Journal of Hydroscience and Hydraulic Engineering
Vol. 16, No. 2, November, 1998, 27-34

APPLICATION OF A NEW OUTDOOR THERMAL SENSATION INDEX TO EVALUATE THERMAL ENVIRONMENT AROUND A RIVER

By

M. Kanda
Tokyo Institute of Technology, O-okayama, Meguroku, Tokyo, Japan

and

T. Kinouchi
Public Works Research Institute Ministry of Construction, Tsukuba Science City 305,Japan

SYNOPSIS

The Meteorological and physiological field observation were conducted in summer over Tama river basin to verify the applicability of a new thermal sensation index to evaluate outdoor thermal environment. The analyses based on energy balance of human body led the following results ; 1) Virtual Thermal Load (VTL) calculated from only meteorological data could represent thermal sensations well, 2) nose temperature was a good physiological signal of thermal sensation, and 3) thermal sensation could be affected by psychological effect such as preconception that forest or river should be cooler than the other places. Temporal and spatial characteristics of thermal environment around a river were also analyzed ,and the results revealed that the atmosphere near the river basin provided more comfortable environment to human than urban region.

INTRODUCTION

Virtual Thermal Load has been proposed theoretically by authors as a new outdoor thermal sensation index (Kanda et al., 1995(3),1996(4)) based on the energy balance of human body. Physiological laboratory experiments in a climate simulator proved that the applicability of this index for evaluating thermal environment was better than those of other indexes such as SET* (Gagge et al, 1976(2)) and PMV (Fanger, 1970(1)) . However, outdoor thermal environments could have more natural fluctuations, and thus could be quite different from thermal environment in a well controlled climate simulator. Additionally, the other kinds of human sensation such as visual, hearing and smelling are likely to make more influence to the thermal sensation outdoors than indoors. Therefore, one of the purpose of this study is to prove if the new index is applicable to evaluate the real outdoor thermal environment. Recently, the atmospheric environment of river basin has been vigorously studied by hydraulic engineers (Takewaka et al., 1993(6)), but much more attention should be paied not only to physical view points but also physiological ones. Another purpose of this study is to evaluate the characteristics of thermal environment around river basin by using the new index.

EXPERIMENTAL PROCEDURES

Experimental Design

(a) Observation site
The observation sites were around Hygoshima park, which was located on the lower Tama river and presented a lively scene with people enjoying their holidays. Fig.1 and Table.1 show the location and environmental characteristics of observation points,

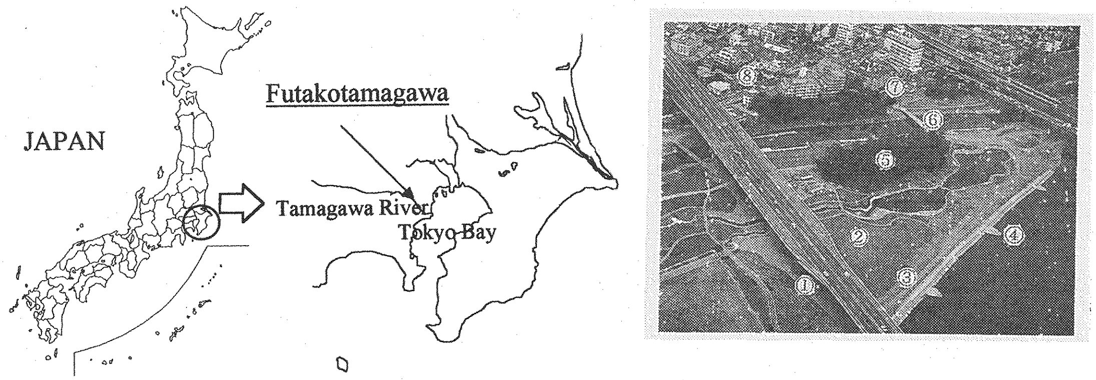

Fig.1 Map and photographs of observation sites. (a) location of tame river in Japan and (b) bird view picture of observation sites. The left hands of Fig.1 (a) and (b) is the upstream of Tama river and just in the west direction.

Table.1 Information of observation sites
Point Numbers correspond to those drawn in Fig.1

No.	Location	Ground surface	Remarks
P1	Under big bridge	Small stones	Noisy
P2	On short grass	Grass	Open view
P3	Waterside (1)	Concrete	
P4	Waterside (2)	Concrete	
P5	Within forest	Wet soil	
P6	On a small bridge	Concrete	
P7	Urban region (1)	Concrete	Residential
P8	Urban region (2)	Concrete	Along street

Table.2 questionnaires

Very hot	5
Hot	4
A little bit hot	3
Warm	2
A little bit warm	1
Neutral	0
A little bit cool	-1
Cool	-2

respectively. A total of 8 observation points were selected along narrow streets for a walk.

(b) Thermal sensation data

The objects for this experiments were five men, whose physical characteristics were similar. Their ages were 25～30, heights about 170cm and weight about 65kg. Their clothing were typical ones in summer seasons ; i.e. jeans, T-shirts, sporting shoes and no caps. Every experimental subjects walked together along the observation point 1 to 8, and both way walk between point 1 and 8 was one set of experiments. At each stations, they kept standing for 10minutes and declared their 10mintes averaged thermal sensations. It took about one hour to perform one set of experiments. During the brakes between each experiments, they relaxed in a car without taking any food and drinks. A total of three experiments were conducted ; 1) 8:30 to 9:30, 2) 11:00 to 12:00 and 3) 14:00 to 15:00. Table.2 represents the contents of questionnaires.

(c) Physiological data

Physiological observations were conducted for only one human subjects. One subjects is not enough to generalize the results, but even so there are very few previous research acquired physiological data in the field and thus it could be a very rare and useful information Perspiration rate integrated for one hour was estimated from the loss of weight measured by a electric balance. The nose surface temperature was measured by a thermo-spot three times at each station and the averaged value was recorded. Some previous clinical experiments in physiology (Nakayam,1981(5)) pointed out that nose surface temperatures could be a representation of the corresponding averaged skin surface temperatures. The first measurements from 8:30 to 9:30 failed to be recorded.

(d) Meteorological data

A total of five meteorological factors were observed automatically 10 seconds at each station ; 1) white globe temperature, 2) black globe temperature, 3) air temperature, 4)

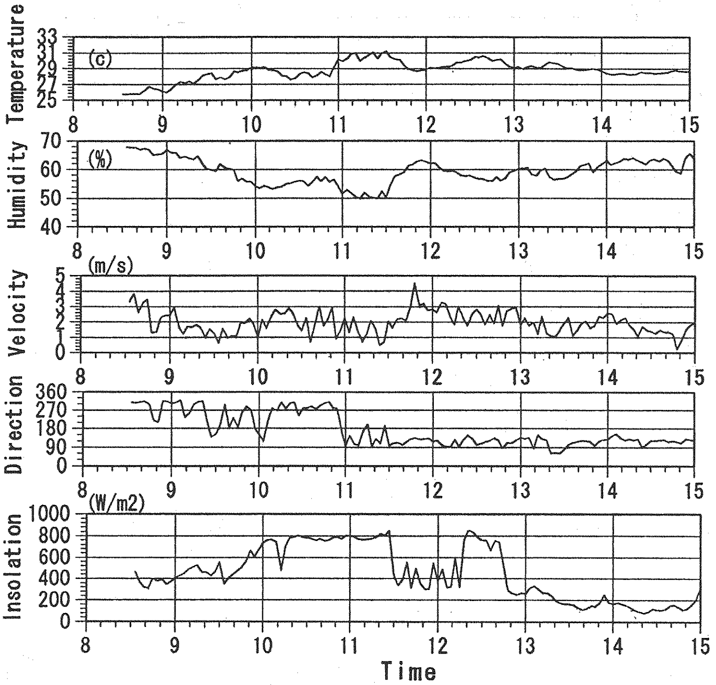

Fig.2 Diurnal variations of meteorological conditions during the experimental periods

relative humidity, and 5) wind velocity. All of them were required for VTL analysis mentioned below.

Meteorological conditions

The observation was conducted at September 6 in 1995. Fig.2 represents the diurnal variations of temperature, relative humidity, wind velocity and wind direction. The summaries of meteorological conditions at each set of experiments are as follows.

(a) 8:30～9:30

It was clear and fine all time. Wind direction was from upstream to downstream along the river, which was defined as a land breeze. The temperature and humidity increased with time.

(b) 11:00～12:00

The former half of this period was fine, while the latter was cloudy and both the decay of insolation and the decrease of temperature were remarkable. Wind direction reversed and a sea breeze front penetrated into this sites.

(c) 14:00～15:00

It was cloudy all time. All factors of meteorological conditions were almost steady. The sea breeze still remained.

RESULTS AND DISCUSSION

Relation of physiological data and thermal sensation

(a) Nose surface temperature

Fig.3 shows the relation of nose surface temperature and thermal sensation. Although the relation is not linear, the nose surface temperature is almost given by a single-valued function of thermal sensation. Therefore, nose surface temperature could be a useful physiological index of thermal sensation. However, the result of case2 (11:00 ～12:00) at point P5 shown by an arrow in Fig.3, is an exception. The thermal sensation number of this data is lower than that of the other data which have almost the same nose surface temperature. One of the reason for this could be explained by a over-reaction of

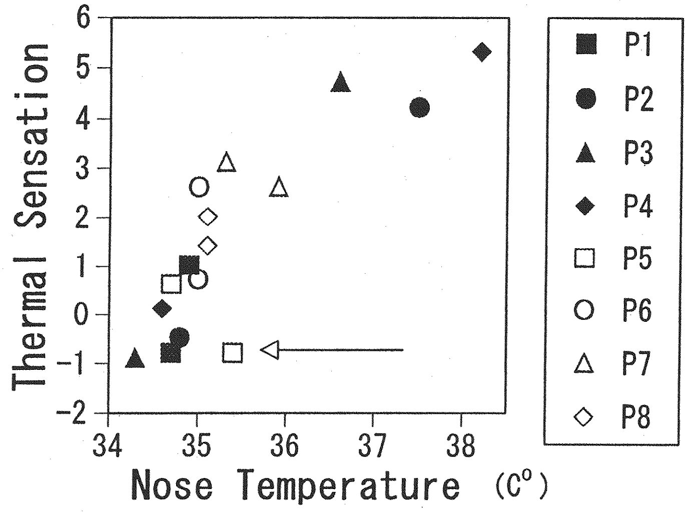

Fig.3 relationship of nose surface temperature and thermal sensation

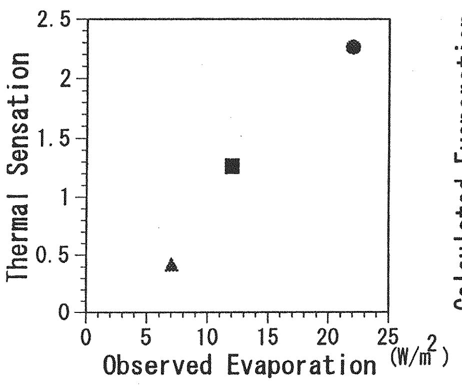

Fig.4 Relation of perspiration and thermal sensation

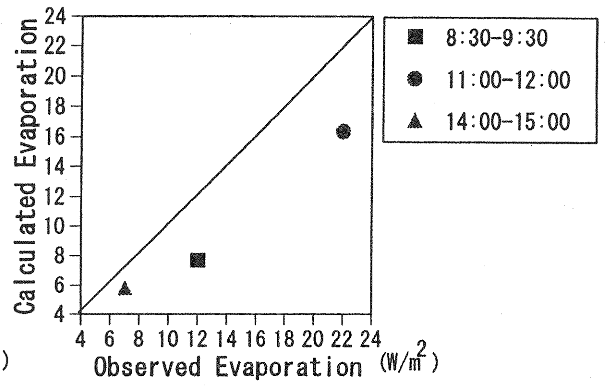

Fig.5 Comparison of the observed perspiration and the calculated

human sensation to a large difference of meteorological conditions. If it is true, the hysteresis of human sensation should be considered in analysis. Another reason could be a general preconception of human sensation that green areas should be cooler than other places.

(b) Perspiration

Fig.4 shows a relation of perspiration rate and thermal sensation. There exists a positive correlation between the both. Within the limits of this field experiments, the latent heat release due to the respiration is not a dominant factor of energy balance of human body as noted later in Fig.8, but a secondary feed-back factor to decrease the thermal load. Fig.5 shows a comparison of observed perspiration rate and the estimated. They have a linear relation, but the estimated value is a little bit under the observed. This is quite natural, because VTL estimation supposes a complete homeostatics of skin temperature while the real skin temperature increases with the thermal load. This agreement is not a serious problem, because the purpose of this analysis is not to estimate the true energy balance but to find the representative index of thermal sensation in utilizing the virtual energy balance Some researchers might think that SET*(Gagge et al., 1976(2)) could estimate real energy balance and real skin temperature. But it is not true at all especially in outdoor hot environments. It should be noted that, SET* assumes the steady state of thermal conditions of human

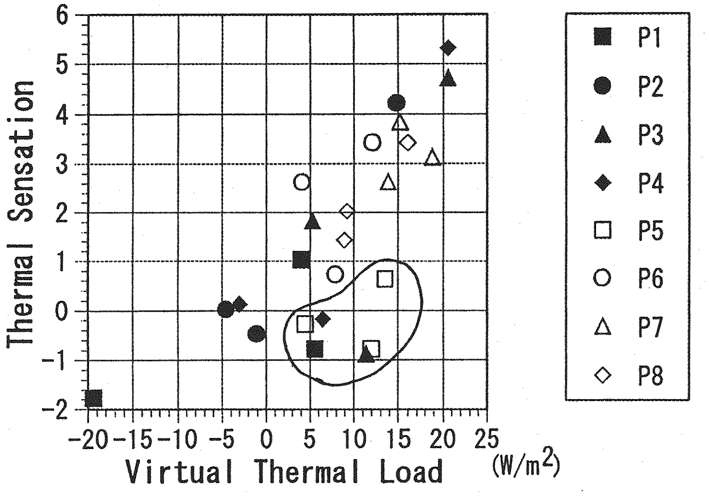

Fig.6 relation of VTL and thermal sensation

body but this assumption is not satisfied in most case under outdoor hot environment. SET* sometimes leads to the unreasonable high skin temperature in hot environment. Our previous report (Kanda et al.,1996(4)) discussed in detail this point and concluded that VTL based on the assumption of unsteadiness of thermal conditions of human body was superior to SET* for evaluating thermal sensation under outdoor hot environment.

Relation of VTL and thermal sensation

(a) Method of VTL analysis

The method of VTL analysis will be briefly reviewed. The virtual energy balance of human body can be expressed by Eq.(1)

$$VTL = M + Rn + E + H \quad (1)$$

$$E = C_h U \beta \ (q_s - q_a) \quad (2)$$

$$\beta = VTL / 3600 \quad (VTL > 0) \quad (3)$$

$$\beta = 0 \quad (VTL < 0) \quad (4)$$

where, VTL: virtual thermal load, M: metabolic rate, Rn : net radiation, E:latent heat, H: sensible heat, C_h : heat transfer coefficient on skin temperature, U : wind velocity, q_s :saturated specific humidity on skin temperature, q_a : specific humidity of air and β : wetness parameter of skin surface. It should be noted that the Eq.(1) is not real but virtual energy balance equation of human body because the skin temperature is assumed to be constant in calculating each term. The metabolic ratio is assumed 60(w/m^2) in the first trial 8:30 to 9:30 and 50(w/m^2) in the other two trials. Rn can be estimated from the energy balance of two globes. The latent heat can be expressed by Eq.(2). The only one but very important physiological parameter in Eq.(2) is the wetness parameter of skin surface β, which has already been investigated experimentally by authors(Kanda et al, 1996(4)) and expressed by Eq.(3) as a function of VTL. The sensible heat can also be calculated by using the bulk coefficient type equation similar to Eq.(2). It should be emphasized that VTL can be determined only from meteorological data easily observed without any physiological observation data.

(b) Relation of VTL and thermal sensation

The Fig.6 shows the relation of VTL and thermal sensation. As a whole, these two are closely correlated and VTL is proved to be a good index of thermal sensation of human exposed in outdoor environment. However, some data near neutral thermal sensation shown by a circle in Fig.6 have large scattering and shift to downward, compared with the other data. All of these exceptional data are obtained within forest (P5) or very close to the river water. Thermal sensation under neutral thermal environment would

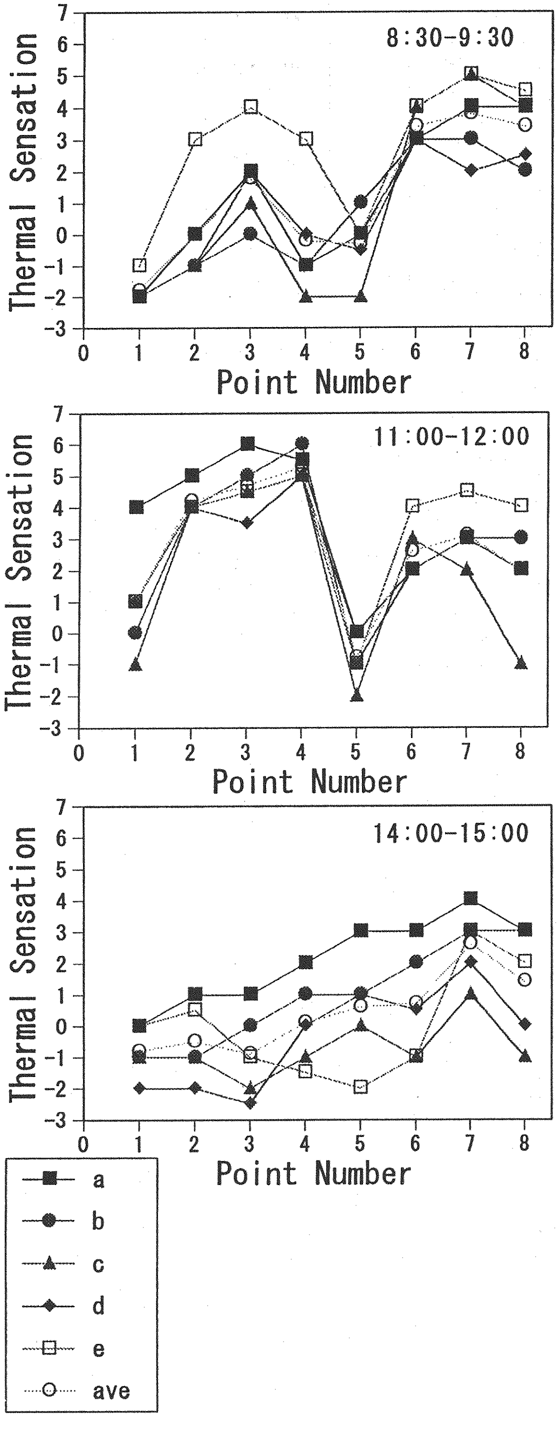

Fig.7 Thermal sensation at each point

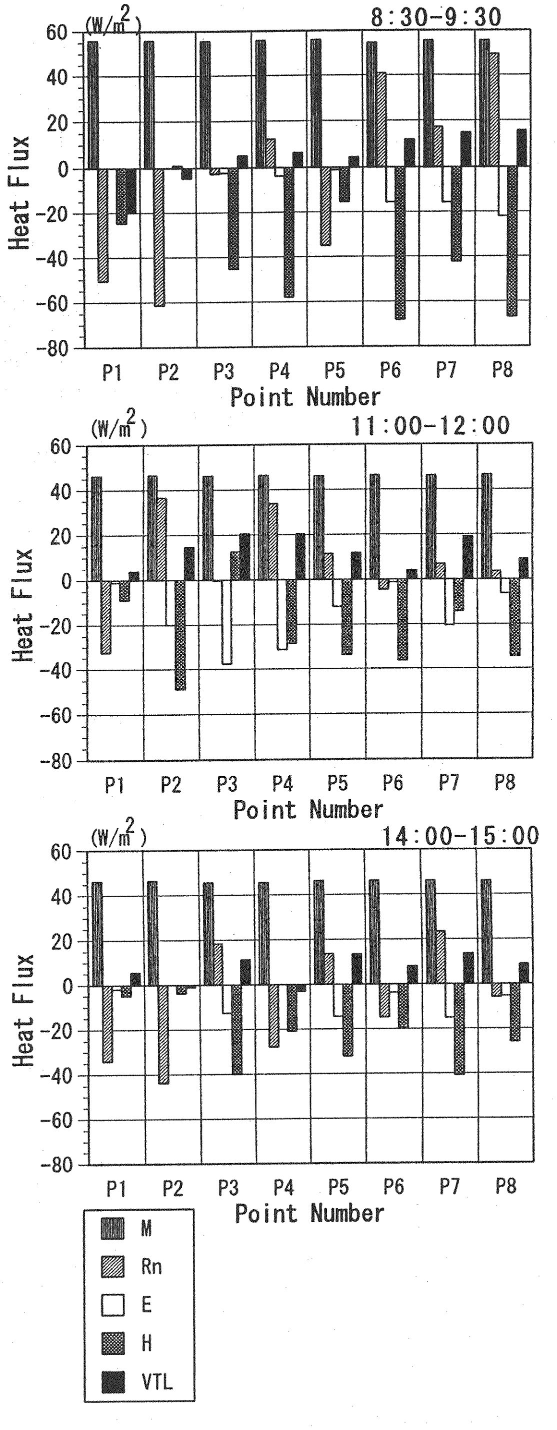

Fig.8 Energy balance of human body

not be a dominant factor of comfort and sensitively affected by some other sensations.

Temporal and spatial characteristics of thermal environment around river

The results of thermal sensation at each point are shown in Fig.7. The results of VTL energy balance analysis are shown in Fig.8.

(a) difference between individuals

The maximum difference of thermal sensation number between individuals is about 4～5. These large differences between individuals were not observed in the climate simulator. This would be due to the unsteadiness of meteorological factors and the influence of the other kinds of human sensations such as visual, hearing and smelling in outdoor environment. .

(b) characteristics of thermal sensation

The results of two experiments at 1) 8:30～9:30 and 2) 14:00～15:00, during which there are not large change of meteorological conditions, helps us to discuss the spatial characteristics of thermal environment around river. As a whole, their thermal sensation increases from river-side region (p1～p5) to urban region (p6～p8) . This tendency is especially clear at 14:00～15:00 when the insolation is relatively small. At 8:30～9:30 when the insolation is stronger, the shaded region such as p1 and p5 are cooler than the other sites. Takewaka et al, 1993 investigated the meteorological characteristics around river but not the thermal sensation. Our results verify that the river sides supply us more comfortable thermal environment than urban areas from the view points of physiology. The thermal sensation of former half of 11:00～12:00 (p1～p5), when it is fine, are higher than those of the latter half (p6～p8), when it is cloudy. This suggests that the insolation makes dominant effect on thermal sensation.

(c) energy balance of human body

The spatial characteristics of VTL is almost similar to those of the thermal sensations mentioned above. It is quite reasonable because that VTL and thermal sensation have close correlation. During 8:30～9:30, VTL is mainly determined by Rn and H. This is because the air temperature is still so low that the contribution of latent heat is relatively small Rn at urban areas (p6～p8) during this period are larger than those at river sides because of a large contribution of long wave radiation from the ground surface.

CONCLUDING REMARKS

Within the limits of this field experiments, the following results were obtained.

1) Virtual Thermal Load (VTL) calculated from only meteorological data could represent thermal sensations well
2) Nose surface temperature is a good physiological signal of thermal sensation.
3) Thermal sensation could be affected by psychological effect such as preconception that
4) The atmosphere near the river basin provides more comfortable environment to human than urban region.

This field observation was conducted under a considerable limited conditions. It should be noted that more experiments will be required to expand this results to the general conclusion.

Acknowledgment This research was supported financially by 1) Grand-in-Aid for Development Scientific (No.07650594) from the Ministry of Education, Science and Culture in Japan, and 29 Foundation of River Watershed Environment management. The authors are also grateful for Mr. Moriwaki, research associate of Tokyo Institute of Technology, for conducting the field observations.

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(Received December 5, 1996; revised April 17, 1998)