American Journal of Climate Change, 2018, 7, 204-217
http://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

# The Influence of the Solar Radiation Absorptivity up on the Outdoor Thermal Environment Evaluation Index and the Thermal Sensory Perceptions

**Yoshihito Kurazumi[1*], Tomonori Sakoi[2], Agnes Nyilas[1]**

[1]School of Life Studies, Sugiyama Jogakuen University, Nagoya, Japan
[2]Academic Assembly, Institute of Textile Science and Technology, Shinshu University, Ueda, Japan
Email: *kurazumi@sugiyama-u.ac.jp

**How to cite this paper:** Kurazumi, Y., Sakoi, T. and Nyilas, A. (2018) The Influence of the Solar Radiation Absorptivity up on the Outdoor Thermal Environment Evaluation Index and the Thermal Sensory Perceptions. *American Journal of Climate Change*, **7**, 204-217.
https://doi.org/10.4236/ajcc.2018.72014

**Received:** January 26, 2018
**Accepted:** June 4, 2018
**Published:** June 7, 2018



## Abstract

When the thermal environment is under heated conditions, short-wavelength solar radiation shows a strong influence on the human body and the heat is accumulated in the human body. In order to demonstrate the effect of the short-wavelength solar radiation absorptivity of clothing on physiological temperature in an outdoor space, the relationship between the thermal environment evaluation index, ETFe, and the thermal sensory perceptions of the human body was investigated. A significant temperature difference of 2.7˚C was shown for an ETFe that was thermally neutral (neither hot nor cold). The effect of short-wavelength solar radiation absorptivity was strongly apparent in ETFe when direct solar radiation was strong and in warmer outdoor spaces. In an outdoor space where the effect of the sky factor and albedo was strong, the setting of the short-wavelength solar radiation absorptivity was demonstrated to greatly impact the estimation of perceived and physiological temperature. When interviewing subjects on clothing in an outdoor space, it is essential to obtain the hue of clothing.

## Keywords

Thermal Environment Evaluation Index, Body Heat Balance, Clothing, Solar Radiation Absorptivity, Thermal Sensory Perceptions

## 1. Introduction

Improvement of the urban thermal environment is becoming a pressing issue due to health problems that can result from a deterioration of it. The evaluation of the urban climate by means of the thermal environment evaluation index is a technique to quantify the improvement of the impact of the urban thermal environment on the human body. It is important to clarify the relationship with the physiological and psychological responses of the human body by quantifying the heat exchange from the environment to the human body. For this, physical values for the climatic and environmental elements of the space in which the human body is present are essential.

When the thermal environment is under heated conditions, short-wavelength solar radiation shows a strong influence on the human body and the heat is accumulated in the human body. This raises the risk of heat stroke. When the air temperature is higher than skin temperature, perspiration is the only way for heat release to occur. However, when the humidity gets higher, it reduces the amount of perspiration from the human body. Short-wavelength solar radiation and long-wavelength thermal radiation from the ground raise the thermal sensory perceptions.

It has been demonstrated that solar radiation affects the thermal sensory perceptions of the human body in an outdoor space [1]-[8]. In addition, it has been demonstrated that the effects of direct and reflected solar radiation are significant in an outdoor space. In addition, the outdoor thermal environment has a strong effect on the thermal and comfort sensations of the human body [9] [10] [11]. It has furthermore been demonstrated that short-wavelength solar radiation becomes significantly stronger as a factor that impacts the thermal environment evaluation index in an outdoor space [7] [8]. According to the effect of albedo, a road surface can become heated to the degree whereby it cannot be touched directly, and sensational and physiological temperature increases. Meanwhile, the sensational and physiological temperature becomes low for bare ground in the shade or surfaces with ground cover. Therefore, it is necessary to consider the effect of short-wavelength solar radiation on the heat balance of the human body.

When investigating the sensational and physiological temperature, it is essential to quantify the heat exchange from the environment to the human body. The method of handling clothing with respect to this quantification differs depending on whether the heat balance of the human body is investigated by a clothed standard, or an unclothed standard. When investigating the sensational and physiological temperature by a clothed standard, it is still necessary to specify the thermal coefficient values of the human body. However, when investigating the sensational and physiological temperature with an unclothed standard, the number of undetermined values is fewer in comparison to the clothed standard. Numerical values related to meteorological environment elements, along with behavioral and autonomic thermoregulation, can be measured and estimated with a certain degree of accuracy. However, it is essential to ascertain the effect that the range of the specified value has on sensational and physiological temperature.

Between the clothing and skin surface, there are sections where the clothing and skin surface are in contact and sections where they are not, and an air layer exists. Therefore, the following heat exchanges exist, making it difficult to handle by simple heat conduction alone: heat exchange due to heat conduction between clothing and the skin surface, heat conduction due to convection due to the flow of air between clothing and the skin surface, heat exchange due to long-wavelength thermal radiation between clothing and the skin surface and heat exchange due to short-wavelength solar radiation passing through clothing. However, as described above, clothing can be treated simply as a thermal resistor when investigating heat exchange from the environment to the human body by an unclothed standard in an outdoor space. Although the process of heat transfer is complicated and there are undefined thermal coefficient values, the specification of the heat transfer area and short-wavelength solar radiation absorptivity is important.

From the above, it may be essential to demonstrate the effect of short-wavelength solar radiation when investigating the effect of thermal environment stimulation on sensational and physiological temperature in an outdoor space. Accordingly, based on the experimental data of Kurazumi *et al.* [12], which clearly shows outdoor thermal environmental factors and the thermal sensory perceptions of the human body, the effect of the short-wavelength solar radiation absorptivity of clothing on the relationship between thermal environment evaluation index ETFe [13] and the thermal sensory perceptions of the human body was investigated.

## 2. Treatment of Short-Wavelength Solar Radiation

When investigating the sensational and physiological temperature with an unclothed standard, the body heat balance is the thermoregulation model in outdoor (**Figure 1**). To investigate the heat conduction owing to behavioral thermoregulation, or the heat exchange owing to short-wavelength solar radiation, it is essential to split the modeling into segments that receive solar radiation directly, segments that receive solar radiation indirectly through reflection or scattering, and segments that receive heat conduction. The solar radiation (solar constant) that arrives in the Earth's atmosphere can be separated into direct solar radiation that propagates directly through the atmosphere and arrives as parallel rays, sky radiation that is scattered by the atmosphere and arrives from the sky and reflected solar radiation that arrives after being reflected by the Earth's surface and surface features (e.g. buildings). From within these, the combination of direct and sky radiation is usually measured as the vertical quantity of total solar radiation.

The specific treatment method for short-wavelength solar radiation is to separate the vertical quantity of total solar radiation into direct and sky radiation, and then find these components. Next, the short-wavelength solar radiation incident on the human body is found using the projected area factor of the human

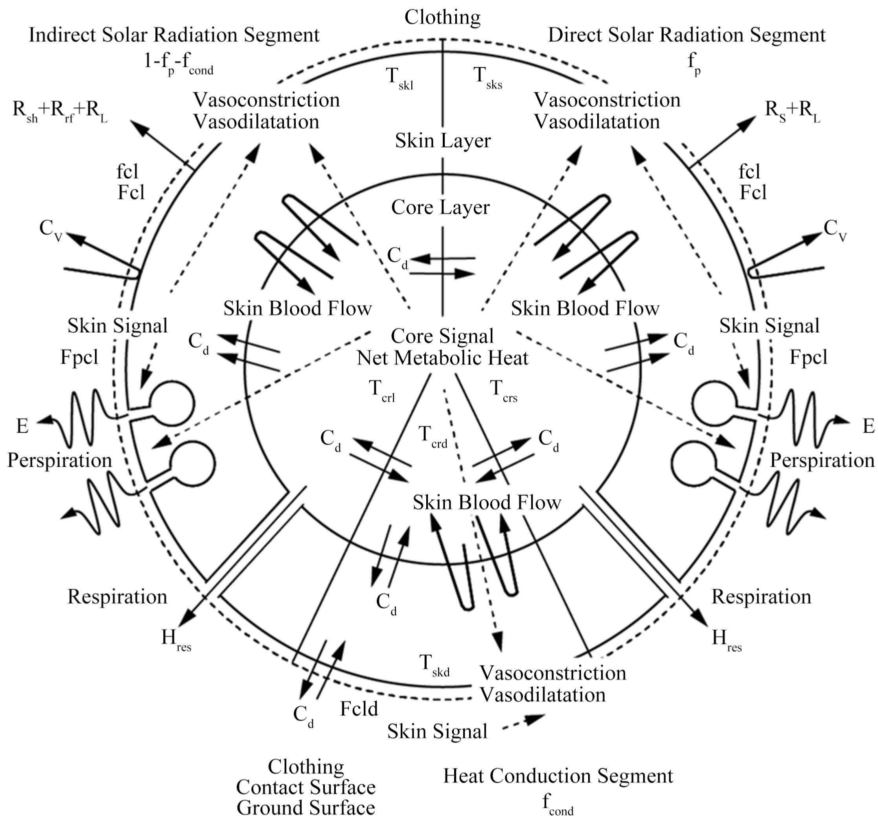


**Figure 1.** Thermoregulation model in outdoor [17]. $R_S$ is short-wavelength solar radiation heat gain on human body. $R_{sh}$ is sky radiation on human body. $R_{rf}$ is reflected solar radiation on human body. $R_L$ is long-wavelength radiation heat loss from human body. $C_v$ is convective exchange at skin. $C_d$ is conductive exchange at skin. E is evaporative heat loss from skin. Hres is respirational heat loss. fcl is effective surface area factor of clothing. Fcl is thermal efficiency factor of clothing. Fpcl is permeation efficiency factor of clothing. Fcld is thermal efficiency factor of clothing. $f_p$ is projected area factor. fcond is conductive heat transfer area factor. Tcrs is core temperature of direct solar radiation part. $T_{sks}$ is skin temperature of direct solar radiation part. $T_{crl}$ is core temperature of indirect solar radiation part. $T_{skl}$ is skin temperature of indirect solar radiation part. $T_{crd}$ is core temperature of heat conduction part. $T_{skd}$ is skin temperature of heat conduction part.

body corresponding to the solar altitude. Then, the sky is treated as a perfect diffusing surface and the sky radiation on the human body is calculated using the angle factor between the human body and the sky. Thereafter, the reflected solar radiation on the human body is calculated using albedo and the shape factor between the human body and surface features. Accordingly, the short-wavelength solar radiation heat value can be expressed by the following equations.

$$R_S = R_{dn} + R_{sh} + R_{rf} \tag{1}$$

$$R_{dn} = \alpha_h I_{DN}\, fcl\, Fcl\, f_p \tag{2}$$

$$R_{sh} = \alpha_h F_{sky-h}\, fcl\, Fcl\, f_{rad} \tag{3}$$

$$R_{rf} = \alpha_h F_{gui-h}\, \rho_g\, I_{TH}\, fcl\, Fcl\, f_{rad} \tag{4}$$

$$f_p = \frac{A_p}{A_s} \quad (5)$$

$$f_{rad} = \frac{A_{rad}}{A_s} \quad (6)$$

In calculating the reflected solar radiation from surface features, the area of the surface features receiving the radiation and the direct solar and sky radiation. Incident on it are essential. However, the specification of these physical quantities is exceedingly difficult. Accordingly, the surface features are treated as having the same reflectance as the Earth's surface in this research. That is, the human body can be considered as existing in an open space enclosed by the sky and the ground surface. Consequently, the reflected solar radiation on human body can be expressed by the following equations.

$$R_{rf} = \alpha_h \left(1 - F_{sky-h}\right)\rho_g I_{TH}\, fcl\, Fcl\, f_{rad} \quad (7)$$

$$F_{sky-h} = 1 - F_{gwi-h} \fallingdotseq \frac{F_{sky}}{2} \quad (8)$$

whereby,

$R_S$: short-wavelength solar radiation heat gain on human body [W/m$^2$]

$R_{dn}$: direct solar radiation on human body [W/m$^2$]

$R_{sh}$: sky radiation on human body [W/m$^2$]

$R_{rf}$: reflected solar radiation on human body [W/m$^2$]

$I_{DN}$: direct solar radiation [W/m$^2$]

$I_{SH}$: sky radiation [W/m$^2$]

$I_{TH}$: solar radiation [W/m$^2$]

$F_{sky-h}$: angle factor between human body and sky [N.D.]

$F_{gwi-h}$: angle factor between human body and surface feature, i, on ground [N.D.]

$F_{sky}$: sky factor [N.D.]

$\alpha_h$: solar radiation absorptivity [N.D.]

$\rho_g$: albedo [N.D.]

fcl: effective surface area factor of clothing [N.D.]

Fcl: thermal efficiency factor of clothing [N.D.]

$f_p$: projected area factor [N.D.]

$f_{rad}$: radiant heat transfer area factor [N.D.].

$A_p$: projected area [m$^2$]

$A_{rad}$: radiant heat transfer area [m$^2$]

$A_s$: total body surface area [m$^2$].

## 3. Results and Analysis

Before the subject experiments of Kurazumi *et al.* [12] were investigated according to the thermal environment evaluation index enhanced conduction-corrected modified effective temperature, ETFe [13]. This approach incorporates the effect of short-wavelength solar radiation in an outdoor space. The thermal environment evaluation index, ETFe, can temperature-convert the effects of wind speed, difference in postural position, long-wavelength radiation temperature, short-wavelength solar radiation, heat conduction and humidity into individual meteorological elements. The addition of each temperature-converted factor is also possible. The composite effect on sensational and physiological temperature in the outdoor space, as well as the discrete effect of each meteorological element, can be quantified on the same evaluation axis. The thermal environment evaluation index, ETFe, for an outdoor space can evaluate differences in postural position as behavioral thermoregulation in the outdoor space. Furthermore, verification tests that demonstrate the relationship between ETFe and the physiological and psychological effect on the human body have been carried out. Its validity as an outdoor environmental evaluation index that includes short-wavelength solar radiation and heat conduction from the ground surface in the outdoor space has been demonstrated [7]. This research demonstrates that short-wavelength solar radiation and heat conduction are significant environmental factors that contribute to ETFe [13]. In addition, the effect on the human body of the outdoor environment is shown by ETFe [12]. The range of thermal comfort of the outdoor environment is also shown by ETFe [14].

Air temperature and humidity, wind speed, short wavelength solar radiation, long-wavelength thermal radiation, ground surface temperature, water surface temperature, sky factor and green coverage ratio were measured as thermal environment conditions. Tympanic temperature, temperature of the skin exposed to airflow and skin temperature of parts in contact were measured as physiological conditions of the human body. Clothing was freely selected by the subjects according to the weather on the day of measurement, and the clo value of the subjects was found by the clo value method [15], which layers the combined clothing of the subjects. Concerning the skin wetness level, values calculated by the Two-Node Model [16], which is a thermoregulation model for an outdoor space, were used because it was difficult to find the perspiration quantity. Kurazumi *et al.* [17] developed and investigated a thermoregulation model for an outdoor space. In the present study, values for skin wetness level calculated by the behavioral thermoregulation model of Kurazumi *et al.* [17] were used.

Measurement points were selected with consideration for 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 in plants or water surfaces. The selection also took into consideration the sky factor, due to buildings or trees. The proportion of the solid angle of components of greenery, water, etc. comprised the solid angle of the total celestial sphere. The subjects consisted of 19 healthy young women for the summer experiments and 19 healthy young women for the winter experiments, for a total of 38 subjects.

The total measurements for all subjects at each observation point were 906. The dates of the measurements were August 4 - October 14, 2010, and January 27 - March 29, 2011. The short-wavelength solar radiation downwards differed significantly in the sun and in the shade.

The effect of the short-wavelength solar radiation absorptivity of clothing on ETFe was investigated based on the experimental data of Kurazumi *et al.* [12]. ETFe [13] is an outdoor thermal environment evaluation index based on the heat balance between the environment and the human body. 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 factor that takes into account the convective heat transfer area [18]. Then, the mean skin temperature used for the physiological response of the human body was calculated using the weighting coefficients that take into account heat conduction [19]. The surface area of the human body was calculated using the values of Kurazumi *et al.* [20] [21]. The values of Kurazumi *et al.* [22] were used for the convective heat transfer area ratio, radiant heat transfer area ratio and conductive heat transfer area ratio of the human body. The values of Miyamoto *et al.* [23] were used for the projection ratio of the human body. The values of Kuwabara *et al.* [24] were used for the radiant heat transfer coefficients and convective heat transfer coefficients of the human body. The Hendler *et al.* [25] value of 0.98, found from the reflectance of skin in electromagnetic waves of wavelength 3 μm or more, was used for the emissivity of the human body. The outdoor thermal environment evaluation index, ETFe, theoretically proposed and verified by Kurazumi *et al.* [7] [13], was calculated from weather observation values, along with the skin temperature and clo value of the human body. In view of the postural position and clothing conditions, there was considered to be no change in heat transfer area because all subjects were standing in the experiment in the outdoor space.

## 4. Effect of Short-Wavelength Solar Radiation Absorptivity

The heat transfer of short-wavelength solar radiation is affected by the short-wavelength solar radiation absorptivity. According to VDI3787-2 [26], the short-wavelength solar radiation absorptivity of a clothed human body is 0.7. Also, the short-wavelength solar radiation absorptivity in the heat balance model was used in the evaluations of an outdoor space by Jendritzky and Nubler [27], and Pickup and de Dear *et al.* [28]. However, Watanabe *et al.* [29] considered the absorptivity of a human body wearing black clothing to be 0.76, and that of one wearing white clothing to be 0.38. They also considered solar radiation absorptivity for other combinations of clothing, or ordinary clothing, to be within the range of the absorptivity of human body wearing black clothing or white clothing. Therefore, in view of these data, this study investigated the relationship between ETFe and the thermal sensory perceptions of the human body in the case short-wavelength solar radiation absorptivity, and the absorptivity was set at 0.7, 0.5 and 0.3.

**Figure 2** shows the relationship between ETFe and thermal sensation value. Although there is spread, a trend is shown whereby the thermal sensation becomes higher as ETFe increases. The spread for the thermal environment with higher ETFe is larger than for the thermal environment with lower ETFe. It may

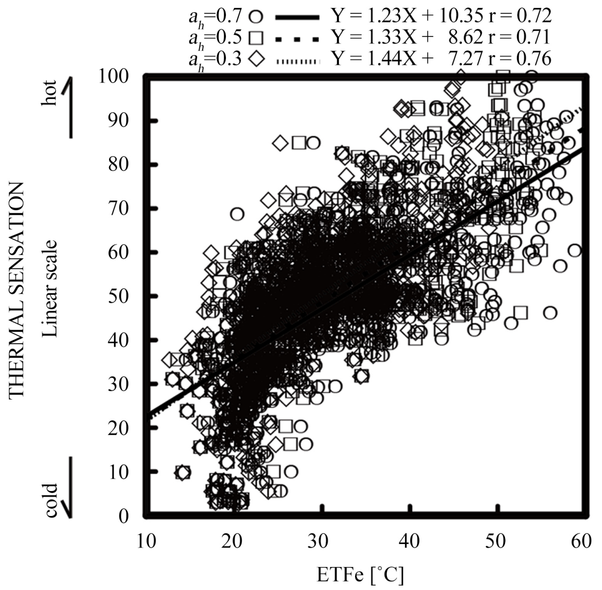


**Figure 2.** Relation between ETFe and thermal sensation. $\alpha_h$ is solar radiation absorptivity.

be that the thermal environment with high ETFe, in which short-wavelength solar radiation tends to be stronger, was more susceptible to short-wavelength solar radiation absorptivity. Kurazumi *et al.* [12] considered the short-wavelength solar radiation and the microclimate due to the air current formed by spreading foliage and dense trees to have affected the thermal sensation of the subjects. Environmental stimuli in outdoor spaces are in a heterogeneous and unsteady state. Also, the environmental stimulus was evaluated at the measurement points of measurement instruments. However, although the reaction of the subjects was evaluated in the vicinity of the measurement instruments, it can be considered to be exceedingly difficult to have multiple subjects exposed to identical environmental stimuli, due to the effect of the screening of short-wavelength solar radiation by foliage, for example, or changes in air current.

Focusing on the regression line for each short-wavelength solar radiation absorptivity, ETFe that can be considered to report the same thermal sensation is higher with higher short-wavelength solar radiation absorptivity. In addition, the effect of short-wavelength solar radiation absorptivity becomes strongly indicated in thermal environment conditions with a higher ETFe, at which direct solar radiation may be stronger.

An inspection of the parallelism of the regression lines gave $p < 0.10$ ($F = 5.68$, $p = 0.003$), indicating a significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p > 0.10$ ($F = 0.00$, $p = 1.00$), indicating no significant difference in the homogeneity of the regression lines. Therefore, in the range of the results of ETFe in this study, the short-wavelength solar radiation absorptivity was considered to influence the thermal environment evaluation during the summer, when the short-wavelength solar radiation is strong. The solar radiation absorptivity was also considered influential at locations where the sky factor is high.

The ETFe shown to report a thermally neutral sensation of 50 is 32.4˚C, 31.1˚C and 29.7˚C in the case where short-wavelength solar radiation absorptivity was 0.7, 0.5 and 0.3, respectively. A temperature difference of 2.7˚C was shown in ETFe for a thermally neutral temperature. In an outdoor space where short-wavelength solar radiation is even stronger, the difference in the thermal neutral temperature may further increase.

As identified by Humphreys [30], Brager and de Dear *et al.* [31], and Kurazumi *et al.* [7] [9] [10] [11] [12], the sense of expectation that the thermal environment of an indoor space will be more comfortable than the air temperature of an outdoor space has an effect. It is, therefore, considered possible that the neutral temperature for the indoor space will change. Unlike indoor spaces, the sense of expectation with regards to comfort in outdoor spaces is low to begin with. They are not judged to be comfortable thermal environments, so it is conceivable that this permissibility raised the neutral temperature, even for thermal environment conditions whereby ETFe is high.

Figure 3 shows the relationship between ETFe and comfort sensation value. ETFe peaks at about 30˚C - 35˚C, and reports tended to be on the uncomfortable side when the ETFe [13] was higher or lower than that.

Similar to the relationship between ETFe and thermal sensation, the spread for the thermal environment with higher ETFe is larger than for the thermal environment with lower ETFe. The thermal environment with high ETFe, in which short-wavelength solar radiation tends to be stronger, may be more susceptible to short-wavelength solar radiation absorptivity. Although it can be considered a kind of thermal adaption, environmental factors other than thermal functions and changes in environmental factor have an effect in outdoor spaces, and this

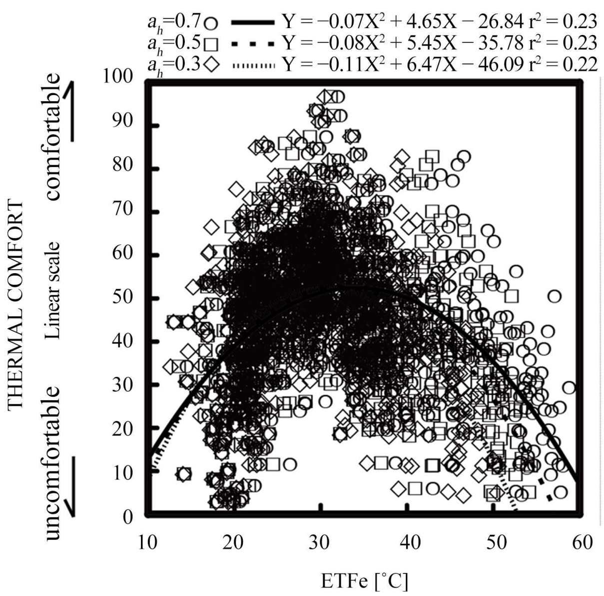


Figure 3. Relation between ETFe and thermal comfort. $\alpha_h$ is solar radiation absorptivity.

may have been expressed as a spread of reported value. Kurazumi *et al.* [12] considered there to be the possibility for the human body to experience discomfort by means of environmental factors changing, and this experience can be thought to induce relative comfort.

Even if the heat balance in the whole human body is the same, there is the potential for contribution from a local factor on the human body. Horikoshi *et al.* [32] demonstrated that the psychological reactions of the human body in an uneven/asymmetric thermal radiation environment have directionality, which changes under the effect of local thermal radiation. Kurazumi *et al.* [33] demonstrated that a parameter exists for the uneven/asymmetric thermal environmental factors in the thermal environment evaluation index that evaluates the effect on the human body in an uneven/asymmetric thermal radiation environment. They showed that there is a large spread in the response of the human body due to the effect of this parameter. Accordingly, changes with an effect that mitigates thermal function are considered to be variables for discomfort with regards to other environmental factors also. Although thermally uncomfortable, the outdoor space in which one's selection of location, or point of focus, may be changed at will may permit a broader range of thermal environment than an indoor space.

A test of equivalence for short-wavelength solar radiation absorptivity was conducted by a nonlinear quadratic regression model. The second order coefficient was $p < 0.10$, between a short-wavelength solar radiation absorptivity of 0.3 and 0.7, indicating a significant difference. Therefore, in the range of the results of ETFe in this study, it was correct to set the short-wavelength solar radiation absorptivity as being able to influence the thermal environment evaluation in summer, when the short-wavelength solar radiation is strong, or at locations where the sky factor is high.

Focusing on the regression line of short-wavelength solar radiation absorptivity, the ETFe at which neither a comfortable, nor uncomfortable, comfort value of 50 may be reported is 28.1˚C in the low temperature region and 40.1˚C in the high temperature region when the short-wavelength solar radiation absorptivity is 0.7. When the short-wavelength solar radiation absorptivity is 0.5, this ETFe is 26.9˚C in the low temperature region and 38.0˚C in the high temperature region. Also, when the short-wavelength solar radiation absorptivity is 0.3, this ETFe is 25.5˚C in the low temperature region and 35.5˚C in the high temperature region. This demonstrates that the allowable range of comfort in an outdoor space is wider than that in an indoor space.

As identified by Humphreys [30], Brager and de Dear [31], Nikolopoulou *et al.* [34] and Kurazumi *et al.* [7] [9] [10] [11] [12], the expectation of a comfortable environment in an outdoor space is considered to be low. These reports consider different thermal sensory perceptions to be reported even in the same climatic conditions. Unlike for indoor spaces, the sense of expectation with regards to comfort in outdoor spaces is low to begin with. They are not judged to be comfortable thermal environments, so it is conceivable that even thermal environment conditions with high ETFe are permitted.

The above demonstrates that the effect of short-wavelength solar radiation absorptivity is strongly indicated in outdoor thermal environments with a higher ETFe, at which direct solar radiation may be stronger. Also, in an outdoor space where the effect of the sky factor and albedo is strong, the selection of the short-wavelength solar radiation absorptivity was demonstrated to greatly affect the estimation of outdoor heat environment index.

When evaluating the thermal environment, clothing is regarded as an insulating material that exists between the human body and the external environment. In ASHRAE Standard 55:2017 [35] and ISO Standard 7730:2005 [36], the thermal resistance of various representative clothes is listed. A method of calculating the thermal resistance of clothing by combining clothes is also given. However, data is rarely presented on short-wavelength solar radiation absorptivity.

It is extremely difficult to individually specify the thermal resistance of the subject's clothing and the short-wavelength solar radiation absorptivity when taking actual measurements and conducting experiments. As described above, it is possible to set the thermal resistance of clothing to within a certain range. However, the short-wavelength solar radiation absorptivity is rarely the representative value.

The short-wavelength solar radiation absorptivity changes in accordance with the hue and lightness of the clothing, along with the short-wavelength solar radiation reflectance. In an outdoor space, the effect of short-wavelength solar radiation is remarkable, and the setting of the short-wavelength solar radiation absorptivity has a significant effect on the thermal environment evaluation. In view of this fact, when taking actual measurements or conducting an experiment, the hue of the clothing as a minimum must be considered an essential requirement when interviewing subjects on clothing, or setting the clothing conditions of the human body.

## 5. Conclusions

In order to demonstrate the effect of the short-wavelength solar radiation absorptivity of clothing on sensational and physiological temperature in an outdoor space, the relationship between the thermal environment evaluation index, ETFe, and the thermal sensory perceptions of the human body in an outdoor space were investigated based on the subject experiments of Kurazumi *et al.* [12], which investigated the effect of the thermal environment on the human body in an outdoor space.

A significant temperature difference of 2.7˚C was shown for an ETFe that resulted in a neither hot nor cold, thermally neutral temperature. The effect of short-wavelength solar radiation absorptivity was strongly indicated in thermal environment conditions with a higher ETFe, in which direct solar radiation may be stronger. Also, in an outdoor space where the effect of the sky factor and albedo is strong, the selection of the short-wavelength solar radiation absorptivity was demonstrated to greatly affect the evaluation of the heat environment.

For the evaluation and estimation of the outdoor thermal environment, it is essential to obtain the hue of clothing as a minimum when interviewing subjects on clothing or setting clothing conditions of the human body in an outdoor space.

## Acknowledgements

We would like to express our sincerest gratitude to the study subjects who participated in the present study.

## References

[1] Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N. and Becker, S. (2003) Outdoor Comfort Research Issues. *Energy and Buildings*, **35**, 77-86. https://doi.org/10.1016/S0378-7788(02)00082-8

[2] Oliveira, S. and Andrade, H. (2007) An Initial Assessment of the Bioclimatic Comfort in an Outdoor Public Space in Lisbon. *International Journal of Biometeorology*, **52**, 69-84. https://doi.org/10.1007/s00484-007-0100-0

[3] Eliasson, I., Knez, I., Westerberg, U., Thorsson, S. and Lindberg, F. (2007) Climate and Behaviour in a Nordic City. *Landscape and Urban Planning*, **82**, 72-84. https://doi.org/10.1016/j.landurbplan.2007.01.020

[4] Nikolopoulou, M. and Steemers, K. (2003) Thermal Comfort and Psychological Adaptation as a Guide for Designing Urban Spaces. *Energy and Buildings*, **35**, 95-101. https://doi.org/10.1016/S0378-7788(02)00084-1

[5] Nikolopoulou, M. and Lykoudis, S. (2006) Thermal Comfort in Outdoor Urban Spaces: Analysis across Different European Countries. *Building and Environment*, **41**, 1455-1470. https://doi.org/10.1016/j.buildenv.2005.05.031

[6] Ishii, J., Horikoshi, T., Kurazumi, Y., Nagano, K. and Fukagawa, K. (2008) A Field Survey of Thermal Comfort in Outdoor Space. *ICB*2008 18*th International Congress of Biometeorology*, Tokyo, 22-16 September 2008, 1-4.

[7] Kurazumi, Y., Tsuchikawa, T., Matsubara, N., Kondo, E. and Horikoshi, T. (2011) Evaluation of Enhanced Conduction-Corrected Modified Effective Temperature ETFe as the Outdoor Thermal Environment Evaluation Index. *Energy and Buildings*, **43**, 2925-2937. https://doi.org/10.1016/j.enbuild.2011.07.019

[8] Kurazumi, Y., Kondo, E., Ishii, J., Sakoi, T., Fukagawa, K., Bolashikov, Z.D., Tsuchikawa, T., Matsubara, N. and Horikoshi, T. (2013) Effect of the Environmental Stimuli upon the Human Body in Winter Outdoor Thermal Environment. *Journal of Environmental and Public Health*, **2013**, Article ID: 418742. https://doi.org/10.1155/2013/418742

[9] Kurazumi, Y., Ishii, J., Fukagawa, K. and Aruninta, A. (2015) The Influence of Tropical Urban Climate upon the Human Body. *International Joint-Conference of SENVAR-iNTA-AVAN* 2015, Johor, 24-26 November 2015, 105-114.

[10] Kurazumi, Y., Ishii, J., Fukagawa, K., Kondo, E. and Aruninta, A. (2016) Ethnic Differences in Thermal Responses between Thai and Japanese Females in Tropical Urban Climate. *American Journal of Climate Change*, **5**, 52-68. https://doi.org/10.4236/ajcc.2016.51007

[11] Kurazumi, Y., Ishii, J., Fukagawa, K., Kondo, E., Nyilas, A. and Aruninta, A. (2017)

Seasonal Differences of Psychological and Physiological Responses in Tropical Urban Climate. *Health*, **9**, 896-920. https://doi.org/10.4236/health.2017.96064

[12] Kurazumi, Y., Ishii, J., Kondo, E., Fukagawa, K., Bolashikov, Z.D., Sakoi, T., Tsuchikawa, T., Matsubara, N. and Horikoshi, T. (2014) The Influence of Outdoor Thermal Environment on Young Japanese Female. *International Journal of Biometeorology*, **58**, 963-974. https://doi.org/10.1007/s00484-013-0681-8

[13] Kurazumi, Y., Fukagawa, K., Yamato, Y., Tobita, K., Kondo, E., Tsuchikawa, T., Horikoshi, T. and Matsubara, N. (2011) Enhanced Conduction-Corrected Modified Effective Temperature as the Outdoor Thermal Environment Evaluation Index upon the Human Body. *Building and Environment*, **46**, 12-21. https://doi.org/10.1016/j.buildenv.2010.06.012

[14] Kurazumi, Y., Tsuchikawa, T., Kondo, E., Ishii, J., Fukagawa, K., Yamato, Y., Tobita, K., Ando, Y., Matsubara, N. and Horikoshi, T. (2012) Thermal Comfort Zone in Outdoor Environment. *Journal of Human and Living Environment*, **19**, 115-127.

[15] Sprague, C.H. and Munson, D.M. (1974) A Composite Ensemble Method for Estimating Thermal Insulating Values of Clothing. *ASHRAE Transactions*, **80**, 120-129.

[16] Gagge, A.P., Fobelets, A.P. and Berglund, L.G. (1986) A Standard Predictive Index of Human Response to the Thermal Environment. *ASHRAE Transactions*, **92**, 709-731.

[17] Kurazumi, Y., Sakoi, T., Tsuchikawa, T., Fukagawa, K., Bolashikov, Z.D. and Horikoshi, T. (2014) Behavioral Thermoregulation Model for Evaluation of Outdoor Thermal Environment. *Journal of Ergonomics*, **4**, 1-14.

[18] Kurazumi, Y., Tsuchikawa, T., Torii, T., Kakutani, K., Matsubara, N. and Horikoshi, T. (2004) Weighting Coefficients for Calculating Mean Skin Temperature When Considering Convective Heat Transfer Areas. *Journal of the Human-Environmental System*, **7**, 19-28. https://doi.org/10.1618/jhes.7.19

[19] Kurazumi, Y., Matsubara, N., Furukawa, N., Fujiwara, M., Ue, A., Ueki, Y., Nagai, H. and Yamamoto, S. (1998) Japanese Weighting Coefficients for Calculating Mean Skin Temperature in Relation to Posture. *Japanese Journal of Biometeorology*, **35**, 121-132.

[20] Kurazumi, Y., Horikoshi, T., Tsuchikawa, T. and Matsubara, N. (1994) The Body Surface Area of Japanese. *Japanese Journal of Biometeorology*, **31**, 5-29.

[21] Kurazumi, Y., Tsuchikawa, T., Kakutani, K., Torii, T., Matsubara, N. and Horikoshi, T. (2003) Evaluation of the Calculation Formula for the Body Surface Area of the Human Body. *Japanese Journal of Biometeorology*, **39**, 101-106.

[22] Kurazumi, Y., Tsuchikawa, T., Matsubara, N. and Horikoshi, T. (2008) Effect of Posture on the Heat Transfer Areas of the Human Body. *Building and Environment*, **43**, 1555-1565. https://doi.org/10.1016/j.buildenv.2007.09.001

[23] Miyamoto, S., Horikoshi, T. and Hirokawa, Y. (1998) Projected Area Factors of the Human Body at Standing Posture under Different Clothing Conditions. *Journal of Architecture*, *Planning and Environmental Engineering*, *Transactions of AIJ*, **513**, 47-52.

[24] Kuwabara, K., Mochida, T., Kondo, M. and Matsunaga, K. (2001) Measurement of Man's Convective Heat Transfer Coefficient by Using a Thermal Manikin in the Middle Wind Velocity Region. *Journal of Human and Living Environment*, **8**, 27-32.

[25] Hendler, E., Crosbie, R. and Hardy, J.D. (1958) Measurement of Heating of the Skin during Exposure to Infrared Radiation. *Journal of Applied Physiology*, **12**, 177-185. https://doi.org/10.1152/jappl.1958.12.2.177

[26] VDI (2008) VDI 3787-2, Environmental Meteorology—Methods for the Human Biometeorological Evaluation of Climate and Air Quality for Urban and Regional Planning at Regional Level Part 1: Climate. Beuth, Berlin.

[27] Jendritzky, G. and Nubler, W. (1981) A Model Analysing the Urban Thermal Environment in Physiologically Significant Terms. *Archives for Meteorology*, *Geophysics and Bioclimatology Serial B*, **29**, 313-326. https://doi.org/10.1007/BF02263308

[28] Pickup, J. and de Dear, R.J. (1999) An Outdoor Thermal Comfort Index (OUT_SET*)—Part I—The Model and Its Assumptions. *International Congress of Biometeorology and International Conference on Urban Climatology*, Sydney, 8-12 November 1999, 279-283.

[29] Watanabe, S., Horikoshi, T. and Tomita, A. (2010) Measurement of Solar Radiation Absorptamce of Clothed Human Body in Outdoor. *Japanese Journal of Biometeorology*, **47**, 165-173.

[30] Humphreys, M. (1976) Field Studies of Thermal Comfort Compared and Applied. *Building Services Engineer*, **44**, 5-27.

[31] Brager, G.S. and deDear, R.J. (1998) Thermal Adaptation in the Build Environment: A Literature Review. *Energy and Buildings*, **27**, 83-96. https://doi.org/10.1016/S0378-7788(97)00053-4

[32] Horikoshi, T., Kurazumi, Y., Hirayama, K., Tsuchikawa, T. and Kobayashi, Y. (1989) Indication of the Effect of Asymmetric Thermal Radiation of the Human Physiological and Psychological Responses. *The* 2*nd World Congress on Heating*, *Ventilating*, *Refrigerating and Air Conditioning*, Sarajevo, 27 August-1 September 1989, 188-193.

[33] Kurazumi, Y., Horikoshi, T., Hirayama, K., Tsuchikawa, T. and Kobayashi, Y. (1993) The Influence of Asymmetric and Uneven Thermal Radiation Environments upon the Human Body, in the Case of Constant Operative Temperature. *Journal of Architecture*, *Planning and Environmental Engineering*, **447**, 17-26. https://doi.org/10.3130/aijax.447.0_17

[34] Nikolopoulou, M., Baker, N. and Steemers, K. (2001) Thermal Comfort in Outdoor Urban Spaces, Understanding the Human Parameter. *Solar Energy*, **70**, 227-235. https://doi.org/10.1016/S0038-092X(00)00093-1

[35] ANSI/ASHRAE (2017) Standard 55: 2017, Thermal Environmental Conditions for Human Occupancy. ASHRAE, Atlanta.

[36] ISO (2005) Standard 7730: 2005, Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. ISO, Geneva.