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A Quantitative Evaluation Method of Pedestrians' Thermal Condition on Road Space

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1. Synopsis

We focus on a logical evaluation method for unsteady thermal state in road space from a viewpoint of pedestrians' thermal sensation affected by road conditions to clarify the relationship between a whole pedestrians' receivable heat fluxes and each constituent factors of road space. Especially in this paper, a relationship between upward heat fluxes from road pavements and some road surface conditions or pedestrians' receivable distances was analyzed based on a measurement of the fluxes in outdoor field. As a result of the estimation of receivable heat fluxes, it revealed that improving a reflectance of solar radiation (albedo) for the reason to lower road surface temperature could not necessarily minimize the whole receivable heat fluxes for pedestrians because of an increase of reflective solar radiation ratio.

KEY WORDS: thermal environment, heat fluxes, road space, thermal sensation

2. Introduction

In urban cities, road pavement has occupied wider area year by year, and its surface temperature extremely becomes high in the summer season because of material characteristics. For example in Osaka City, the road pavement's share of whole land use amounts to 20 % in 1994, and maximum surface temperature of asphalt pavements through the year reaches nearly 65 degrees centigrade. Besides, many other artificial heat flux originated from vehicles or air conditionings of buildings concentrate into road space in urban area, pedestrians or roadside residents might be affected not only uncomfortable sensations but also health as physiological sunstroke for walking upon asphalt pavements.

As a quantitative evaluation method of these thermal conditions on road space, some indicators such as Predicted Mean Vote (PMV), Standard New Effective Temperature (SET*) are already proposed, but these indicators are comparatively suitable for evaluating a steady thermal state.

We focus on a logical evaluation method for unsteady thermal state in road space from a viewpoint of pedestrians' thermal sensation affected by road conditions to clarify the relationship between whole pedestrians' receivable heat fluxes and each constituent factors of road space. To begin with as a fundamental study, this paper contains relationship between upward heat fluxes from road pavements and some road surface conditions or pedestrians' receivable distances based on the measurement of the fluxes in outdoor field.

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3. Measurement of spatial characteristics about thermal environment

On common road spaces, pedestrians pointed out that there were direct rays of the sun, sensible heat from ground, reflective rays of the sun, and exhaust heat fluxes from cars in uncomfortable factors concerned with thermal condition. According to the former survey, if a surface temperature of road pavement is more than 42 degrees centigrade during the day, the sensible heat from ground was evaluated as the most uncomfortable factor for pedestrians (Yoshida et al., 2000).

In an another analysis which tried to prove a causal relationship between occurrences of heatstroke and spatial characteristics of road spaces, by using a relief activities database of the Kobe city fire bureau reported during from 2000 to September 2001, the developed number of sunstroke in walking is 25 percent of the total record number 181, and many of them were concentrated around noon. Furthermore, in additional analysis, characteristics of road space and pavement types in case of many heatstroke patients were categorized. As a result, the black colored asphalt with no roadside trees, and relatively narrow streets were pointed out as the major factors.

Some pedestrians' receivable heat factors on walking can be divided into two directive types. One is vertical elements, another is horizontal one. The former contains fluxes from road pavement, direct rays of the sun, and so on. The latter includes exhaust heat fluxes from cars or air conditioning of buildings etc. On the part of receiver conditions, the amount of those heat fluxes may also change according to the individual property such as height or clothes. In this study, the upward heat fluxes from pavement which mainly affects uncomfortable sensation for pedestrians as a major vertical element was chosen, and a measurement device with some heat sensors was manufactured to quantify a vertical distribution of whole elements which include proportion of a long wave of infrared radiation, a ground-reflective short wave of infrared radiation, and a sensible heat flux (See **Figure-1**). With this device, some meteorological observations which are showed in **Table-1** were held from 19 September 2001 to 12 October 2001 at the pavement test site made with an experimental purpose in Osaka City University. The construction area has 16 meters length, 4 meters width, and the pavement's albedo is 0.31.

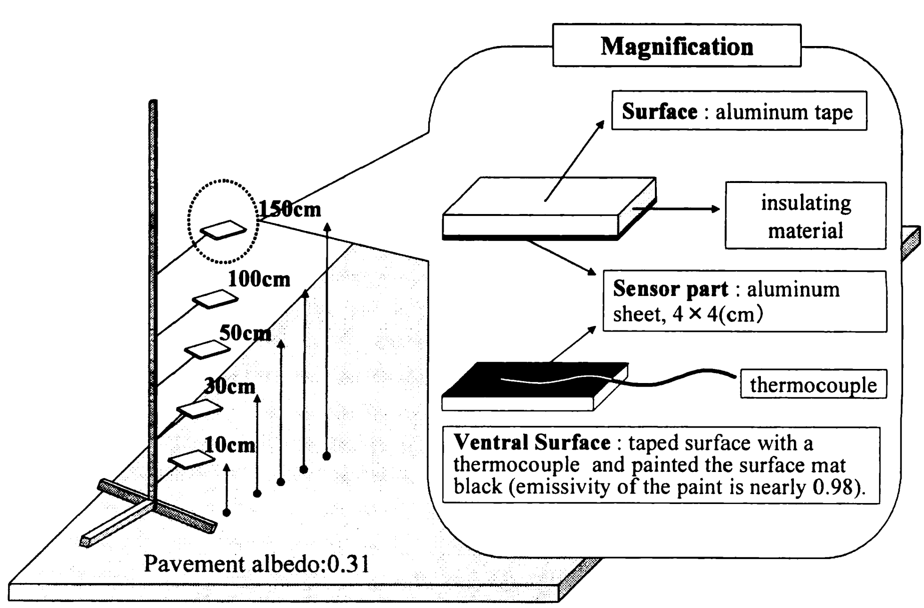


Figure-1 Outline of a measurement device proposed in this study

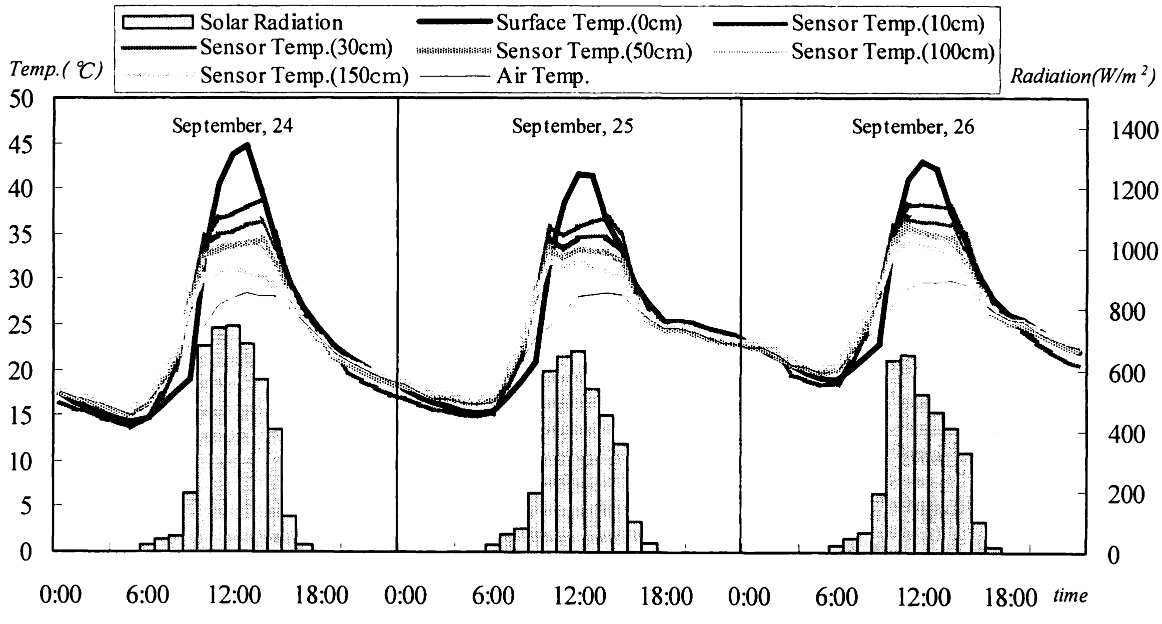
Table-1 List of observation items and measurement devices

Measurement Item	Measurement Instrument	Interval / the point number	Method
Air temperature	Thermometer with a ventilator	Sequence / 1 point	
Solar radiation	Pyranometer	Sequence / 1 point	
Reflected solar radiation	Albedometer	Sequence / 2 point	
Surface temperature	Infrared thermometer	10 minutes intervals / 4 point	
	Thermocouples, T-type	Sequence / 4 point	Paste over the ventral surface
Wind speed	Anemometer with cups	Sequence / 1 point	Setting upon the ground

4. Vertical distribution and Convective Heat Transfer Coefficient

(1) Change of pavement's surface and sensor temperature

Some summarized measurement values in fine days which include sensor, air, and surface temperature and solar radiation are shown in **Graph-1**. From the graph, a maximum surface temperature of road pavement reaches 46 degrees centigrade on 24th, and at this moment, the difference of sensor temperature between 10cm and 150cm is over 8 degrees centigrade. It suggested that receivable heat quantity from vertical ground surface is considerably changed according to the height concerned with individual property.



Graph-1 Summary of Measurement Result

(2) Vertical distribution of heat elements

Using heat equations as shown in below, whole heat quantity of each sensor's temperature was resolved into heat elements. Naturally, a long wave radiation from pavement surface and a reflective solar radiation (short wave) attenuate according to a form factor (see **Table-2**) which depends on the area and the distance between a sensor and pavement. After the analysis, it proved that a total radiation in 150 cm accounted for 60 percent of that in 10 cm and its component ratio in 150cm showed that a long wave radiation from pavement amount to 70%, a reflective solar radiation amounted to 20%, and the remainder part is a sensible heat flux.

$$L+I=\Delta H \quad \cdots\cdots (1)$$

where: $L=\varepsilon_p\varepsilon_s\sigma(T_p^4-T_s^4)\phi_s+\varepsilon_{ep}\varepsilon_s\sigma(T_{ep}^4-T_s^4)\phi_{ep}$ ······(2)

$$I=I_r\times\phi_s \quad \cdots\cdots (3)$$

$$\Delta H=\alpha(T_p-T_s) \quad \cdots\cdots (4)$$

L : Long wave radiation (W/m^2)
I : Short wave radiation (W/m^2)
H : Convection heat transfer (W/m^2)
ε_i : Emissivity (W/m^2)
ϕ_i : Form value
T : Temperature (K)
σ : Stefan-Boltzman constant
I_r : Reflective short wave radiation (W/m^2)
α : Convective heat transfer coefficient ($W/m^2{\cdot}K$)
i : p=pavement, s=sensor, ep=except pavement

Table-2 calculated form value of sensor by height

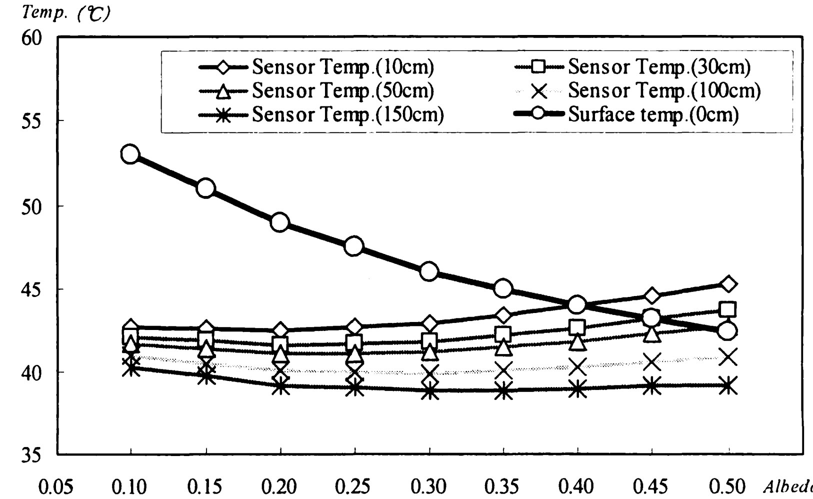
height	10cm	30cm	50cm	100cm	150cm
Form value	1.00	0.98	0.92	0.84	0.68

(3) Variation factor of Convective Heat Transfer Coefficient

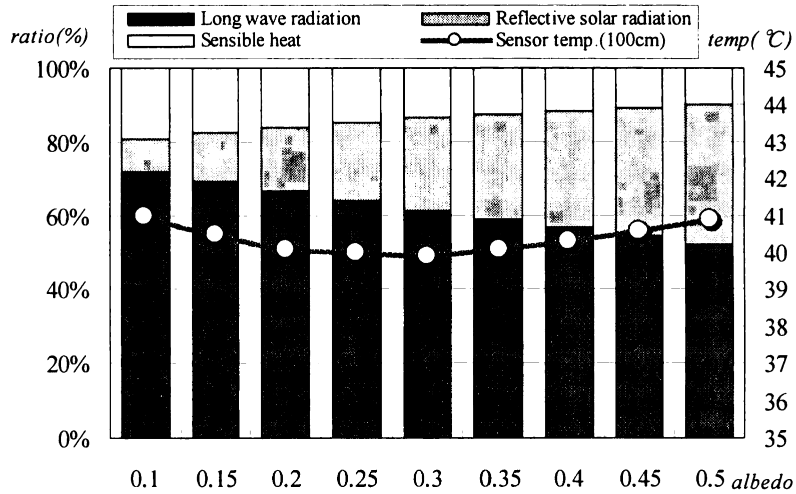
Calculating a convective heat transfer coefficient by using equations, it showed that the coefficient fluctuates sensibly by time or weather conditions. But in case of hours between from 12 to 14 in fine weather, all of the coefficients and their variation patterns by height were comparatively stable. As a result of analysis between the coefficient and weather conditions, it demonstrated that the coefficient and a wind velocity have a significant correlation, and this result supports a theoretical equation which determines the coefficient. For the reason stated above, the coefficient values were prepared as a function of wind velocity by height for the following some estimations of change according to road or meteorological conditions.

5. Estimation of receivable heat fluxes

Sensor temperature which represents a whole receivable heat fluxes might be varied according to spatial or meteorological conditions. In this section, changes of sensor temperature were estimated by using the calculated convective heat transfer coefficients by height and some meteorological variances. To begin with, only albedo which determined an absorption rate of solar radiation, was using for the estimation



Graph-2 Estimation result of sensor temperature by height as a variance. In this case, meteorological conditions as input data were assumed that solar radiation was 650 W/m2 and wind velocity was 1 m/s both as a constant. As a result of the test calculation, a sensor temperature showed the least value when albedo changed around 0.25 (**Graph-2**). From this result, it revealed that improving a reflectance of solar radiation (albedo) for the reason to lower road surface temperature could not necessarily minimize the receivable heat fluxes for pedestrians because of an increase of a reflective solar radiation ratio (**Graph-3**).



Graph-3 Estimation result of heat component ratio

6. Conclusion

The outcomes of this study are summarized in below;

1) A measurement device with some heat sensors was manufactured, and quantified a vertical distribution of whole elements which include proportion of a long or short wave of infrared radiation.
2) The estimation of receivable heat fluxes by height according to some conditions resulted in understanding of change in factor proportion.
3) When albedo of road surface was only changed under same conditions, a sensor temperature showed the least value around 0.25. From this result, it revealed that improving a reflectance of solar radiation (albedo) for the reason to lower road surface temperature could not necessarily minimize the receivable heat fluxes for pedestrians.

After this fundamental study, we are trying to make an estimation of horizontal heat elements as the same way, and evaluate a relationship between pedestrians' thermal sensation and the whole receivable heat fluxes, finally make a synthetic evaluation model for thermal condition in road spaces.

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Reference

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