THERMAL CHARACTERISTICS OF URBAN LAND COVER BY INDOOR LAMP-IRRADIATION EXPERIMENT

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Abstract

An indoor lamp-irradiated experimental apparatus, which was covered by an insulator to prevent influences from room conditions, was created to evaluate urban surface materials such as water-retentive pavement blocks. Testing was conducted under dry, wet and submerged conditions. Differences in the effect of decreasing or increasing surface temperature under all three conditions were found. Also, an experiment for natural surfaces such as grass was also performed. The result showed better effects under natural surface conditions than artificial conditions. We discuss the qualities desired in effective urban surface coverings in context of our experiments using the indoor lamp-radiated experiment apparatus.

Key words: heat-island phenomena, urban cover material / condition, indoor experiment, thermal characteristics

1. INTRODUCTION

City planners now look to water-retentive pavements as a way to mitigate urban heat island phenomena. To evaluate their effects, they need to be constructed outdoors, and field observations must be performed. However, because examining many types of heat characteristics of urban covering materials in a short time is difficult, an indoor experiment using lamp radiation is useful.

2. PREVIOUS STUDIES AND INDOOR LAMP-IRRADIATION EXPERIMENTS

2.1. Previous studies regarding heat characteristics of surface covering materials

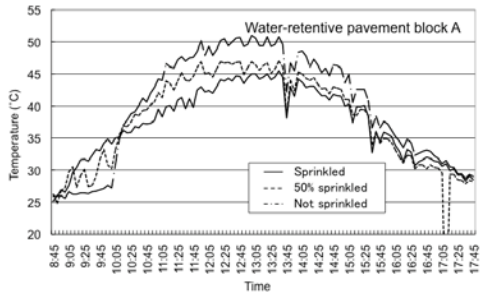
Field experiments to examine pavement materials in summer and winter were reported by Fukuda *et al.* (1997, 1999a, b). They showed the effectiveness of permeable pavements with water supplied or sprinkled on them. Under natural conditions with little water, those pavements, which have large air spaces, also had lower surface temperatures due to air exchange at or near the surface.

2.2. Indoor lamp-irradiation experiments

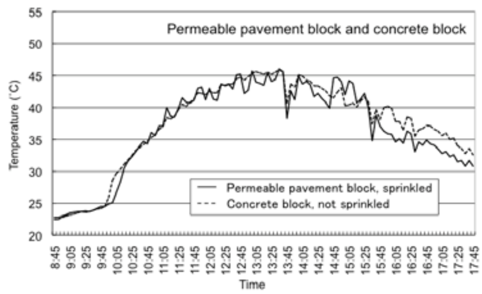
The Tokyo Metropolitan Government (2007) defined the method of indoor lamp-irradiation experiments for water-retentive pavement materials. This method facilitates experiments aiming to evaluate the heat characteristics of pavement materials. However, conditions around the experimental apparatus were not determined. Therefore, during experiments with many test pieces, room temperature conditions should be controlled.

2.3. Field tests of temperature change of pavement materials

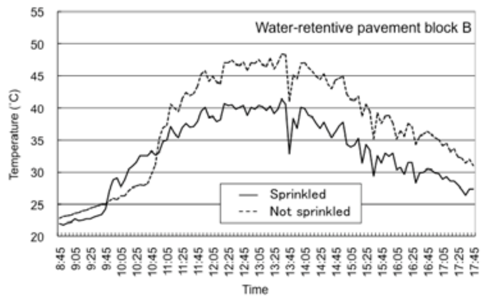
Before undertaking our indoor lamp-irradiation experiments, we performed outdoor experiments to evaluate surface pavement materials. In the outdoor experiments, sprinkled amounts of water were varied and the observed surface temperatures compared. The results shown in Fig. 1 suggest that water-retentive pavement blocks may well have higher surface temperatures than that of normal concrete blocks, especially in



(a) Water-retentive pavement block A



(b) Permeable pavement and concrete blocks



(c) Water-retentive pavement block B

Figure 1. Field observation (17-18 Sept 2003)

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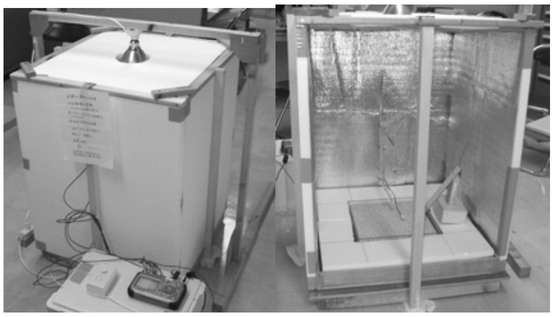
dry conditions. The outdoor experiment is sensitive to weather, thus it is likely that difficulties will occur while performing experiments in a limited amount of time. Since the mitigation of surface temperature differed with water content, the indoor lamp-radiated experiments, as shown in the following section, were done in three conditions, dry, wet and submerged. Moreover, the experimental apparatus was covered with insulation to prevent any influence by room temperature.

3. METHODS

3.1. Experimental apparatus

Fig. 2 shows the apparatus used in this research. The width and depth was about 60 cm each, and test material such as a water-retentive pavement block that was set in a foam polystyrene plank was 6.5 cm thick. Under the plank, 1 cm thick plywood was laid as framework and 3 cm thick foam polystyrene as an insulator. The lamp (TOSHIBA BRF110V120W150) was set at a height of about 90 cm. The enclosure was insulated with a 3 cm thick foam polystyrene and aluminium sheet. Temperatures were measured at the surface at heights of 5, 10, 20 and 45 cm in the room and wet globe for relative humidity using thermocouples (type K) and data logger equipment (GRAPHTECH midi LOGGER GL2000). The thermocouples were covered with aluminium foil to reduce the influence of radiation. Blocks were set in an acrylic resin case (inside dimensions: 310 × 310 × 70 mm^3, thickness: 5 mm) to fit other materials as shown in the following section.



(a) outward (b) inside

Figure 2. Experimental apparatus with insulator

Table 1. Using surface covering materials (blocks)

Types	Length × Width × Thick (m) (m) (m)	Mass (kg)
Water-retentive pavement block A	0.3 × 0.3 × 0.06	7.5
Water-retentive pavement block B	0.2 × 0.2 × 0.06	4.9
Permeable pavement block	0.3 × 0.3 × 0.06	11.1
Concrete block	0.3 × 0.3 × 0.05	9.6

Table 2. Using natural surface coverings, etc.

Types	Length × Width × Thick (m) (m) (m)	Mass (kg)
Water	0.3 × 0.3 × 0.06	6.0
Sand	0.3 × 0.3 × 0.06	6.0
Soil	0.3 × 0.3 × 0.06	4.0
Grass	0.3 × 0.3 × 0.06	4.0
Bamboo Charcoal	0.3 × 0.3 × 0.06	2.0

Table 3. Experiment dates and times (in 2007)

Types	Dry	Wet	Submerged
Water-retentive pavement block A	Nov.13	Dec.13	Nov.30
Water-retentive pavement block B	Nov.16	Dec.14	Dec.27
Permeable pavement block	Nov.14	Nov.21	Nov.28
Concrete block	Nov.15	Nov.2	Nov.29
Water		Dec.1	
Sand		Dec.10	
Soil		Dec.12	
Grass		Dec.19	
Bamboo Charcoal		Dec.11	

Note: Each experiment was done from 10:30 a.m. to 4:30 p.m.

3.2. Sample materials

Table 1 lists the materials used for these experiments, which were pavement materials for urban surfaces (about 30 × 30 × 6 cm^3). Table 2 shows other materials such as natural surfaces. These materials were set in an acrylic resin case to make their shape and size equal.

3.3. Experiment

a) Experimental conditions

Experimental observations were made under three simulated conditions; dry conditions with no rain, wet conditions after rainfall and submerged conditions immediately following rainfall.

b) Preparations

In the dry condition, test blocks were kept at 20 °C for 1 d before the experiment to minimize the influence of initial temperature differences. In wet and submerged conditions, test blocks were immersed 2 d before the experiment to absorb sufficient water, and kept at 20 °C for 1 d before the experiment began. In the wet condition, water contents of water-retentive pavement blocks A and B, permeable pavement blocks and concrete blocks were 0.21, 0.08, 0.03 and 0.05 in weight ratios, respectively.

c) Lamp irradiation

In each experiment for one test material, the lamp irradiated for 1 hr and was turned off for 1 hr. This process was repeated three times (totalling 6 hr for one experiment).

d) Verification of experimental apparatus

The experimental apparatus was inspected by repeating the experiment at a different time using the same block. To prevent the influence of different room temperatures on the experimental results, the apparatus was covered with insulators. In some cases, temperature differences between different times at the surfaces were measured to be about 2 to 3 °C.

e) Experiment date and time

Table 3 lists the date and time of experiments.

4. RESULTS AND DISCUSSION

4.1 Artificial covering materials

Fig. 3 shows the results of the experiments for all types of blocks used under dry, wet and submerged conditions.

a) Dry condition

Over the first two irradiations, the surface temperature of water-retentive pavement block A was highest; and the next-highest was that of block B. During the third irradiation, block B was highest, while block A decreased in temperature. When the lamp was turned off, the temperature of both water-retentive blocks A and B seemed to decrease readily.

b) Wet condition

Temperatures were lower on average by about 5 °C in the wet condition than in the dry condition. However, the order within the group was almost the same, except during the third irradiation period. Over three irradiations, the temperature rise of the permeable pavement block was highest. This shows that the characteristics of the permeable blocks allowed for easy evaporation.

c) Submerged condition

In the submerged condition, temperatures were lower than the wet condition by about 1 ~ 2 °C. The difference was especially pronounced between water-retentive block A and B. The temperature of Block B decreased more readily than that of block A.

d) Comparison between four types of blocks in three conditions

Within each condition, it was found that the effect of temperature mitigation differed little due to material. However, the figure shows that there was a large difference in surface temperatures between the three conditions.

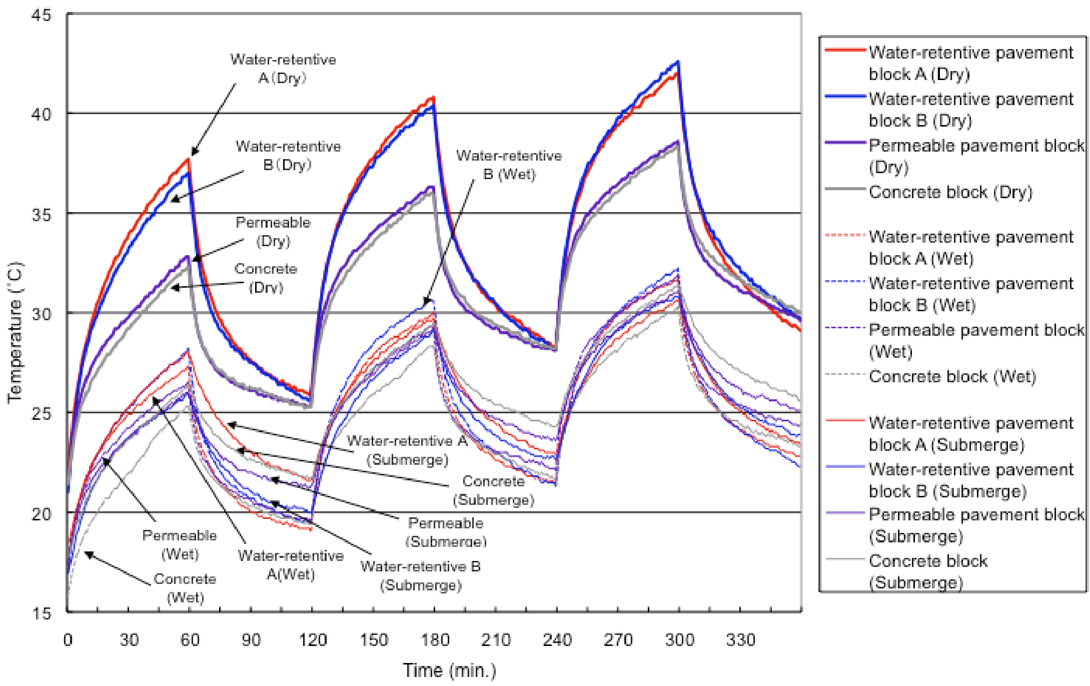


Figure 3. All types of blocks in the dry, wet and submerged conditions.

4.2 Natural covering materials

In this research, natural surface conditions were also examined. Water, sand, soil and grass were used, and pieces of bamboo charcoal, which were cut and made in the course of maintaining bamboo trees on the Sojo University campus, were also used. In these experiments, neither water supply nor sprinkle was performed, and the conditions were made as normal as possible.

Fig. 4 shows the results. The temperature of charcoal bamboo increased considerably. The temperature of grass was fairly high during the first irradiation period, but did not increase as much as in the second and third periods. The curve of the temperature change of the grass was especially different from the other non-organic materials, such as sand and soil. This difference may be due to temperature-adjustment mechanisms of living vegetation. Water exhibited little change in temperature.

Overall, maximum temperatures were not lower than the artificial surface-covering materials. Considering minimum temperatures, however, the decrease in surface temperatures was also large. In fact, natural surfaces have remarkable preventative effects to keep the minimum temperature from rising. These heat-mitigating effects should be an important factor in choosing artificial surface materials for urban heat environments.

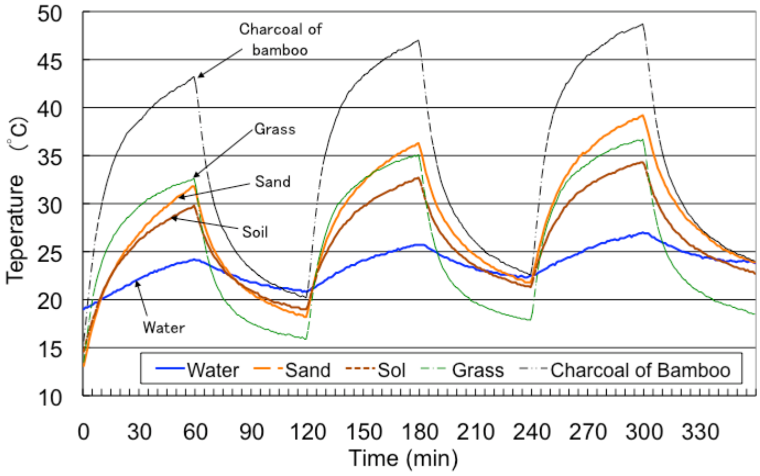


Figure 4. Natural and other materials.

4.3 Discussion

In general, water-retentive pavement blocks were expected to help prevent increases in temperature. It was found that the mitigating effects of these blocks were not as effective, especially in the dry condition. Besides, the characteristics were not same between the 'water-retentive' pavement blocks.

In the previous study, field experiments were performed to confirm the effect of water-retentive blocks. Those results showed similar differences in the effects under the conditions of land cover materials. However, the shortcomings were lightly discussed.

It was difficult to clearly divide the conditions of test materials in field experiments in this research. The comparison between the previous studies and this study, experiments in three conditions, will thus be difficult. Concerns regarding rain conditions during field experiments could also be discussed. Moreover, the experiments should be conducted under clear conditions.

In this research, the differences between three conditions were recognized with some certainty, but there is room to improve accuracy. Also, only two types of water-retentive pavement blocks were examined in this research – research outcomes may be improved with the use of more types of pavement blocks.

In the experiments on natural surface materials, the mitigating effects on temperature increase were normal. But, the effects on minimum temperatures were superior to those of artificial materials. New urban surface pavement materials should be developed taking the characteristics of natural surface materials into consideration.

5. CONCLUSION

In this study, we constructed an apparatus that was covered with an insulator to test the temperature characteristics of urban surface materials. The experiments were performed under three conditions, dry, wet and submerged. As a result, the differences in surface temperature reduction effects were examined.

Natural surface materials were also tested. The maximum temperatures were not reduced compared with water-retentive pavements, but the minimum temperature was decreased more than with artificial materials.

This apparatus made it possible and easier to evaluate the heat characteristics of not only artificial pavement blocks, but of many kinds of surface materials.

The following efforts should be made to improve the apparatus and the method of experiments:

a) Experiment methods were not standardized. The accuracy of the experiments should be improved, especially with respect to the procedure and the experimental conditions. There were concerns about retests and reliability.

b) Model simulations should be performed.

c) Evaporation or transpiration and wind effects should be discussed.

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