and the ground surface temperature decreased. The main house area was surrounded by the other cool areas. Relative humidity showed some variation between areas due to spatial variations in ground surface moisture. The values of absolute humidity in the main house area and the forest area were lower than those in other areas. In the forest area, the ground surface was covered with leaf litter.

The participants' thermal sensation indicated that there were cooler temperatures in the premises woods than in the park (Figure 11). The participants felt more comfortable and healing in the premises woods than they did in the park. For all categories except for V (Vigor), the reference area provided the



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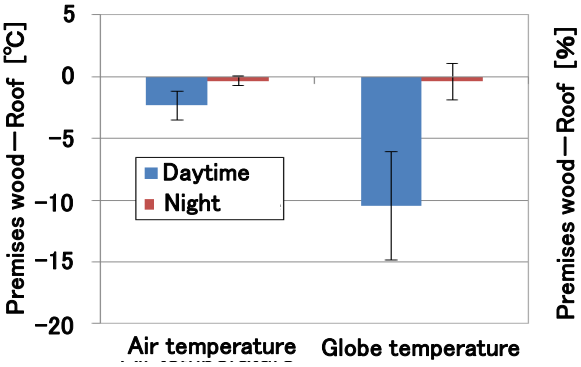

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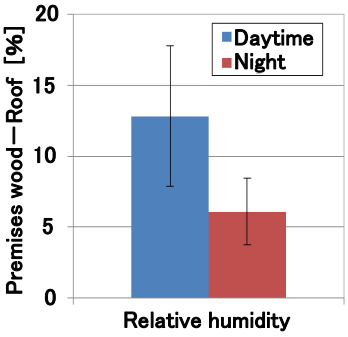
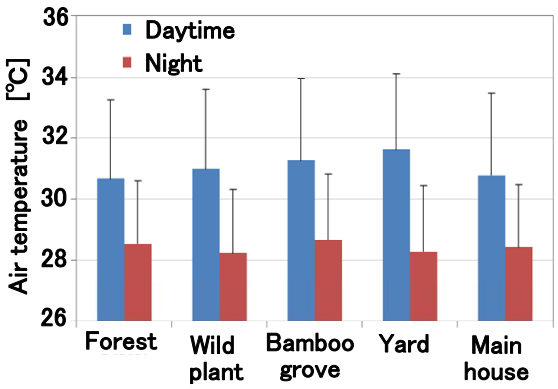


(c)

Fig. 9 Environmental elements within the premises woods and from the rooftop of an adjacent building



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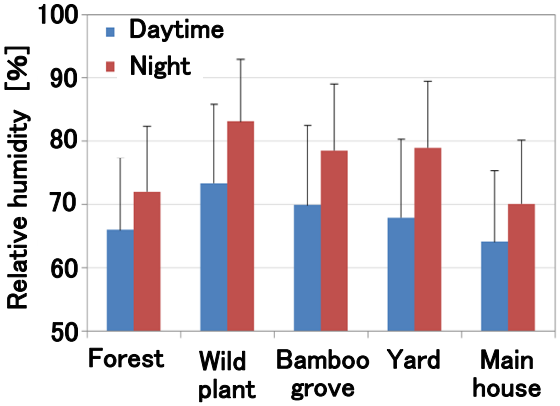

(b)

Fig. 10 Air temperature and relative humidity within premises woods

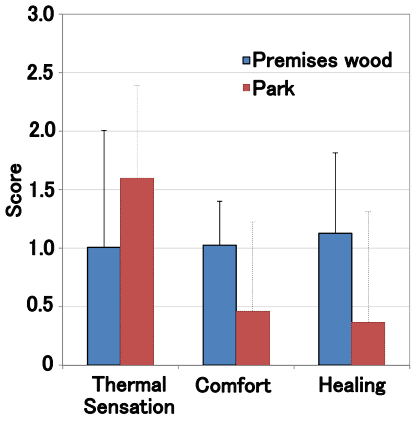

Fig. 11 Thermal sensation, comfort, and healing within the premises woods and park

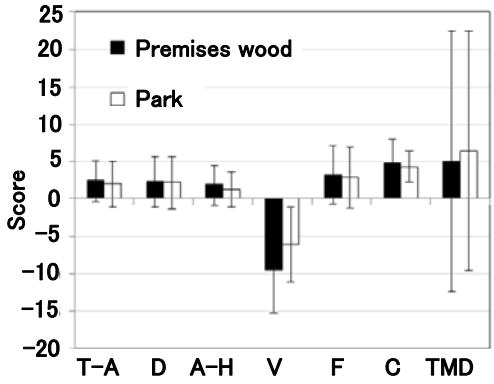

Fig. 12 POMS categories of mental state in the premises woods and park

participants with a more pleasant experience than did the premises woods (Figure 12). Positive aspects of the premises woods were seen in the average values of TMD because of the significant difference in V between the premises woods and the reference area. However, the significant difference in TMD was not recognized because of the large deviation.

Through factor analysis, SD items were classified into 'sense and space', 'brightness', and 'feeling of life' factors (Figure 13). 'Sense and space' factors were better in the premises woods than those in the reference area. Because canopy cover blocked much of the sky in the premises woods, 'brightness' scored low in this area. As a whole, the greenery of the premises woods provided a psychologically relaxing effect, confirming that premises woods provide the impression of a pleasant space.

4. Conclusions

The thermal environment parameters of premises woods in an urban area were measured and compared with those in an adjacent open space. Several data collection locations within the premises woods were selected for continuous month-long data

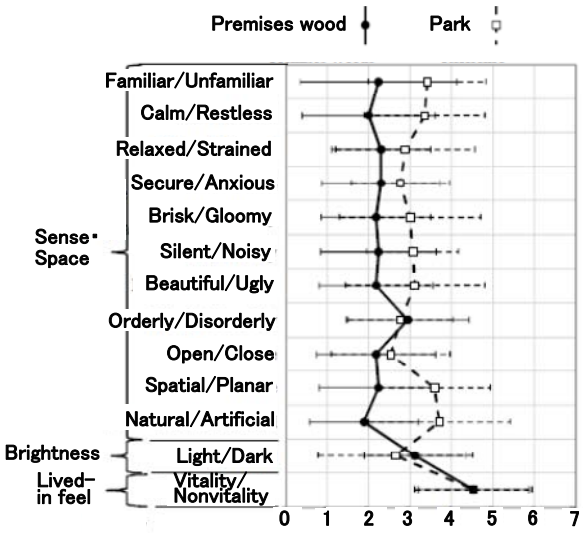

Fig. 13 SD classification of scenic impressions in the premises woods and park

collection. Human-participant experiments were conducted to determine the psychological effects of premises woods and the impressions that study participants had of these woods. The premises woods had less sunlight and lower wind speeds during the day than did the adjacent open space. Participants' daytime thermal comfort was higher in the premises woods than in the adjacent open space. Differences in air temperature between the land-use types in the premises woods were small. The spatial distribution of humidity was related to ground surface cover. Values representing participants' thermal comfort, healing, and mental state were higher in the premises woods than those in green park.

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