Study on the urban heat island mitigation effect achieved by converting to grass-covered parking

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Abstract: The urban heat island mitigation effect of conversion from asphalt-covered parking areas to grass-covered ones is estimated by observation and calculation. The mean surface temperature in a parking lot is calculated from a thermal image captured by an infrared camera. The sensible heat flux in each parking space is calculated based on the surface heat budget. The reduction in the sensible heat flux is estimated to be approximately 100-150 Wm^{-2} during the day and approximately 50 Wm^{-2} during the night, in comparison with an asphalt surface. The air temperature reduction by the spread of grass-covered parking areas is calculated to be about 0.1 °C. Furthermore, consideration is given to the appearance of the parking lot, the growth of grass, the effects of the weight of a car and the heat radiated from its engine, the costs of construction and maintenance, etc.

1. Introduction

The following factors have been established as causes of the urban heat island effect: the decrease in the evaporative cooling ability that results from the natural ground surface being changed to an artificial surface and the increase in the amount of heat stored by this artificial surface, the increase in anthropogenic heat release with the increased air conditioning load for maintaining the comfort of indoor environments, ventilation obstruction caused by the high density of buildings, and restricted long wave radiant losses at night due to the reduced sky view factor etc. The purpose of this study is to investigate the urban heat island mitigation effect achieved by conversion from asphalt-covered parking lots to grass-covered parking lots as a ground surface improvement, which is an urban heat island mitigation technique. This investigation involved an analysis of surface temperature and surface heat budget. Other factors related to grass-covered parking lots are also discussed, for example, the appearance of this type of parking lot, the growth of grass, the effects of a car's weight and the heat radiated from its engine, and the costs of lot construction and maintenance. Green roofs have been studied for thermal benefits to both buildings and their surrounding environments by several researchers, e.g. Teemusk et al. (2009), Takebayashi et al (2007), Wong et al. (2003), Onmura et al. (2001), Eumorfopoulou et al. (1998), Hoyano (1988). Effects of green park have been also studied by several researchers, e.g. Yu et al. (2006), Ca et al. (1998), Honjo et al. (1990-1991), Saito et al. (1990-1991), Kawashima (1990-1991). The urban heat island mitigation effect by green planting was pointed out by several researchers, e.g. Avissar (1996), Taha et al. (1999). In the urban canyon temperature decreases by the effect of covering the building envelope with vegetation are estimated by Alexandri et al. (2008). However, these studies assume the general plants and they don't pay attention to the parking lot. This study takes up a parking lot and performs the several examinations.

With regard to grass-covered parking lots, certain types have been used for nearly 10 years, but they have never been evaluated from the viewpoint of the urban heat island mitigation effect. In this regard, an investigation was conducted Osaka Prefecture (2005). From the Osaka Prefecture report, a maximum surface temperature reduction of 14.7°C was observed from asphalt surfaces to grass-covered parking lots during sunny conditions in the summertime. These parking lots with a large proportion of grass had a superior surface temperature reduction effect. However, in this investigation, the surface temperature observations were performed only at representative points for each parking space. To evaluate a parking lot composed of various materials, it is necessary to obtain the mean surface temperature of the entire parking lot.

Therefore, in this study, surface temperature changes were measured using thermocouples placed on the representative constituent materials in each parking space; thermal images were captured using an infrared radiation camera, and the mean surface temperature of the entire parking lot was calculated from these thermal images. In addition, the net radiation from each parking space and the underground temperatures were also measured. The surface heat budget for each parking lot and the sensible heat flux from each parking lot were then estimated.

2. Outline of observation

2.1 Outline of the site

The examination site is a public parking space managed by Hyogo Prefecture. It is located near Kobe City Center. 36 parking lots are built by the different private companies, and each parking lot is maintained by each company. Characteristics of each parking lot are shown in Table 1. The period for execution and maintenance of grass is from June 10 to July 27; our observation began on July 28. In this study, we evaluated the urban heat island mitigation effects during the period just after the end of the execution and maintenance when it was in the state it is used for.

An overall view of the observation site is shown in Figure 1, and a plan of the parking spaces and the neighborhood is shown in Figure 2. The observation site is located in the residential area of the central ward, Kobe City. The southern side of the site is open, facing the road, with a five-storey building adjacent to the western side and a two-storey building adjacent to the northern side of the site. The picture in Figure 1 was taken from the roof of the building in the west, with the north on the left. The characteristics of each parking lot emerge in relation to the materials used to support the weight of the cars and their arrangements. Grass has been laid without removal of the older asphalt surface. The older asphalt surface that remains can be observed at the top right corner of Figure 1 as a gray area. The new, black asphalt surface was constructed to even the surface of the parking lots.

The size of each parking lot is 5.3 m × 2.5 m, and the access aisle is approximately 7.4 m wide; thus, the size of the site is approximately 56 m × 18 m. The thickness of the material surface in 19 lots located in the western part of the site is 25 cm, and the lot with the thinnest material surface, i.e., 10 cm, is at the northeast edge. The incline for water drainage exceeds 2% from the north to the south. Rainwater penetration in the northern part does not influence the southern part. A drainpipe is set at the front of the southern side of the lot to allow water drainage.

The classification of parking spaces based on the system used to support the weight of cars is shown in Table 2. Grass and other materials are arranged for supporting the weight of cars in every parking lot. A shield for the heat radiated by the cars' engines has been used only in 1 parking lot. It is a rubber mat which is set up under the car's engine. For each parking lot, improvements in the thermal environment were considered, such as the installation of a water-keeping block, an underground sprinkler system, or an underground water preservation system, in which a water tank is installed under the parking lot. In addition, different environmentally friendly materials (recycled materials and materials of the local product), plants (cold proof, heat proof, shade resistant, etc.), and soils are also considered for use.

The building in the west begins to provide shade from the sun at 12:00 from the northwest edge of the parking lot, and it slowly increases toward the eastern part during the summer. Solar radiation meters were set in parking spaces from the western end to the eastern end of the site in order to measure the total solar radiation for 1 day during sunny conditions; those in the central to eastern part of the lot showed approximately equal values as the total solar radiation for the day as observed from the roof of the building near the parking lot. Further, those in the western part of the lot showed values that were approximately two-thirds of the total solar radiation for the day as observed from the roof of the building. It is necessary to consider the shade of the western building while evaluating the urban heat island mitigation effect, but it does not negatively influence grass growth. These parking spaces are for people occupying the building in the west; the number of people is typically less than the parking areas, unless a large meeting is being conducted. In addition, the cars are concentrated in the parking spaces closest to the exit at the eastern side of the site. The actual usage of the parking spaces in August and September 2005 was observed by using a video camera that captured pictures every 15 minutes. The average time for which the northeast parking spaces were used was approximately 2 to 3 hours, and that for which the other parking spaces were used was approximately 10 to 20 minutes. This evaluation was carried out at a parking lot used less frequently.

2.2 Outline of the observation

The investigation elements in this study are as follows.

- Urban heat island mitigation effect
- Appearance of the parking lot
- Growth of grass
- Effects of the weight of cars and the heat radiated from their engines
- Costs of construction and maintenance

In this study, determination of the urban heat island mitigation effect was the principal objective. The methods used to evaluate the other elements are summarized here. The appearance of the parking lot was evaluated via a questionnaire. The growth of the grass was evaluated based on the ratio of the grass-covered area and the area where grass was observed to be actively growing. The effects of the weight of cars and the heat radiated from their engines were evaluated by a short experiment using a few cars. The costs of construction and maintenance were evaluated from the reports from each leasing company.

To determine the urban heat island mitigation effect, surface temperatures and underground temperatures were continually measured in each parking space by using thermocouples (t-cc). The placement of these t-cc is shown in Figure 3. The surface temperature of the grass was substituted for the underground temperature at 1 cm from the surface. So, the sensor is not affected by the solar radiation directly. Thermocouples were also set on the surface of the other materials. In cases in which the parking lot consisted of multiple materials, different measurement points were included. Every parking lot consisted of several material layers; therefore, the thermocouple used to measure the underground temperature was set in the lower part of the first layer from the surface for both grass and the other materials. The observation points for the thermocouples were set at the back of each parking lot so that the lines would not be cut by cars. However, several lines cut by cars and grass-cutting equipment were observed by the end of the summer of the first year, September 2005. As a result, the observations using thermocouples were insufficient for all the parking spaces.

To estimate the weather conditions, solar radiation and infrared radiation were recorded on the roof of Kobe University, which is a short distance away from the site. Air temperature and relative humidity were measured at the northern side of the site by using a thermo-hygrometer with a radiation shield and mechanical fan. Wind direction and velocity were measured at the southeastern corner of the site by using a three-cup type anemometer.

Independent of the continual observation mentioned above, during the weekend, when the lot was empty, the surface temperature distribution was monitored by using an infrared camera; the observation wavelength was 8–14 μm, and the solar reflectance for each parking space was measured using a net radiation meter. The surface temperature distribution for the entire site was observed from the roof of the building in the west, and that of each parking space was observed from a stepladder. These observations were carried out at 0300, 0600, 0900, 1200, 1500, 1800, 2100, and 2400 hours. Solar reflectance observations were carried out in July, August, September, and December of 2005 and in March, July, August, and September of 2006. These were carried out in the morning when the shade influence from the building in the west was absent.

3. Observation results

3.1 Observation results for surface temperature

The observation results for the surface temperature of a typical parking space are shown in Figure 4. These are the results from a summer day with good weather just after the execution and maintenance of grass. Asphalt surfaces remain at a higher temperature until dawn. The surface temperature of the wooden surfaces was higher than that of the others during the day and lower at night because of the low heat capacity of wood. The surface temperature of concrete and blocks was not as high as that of asphalt, but it was slightly higher than the air temperature at night because of their high heat capacity.

The observation results for the surface temperature distribution during days with good weather are shown in Figure 5. They pertain to the period just after the execution and maintenance of the grass. Several images are connected to confirm total surface temperature distribution. The distance between the observation points and the objects and the emissivity of each objective element was not revised. The surface temperature of the region in the left part of the image at 1500 h is lower than that of the regions in the other parts because of the shadow cast by the building in the west. Except the wooden surface, the asphalt surface temperature was the highest at all times because of the thermal storage of daytime solar radiation by asphalt. In cases in which different materials were used to support the carload, it is easy to identify the difference between the surface temperature of the grass and the other materials.

Observations were carried out on a stepladder, and the images are diagonal photographs as shown in Figure 6. Therefore, conversion of the thermal images was carried out as in Figure 6, and the mean surface temperature of each parking space was calculated from these images. Simultaneously with the infrared camera observation, we also measured the surface temperature of a representative point by using a contact thermometer. We checked the relation between the observation results obtained via the infrared camera and contact thermometer. We did not revise these measurements based on the emissivities of the different materials. It is thought that the emmisivities of the materials in the grass-covered parking are between 0.9 and 1.0. The emmisivities of all materials were not able to specified, so the same value was used for all materials. The error of the surface temperature by the emmisivities is estimated about less than 10 K. However, it is confirmed that emmisivities of grass are approximately constant values by our conventional studies, so the error between each parking lot is small.

An example of the observation results for the surface temperature is shown in Figure 7. The surface temperature of the grass was lower than that of the other materials used to support a car's weight. The surface temperature of car engine protector was also high. In this study, grass-covered covers most of each parking lot and variation of solar reflectance of grass is not so large, so the difference of the mean solar reflectance of the parking lot is small. Observation result of the mean solar reflectance of the parking lot is shown in figure 8.

The relationship between the green cover ratio and the mean surface temperature of the parking lot is shown in Figures 9–11. The air temperatures and asphalt surface temperatures are also shown in these figures. The green cover ratio was calculated from the survey results comparing the area that was green with the area that could potentially be green in each parking space.

In cases in which the green cover ratio was high, the mean surface temperature of the parking space was lower at all times and was lower than that of the asphalt surface. The mean surface temperature of the parking space was higher than the air temperature, and a sensible heat flux was supplied from the surface to the air during the day. During the night in July and August, the mean surface temperature of the parking space was the same as the air temperature; therefore, it was not a cause of higher air temperature. Further, it was lower than the air temperature in September, and it thus contributes to a reduction in the air temperature. It is thought that the radiant cooling is larger due to a little atmospheric humidity in September. The relationship between the green cover ratio and mean surface temperature of the parking lots in the summer of 2006 is similar to those in the summer of 2005.

3.2 Estimation of sensible heat flux

The direct cause of an urban heat island is sensible heat flux from the ground surface to the atmosphere. There are several methods for the observation of sensible heat flux, for example, the eddy correlation method using an ultrasonic anemometer and the scintillation method (e.g. Moriyama, M. et al. (2004)). However, it is practically difficult to apply a relative evaluation to the numerous spaces being observed in this study. Therefore, the sensible heat flux from each parking space was estimated using the bulk method, which assumed the convection heat transfer coefficient. The expression used for this calculation is shown below.

$$V = \alpha_c (T_s - T_a) \quad (1)$$

where V is the sensible heat flux (W m^{-2}), α_c is the convection heat transfer coefficient (W m^{-2} K^{-1}), T_s is the surface temperature (K), and T_a is the air temperature (K). The sensible heat flux from each parking space at 2100 h during the summer of 2005 is shown in Figure 12. It was calculated using the mean surface temperature of each parking space and the air temperature. The convection heat transfer coefficient was calculated using the Jurges formula ($\alpha_c = 4.2 \times v + 6.2$, v is wind velocity (m s^{-1})) with the observation results of wind velocity. Hagishima et al. (2005) compared recent experimental research on the convection heat transfer coefficient of urban surfaces in the field and in wind tunnel. They pointed out that our overall understanding of the convection heat transfer coefficient remains too low for accurate modeling of urban surface climate. So, the convection heat transfer coefficient calculated by the traditional method in this study may be small. However, the convection heat transfer coefficient on the parking lot located in the bottom of the urban canopy may be small, too. The heat island effect was very apparent in the night. Since the increase in the uncomfortable feeling caused by the fact that the air temperature did not decrease during the night was considered to be a problem, we adopted the sensible heat flux from the ground surface to the atmosphere during the night as an examination target. A sensible heat flux of around 50 W m^{-2} was supplied from the asphalt surface to the air at 2100 h in July and August, which is the reason why high air temperatures persist during the night in urban areas. The sensible heat flux from grass-covered parking spaces was approximately 0, which confirmed the urban heat island mitigation effect of using grass-covered parking spaces.

3.3 Estimation of new standard effective temperature (SET*)

An increase in the incidence of heat stroke has been noted, and the inferior outdoor thermal environment during the day is another problem associated with the urban heat island effect. To evaluate the improvement in this inferior thermal environment by the use of grass-covered parking, a new standard effective temperature (SET*) for each parking space was calculated from the mean surface temperature of the parking space and weather data such as air temperature, relative humidity, wind velocity, and solar radiation. We assumed that a metabolic rate of 1.0 was achieved, along with a clothing insulation value of 0.7 clo. The only variable factor was the mean radiation temperature (MRT) for the individual parking spaces. Air temperature change is estimated to be around 0.1 degree (refer to section 3.5) and the influence on the SET* is less than 0.1 degree, so it is ignored in comparison with the change of MRT. It seems that the next two points are left as main research themes; the application possibility to the summer severe thermal environment, and the application method to the non-steady state of a human body. However, in this study, SET* is used for comparison of the influence on human body by various grass-covered parking.

For the MRT calculation, we assumed that the influence of the surrounding buildings was negligible and that the entire ground surface was covered by the target grass-covered parking spaces. Short- and long-wave radiation from the sky were assumed from the observational results, reflected solar radiation was calculated by the solar reflectance observed for every parking space, and long-wave radiation from the surface was calculated from the mean surface temperature of each parking space. The absorption ratio of solar radiation for the human body was assumed to be 0.66.

The SET* estimation results for each parking space at 1200 h during the summer of 2005 are shown in Figure 12. The thermal sensation vote is also shown in Figure 13 based on the reference (The society of heating, air-conditioning, and sanitary engineers of Japan (2001)). However, studies about thermal sensation in outdoor spaces under high air temperatures are limited. Calibration of outdoor thermal comfort models were carried out by Monteiro et al. They pointed out that most indexes can be applied to assess thermal comfort in outdoor spaces if they are calibrated with empirical data. The SET* was calculated according to an estimation program based on the human body thermal equilibrium model of Gagge et al. (1986). "With solar radiation" implies the assumption that the solar radiation was directly incident on the human body in the parking space and "without solar radiation," the assumption that solar radiation was not directly incident.

The right-side end point in the figure is the SET* of the asphalt. The differences among the parking spaces were not substantial in July and August because the mean surface temperature of the parking lot is similar to the asphalt surface temperature, depending on the constituent materials, and the reflective solar radiation from grass is greater than that from asphalt. The differences among the parking spaces are less than those that result from the presence or absence of solar radiation or from changes in the weather conditions. It may be said that providing shade from solar radiation with an umbrella is more effective than improving the surface coating under the person. The solar radiation absorption ratio of the human body has been assumed to be 0.66. It is thought that wearing clothes with a lower absorption ratio for solar radiation is also effective. As observed in figure 8, the tendency of the mean surface temperature of the parking lot to decrease with an increase of the green coverage ratio is confirmed, but the data at 1200 h varies greatly, and a consideration of materials other than grass is therefore also important.

3.4 Analysis of surface heat budget for representative parking spaces

The surface heat budget for the representative parking spaces was analyzed, and the heat island mitigation effect and outdoor thermal environment improvement effect were considered. The surface heat budget equation for a parking space consisting of various materials is expressed by the following expressions.

$$\Sigma\ Rn_i \times S_i = \Sigma\ V_i \times S_i + \Sigma\ lE_i \times S_i + \Sigma\ A_i \times S_i \qquad (2)$$

where the heat budget components are calculated by the following expressions. Rn is the net radiation (W m^{-2}), lE is the latent heat flux (W m^{-2}), A is the conduction heat flux (W m^{-2}), and S_i is the ratio of i area for the parking space (–).

$Rn_i = (1 - \rho_i) S\downarrow + \varepsilon_i (L\downarrow - \sigma T_{si}^4)$ (3)

$V_i = \alpha_{ci} (T_{si} - T_a)$ (4)

$lE_i = \beta_i l \alpha_{wi} (X_{si} - X_a)$ (5)

$A_i = \lambda_i (T_{si} - T_{\Delta zi})/\Delta z$ (6)

where $S\downarrow$ (solar radiation, W m^{-2}), $L\downarrow$ (downward long wave radiation, W m^{-2}), T_a (air temperature, °C), X_a (absolute humidity, kg kg'^{-1}) are obtained from the observation results and α_c, α_w (mass transfer coefficient, kg m^{-2} s^{-1} (kg $kg'^{-1})^{-1}$) are calculated by the Jurges formula and Lewis equation. σ is the Stephan-Boltzman constant (=5.67 × 10^{-8}, W m^{-2} K^{-4}). $T_{\Delta z}$ (temperature of first layer of the soil, K) in Δz (depth to first layer of the soil, m) is calculated by the following one-dimension unsteady heat conduction equation.

$C_p \gamma (\partial T / \partial t) = \lambda (\partial^2 T / \partial z^2)$ (7)

ρ (solar reflectance, –), ε (emissivity, –), β (evaporative coefficient, –), λ (thermal conductivity, W m^{-1} K^{-1}), C_p (specific heat, kJ kg^{-1} K^{-1}), γ (density, kg m^{-3}) are the parameters for an unknown T_s (surface temperature, °C). The parameters for a surface heat budget model for each surface is shown in Table 3. It is assumed that ε is 1. With regard to grass surfaces, heat budgets are calculated for both grass and soil surfaces. ρ is given by the result of observations and $C_p\gamma$, by reference. β and λ are estimated from a comparison between observed values and calculated values (Takebayashi and Moriyama (2007)). The observation and simulation results for the mean surface temperature of the parking spaces on July 30, 2005, are shown in Figure 14. It may be said that the tendency of the surface temperature to change generally reappeared. The calculation result for the mean sensible heat flux of the parking lot on July 30, 2005, is shown in Figure 15. The sensible heat flux reduced from around 100–150 W m^{-2} in the day to around 50 W m^{-2} in the night in comparison with asphalt; thus, the urban heat island mitigation effect was confirmed. In the parking spaces considered as examination objects in this study, the sensible heat flux for spaces consisting of grass and concrete surfaces was reduced by a maximum of around 200 W m^{-2}, because the solar reflectance of concrete surfaces is high.

3.5 Estimation of air temperature changes in a case in which grass-covered parking spreads to an entire urban area

The area to the east of Sannomiya Station, central ward, Kobe City was selected as the study area. The land use ratio for the study area, as taken from detailed land use information, is shown in Figure 16. The air temperature was calculated based on the land use ratio. The ratio of parking lot to the total area was 6.0%, and it was included in the concrete building category. All parking spaces were assumed to have been changed to grass. A one-dimensional surface boundary layer model was used for surface air temperature calculation, and the upper boundary condition was obtained by the observation data from Osaka tower (120 m) from August 1–31, 2005 (Moriyama and Takebayashi (1999)). It was assumed that an urban area with the same land use ratio was equally spread in both horizontal directions.

In addition to assuming that all parking spaces (6.0% of this area) had been changed to grass-covered parking, calculations were also made for changing 10%, 20%, or 30% of this area into a green area. The calculation results for hourly mean air temperature differences under basic conditions are shown in Figure 17. The air temperature decreased by around a maximum of 0.1K by spreading grass-covered parking to the entire urban area. Since only 6% of this area is parking lots, a little temperature decrease is predicted only by the introduction of measures for the parking lots. Because the parking spaces are limited in the urban area, air temperature decrease by only the grass-covered parking method is small. So, it is necessary to introduce the grass-covered parking method with measures for urban heat island to other places; for example, the building rooftop and the road surface, etc. If a higher green cover ratio is achieved, a greater air temperature decrease is expected. Air temperature reduction is relative large although a sensible heat flux reduction is a little in the nighttime in comparison with the daytime, because of the atmospheric stability difference between the nighttime and the daytime.

4. Consideration of the other aspects

The appearance of the parking lot, walkability, growth of grass, the effect from the weight of cars and the radiated heat from their engines, and the costs for construction and maintenance were considered. Summaries of the evaluation results for each of these aspects follow.

(1) Appearance of parking lot

The appearance of the parking lot was evaluated using a questionnaire submitted both by users and non-users who were shown a montage of photographs of the parking lot. It received good evaluation by users generally. In the montage-based evaluation, parking lots that blended well with the surrounding structures or that had growing and homogeneous green grass were considered to be better than parking lots with artificial material structures.

(2) Walkability

Walkability was evaluated using a questionnaire given to users. Parking spaces with soft soil or small steps between the grass and other materials obtained lower evaluations.

(3) Growth of grass

The growth of grass was evaluated by the ratio of the grass-covered area and the area in which grass was observed to be actively growing. Each parking space was divided into 50 sections, and the green cover was estimated for each section. There are some parking spaces where the grass was about to die during sunny weather, but they were mostly acceptable throughout the periods. A few parking spaces were considered in this investigation, and the maintenance of grass was adequate.

(4) Effects from the weight of a car

The effects from the weight of a car were evaluated by a short experiment using a few cars. These effects were evaluated by the changes in the ratio of green cover area and soil hardness before and after a car was parked, and this was carried out 30 times for each space over 2 days. The changes in the ratio of the grass-covered area and soil hardness were confirmed in the parking spaces classified according to the information in Table 2. In this investigation, a one-time evaluation was carried out by a short experiment, but a long-term evaluation involving a large number of parked cars is necessary in the future.

(5) Effects of radiated heat from a car's engine

The effects on the surface temperature of the grass of the heat radiated from a car's engine were evaluated using a short experiment using a few cars, as shown in Figure 18. A rise in the surface temperature of the grass was also confirmed using a short experiment (10 minutes parking), but it did not reach the point of decisive damage. The grass was able to revive.

(6) Costs of construction and maintenance

The costs of construction and maintenance were evaluated based on reports from each leasing company. The construction and maintenance costs were reported by each company. The former were around 2–7.5 times that of asphalt pavement (5,000 yen m^{-2}), and the latter were around 0.1–7 times that of asphalt pavement (500 yen m^2 $month^{-1}$). The maintenance costs have a large frequency. The maintenance costs for the second year were lower than those for the first year for many parking spaces.

5. Conclusions

The urban heat island mitigation effect from changing asphalt-covered parking areas to grass-covered ones was estimated by the analysis of surface temperature decrease and the surface heat budget. In addition, the appearance of the parking lot, the growth of grass, the effects from the weight of a car and the heat radiated from its engine, and the costs of construction and maintenance were also considered.

The urban heat island mitigation effect and the thermal environment improvement effect were estimated by observing the mean surface temperature of the parking lot by using an infrared camera. The tendency for the mean surface temperature of a parking space to decrease with an increase in the green coverage ratio was confirmed, but the mean surface temperature of parking spaces varied greatly depending on the other materials used in addition to grass. From the analysis of the surface heat budget for representative parking spaces, the sensible heat flux was reduced from around 100–150 W m^{-2} in the daytime to around 50 W m^{-2} during the night, in comparison with asphalt.

From the estimation result of air temperature changes in a case where grass-covered parking spreads to an entire urban area, the air temperature decrease by around a maximum of 0.1K by the spread of grass-covered parking. Since the parking lot area in the urban area is limited, a little temperature decrease is predicted only by the introduction of measures for the parking lots.

From a consideration of the other aspects, it was confirmed that a grass-covered parking area with a more than 60% green cover ratio generally has high evaluation results in relation to the thermal environment, the appearance of the parking lot, and the growth of grass. However, consideration of the effects of a car's weight is necessary. Further examinations are required to determine the long-term influence of a car's weight and engine radiation, as well as the maintenance technique (cutting grass, sprinkling, fertilizer, etc.).

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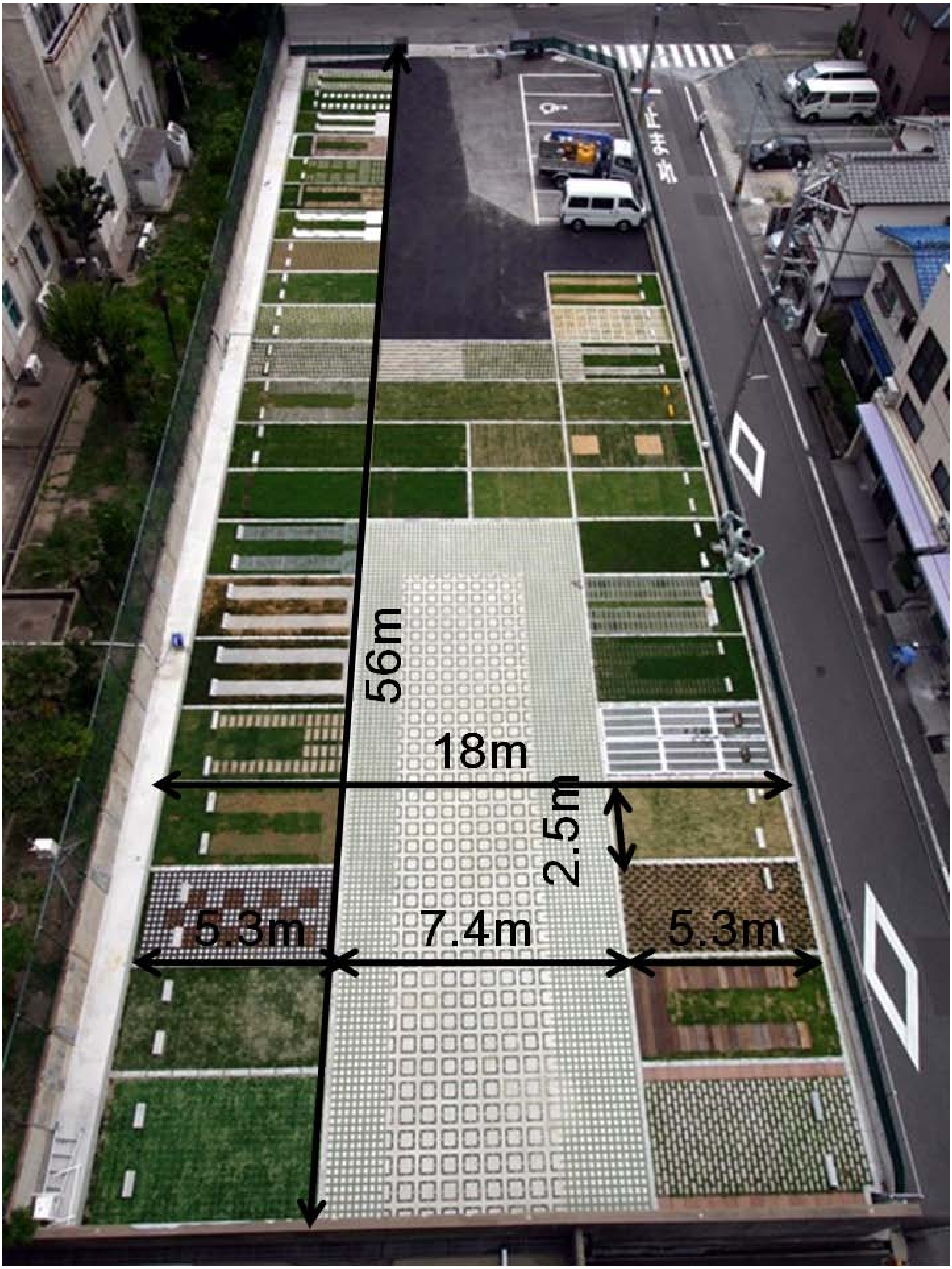
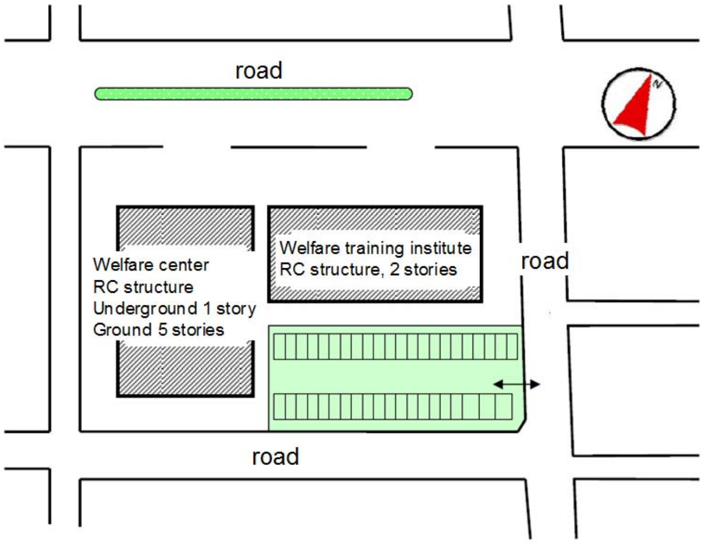


Figure 1



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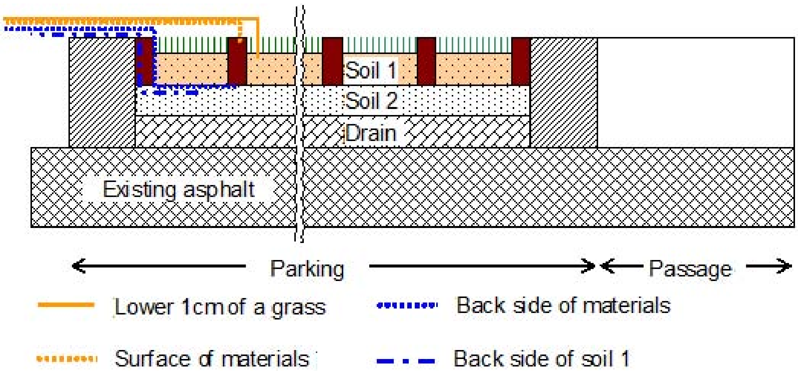

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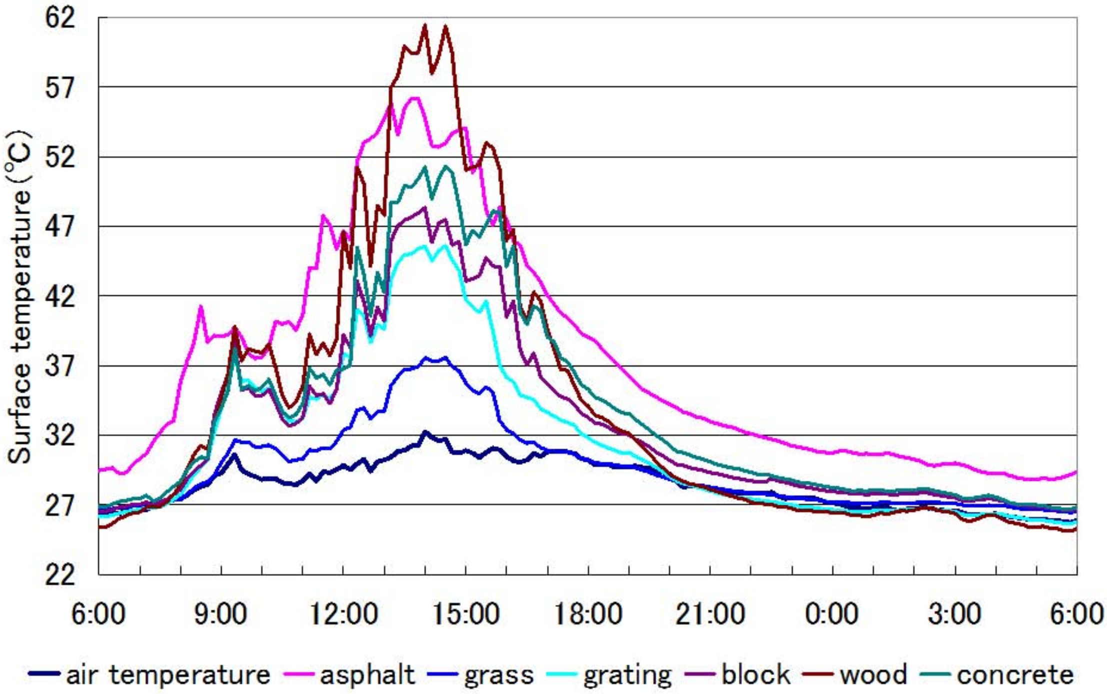

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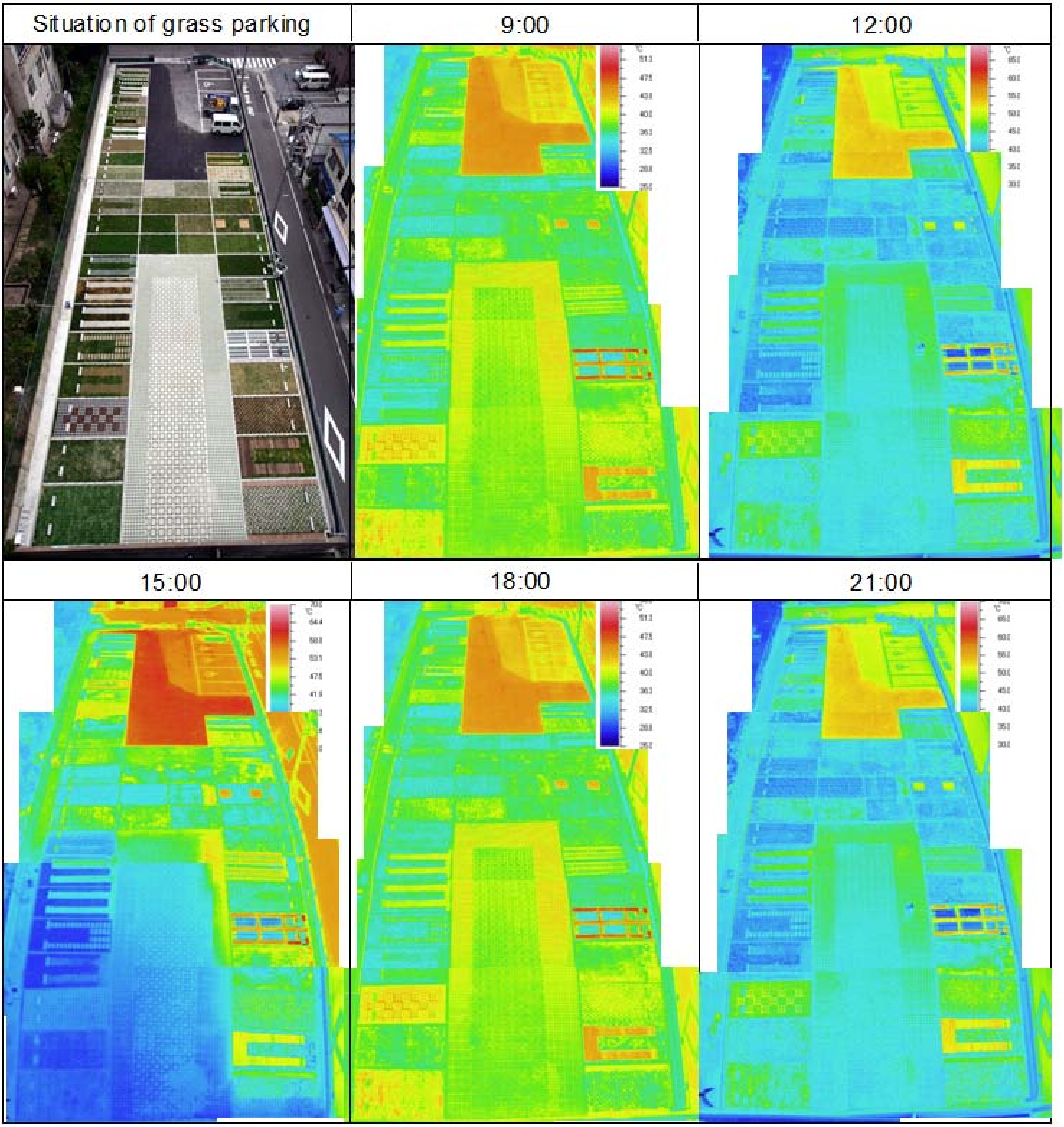

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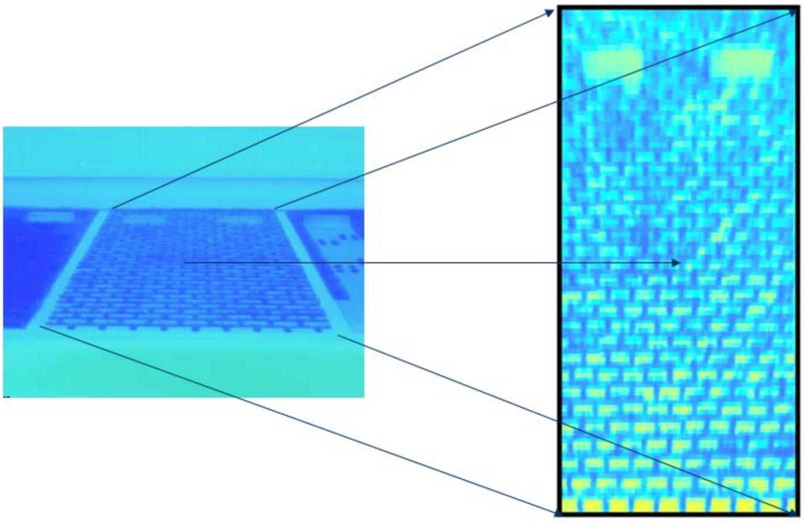

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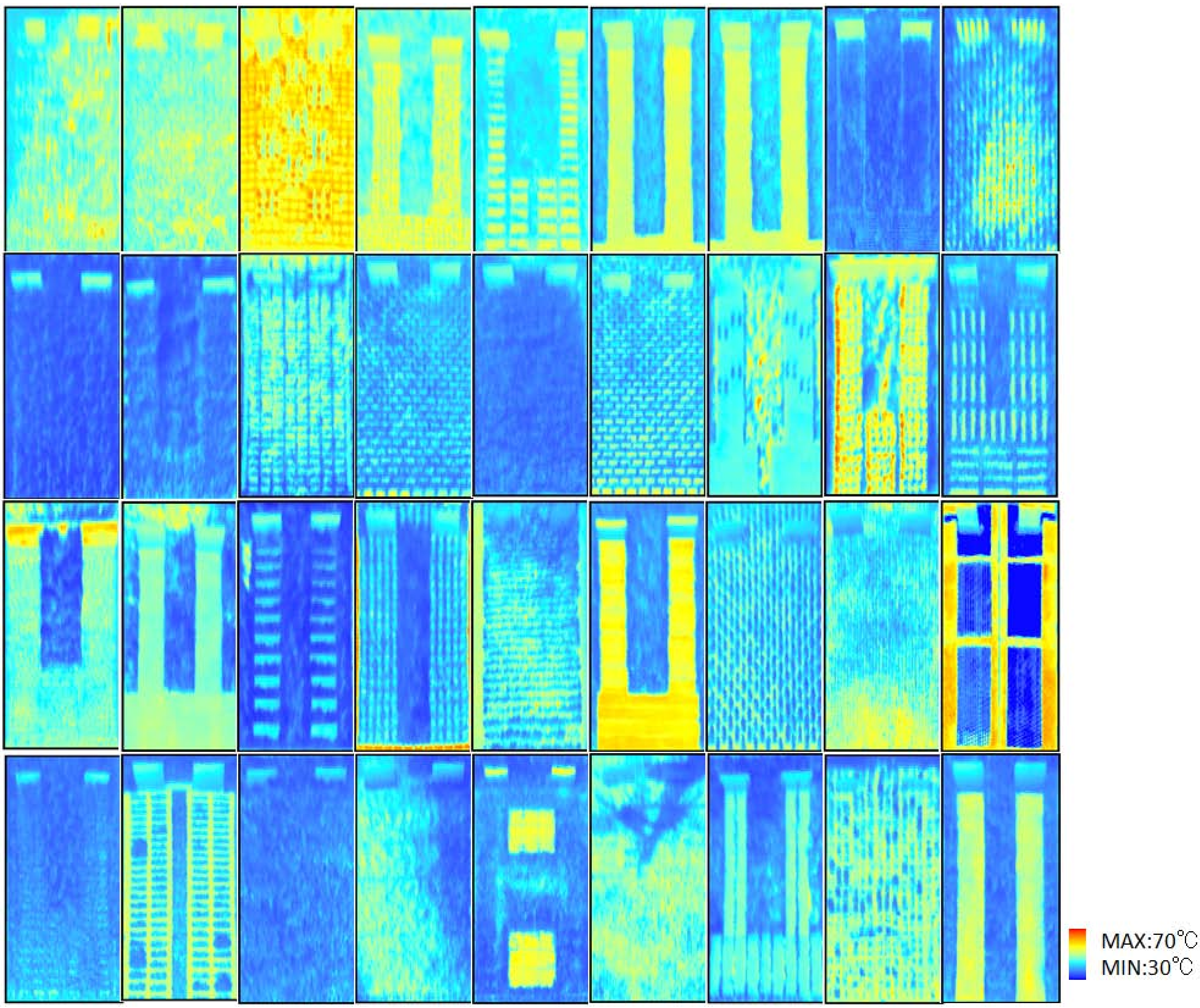

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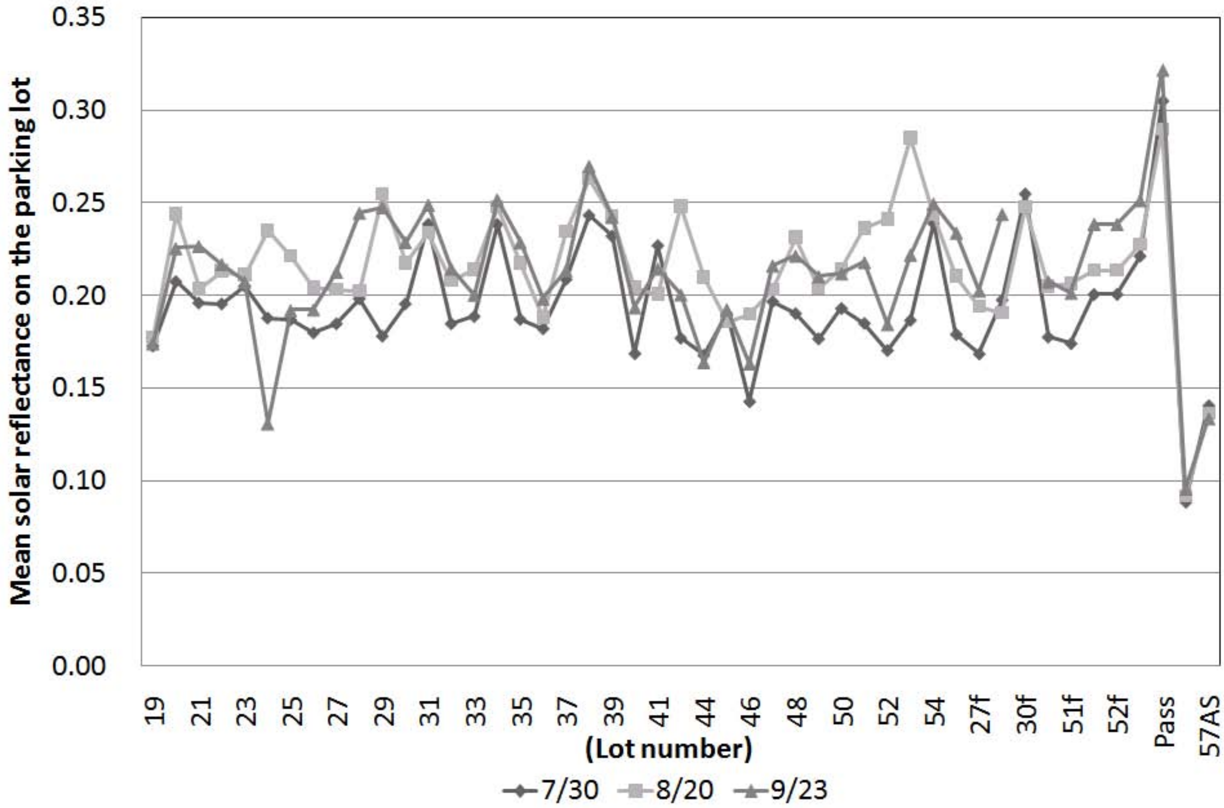

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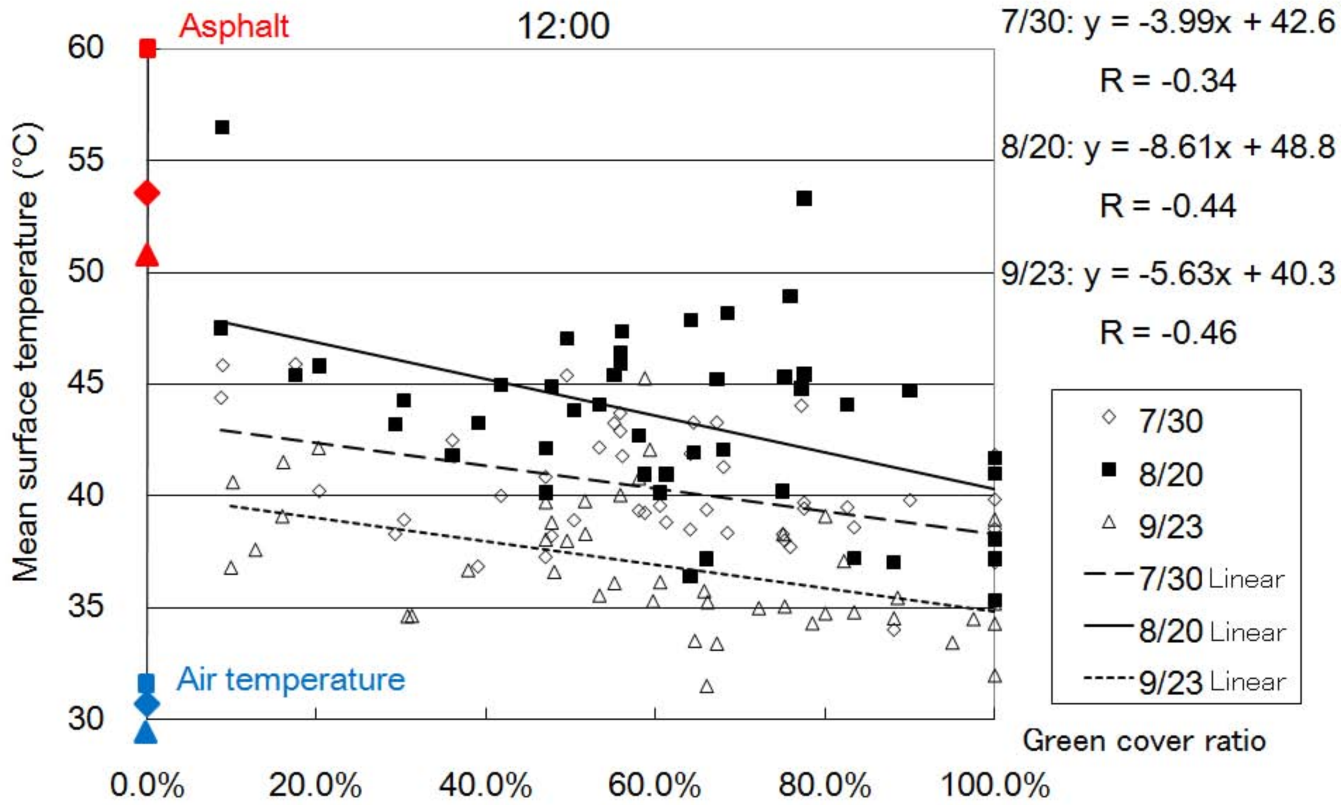

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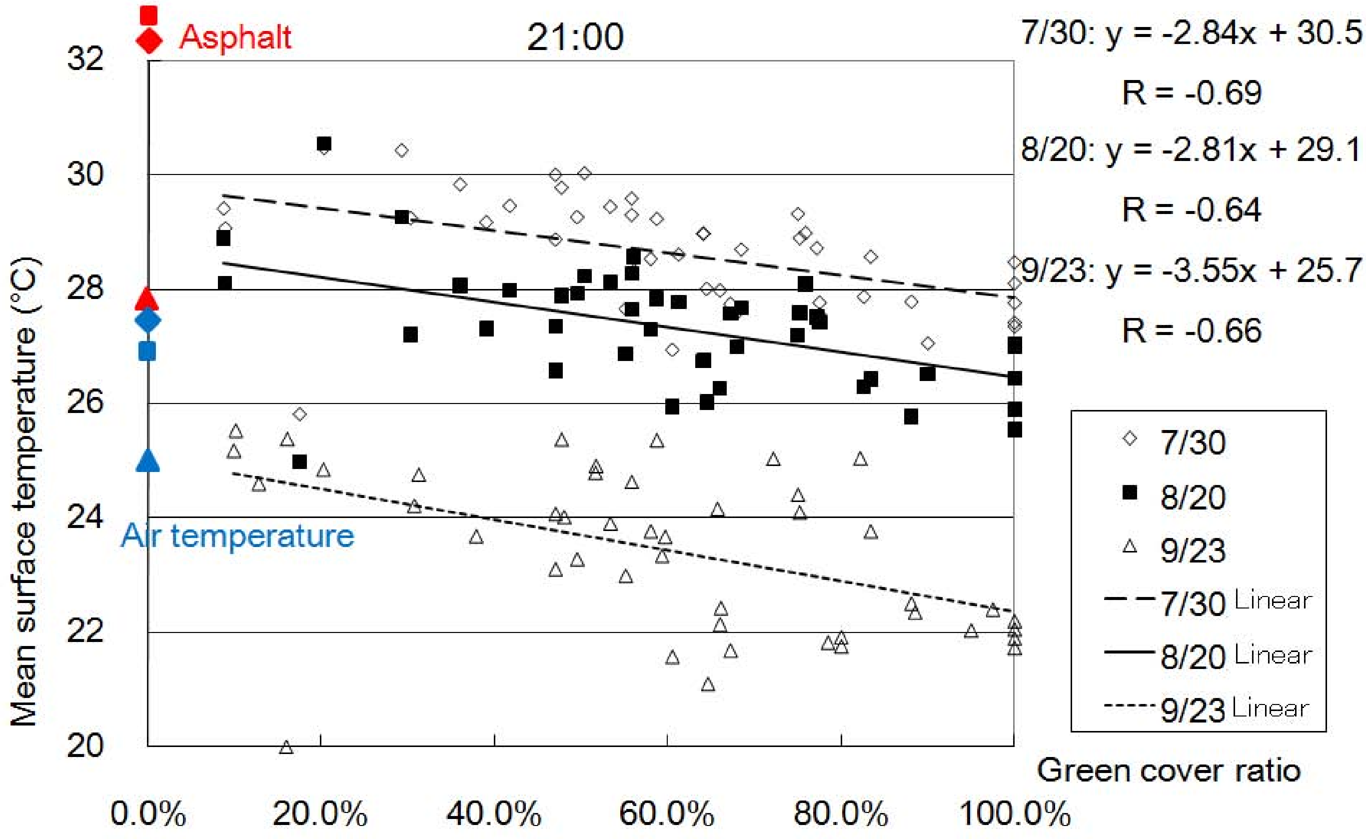

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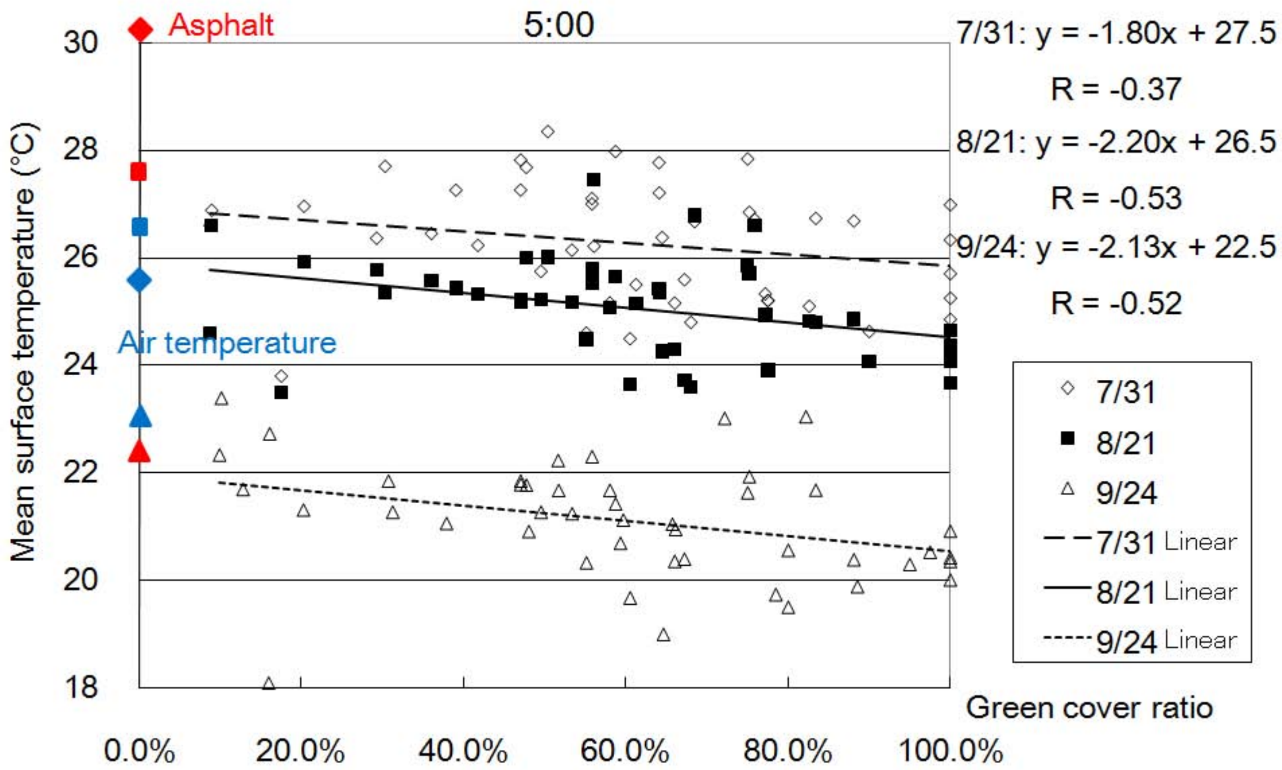

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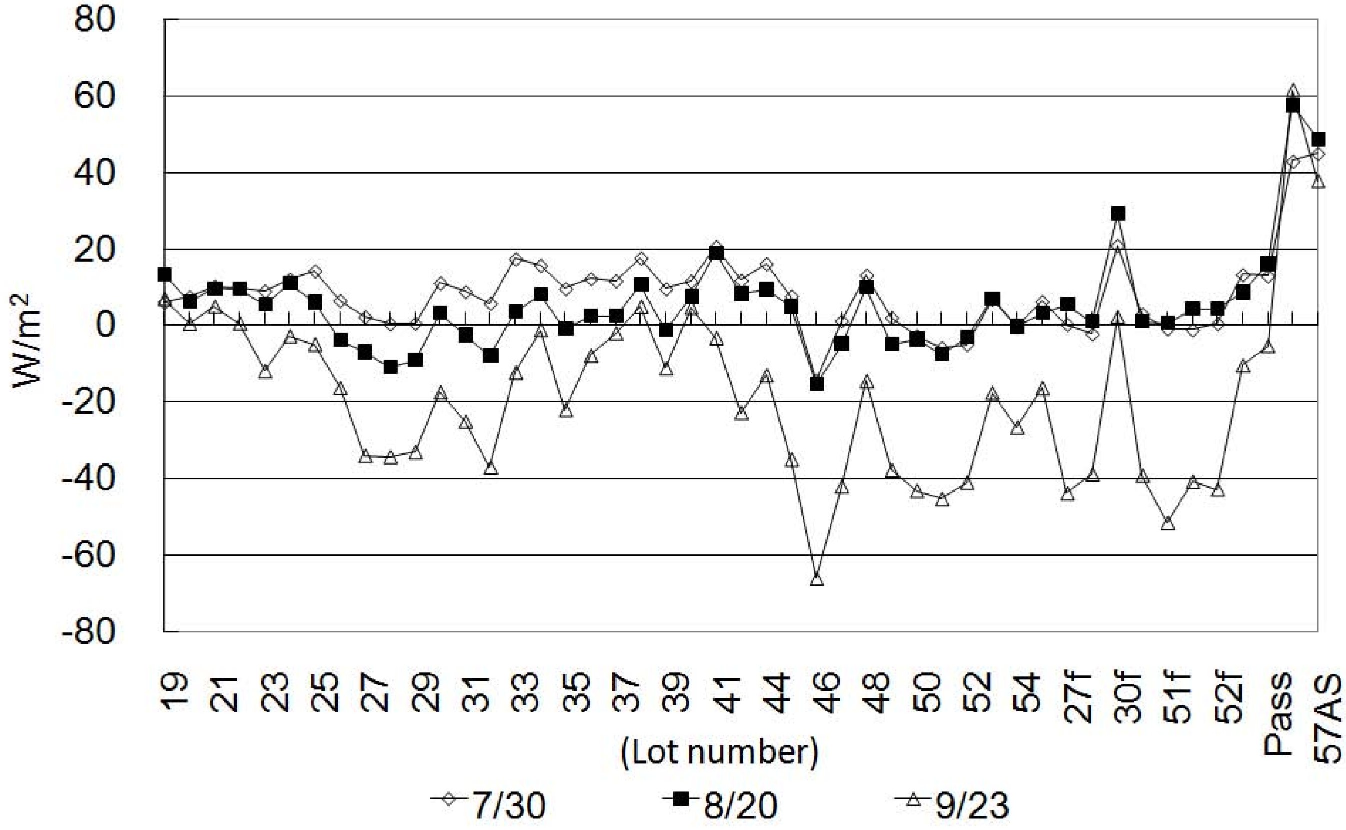

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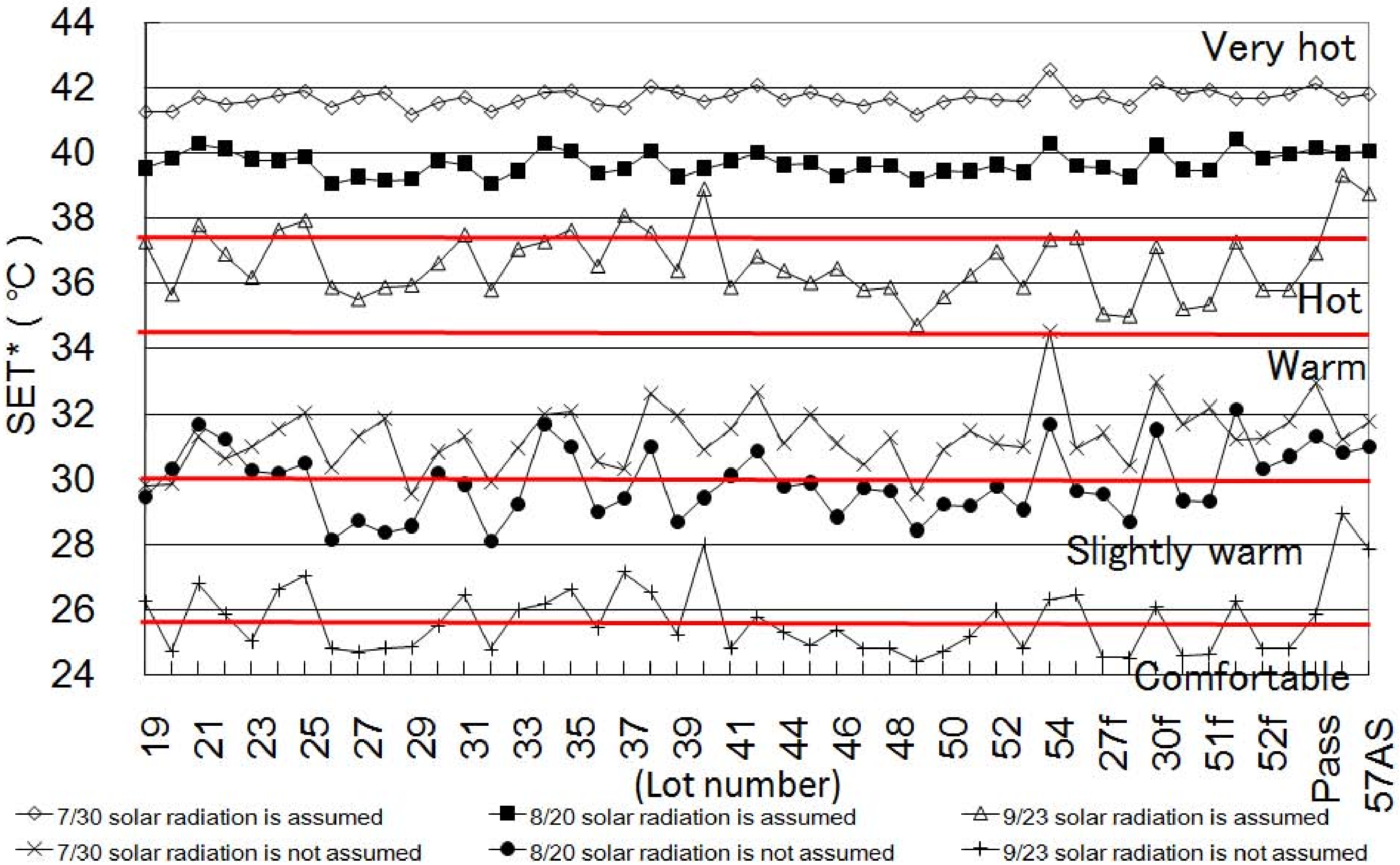

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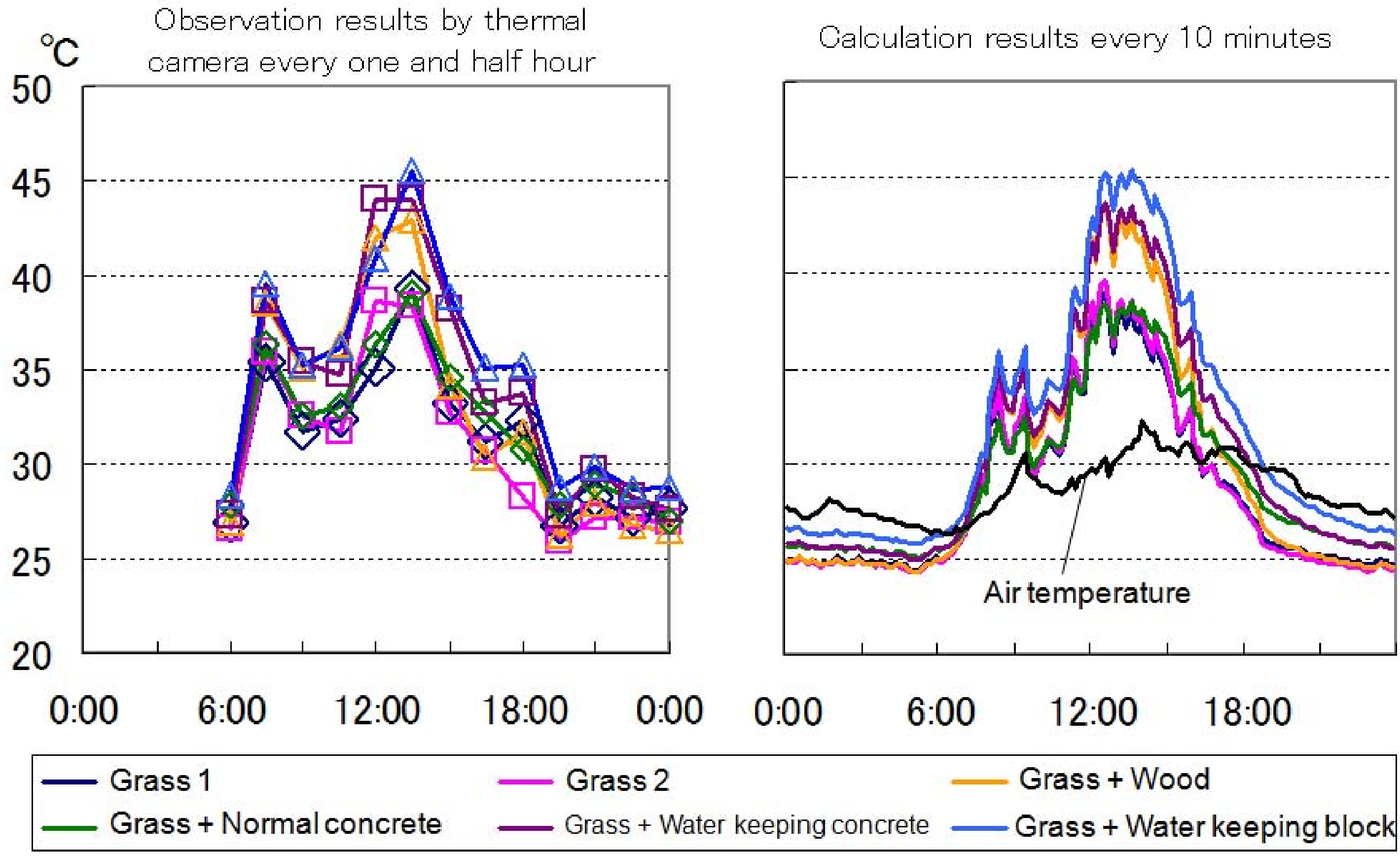

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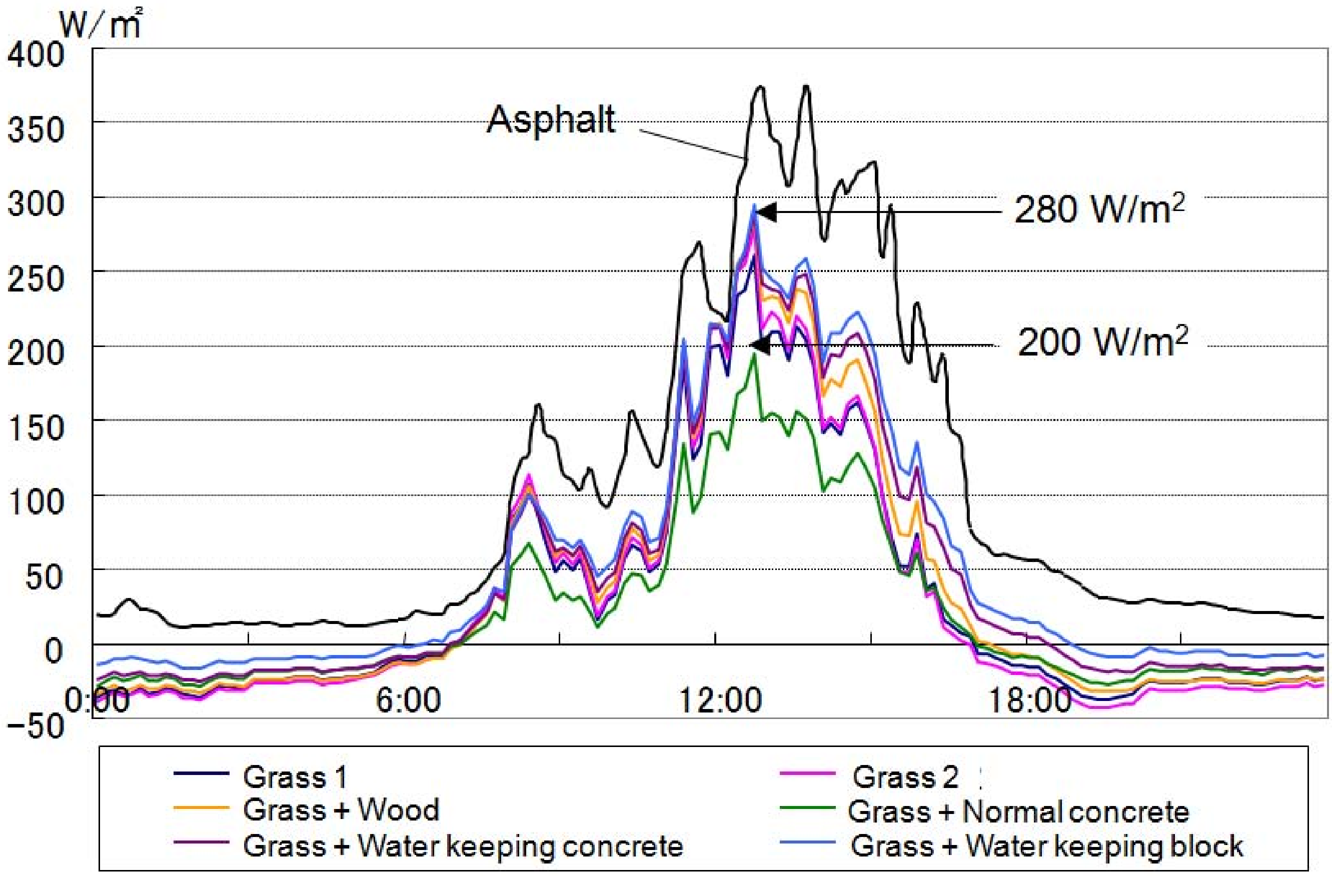

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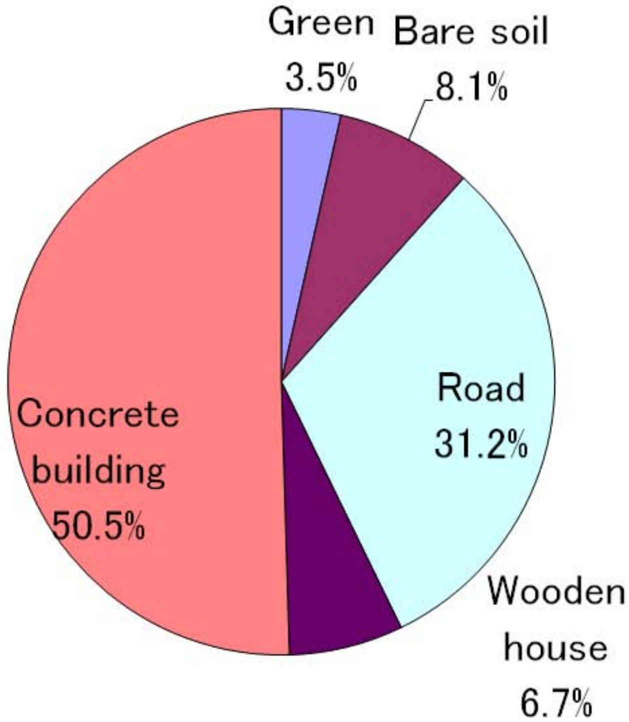

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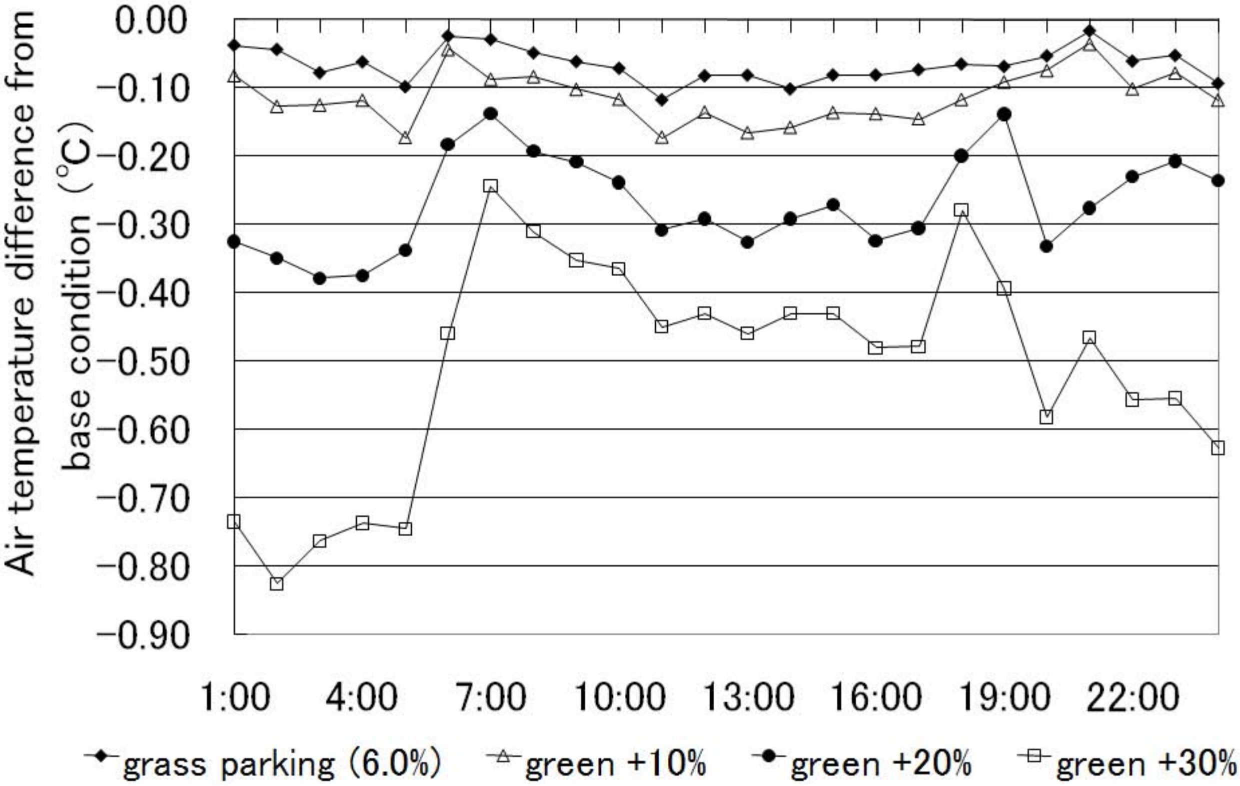

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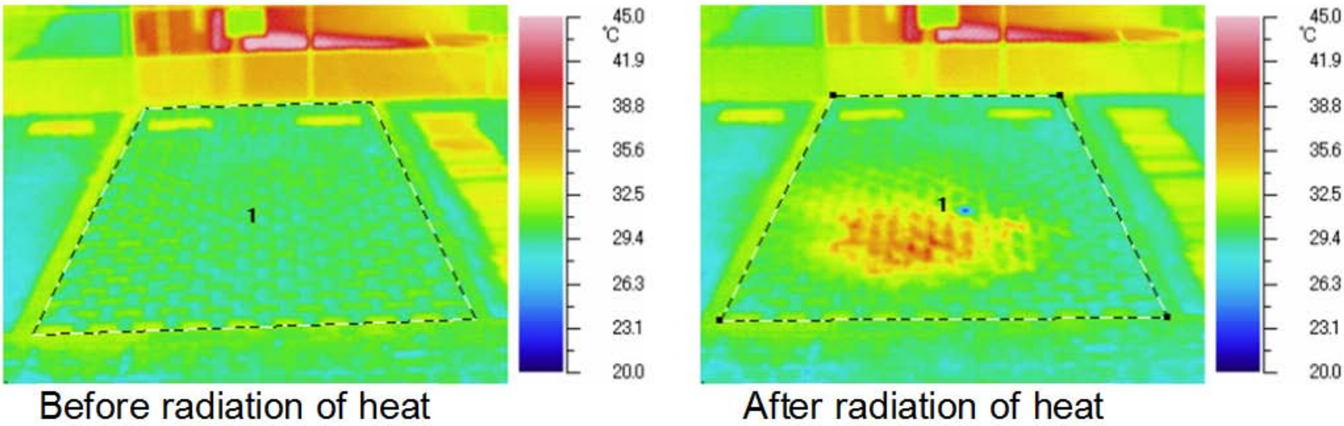

Figure 18

Parking lot number	Cover	Supporting part	Green cover area	Thickness	Observed solar reflectance*
19	Japanese (korai) turf	Plastic protector	57.5 %	250 mm	0.175
20	Japanese (korai) turf	Plastic protector	74.0 %	250 mm	0.225
21	Bermuda grass	Plastic, concrete and wood protector	35.6 %	250 mm	0.209
22	Japanese turf	Water keeping block	84.3 %	250 mm	0.208
23	Japanese turf	Concrete block	75.2 %	250 mm	0.208
24	Ophiopogon japonicus	Water keeping concrete	55.8 %	250 mm	0.184
25	Ophiopogon japonicus	Water keeping concrete	55.8 %	250 mm	0.200
26	Japanese turf	Steel mesh	83.4 %	250 mm	0.192
27	Bermuda grass, Centipede grass	Wooden log	66.1 %	250 mm	0.200
28	Japanese (korai) turf	Plastic protector	100.0 %	250 mm	0.215
29	Japanese turf	Steel mesh	88.1 %	225 mm	0.227
30	Fescues, Ryegrasses, Bluegrass	Water permeability block	47.3 %	225 mm	0.214
31	Japanese turf	Water keeping block	47.0 %	200 mm	0.240
32	Bermuda grass, Bluegrass, Japanese turf	Plastic protector	90.0 %	175 mm	0.202
33	Japanese (korai) turf	Water keeping block	47.0 %	150 mm	0.201
34	Japanese (korai) turf	Water keeping plate	53.0 %	150 mm	0.246
35	Bermuda grass	Wooden log	64.1 %	150 mm	0.211
36	Centipede grass	Concrete block	75.0 %	150 mm	0.189
37	Japanese (korai) turf, Moss	Brick and block	57.7 %	140 mm	0.219
38	Japanese turf	Water keeping plate	53.0 %	120 mm	0.259
39	Japanese (korai) turf	Concrete plate	65.7 %	110 mm	0.239
40	Japanese turf	Water keeping block and recycle brick	58.7 %	100 mm	0.189
41	Japanese turf	Water keeping block	39.0 %	280 mm	0.214
43	Japanese turf	Wooden railroad tie	50.5 %	250 mm	0.208
44	Ophiopogon japonicus	Water keeping block	48.0 %	250 mm	0.180
45	Japanese (korai) turf	Plastic protector	100.0 %	250 mm	0.189
46	Japanese (korai) turf, Ophiopogon japonicus, Hedera, Canariensis	Metal and wooden railroad tie	21.2 %	250 mm	0.165
47	Bermuda grass	Water permeability block	82.6 %	250 mm	0.205
48	Japanese turf	Water permeability block	54.7 %	250 mm	0.214
49	Japanese (korai) turf	Bamboo	66.0 %	250 mm	0.197
50	Japanese turf	Plastic protector	100.0 %	250 mm	0.206
51	Bermuda grass, Japanese turf, Ryegrasses	Wood and recycle rubber mat	60.5 %	250 mm	0.213
52	Japanese (korai) turf	Plastic protector	100.0 %	225 mm	0.198
53	Fescues, Ryegrasses, Bluegrass	Water permeability block	62.8 %	225 mm	0.231
54	Japanese (korai) turf	Recycle wooden material	38.3 %	200 mm	0.244
55	Japanese (korai) turf	Wood skin	58.0 %	200 mm	0.208

* Solar reflectance is mean value observed on July 30, August 20 and September 23, 2005.

Table 1

Supporting part	State	Number of spaces
No grass	Supported by only other materials (concrete, wood)	6
Independent grass	Supported by block, wood Grass is in the gap independently	5
Connected grass	Supported by block, wood, concrete Grass is connected in the gap	13
Supported in lines	Supported by grating, protector, woods Grass is almost connected	8
Supported in points	Supported by protector Grass is almost connected	4

Table 2

	ρ (–)	β (–)	λ (W m^{-1} K^{-1})	Cpγ (kJ m^{-3} K^{-1})
Grass	0.20–0.21	0.07–0.20	0.53	1,700
Wood	0.21	0.07	0.8	6,500
Normal concrete	0.35	0	3.8	1,900
Water keeping concrete	0.21	0.07	2.1	1,500
Water keeping block	0.17	0	1.8	1,600

Table 3