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Refuge behaviour from outdoor thermal environmental stress and seasonal differences of thermal sense in tropical urban climate

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Abstract. Thermal sensation affects body temperature regulation. As a starting point for behavioral body temperature regulation taken to improve from a poor thermal environment to a more pleasant environment, thermal sense of thermal environment stimulus is important. The poupose of this sutudy is to use the outdoor thermal environment evaluation index ETFe to quantify effects on thermal sensations of the human body of a tropical region climate with small annual temperature differences, and to examine seasonal differences in thermal sensation. It was found temperature preferences were lower in the winter season than in the dry season, and that a tolerance for higher temperatures in the dry season than in the winter season. It was found effects of seasonal differences of the thermal environment appear in quantitative changes in thermal sensations. It was found that effects of seasonal differences of the thermal environment do not greatly affect quantitative changes in thermal comfort.

1. Introduction

The Paris Agreement, a new international legal framework for greenhouse gas reduction, was adopted in December 2015 at the 21st Conference of Parties to the Framework Convention on Climate Change (COP 21) [1]. In order to reduce the serious effects due to climate change, countries throughout the world are aiming for global consensus to keep the average temperature rise to less than 2°C compared to before the industrial revolution. This agreement also mentioned that holding the average temperature rise to less than 1.5°C greatly contributes to reducing the risk.

This situation is affected by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in April 2014 [2]. If no actions are taken to reduce greenhouse gas emissions, the average temperature of the earth is likely to rise by 3.7°C to 4.8°C compared to before the Industrial Revolution, indicating the possibility of poor outdoor thermal environments. Areas with moderate thermal environments would transform into tropical areas, and there is a possibility that those areas will have smaller annual temperature differences. That is, changes in the four seasons could become less dramatic, with smaller seasonal changes. Physiological functions of the human body are affected by annual temperature differences and nutrition intake ratios, which climate change also affects. In particular, seasonal variation of basal metabolism has been found [3].

Thermal sensation affects body temperature regulation. As a starting point for behavioral body temperature regulation taken to improve from a poor thermal environment to a more pleasant environment, thermal sense of thermal environment stimulus is important. Decrease in the autonomous body temperature regulation function leads to changes in deep temperature. Delay in environmental shelter behavior occurs when there is delay or dullness in thermal sensation reaction to heat and the body's overheating. In order to prevent health damage, it is indispensable to clarify effects of body temperature control load on the human body.

In outdoor environments that are in an unsteady state, thermal adaptation results in a thermal sensation different from the indoor environment. In winter, people prefer a lower temperature than in summer, and tolerate higher temperatures in summer than in winter [4-11]. As in surveys of indoor environments, it is inferred that effects of clothing and environmental history appear as seasonal differences. In addition, in these studies, thermal comfort was targeted to a non-specific overall comfort feeling rather than a thermally unique pleasant sensation. Therefore, it was considered to be thermal comfort, but it cannot be denied that it was a comprehensive comfortable feeling including not only the thermal comfort but also effects of that space. Kurazumi et al. [12, 13] quantified the human body effects by the outdoor thermal environment evaluation index ETFe [14] based on heat balance of the human body. Even actual measurements in outdoor environments limited to thermal sensation showed that people prefer a lower temperature in summer than in winter, and tolerate higher temperatures in summer than in winter.

As mentioned above, physiological functions of the human body are affected by annual temperature differences and the nutrition intake ratio, which climate change also affects. Effects of climate acclimatization due to seasonal variation may appear as seasonal differences in thermal sensation. It is suggested that thermal sensations change due to effects such as acclimatization to thermal environment, but it is not limited to thermal sense according to specific sensation dependent heat exchange. In this study, the pourpose was to compare seasonal differences in thermal sensations by using ETFe to quantify effects on thermal sensations of the human body in a tropical region climate with small annual temperature differences.

Considering that the average temperature of the earth is forecast to rise, studying effects on the human body from outdoor thermal environments in tropical regions may be important for considering how to spend time outdoors in the future. In this study, the effect on thermal sense of the human body were measured in an outdoor thermal environment in winter in Bangkok, Thailand, a tropical region. Then, by comparing it with the results of the study of the dry season in Thailand by Kurazumi et al. [15], it was clarified seasonal differences in effects on the human body.

It is rare to perform a subjective experiment that measures physiological and psychological quantities according to the response of the human body using a large number of subjects. It is difficult to perform an experiment that is hypothesized on a statistical population. Accordingly, as only a small number of subjects was used in this study, the new data are a significant addition to the literature.

2. Experimental design

In order to maintain consistency with the actual measurements in the outdoor environment that Kurazumi et al. [15] performed in the dry season in Bangkok, Thailand, the measurement items were the same as the dry season measurement.

The measurements were carried out in December in the Thai winter season. Mobile measurements were carried out on the campus of Chulalongkorn University, Bangkok, Thailand. A speed of movement slower than a normal walking speed of around 0.7 m/s was used to transport the

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instruments for measuring the thermal environment. The observation points were drawn at random and the routes to the points were not decided in advance.

After arriving at each measurement point, the subjects waited in a standing posture for five minutes while the test staff setup the measurement instruments for the thermal environment, and preparations for measurement were concluded. Thereafter, the subjects were exposed to the thermal environment in a standing posture for ten minutes. As the subject of the research was the environment surrounding the observation stations, the point of gaze of the subjects was free and unfixed. After ten minutes' exposure, the subjects reported the average thermal sensation and the average thermal comfort of the whole body that they experienced while exposed at the observation point.

For the measurements, observation points were selected with consideration of the condition of the ground surface such as bare ground where the surface is gravel or soil, paved ground such as concrete, asphalt, or blocks, green areas covered with plants, and water surfaces comprising the solid angle of the total celestial sphere (hereafter, green cover ratio), and with consideration of the condition of the sky factor due to buildings, trees, and so on. Five observation points were chosen.

The subjects were 15 healthy young Thais who were 4 young male and 11 young female university students. They were considered to be subjects by most physical standard. In accordance with the Declaration of Helsinki [16], the details of the experiment were explained sufficiently well in advance to the subjects and their consent was obtained for their voluntary participation.

The ETFe [14] is an outdoor thermal environment evaluation index based on the heat balance of the human body. Figure 1 shows the relationship between the ETFe and the main parameters. Accordingly, the calculation of the mean skin temperature used for the calculation of the heat balance of the human body was performed using a weighting coefficient that takes into account the convective

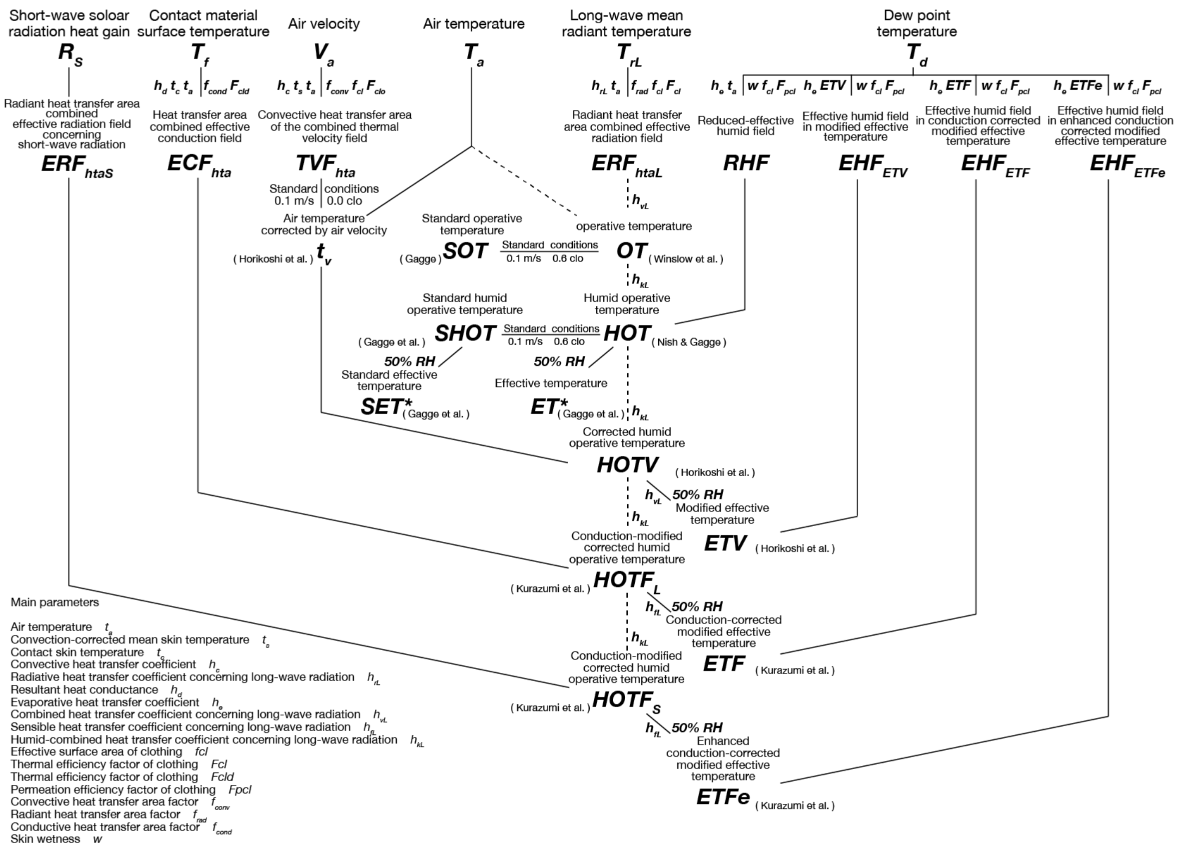

Figure 1. Relationship between the ETFe and the main parameters.

heat transfer area [17]. In calculating the body surface area of the human body, we used the calculation formula of Kurazumi et al. [18]. Then, the calculation of the mean skin temperature used for the physiological response of the human body was performed using a weighting coefficient that takes into account heat conduction [19]. The values of Kurazumi et al. [20] were used for the convective heat transfer area factor, the radiant heat transfer area factor, and the conduction heat transfer area factor for the human body. The value of Miyamoto et al. [21] was used for the projection area ratio of the human body. The values of Kuwabara et al. [22] were used for the radiant heat transfer coefficient and convective heat transfer coefficient of the human body. The value of Hendler et al. [23], found from the reflectance by the skin of electromagnetic waves with wavelengths of 3 μm or more, was used for the emissivity of the human body. The values of Hendler et al. [23] and Elam et al. [24], found from the reflectance by skin of electromagnetic waves with wavelengths of 3 μm or less, were used for the solar radiation absorption coefficient of the human body. The short-wave solar radiation heat gain of the human body is affected by the short-wave solar radiation absorption. According to VDI3787-2 [25], the direct solar radiation absorption of a clothed body is 0.7. However, Watanabe et al. [26] showed that the direct solar radiation absorption of a body clothed in black is 0.76 and that of a body clothed in white is 0.38. Also, the direct solar radiation absorption of other clothing combinations or everyday clothing falls within the range of direct solar radiation absorption for a body in black or white clothing. In this study, a value for the short-wave solar radiation absorption of 0.7, which is standard for a naked body, was used. It was difficult to measure the skin wetness. Therefore, the calculation method used to arrive at these values of skin wetness was the thermoregulation model of Kurazumi et al. [27]. In addition, the value calculated by means of the thermoregulation model of Kurazumi et al. [27] was also used for the physiological quantity that became a missing value. The standard air velocity was considered to be 0.1 m/s and the standard clothing was considered to be a naked body (0clo) in this research. The ETFe index theoretically proposed by Kurazumi et al. [14, 28] was calculated from weather observation values, the skin temperature of the human body, and the clothing value. It was difficult to measure the skin wetness. Therefore, the calculation method used to arrive at these values of the skin wetness was the thermoregulation model of Kurazumi et al. [29].

These explanatory variables of thermal sensation are direct environmental stimuli to thermal sensation, and greatly affect physiological and psychological reactions of the human body: temperature, humidity, wind speed, short wavelength solar radiation heat, long wavelength radiant heat, surface temperatures of materials that contact the human body. In this study, considering that the psychological reaction of the human body in an outdoor environment is likely to cause many disturbances and variations, as a criterion for comparing explanatory variables for deriving results of regression analysis with greater usefulness from practical point of view, the significance probability was set to 10%. JMP 12.2.0 (SAS Institute Japan) was used for statistical analysis.

3. Results and discussion

3.1. Observed thermal environment summary

The temperature dropped under 30°C at some observation points. The climate of Bangkok was in winter, during which temperatures were relatively low. There was a large amount of downward short-wave solar radiation of open observation points with a high sky percentage, but there was much less downward short wavelength solar radiation at observation points where sunlight was obstructed by trees etc. with low sky ratio. The effect of sunlight is very noticeable.

There were great amounts of long-wavelength radiation at all the observation points. Even if one is sheltered in a place with solar radiation shielding avoiding short wavelength solar radiation, one still receives much heat radiation. At observation points with concrete pavement where there is high heat capacity and strong effects of short wavelength solar radiation, the ground surface temperature in the vicinity of the observation point is remarkably higher than other observation points. There is very little contact area between the standing posture human body and the ground surface, but it is conjectured that the heat acquisition of the human body by heat conduction strongly affects contact skin temperature. In addition, it is conjectured that the high surface temperature in the vicinity of the human body strongly affects the heat radiation amount because the shape factor increases. The trend of the measured results of short wavelength solar radiation and long wavelength radiation at the observation points was similar to the dry season results of Kurazumi et al. [15].

The measured average value of relative humidity is 60.4%, the standard deviation is 7.4%, and no notable difference in actual measurement results is shown. Therefore, there may be weak effects on the sensed temperature by the difference in evaporative heat exchange amount.

The average wind speed was a relatively calm 2m/s or less through all the observations. The standard deviation was 0.4 m/s. Therefore, difference in convective heat exchange amount may weakly affect sensed temperature. This may be affecting thermal sensation as a factor of environmental change.

The following discussion will clarify seasonal differences of effects on the human body, by comparison with results of research in Thailand's dry season by Kurazumi et al. [15].

3.2. Relationship between ETFe and thermal sensation

Figure 2 shows the relationship between ETFe and Thermal sensation. It shows a tendency for people to report on the "hot" side when ETFe becomes higher. Thermal sensation shows a wide distribution from "cool" to "hot", showing remarkable individual differences.

When ETFe is in the range 30-40ºC, thermal sensation in the range from "Slightly cool" to "Slightly warm" tends to be reported. Similar to what Kurazumi et al. [12, 13, 28] points out, it seems that expectation for comfort in the outdoor space is originally low, judging that it is not a comfortable thermal environment, so ETFe was acceptable even under high thermal environmental conditions. Although it is uncomfortable thermally, it could be that people tolerate a wider range of thermal environments in outdoor spaces where they can change the selection of place and viewpoint by their own will. That is, it is thought that due to the degree of freedom of behavior in the experimental environment, large fluctuations in the psychological reactions of the human body occurred in the

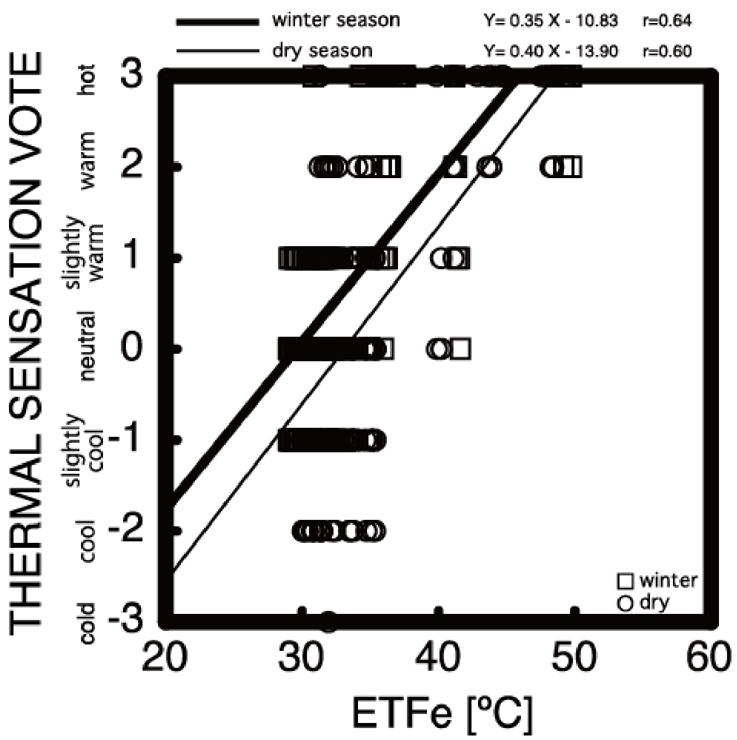

Figure 2. Relation between ETFe and thermal sensation.

outdoor space [13]. The outdoor thermal environmental factors of short wavelength solar radiation, long wavelength radiation and air current are uneven and non-targeted evaluation factors. These evaluation factors may contribute to local effects on the human body, even if heat balance in the whole body is the same.

Focusing on the regression line, there is no large difference in the slope of the regression line, and it seems there is a tendency that in winter, people prefer a thermal environment that is about 4°C lower than in the dry season. People like winter temperatures that are lower than they like in summer, and tolerate higher temperatures in summer than in winter, as found by Kurazumi et al. [12, 13]. The climate of Bangkok in Thailand is hottest season in the dry season, so it can be regarded as summer. Therefore, this study also inferred that effects of environmental history appear as seasonal differences.

The result of testing parallelism of the regression line was $p>0.10$, and no significant difference in parallelism of the regression line was shown. The result of testing homogeneity of regression was $p<0.10$, indicating a significant difference in homogeneity of the regression line. Therefore, in the range of the results of ETFe in this study, it seems that effects of seasonal differences, which seem to be lower in winter than in the dry season, appeared in the amount of change to thermal sensation.

3.3. Relationship between ETFe and thermal comfort

Figure 3 shows the relationship between ETFe and thermal comfort. As ETFe increases, the strength of "uncomfortable" tends to increase. The feeling of comfort shows a wide distribution from "comfortable" to "extremely uncomfortable", showing remarkable individual differences.

In this research, an experimental method that isolates environmental history as much as possible was used, but it seems that there are effects of thermal environment history, and an expectation of environmental sheltering thermal environment accompanying mobile observation. Kurazumi et al. [12] states that 38.5°C is the upper limit ETFe of the optimal environmental range in summer. After ETFe exceeds that upper limit ETFe temperature, the variation becomes large. Therefore, subjects subjects were instructed to report thermal comfort according to specific sensation dependent heat exchange, but

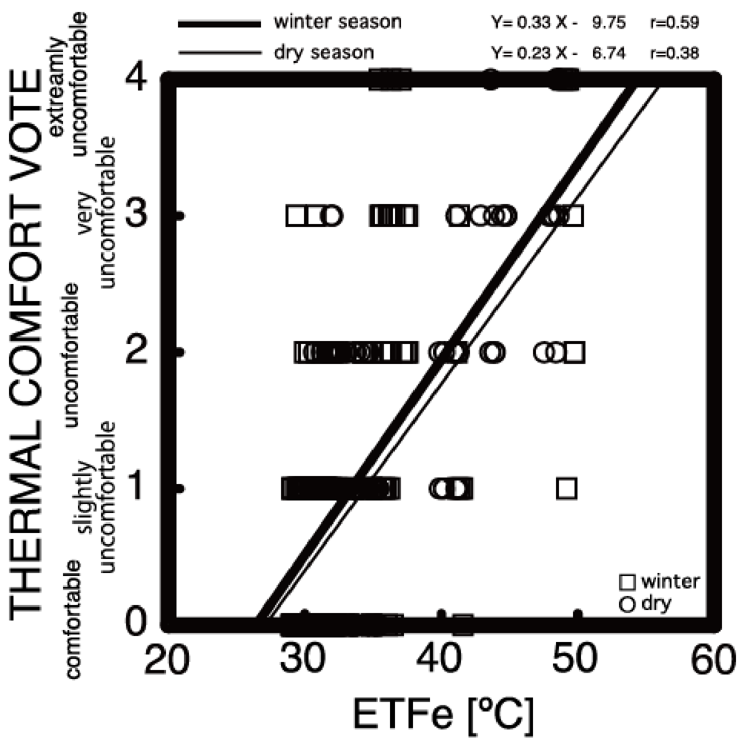

Figure 3. Relation between ETFe and thermal comfort.

the possibility that they are reporting comprehensive thermal comfort including the effects of spatial impression cannot deny. As pointed out by Kurazumi et al. [13], outdoor thermal environmental factors (short-wavelength solar radiation, long-wavelength radiation, and airflow) are uneven and non-targeted evaluation factors, and effects of parameters of these environmental factors could cause variations in human body reactions. It is possible for the human body to experience discomfort due to variation in environmental factors, and this experience can be considered to induce relative comfort. Accordingly, variations with an effect that mitigates thermal action are considered to be variables for discomfort with regard to other environmental factors as well.

Focusing on the regression line, similar to what Kurazumi et al. [12, 13, 28] points out, it seems that expectation for comfort in outdoor spaces is originally low, and people judge that it is not a comfortable thermal environment, so ETFe is tolerable even under high thermal environmental conditions. The slope of the regression line is slightly greater in winter than in the dry season, so it seems that reactions to thermal sensation for thermal comfort appears more strongly in winter than in the dry season, even at almost the same ETFe.

The result of testing parallelism of the regression line was $p>0.10$, and no significant difference was shown in parallelism of the regression line. The result of testing homogeneity of regression was $p>0.10$, showing no significant difference in homogeneity of the regression line. Therefore, it seems that within the range of ETFe results of this experiment, effects of seasonal differences do not exert a large influence on the amount of change to thermal comfort.

The laboratory experiment of Fanger [30] found no seasonal differences in thermal comfort. However, according to a questionnaire survey at the office of Miura et al. [31], the thermal neutral temperature has a seasonal difference, which is higher in summer than in winter. In subject experiments in outdoor environments of Kurazumi et al. [12, 13], in Japan where the annual difference in temperature is larger than in Bangkok, people tolerate higher temperatures in summer than in winter, and they state that thermal comfort has seasonal differences. In 2016, the annual difference in temperature in Bangkok was around 4°C, but the annual difference in temperature in Tokyo was around 21°C [21].

4. Conclusion

Effects on thermal sensation of the human body from the outdoor thermal environment of a tropical region with small annual temperature differences was quantified by the total thermal environment evaluation index ETFe of the outdoor environment, and seasonal differences of thermal sensation were compared. Thermal sensation affects body temperature regulation. As a starting point for behavioral body temperature regulation taken to improve from a poor thermal environment to a more pleasant environment, thermal sense of thermal environment stimulus is important. The findings obtained in this study are shown below.

In the dry season. People prefer lower temperatures in winter than in the dry season, and tolerate higher temperatures in the dry season than in winter. It seems that effects of seasonal differences appeared in the amount of change to thermal sensation.

It is possible for the human body to experience discomfort due to variation in environmental factors, and this experience can be considered to induce relative comfort. It is thought that one cannot rule out the possibility that people are reporting comprehensive thermal comfort including effects of space impression. on thermal comfort according to specific sensation dependent heat exchange. In other words, it seems that effects of seasonal differences are not likely to greatly affect the thermal sensation change amount for thermal comfort.

When planning the safety urban development, the consideration for the outdoor environment becomes an important matter. Thus, it is to clarify the psychological and the physiological reactions of the human body in outdoor thermal environment. This study inferred that effects of environmental history appear as seasonal differences. There is a need for further study that takes seasonal acclimatization into account is necessary.

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