

Effects of Outdoor Thermal Environment upon the Human Responses

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Abstract

In a summer outdoor space, the influence of short-wave length solar radiation on the human body is strongly apparent, heat is retained in the body, and the risk of heat disorders such as heat stroke increases. To avoid this, it is essential to seek shade to avoid the influence of short-wave length solar radiation. In addition, natural ground surfaces such as green spaces and water surfaces are useful in reducing the air temperature. It is indispensable to consider climate mitigation effect of outdoor space. The purpose of this study is to clarify the influence of the thermal environment of an outdoor space on the human body in rural and suburban regions where paddy fields remain. Subject experiments were conducted to examine the relationship between the thermal environment evaluation index enhanced conduction-corrected modified effective temperature (ETFe) in an outdoor space and the physiological and psychological responses of the human body. Experiment sites were selected with consideration for the natural 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; and water surfaces, as well as the sky factor due to buildings or trees etc. and the proportion of the solid angle of components of greenery and water etc. comprising the solid angle of the total celestial sphere. A ground surface feature with a high heat capacity may promote sensation of hot and deteriorate the thermal sensation. A landscape of thick vegetation with a high green factor may have a strong feeling of confinement, which can make it somewhat hot and somewhat uncomfortable thermal environment due to the sense of stagnation. Compared with the ur-

ban environment, it is conceivable that the difference in the perceptual environment, whereby it is subconsciously assumed to be a comfortable thermal environment, had an effect in the rural and suburban regional environment, resulting in an ETFe lower than the upper limit of comfort in a summer urban environment.

Keywords

ETFe, Mean Skin Temperature, Outdoor Environment, Rural Area, Thermal Comfort, Thermal Sensation, Urban Area

1. Introduction

In an outdoor space, in addition to physical and biological environmental factors, psychological environmental stimuli are important in determining thermal comfort [1]-[8]. Adaption to the thermal environment according to cultural background, experience of being in hot/cold thermal environments and the like, sense of expectation of the thermal environment, behavioral thermal regulation and the effect of the thermal environment history such as the time spent exposed to it are apparent in reported comfort. In these studies, the association between the outdoor thermal environment evaluation index and the thermal sensation of the human body is not made clear, and remains within the category of qualitative discussion.

Kurazumi *et al.* [9] [10] [11] quantitatively evaluate the influence on the human body in the outdoor thermal environment using enhanced conduction-corrected modified effective temperature (ETFe) [12] as an evaluation axis. In this series of studies, the sense of expectation with regards to comfort in outdoor spaces is low and the subjects are not judged to be comfortable thermal environments, so it is considered that even thermal environmental conditions with a high ETFe and thermal environmental conditions with high mean skin temperature can be tolerated as well as thermal environment conditions with a low ETFe and thermal environmental conditions with low mean skin temperature. The outdoor thermal environment being in a harsh condition is shown quantitatively by the outdoor thermal environment evaluation index ETFe.

Givoni *et al.* [13], Oliveira and Andrade [14], Eliasson *et al.* [15], Nikolopoulou and Steemers [5], Nikolopoulou and Lykoudis [7] and Ishii *et al.* [16] show the relationship between the physical environmental factors of the outdoor space and the thermal sensation of the human body, and clarify that the outdoor environmental factors that influence the thermal sensation of the human body are air temperature, wind speed and short-wave length solar radiation. However, these studies do not measure the physiological parameters of the human body necessary to calculate the heat balance of the human body. Kurazumi *et al.* [9] [17] measure the physiological parameters of the human body necessary to calculate the heat balance of the human body, and demonstrate the effect of outdoor

thermal environment factors on the thermal sensation of the human body. Kurazumi *et al.* [9] clarify that the variable factors by which summer outdoor environmental factors influence the thermal sensation of the human body are heat conduction, humidity and short-wave length solar radiation. In addition, it clarifies that the variable factors that affect the thermal comfort of the human body are air current, heat conduction and humidity. Also, Kurazumi *et al.* [17] clarify that the variable factors by which winter outdoor environmental factors influence the thermal sensation of the human body are air temperature, long-wave length thermal radiation and short-wave length solar radiation. In addition, it clarifies that the variable factors that influence the thermal comfort of the human body are air temperature, humidity, long-wave length thermal radiation, short-wave length solar radiation and heat conduction. These studies quantitatively show the influence of outdoor thermal environmental factors on the thermal sensation of the human body.

Kurazumi *et al.* [18] [19] [20] demonstrate the influence of an outdoor thermal environment on the human body for the influence of a tropical climate with strong short-wave length solar radiation on the thermal sensation of the human body as the evaluation axis. It clarifies that in tropical areas where the effects of nighttime cooling cannot be expected, the effect of long-wave length thermal radiation is strong in the shade of objects made of materials with high heat capacity, and the effect of improving the thermal sensation of the human body through shade is low. These studies quantitatively show that when the outdoor thermal environment is harsh, it is essential to reduce the influence of long-wave length thermal radiation.

The influence of large-scale green space, rivers, etc. on the summer outdoor thermal environment is measured [21]-[26]. These studies quantitatively show the influence of outdoor thermal environmental factors on the thermal sensation of the human body. Meanwhile, the influence of park lakes, agricultural ponds, etc., on the summer outdoor thermal environment is measured [27] [28] [29]. The environment is influenced by the depth of water, the temperature of the surface of the water and the direction of the wind, but the trend is observed whereby the air temperature tends to be lower directly above the water surface and in the vicinity of the pond compared to the surrounding area. However, they consider air temperature reduction effect to be within a limited range. If the temperature of the water surface is higher than the air temperature, the air temperature on the downwind side of a pond across which wind blows tends to increase.

From the above, in a summer outdoor space, the influence of short-wave length solar radiation on the human body is strongly apparent, heat is retained in the body, and the risk of heat disorders such as heat stroke increases. To avoid this, it is essential to seek shade to avoid the influence of short-wave length solar radiation. However, under the cover of objects with large heat capacity, the effect of long-wave length thermal radiation becomes stronger and the environmental mitigation effect becomes lower. In addition, natural ground surfaces such as

green spaces and water surfaces are useful in reducing the air temperature. However, concerning the effects of water surfaces, water depth, water flow and water temperature influence the temperature reduction effect.

Japan has a cereal-crop culinary culture and rice cultivation is actively carried out. There are many paddy fields in the suburbs, countryside, and mountainous areas. Even in urban areas, some paddy fields still remain. Although there are differences depending on the area, from May to September, paddy fields can be expected to be effective as green spaces and water surfaces. According to Nishida *et al.* [30] etc., the irrigation water temperature of the paddy field is influenced by the water temperature of the irrigation channel. In addition, the water temperature of the irrigation channel rises as it flows from upstream to downstream. Therefore, the irrigation water temperature is strongly affected by the water temperature of the water near the inlet. Meanwhile, the influence of the depth of irrigation is considered to be stronger near the paddy field drain. Regarding the relationship between the growth of rice and the water temperature of the paddy field, the influence of short-wave length solar radiation is stronger at the early stage of rice formation because the leaf area of the rice is small with respect to the change of the irrigation water temperature. At the stage of ripening of the head of the rice, regarding the change in the irrigation water temperature, the shielding rate of short-wave length solar radiation increases due to the increase in the leaf area due to the growth of the rice, and in addition to short-wave length solar radiation the influence of the air temperature increases. From the heading stage of rice onwards, the short-wave length solar radiation shielding rate further increases due to the inclination of the leaves of the rice, and changes in the irrigation water temperature are considered to be strongly influenced by air temperature.

Therefore, this study focused on the rural and suburban regions where paddy fields still remain, and aimed to clarify the relationship between outdoor thermal environment evaluation index ETFe [12] and the response of the human body with respect to thermal sensory perception. We decided to collect phenomena and information to quantitatively examine the outdoor thermal environment and effects on the human body.

2. Experimental Plan

2.1. ETFe

The thermal environment evaluation index for an outdoor space ETFe (enhanced conduction-corrected modified effective temperature) was developed by Kurazumi *et al.* [12]. Also, verification tests that clarify the relationship between ETFe and the physiological and psychological effect on the human body have been carried out, and its effectiveness as an outdoor environmental evaluation index has been clarified [9]. This sensational and physiological climatic environment index ETFe is considered to enable temperature-conversion of each effect of wind speed, long-wave length thermal radiation in the outdoor space,

short-wave length radiation, surface temperature of the material in contact with the human body and humidity into individual meteorological elements.

The influence of these five environmental factors on the heat balance of the human body is considered to be expressible in newly defined thermal environment evaluation indices as follows: convective heat transfer area combined with the thermal velocity field TVF_{hta} for wind speed; radiant heat transfer area combined with the effective radiation field concerning the long-wave length thermal radiation in outdoor space ERF_{htaL} [12] for long-wave length thermal radiation; radiant heat transfer area combined with the effective radiation field concerning the short-wave length solar radiation in outdoor space ERF_{htaS} [12] for short-wave length solar radiation; heat transfer area combined with the effective conduction field ECF_{hta} [12] for surface temperature of the material in contact with the human body; and effective humidity field at enhanced conduction-corrected modified effective temperature EHF_{ETFe} [12] for humidity. The addition of each temperature-converted factor is also considered to be possible and quantifying the composite effect on sensation in the outdoor space as well as the discrete effect of each meteorological element to possible on the same evaluation axis.

$$ETFe = T_a + TVF_{hta}/h_{fL} + ERF_{htaL}/h_{fL} + ECF_{hta}/h_{fL} + EHF_{ETFe}/h_{fL} + ERF_{htaS}/h_{fL} \quad (1)$$

$$TVF_{hta} = (h_o fclFcl_{conv} - h_c fclFcl_{conv})(T_s - T_a) \quad (2)$$

$$ERF_{htaL} = h_{rL} fclFcl_{rad}(T_{rL} - T_a) \quad (3)$$

$$ECF_{hta} = h_d Fcl_{cond}(T_f - T_a) \quad (4)$$

$$EHF_{ETFe} = Lwh_c fclFp_{cl}(p_a - 0.5p_{ETFe}^*) \quad (5)$$

$$ERF_{htaS} = R_s \quad (6)$$

$$h_{fL} = h_o fclFcl_{conv} + h_{rL} fclFcl_{rad} + h_d Fcl_{cond} \quad (7)$$

where:

$ETFe$: enhanced conduction-corrected modified effective temperature [K];

T_a : air temperature [K];

TVF_{hta} : convective heat transfer area combined with the thermal velocity field [W/m^2];

ERF_{htaL} : radiant heat transfer area combined with the effective radiation field concerning the long-wave length thermal radiation in outdoor space [W/m^2];

ERF_{htaS} : radiant heat transfer area combined with the effective radiation field concerning the short-wave length solar radiation in outdoor space [W/m^2];

ECF_{hta} : heat transfer area combined with the effective conduction field [W/m^2];

EHF_{ETFe} : effective humidity field at enhanced conduction-corrected modified effective temperature [W/m^2];

h_{rL} : radiant heat transfer coefficient concerning the long-wave radiation in outdoor space [W/m^2K];

f_{cl} : effective surface area of clothing [-];
 f_{conv} : convective heat transfer area factor [-];
 f_{cond} : conductive heat transfer area factor [-];
 f_{rad} : radiant heat transfer area factor [-];
 F_{cl} : thermal efficiency factor of clothing in the exposed airflow area [-];
 F_{cld} : thermal efficiency factor of clothing in the heat conduction area [-];
 F_{clo} : thermal efficiency factor of clothing under the standard condition [-];
 F_{pcl} : permeation efficiency factor of clothing [-];
 h_c : convective heat transfer coefficient [W/m^2K];
 h_d : resultant heat conductance [W/m^2K];
 h_{fl} : sensible heat transfer coefficient in outdoor space [W/m^2K];
 h_o : convective heat transfer coefficient under the standard condition [W/m^2K];
 L : Lewis relation coefficient [K/kPa];
 p_a : water vapor pressure at the outdoor air temperature [kPa];
 p_{ETFe}^* : saturated water vapor pressure at enhanced conduction-corrected modified effective temperature [kPa];
 R_s : short-wave length solar radiation heat gain of human body [W/m^2];
 T_s : convection-corrected mean skin temperature [K];
 T_f : surface temperature of the contacted material [K];
 T_{rL} : mean radiant temperature concerning long-wave length thermal radiation in outdoor space [K];
 w : skin wettedness [-].

2.2. Experimental Procedure

In order to maintain consistency in the experimental data collection and measurement method of the outdoor environment taking the thermal environment evaluation index for an outdoor space ETFe [12] as an evaluation axis, the experimental method and test items of this study are the same as described in Kurazumi *et al.* [9] [10] [11] [17] [18] [19] [20].

Experiments were conducted in late July 2016 and from late August 2015 to the beginning of September, corresponding to the ripening period of rice in paddy fields. The observation points were drawn at random and the route to the points was undecided. With consideration for the burden on subjects, the experiment was concluded at a point two hours after commencement of the mobile observations on foot. Morning measurements were carried out in a period from around 10:00 to 13:00 and afternoon measurements were carried out in a period from around 13:00 to 16:00.

In indoor spaces such as laboratory experiments, it is exceedingly rare to test the subject in extremely hot or cold thermal environments. In general experiments that include a transition period or a heterogeneous thermal environment, the exposure experiment time period for the heat balance between the human body and the environment to become almost a steady state is the subject of the

investigation. However, the thermal environment of summer outdoor spaces can be harsh to the extent that there are cases of death by heat stroke. Accordingly, one must avoid extended periods in outdoor spaces where one would be struck by direct high temperature solar radiation or strong low temperature winds. It is unavoidable that experiments on subjects in outdoor spaces treat a necessary transition period of a short time. Unlike an indoor space, it is difficult to consider spending extended periods in an outdoor thermal environment that can be considered uncomfortable, due to behavioral thermoregulation by means of environmental refuge behavior. With that, in consideration of the subjects' maintenance of a posture in a standing position and the response time of the Assman ventilated psychrometer, the actual measurement of the human body response and thermal environment in the mobile observations were performed ten minutes after having established the observation device. Naturally, it can be conjectured that the human body response will differ the longer the exposure time of the subjects, and the experimental period was determined with consideration for the safety of the subjects.

Subjects moved on foot to the observation point after having been seated and at rest for 60 minutes or longer in an air-conditioned indoor space inside a building. The experiment staff instructed the subjects that the psychological reporting was thermally specific thermal sensation and thermal comfort, and that they should report the average sensation during the exposure time. The movement speed of the subjects was made about 0.7 m/s.

After arriving at each measurement point, the subjects waited in a standing posture, during which time the experiment staff set up 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 detailed above. The subjects were positioned around the thermal environment measurement instruments with the thermal environment measurement instruments in the center. 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 exposure, the subjects reported the average thermal sensation and the average thermal comfort for the whole body that they experienced for the time exposed at the observation point.

2.3. Outline of the Observation Points

Figure 1 shows the observation sites. **Table 1** shows a summary of the observation points. Observation points were selected with consideration for the natural 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; and water surfaces, as well as the condition of sky factor due to buildings or trees etc. and the proportion of the solid angle of components of greenery and water etc. comprising the solid angle of the total celestial sphere (hereafter, green factor). Nineteen observation points were chosen.

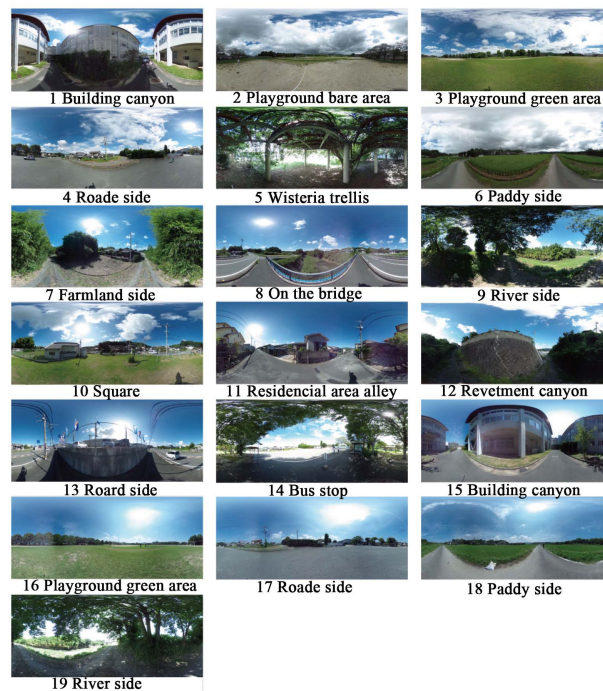


Figure 1. 360-degree panoramic photographs of observation site.

Table 1. Summary of observation points.

Point	Survey site	Ground surface	Skywards surface	Surrounds North side	Surrounds East side	Surrounds South side	Surrounds West side	Sky factor	Green factor
1	Building canyon	Asphalt & Weed	Open	Building	Building	Building & Tree	Open	0.295	0.116
2	Playground bare area	Grass	Open	Open	Open	Open	Open	0.920	0.046
3	Playground green area	Bare ground	Open	Open	Open	Open	Open	0.951	0.481
4	Roadside	Asphalt	Open	Open	Open	Open	Open	0.873	0.046
5	Wisteria trellis	Bare ground	Wisteria	Ivy	Ivy	Ivy	Ivy	0.104	0.135
6	Paddy side	Asphalt & Paddy field	Open	Open	Open	Open	Open	0.938	0.132
7	Farmland side	Weed	Bamboo	Bamboo	Open	Open	Open	0.506	0.338
8	On the bridge	Concrete & River	Open	Open	Open	Open	Open	0.913	0.035
9	River side	Gravel & Weed & River	Tree	Open	Open	Tree	Open	0.352	0.411
10	Square	Grass & Weed	Open	Open	Open	Building	Open	0.870	0.532
11	Residencial area alley	Asphalt	Open	Building	Open	Open	Building	0.690	0.019
12	Revetment canyon	Stone revetment	Open	Steep slope	Open	Stone revetment	Open	0.620	0.157
13	Roadside	Asphalt	Open	Open	Open	Concrete revetment	Open	0.718	0.000
14	Bus stop	Asphalt & Weed	Tree	Open	Open	Tree	Open	0.359	0.306
15	Building canyon	Asphalt & Weed	Open	Building	Building	Building & Tree	Open	0.287	0.051
16	Playground green area	Grass	Open	Open	Open	Open	Open	0.852	0.534
17	Roadside	Asphalt	Open	Open	Open	Open	Open	0.864	0.091
18	Paddy side	Asphalt & Paddy field	Open	Open	Open	Open	Open	0.881	0.100
19	River side	Gravel & Weed & River	Tree	Open	Open	Tree	Open	0.109	0.556

Green factor is green covering factor. Green covering factor is defined as the ratio of green, water surface solid angles to celestial globe solid angle.

2.4. Subjects

The subjects were 38 healthy young males and females. The age of the 21 young males was 22.0 ± 2.1 , their height was 157.5 ± 3.4 cm, and their weight was 50.4 ± 5.6 kg. The age of the 17 young females was 22.0 ± 2.1 , their height was 157.5 ± 3.4 cm, and their weight was 50.4 ± 5.6 kg. With a BMI of 20.3 ± 2.0 , they can be considered to be unremarkable test subjects.

In accordance with the Helsinki Declaration [31], the details of the experiment were fully explained to the subjects in advance and their consent to participate in the experiment was obtained.

To calculate the surface area of the human body, the body surface area calculation formula of Kurazumi *et al.* [32], the effectiveness of which as a calculation formula is verified [33], was used.

It is rare to perform a test subject experiment that measures physiological and psychological quantities as a response of the human body using a great number of test subjects. It is also difficult to perform an experiment that hypothesizes a statistical population. Therefore, this study is considered significant as being new data.

2.5. Experimental Parameters

Air temperature and humidity, wind speed, short-wave length solar radiation, long-wave length thermal radiation, and ground surface temperature of the central part of the experimental equipment were measured as thermal environment conditions. The air temperature and humidity were measured at a height of 90 cm above the ground by means of an Assmann ventilated psychrometer. The average wind speed was measured for 10 minutes at a height of 90 cm above the ground by a non-directional anemometer (Kanomax Japan, Inc.: 6533, measurement range 0.05 - 5.00 m/s). Concerning the short-wave length radiation in the regions from the visible to the near-and-mid-infrared and the terrestrial radiation in the far infrared region, radiation in downwards and upwards directions were measured at a height of 90 cm above the ground by long and short-wave length radiometer (EKO Instruments: MR-50, sensitivity $7 \mu\text{V}/\text{Wm}^{-2}$, short-wave length range 305 - 2800 nm, long-wave length range 5000 - 50,000 nm). The ground surface temperature was measured by a radiation thermometer (KONICA MINOLTA: HT-10D, measurement wavelength 8 - 14 μm , measurement angle 1.4° - 2.0° , emissivity measurement range 0.10 - 1.00).

The sky factor was measured by a photograph of the sky taken 90 cm above the ground at the observation point using a fisheye lens with an orthographical projection format (Yasuhara: Madoka 1807.3 mm f/4) and a 35 mm digital SLR camera (Sony: $\alpha 7$). The proportion of the solid angle of components of greenery and water surfaces etc. comprising the solid angle of the total celestial sphere was measured by converting the orthographic projection map (Hugin by Pablo d'Angelo) in the zenith direction and nadir direction into a solid angle map. The albedo, sky temperature, and surface temperature were calculated from each di-

rectional component of the short-wave length solar radiation and the long-wave length thermal radiation.

Skin temperature was measured as a physiological condition for the human body by a thermistor thermometer (NIKKISO-THERM N542R data logger, measurement range -50°C - 230°C , resolution 0.01°C and a NIKKISO-THERM ITP8391 body surface probe). Medical surgical tape (NICHIBAN, NICHIBAN SURGICAL TAPE-21N) with excellent moisture permeability was used to attach the skin temperature sensor to the human body. The temperature of skin exposed to the airflow was measured at the seven positions of the head, trunk, arm, hand, thigh, lower leg and foot. The sole of the foot was measured for the temperature of the contact part skin. The subjects freely selected their clothing to be suitable to the weather on the measurement day. The clothing quantity of the subjects was found by the clo value given by layering the clothing reported by the subjects [34] [35].

As a psychological condition for the human body, the psychological response was measured after staying at the observation point for ten minutes by means of rating the whole-body thermal sensation (cold-hot) and the whole-body thermal comfort (uncomfortable-comfortable) on a linear scale [36] [37]. Linear rating scales are given for the hot (100) and cold (0), and comfortable (100) and uncomfortable (0) directions only. The arbitrary values of 0 and 100 are given for each endpoint, the reported values are read in, and the entire length is converted into a numerical value with the arbitrary scale of 100 for the linear rating scale.

Air temperature, humidity, wind speed, short-wave length solar radiation, long-wave length thermal radiation, and temperature of the ground surface in contact with the human body etc., which are direct environmental stimulus, have a large physiological or psychological influence on thermal sensory perception as explanatory variables for thermal sensory perception. Considering that the psychological reaction of the human body in an outdoor environment is likely to cause many disturbances and variations, the significance probability in this study is set at 10%, as a criterion for comparison of explanatory variables for deriving results of regression analysis with higher usefulness from a practical perspective. JMP 14.3.0 (SAS Institute Japan) was used for statistical analysis.

3. Results

The total measurements for the total number of subjects at each observation point were 608. **Table 2** shows the measurement results of the thermal environment factors at observation points during the measurement period. The short-wave length solar radiation downwards differed greatly in the sun and in the shade. Although it depends on the solar altitude and solar azimuth, and the influence of shielding on the south side, downward short-wave length solar radiation becomes stronger the higher the sky ratio of the observation site. Long-wave length thermal radiation is large at every observation site, and the influence of downward and upward thermal radiation is considered to be strong

Table 2. Results of field survey.

Date	Period	Survey site	Ta [°C]	Tf [°C]	RH [%]	Va [m/s]	RSdwn [W/m ²]	RSup [W/m ²]	RLdwn [W/m ²]	RLup [W/m ²]
28 Aug. 15	10:20-10:30	1	26.2	32.5	82.5	0.55	174.0	17.3	445.4	480.2
28 Aug. 15	10:37-10:47	4	27.1	44.4	83.6	0.92	646.1	55.0	414.6	521.7
28 Aug. 15	10:55-11:05	2	26.8	37.1	80.6	1.26	873.4	284.3	417.2	512.1
28 Aug. 15	11:10-11:20	3	27.1	32.2	82.1	0.32	715.4	116.0	421.4	492.9
28 Aug. 15	11:30-11:40	5	27.9	25.5	76.5	0.72	18.8	0.6	463.4	459.0
28 Aug. 15	13:41-13:51	10	28.8	32.7	67.1	1.03	437.2	86.3	423.0	482.4
28 Aug. 15	14:09-14:19	11	29.2	44.4	61.2	0.80	435.9	46.5	437.1	540.5
28 Aug. 15	14:34-14:44	12	28.0	40.4	66.1	0.59	180.9	14.1	442.4	496.4
28 Aug. 15	14:56-15:06	13	30.0	40.0	59.6	0.87	183.3	16.9	436.8	518.8
28 Aug. 15	15:29-15:39	9	26.8	26.1	79.7	0.23	36.5	1.1	452.5	455.8
9 Sep. 15	9:41-9:51	1	25.0	30.5	79.4	0.62	249.7	26.7	430.7	473.1
9 Sep. 15	9:58-10:08	2	25.1	30.4	78.4	2.63	770.2	283.7	407.1	486.2
9 Sep. 15	10:18-10:28	4	26.4	43.4	75.8	1.63	862.9	77.0	420.0	536.5
9 Sep. 15	10:47-10:57	6	25.8	42.0	78.5	1.39	305.6	42.4	425.2	512.1
9 Sep. 15	11:05-11:15	7	27.0	40.2	75.0	1.46	420.7	51.4	434.4	478.8
9 Sep. 15	11:22-11:32	9	24.6	25.4	82.3	1.23	91.4	10.7	442.0	451.6
9 Sep. 15	11:41-11:52	8	26.0	44.9	78.6	1.80	988.3	96.7	401.5	534.4
9 Sep. 15	12:07-12:17	5	24.6	24.6	80.3	1.93	10.7	0.0	446.3	443.3
9 Sep. 15	13:45-13:55	13	25.6	39.7	76.6	2.48	757.2	47.2	412.2	506.8
9 Sep. 15	14:06-14:16	12	24.6	38.5	81.3	1.20	241.7	22.4	440.6	487.0
9 Sep. 15	14:38-14:48	10	24.8	25.9	79.4	2.21	395.7	77.5	421.7	468.7
10 Sep. 15	9:34-9:44	5	23.8	23.9	79.2	0.82	11.9	2.8	434.6	434.2
10 Sep. 15	9:52-10:02	1	24.3	29.7	77.8	0.51	149.3	36.2	423.3	470.2
10 Sep. 15	10:08-10:18	4	25.2	42.9	76.1	2.16	813.7	67.8	377.5	519.4
10 Sep. 15	10:26-10:36	3	25.0	30.0	78.4	1.59	709.8	123.4	381.1	478.0
10 Sep. 15	10:42-10:52	2	25.6	35.5	76.6	2.07	759.4	252.1	388.6	491.9
10 Sep. 15	11:36-11:46	14	23.2	24.4	85.3	1.89	98.8	1.6	422.9	442.5
10 Sep. 15	13:15-13:25	6	27.4	50.6	72.3	1.51	844.9	129.0	377.8	539.0
10 Sep. 15	13:34-13:44	7	27.8	45.8	69.8	1.53	852.0	132.0	426.5	541.5
10 Sep. 15	13:51-14:01	8	27.4	49.8	68.9	2.09	839.1	78.3	381.8	558.1
10 Sep. 15	14:16-14:26	14	26.2	25.2	71.2	2.79	58.9	2.6	423.7	451.3
23 Jul. 16	9:28-9:38	15	30.6	48.1	71.2	0.01	672.1	68.1	448.9	525.9
23 Jul. 16	9:51-10:01	16	30.9	41.8	71.3	0.01	785.3	155.7	409.0	512.8
23 Jul. 16	10:33-10:43	17	32.3	51.8	67.8	0.75	849.5	69.1	421.1	368.6
23 Jul. 16	11:04-11:14	18	32.2	56.6	65.8	0.48	908.2	124.0	422.9	574.7
23 Jul. 16	11:26-11:36	19	31.0	27.5	73.9	0.17	41.2	0.7	474.7	486.3
23 Jul. 16	13:30-13:40	19	32.4	29.7	69.4	0.01	44.7	6.6	474.8	485.7
23 Jul. 16	13:51-14:01	18	34.9	62.2	63.3	0.01	797.0	100.9	429.6	583.7

Continued

23 Jul. 16	14:43-14:53	17	34.8	63.9	57.2	1.62	765.8	69.7	435.3	612.9
23 Jul. 16	14:58-15:08	16	34.1	42.7	65.8	1.18	741.5	138.3	437.6	542.6
23 Jul. 16	15:27-15:37	15	35.4	58.2	57.3	0.64	466.4	43.8	476.9	589.3
24 Jul. 16	9:30-9:40	19	30.6	29.7	75.6	0.00	58.0	12.7	465.0	477.2
24 Jul. 16	9:52-10:02	18	32.3	47.2	73.2	0.00	801.9	113.5	427.4	507.7
24 Jul. 16	10:21-10:31	17	32.0	50.5	72.7	0.83	713.9	47.0	435.2	577.3
24 Jul. 16	10:43-10:53	16	32.2	45.1	75.8	1.21	881.3	171.3	427.5	540.6
24 Jul. 16	11:03-11:13	15	32.1	56.1	71.1	0.60	811.1	75.1	466.5	585.4
24 Jul. 16	13:08-13:18	15	33.7	57.8	65.3	0.54	645.3	62.8	477.9	587.4
24 Jul. 16	13:28-13:38	16	34.8	46.7	67.5	0.94	977.2	185.3	439.1	561.2
24 Jul. 16	13:51-14:01	17	35.3	61.8	59.1	1.58	970.4	85.0	440.6	630.9
24 Jul. 16	14:20-14:30	18	33.7	61.4	59.7	0.97	766.6	98.8	445.0	609.5
24 Jul. 16	14:40-14:50	19	33.1	31.0	70.4	0.12	55.6	1.7	486.4	494.0

Ta is range of air temperature. Tf is range of ground surface temperature in the vicinity of the human body. RH is range of relative humidity. Va is range of air velocity. RSdwn is range of downward short wave solar radiation. RSup is range of upward short wave solar radiation. RLdwn is range of downward long wave radiation. RLup is range of upward long wave radiation.

even at observation sites where direct solar radiation is shielded. There is no remarkable difference between the average values of downward short-wave length solar radiation and downward long-wave length thermal radiation, and the intensity of long-wave length thermal radiation from the ground surface is shown. Therefore, it is considered that large environmental mitigation effect cannot be expected by simply seeking shade.

Kurazumi *et al.* [18] [19] [20] clarifies that when long-wave length thermal radiation is strong, the effect of shade in improving the thermal sensory perception of the human body is low. Compared with these studies, the outdoor thermal environment in the present study has an extremely high air temperature. Therefore, reducing the influence of long-wave length thermal radiation is also considered indispensable for mitigation of the thermal environment in the rural and suburban regions.

Instances where the temperature of the ground surface exceeds 60°C are also indicated at observation sites covered by asphalt pavement. Although the air temperature also has an effect, the influence of heating by downward short-wave length solar radiation and solar radiation absorptivity of the ground surface is observed. In addition, in a location where the ground surface is covered with plants or where there is a water surface, taking into account downward short-wave length solar radiation and the high temperature, long-wave length thermal radiation from the ground surface is relatively low.

Kurazumi *et al.* [9] [17] clarifies that heat conduction also influences the variable factors of the outdoor environment on the thermal sensory perception of the human body. Although the contact area between the human body in a standing posture and the ground surface is small, on ground surfaces with a low albedo,

where short-wave length solar radiation is strong, and the reflected solar radiation is weak, heat gain of the human body by heat conduction is conjectured to have a strong effect on the contact skin temperature.

The surface temperature of the water surface is lower than the ground surface, which receives other short-wave length solar radiation, due to the influence of the heat capacity of paddy fields. According to Nishida *et al.* [30] etc., regarding the change in the irrigation water temperature at the stage of ripening of the head of the rice, the shielding rate of short-wave length solar radiation increases due to the increase in the leaf area due to the growth of the rice, and in addition to short-wave length solar radiation the influence of the air temperature increases. That is, it is conjectured that a natural ground surface such as the green areas and the water surfaces of paddy fields contribute to a long-wave length thermal radiation reduction effect.

The average value of the relative humidity is 72.8%, the standard deviation is 7.3%, and a noticeable difference in the measurement results is not shown. Accordingly, the influence that the difference in evaporation heat exchange has on sensational and physiological temperature is considered to be weak. However, taking into account the high-humidity thermal environment, this is considered to cause a humid heat.

Average wind speed was 1.1 m/s and under 3 m/s throughout all observations. The standard deviation is 0.7 m/s, and it may have an effect on thermal sensory perception as a variable factor of environmental change.

Oliveira and Andrade [14] states that wind speed has the strongest influence overall on thermal comfort. Kurazumi *et al.* [9] [17] considers the influence of the air current in both summer and winter seasons to be a factor that causes the outdoor thermal environment to affect the thermal sensation and thermal comfort of the human body. The human body may experience discomfort due to changing environmental factors, and so this experience can be thought to induce the condition of relative comfort. Accordingly, changes with an effect that mitigates thermal function are considered to be possible variables for discomfort with regards to other environmental factors also.

ETFe is an outdoor thermal environment evaluation index based on the heat balance of 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 coefficient that takes into account the convective heat transfer area [38]. Then, the mean skin temperature used for the physiological response of the human body was calculated using a weighting coefficient that takes into account the conductive heat transfer area [39]. The calculation formula of Kurazumi *et al.* [32], the validity of which as a calculation formula is verified [40], was used to calculate the surface area of the human body. The values of Kurazumi *et al.* [41] were used for the convective heat transfer area factor, radiant heat transfer area factor and conductive heat transfer area factor of the human body. The values of Miyamoto *et al.* [42] were used for the projected area factor of the human body. The values of Kuwabara *et al.* [43] were used for the

radiant heat transfer coefficient and convective heat transfer coefficient of the human body. The Hendler *et al.* [44] 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 short-wave length solar radiation heat gain is affected by the solar radiation absorption factor. According to VDI3787-2 [45], the absorptivity of a clothed human body is 0.7. However, Watanabe *et al.* [46] shows the absorptivity of a human body wearing black clothing to be 0.76 and that of one wearing white clothing to be 0.38. It also considers 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. In this study, the Hendler *et al.* [44] and Elam *et al.* [47] value of 0.70 found from the reflectance of skin in electromagnetic waves of wavelength 3 μm or less was used for the solar radiation absorption factor of the human body. Concerning the skin wettedness, values calculated by the Kurazumi *et al.* [48] behavioral thermoregulation model were used because it was difficult to find the perspiration quantity. For the missing physiological quantities, values calculated by the behavioral thermoregulation model of Kurazumi *et al.* [48] were used. Moreover, the activity metabolic heat production was calculated using the ratio while seated position of Kurazumi *et al.* [49]. The outdoor thermal environment evaluation index ETFe theoretically proposed and verified by Kurazumi *et al.* [9] [12] was calculated from weather observation values, and the skin temperature and clo value of the human body.

4. Discussion

4.1. Relationship between ETFe and Thermal Sensation

Figure 2 shows the relationship between ETFe and thermal sensation. There is a spread in the psychological reaction of the human body in an outdoor environment due to many disturbances, but as the ETFe increases, the distribution of thermal sensation increases and the tendency for the sensation of hot to increase is shown. Significant spread in the psychological response of the human body is considered to occur due to the degree of freedom of mobilization in an outdoor space. The spread in thermal sensation becomes large in outdoor spaces due to the influence of environmental stimuli in addition to the psychological response to thermal action in the outdoor space. Although it can be thought of as a thermal adaptation, in this study experiments were carried out with the subjects instructed to give thermally unique evaluations of psychological reactions. However, in outdoor spaces that differ from laboratory tests, it is considered that the potential for environmental factors such as sight and hearing to impact on psychological response becomes high and this is expressed as a spread in evaluation values.

In addition, environmental stimuli in outdoor spaces are in a heterogeneous and unsteady state. Environmental stimuli are evaluated by the measurement points of measurement instruments. Although the physical reaction of the

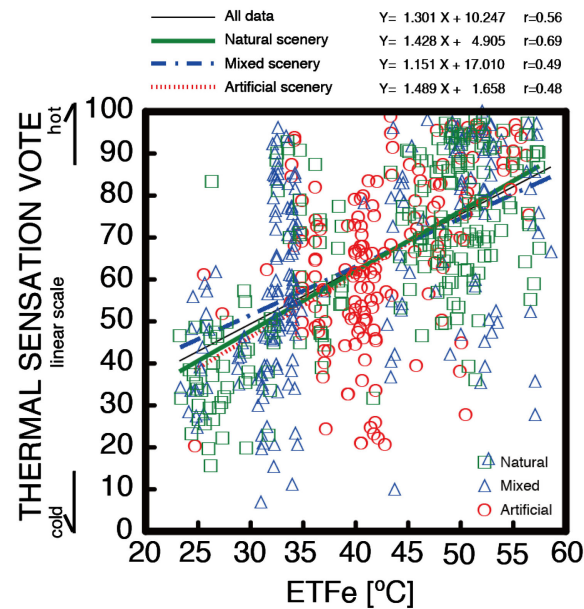


Figure 2. Relationship between ETFe and thermal sensation.

subjects is evaluated in the vicinity of the measurement instruments, it is exceedingly difficult to have multiple subjects exposed to identical environmental stimuli due to the effect of the influence of short-wave length solar radiation heat gain such as solar radiation shielding and the orientation of the human body with respect to the solar azimuth angle, and fluctuations in the air current, etc. The microclimate around the subjects may have affected the subjects' thermal sensation due to the difference in these environmental factors.

The outdoor thermal environmental factors of short-wave length solar radiation, long-wave length thermal radiation and the air current are nonuniform and non-targeted evaluation factors. These evaluation factors may contribute as a local effect on the human body, even if the heat balance in the whole human body is the same. Horikoshi *et al.* [50] clarifies that the psychological reactions of the human body in a heterogeneous/asymmetric thermal radiation environment have directionality which changes under the effect of local thermal radiation. Kurazumi *et al.* [51] [52] clarify that a parameter exists for the heterogeneous/asymmetric thermal environmental factors in the thermal environment evaluation factors that evaluate the effect on the human body in a heterogeneous/asymmetric thermal radiation environment. They show that there is a large spread in the response of the human body due to the effect of this parameter. That is, the spread in thermal sensory perception becomes large in outdoor spaces due to the influence of environmental stimuli in addition to the psychological response to thermal action in the outdoor space.

Kurazumi *et al.* [53] considers green factor to influence the thermal sensation of the human body. Taking less than 10% as artificial scenery, over 10% and less than 30% as mixed scenery, and 30% or more as natural scenery in order to grasp the relationship between the environment and the human body reaction

makes it easy to explain the interaction. Accordingly, the relationship between ETFe and thermal sensation was examined by the green factor classification of Kurazumi *et al.* [53].

In a study to measure the psychological and physiological reactions in the outdoor environment, as a rule of thumb, good results have been obtained if there is about 0.4 coefficient of correlation [9] [10] [11] [17] [18] [19] [20] [53] [54]. In other words, the coefficient of determination is less than about 0.16. Therefore, it can be said that the measurement result in this research is appropriate.

Focusing on the regression line, the Thermal sensation tends to be higher as the ETFe becomes higher. Mixed scenery shows the tendency of the highest environmental mitigation effect. Looking at the difference in green factor at almost the same ETFe, mixed scenery shows a slightly different tendency from natural scenery and artificial scenery. When ETFe is low, the thermal sensation is high. Meanwhile, when ETFe is high, the thermal sensation is low.

Given the measurement results of thermal environment factors in **Table 2**, the mixed scenery observation point with high ETFe is 18 Paddy side. The condition of 18 is strong short-wave length solar radiation and long-wave length thermal radiation from the ground surface. Nishida *et al.* [30] considers the environmental mitigation effect of the surface of paddy field to be related to water depth and water flow. The measurement period is at the ripening stage of the head of the rice, so the short-wave length solar radiation shielding rate on the water surface is high, but due to the fact that there is no flow of water and the heat capacity is high, in the time period when there is a large cumulative amount of short-wave length solar radiation, long-wave length thermal radiation may increase.

As pointed out by Kurazumi *et al.* [53], it is conjectured that there is also a visual influence due to the natural surface coverage by vegetation, etc. However, natural scenery shows a thermal sensation slightly hotter than mixed scenery, giving a result whereby the effect of natural surface coverage by vegetation, etc. is not apparent. Fukagawa *et al.* [55] and Kurazumi *et al.* [56] [57] [58] consider a landscape of thick vegetation with a high green factor to have a strong feeling of confinement, which makes it somewhat hot and somewhat uncomfortable thermal environment due to the sense of stagnation. In this study too, it can be conjectured that thermal sensation increased due to the influence of the green factor enhancing this sense of confinement.

Similarly, given the measurement results of thermal environment factors in **Table 2**, the observation points of mixed scenery with low ETFe are 1 Building canyon, 5 Wisteria trellis, 6 Paddy side, 12 Revetment canyon. The weather was such that air temperatures at all observation points were relatively low. At 1 and 12, the human body did not receive direct solar radiation due to the solar azimuth. However, it is considered that the long-wave length thermal radiation from the concrete wall surface of a building with a high heat capacity subjected to short-wave length solar radiation and the stone wall of the revetment is

strong. Both the concrete wall surface of the building and the stone wall of the revetment are close to the human body, so the angle factor with the human body is large and it is conjectured that the long-wave length thermal radiation heat gain increased. 6 is considered to have strong long-wave length thermal radiation from paddy fields in the time period when accumulated amount of short-wave length solar radiation becomes large, as a result of the high heat capacity of paddy fields. For 5, it is conjectured that the feeling of confinement caused by the surrounding wisteria promoting a sense of heat and increased the thermal sensation.

Therefore, it can be said that ground surface features with a high heat capacity and situations that evoke a feeling of confinement tend to increase the thermal sensation by promoting the sensation of hot.

An inspection of the parallelism of the regression lines gave $p > 0.10$ (RMSE = 17.95, $F = 1.64$, $p = 0.19$), indicating no significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p < 0.10$ (RMSE = 21.64, $F = 2.52$, $p = 0.08$), indicating a significant difference in the homogeneity of the regression lines. As a result of multiple comparison by Tukey-Kramer, natural scenery and mixed scenery were $p < 0.10$ ($p = 0.08$), showing a significant difference. Therefore, it can be considered that the influence of the green factor was expressed in the thermal sensation.

Focusing on the regression line for all experimental results, the ETFe that gives a neither hot nor cold, thermally neutral thermal sensation of 50 is 30.6°C. As identified by Humphreys [1], Brager and de Dear [2], and Kurazumi *et al.* [9] [10] [11], 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 and it is 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 and 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. In this study on rural and suburban regions, the ETFe that gives a neutral thermal sensation of 50 is low in comparison to the subject experiments in the urban environment in Kurazumi *et al.* [9] [10] [11]. Compared with the urban environment, it is conceivable that the difference in the perceptual environment, whereby it is subconsciously assumed to be a comfortable thermal environment, had an effect in the rural and suburban regional environment.

4.2. Relationship between ETFe and Thermal Comfort

Figure 3 shows the relationship between ETFe and thermal comfort. There is a spread in the psychological reaction of the human body in an outdoor environment due to many disturbances, but as the ETFe increases, the distribution of thermal comfort decreases and the tendency for the sense of discomfort to increase is shown. In this research, the experiment was carried out having

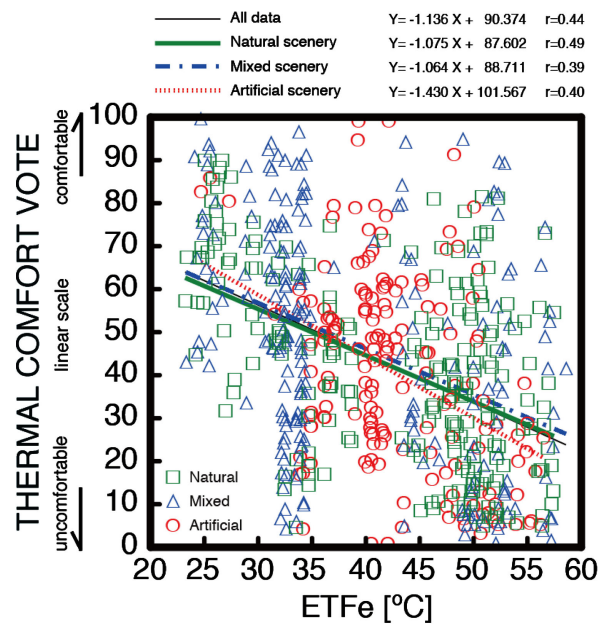


Figure 3. Relationship between ETFe and thermal comfort.

instructed the subjects instructed to give thermally unique evaluations of psychological reactions. However, in outdoor spaces that differ from laboratory tests, it is considered that the potential for environmental factors such as sight and hearing to impact on psychological response becomes high and this is expressed as a spread in evaluation values.

As stated in “Relationship between ETFe and thermal sensation”, environmental stimuli in outdoor spaces are in a heterogeneous and unsteady state. The human body may experience discomfort due to changing environmental factors, and so this experience can be thought to induce the condition of relative comfort. Accordingly, changes with an effect that mitigates thermal function are considered to be variables for discomfort with regards to other environmental factors also [9] [10] [11].

Focusing on the regression line, the Thermal comfort tends to be lower as ETFe becomes higher. The tenancy was shown for artificial scenery to have the strongest level of discomfort. As identified by Kurazumi *et al.* [53], it is conjectured that there is also a visual influence due to the natural surface coverage by vegetation, etc.

An inspection of the parallelism of the regression lines gave $p > 0.10$ (RMSE = 21.90, $F = 0.78$, $p = 0.46$), indicating no significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p < 0.10$ (RMSE = 24.15, $F = 4.64$, $p = 0.01$), indicating a significant difference in the homogeneity of the regression lines. As a result of multiple comparison by Tukey-Kramer, mixed scenery and natural scenery, and mixed scenery and artificial scenery were both $p < 0.10$ ($p = 0.02$, $p = 0.03$), showing a significant difference. Similar to the relationship between ETFe and thermal sensation, the comfort of mixed scenery is relatively high. Therefore, it can be considered that the influ-

ence of green factor was expressed in the thermal comfort.

Focusing on the regression line for all experimental results, the ETFe that gives a neither comfortable nor uncomfortable thermal comfort of 50 is 35.5°C. As already stated, the environmental stimuli in an outdoor space may evoke a human body response that differs to an indoor space. Also, unlike the relationship acquired for indoor spaces, the sense of expectation with regards to comfort in outdoor spaces is low to begin with and they are not judged to be comfortable thermal environments, so it is conceivable that even thermal environment conditions with high ETFe are permitted. In this study on rural and suburban regions, the ETFe that gives a neither comfortable nor uncomfortable thermal comfort of 50 is low in comparison to the subject experiments in the urban environment in Kurazumi *et al.* [9] [10] [11]. Compared with the urban environment, it is conceivable that the difference in the perceptual environment, whereby it is subconsciously assumed to be a comfortable thermal environment, had an effect in the rural and suburban regional environment.

4.3. Relationship between Mean Skin Temperature and Thermal Sensation

Figure 4 shows the relationship between mean skin temperature and thermal sensation. The trend is shown for the distribution of thermal sensation to increase as the mean skin temperature rises, and for sensation of hot to become strong. Significant spread in the psychological response of the human body in the outdoor space can be considered to occur due to the degree of freedom of mobilization in the experiment environment.

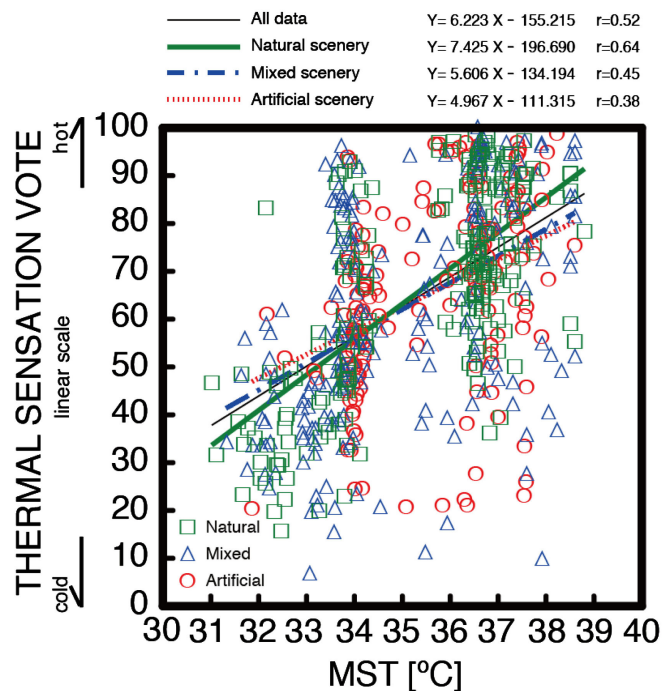


Figure 4. Relationship between mean skin temperature and thermal sensation.

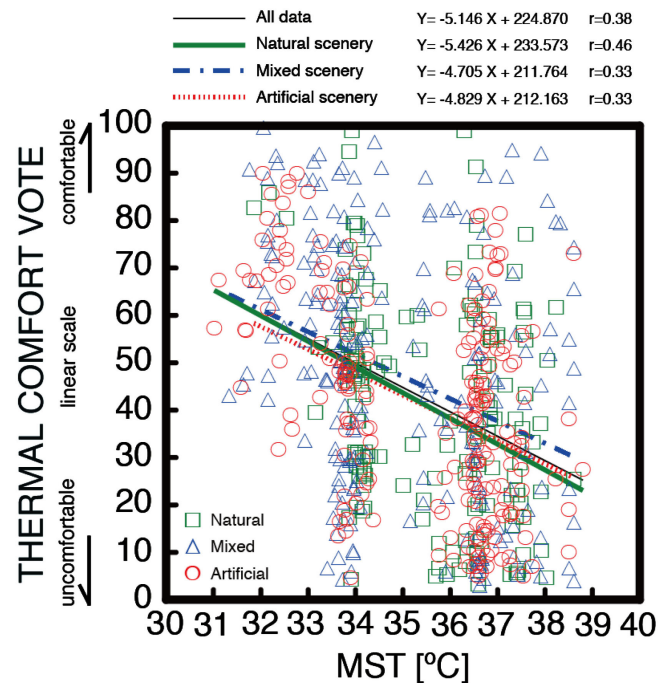


Figure 5. Relationship between mean skin temperature and thermal comfort.

As identified by Kurazumi *et al.* [59], when the measurement site of skin temperature is receiving strong short-wave length solar radiation and faces the azimuth angle of the short-wave length solar radiation, skin temperature exceeds 40°C , and mean skin temperature is also significantly higher. In this study, it is considered that individual differences in mean skin temperature resulted from whether or not the skin temperature measurement site on the subject exposed to the thermal environment surrounding the environmental measuring instrument was directly facing the solar azimuth. It is considered essential to investigate the measurement site of the mean skin temperature in outdoor environments taking into account parts in the sun and in shade. From the measurement results of the above thermal environment factor, it is conceivable that the influence of short-wave length solar radiation and long-wave length thermal radiation is strong. Focusing on the regression line, the thermal sensation tends to be higher as the mean skin temperature becomes higher. The slope of natural scenery is the largest and the variation of thermal sensation with respect to the change of mean skin temperature is large. As stated in “Relationship between ETF_e and thermal sensation”, a situation that tends to generate a sense of confinement can be considered to increase thermal sensation by promoting the sensation of hot.

An inspection of the parallelism of the regression lines gave $p < 0.10$ ($\text{RMSE} = 18.48$, $F = 2.95$, $p = 0.05$), indicating a significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p < 0.10$ ($\text{RMSE} = 21.64$, $F = 2.52$, $p = 0.08$), indicating a significant difference in the homogeneity of the regression lines. As a result of multiple comparison by Tukey-Kramer, mixed scenery and natural scenery were $p < 0.10$ ($p = 0.08$), show-

ing a significant difference. Similar to the relationship between ETFe and thermal sensation, it can be considered that the influence of green factor was expressed in the thermal sensation.

Focusing on the regression line for all experimental results, the mean skin temperature that gives a neither hot nor cold, thermally neutral thermal sensation of 50 is 33.0°C. In the subject experiments of Tsuchikawa *et al.* [60] on subjects in an indoor space, the mean skin temperature by which a standing human experiences a neither hot nor cold, thermally neutral sensation is reported to be 32.5°C. In subject experiments of Kurazumi *et al.* [11] on subjects in an outdoor space, the mean skin temperature by which a standing human experiences a neither hot nor cold, thermally neutral sensation is reported to be 33.3°C. The difference in mean skin temperature that gives a thermally neutral sensation between the urban environment and the rural and suburban environment is not large, but mean skin temperature is higher in the outdoor space than in the indoor space.

4.4. Relationship between Mean Skin Temperature and Thermal Comfort

Figure 5 shows the relationship between mean skin temperature and thermal comfort. The trend is shown for the distribution of thermal comfort to decrease as the mean skin temperature rises, and for discomfort to become strong. Significant spread in the psychological response of the human body in the outdoor space can be considered to occur due to the degree of freedom of mobilization in the experiment environment.

Focusing on the regression line, the thermal comfort tends to become lower as mean skin temperature increases. The slope of mixed scenery is the smallest and the variation of thermal comfort with respect to the change of mean skin temperature is large. The thermal comfort of the mixed scenery is the highest. As stated in “Relationship between ETFe and thermal comfort”, it is conjectured that there is also a visual influence due to the natural surface coverage by vegetation, etc. [53]. However, the green factor classified as natural scenery is likely to produce a sense of confinement, conceivably promoting discomfort and lowering thermal comfort.

An inspection of the parallelism of the regression lines gave $p > 0.10$ (RMSE = 22.45, $F = 0.22$, $p = 0.81$), indicating no significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p < 0.10$ (RMSE = 24.15, $F = 4.64$, $p = 0.01$), indicating a significant difference in the homogeneity of the regression lines. As a result of multiple comparison by Tukey-Kramer, mixed scenery and natural scenery, and mixed scenery and artificial scenery were both $p < 0.10$ ($p = 0.02$, $p = 0.03$), showing a significant difference. Similar to the relationship between ETFe and thermal comfort, it can be considered that the influence of green factor was expressed in the thermal comfort.

Focusing on the regression line for all experimental results, the mean skin temperature that gives a neither comfortable nor uncomfortable thermal com-

fort of 50 is 34.0°C. In the subject experiments of Tsuchikawa *et al.* [60] on subjects in an indoor space, the mean skin temperature by which a standing human experiences a neither comfortable nor uncomfortable, thermally neutral sensation is reported to be 33.0°C. As stated in “The relationship ETfe and thermal sensation”, unlike indoor spaces, the sense of expectation for the degree of comfort in outdoor spaces is low to begin with and they are not judged to be comfortable thermal environments, so it is conceivable that even thermal environment conditions in which mean skin temperature becomes high were permitted. In addition, the effect of variations of the environmental factors is considered to contribute to mitigating the effect of discomfort.

4.5. Relationship between Thermal Sensation and Thermal Comfort

Figure 6 shows the relationship between thermal sensation and thermal comfort. The trend is shown for the distribution of thermal comfort to decrease as the thermal sensation increases, and for discomfort to become strong. Significant spread in the psychological response of the human body in the outdoor space can be considered to occur due to the degree of freedom of mobilization in the experiment environment.

Focusing on the regression line, the thermal comfort of the mixed scenery is the highest. An inspection of the parallelism of the regression lines gave $p > 0.10$ (RMSE = 17.16, $F = 0.11$, $p = 0.90$), indicating no significant difference in the parallelism of the regression lines. An inspection of the homogeneity of regression gave $p < 0.10$ (RMSE = 24.15, $F = 4.64$, $p = 0.01$), indicating a significant

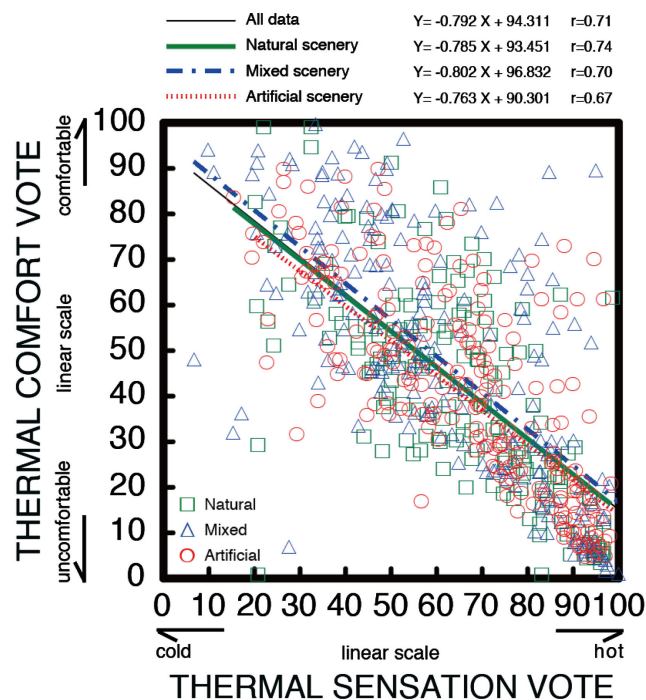


Figure 6. Relationship between thermal sensation and thermal comfort.

difference in the homogeneity of the regression lines. As a result of multiple comparison by Tukey-Kramer, mixed scenery and natural scenery, and mixed scenery and artificial scenery were both $p < 0.10$ ($p = 0.03$, $p = 0.02$), showing a significant difference. Similar to the relationship between ETFe and thermal comfort, the comfort of mixed scenery is relatively high. Therefore, it can be considered that the influence of green factor was expressed in the thermal comfort.

Focusing on the regression line for all experimental results, the thermal sensation that gives a neither comfortable nor uncomfortable thermal comfort of 50 is the neither hot nor cold thermally neutral 56.0. When a comfortable ETFe is obtained from the relationship between ETFe and thermal sensation according to this condition as shown in **Figure 2**, ETFe is obtained as 35.2°C. As stated in Kurazumi *et al.* [11], the sense of expectation for the degree of comfort in outdoor spaces is low to begin with and they are not judged to be comfortable thermal environments, so it is conceivable that even thermal environments with a high ETFe or in which mean skin temperature becomes high were permitted.

Höppe [61], Nikolopoulou and Steemers [5], Spagnolo and de Dear [62], Nakano and Tanabe [63], Ahmed [64], Oliveira and Andrade [14], Lin and Matzarakis [65], Cheng *et al.* [66] and Kurazumi *et al.* [10] consider the allowable range of comfort in an outdoor space to be wider than that in an indoor space. Also, Kurazumi *et al.* [10] shows an ETFe of 31.6°C - 38.5°C to be a comfortable thermal environment range for outdoor spaces in urban areas.

Kurazumi *et al.* [53] shows that tolerance limit is higher in an outdoor space than in an indoor space. Compared with the urban environment, the difference in the perceptual environment, whereby it is subconsciously assumed to be a comfortable thermal environment, had an effect in the rural and suburban regional environment, resulting in an ETFe lower than the upper limit of comfort in a summer urban environment of Kurazumi *et al.* [10].

5. Conclusions

Focusing on the rural and suburban regions where paddy fields remain, subject experiments were conducted to clarify the effect of thermal environmental factors on the human body in an outdoor space. The relationship between thermal environment evaluation index (ETFe) and the physiological/psychological response of the human body was investigated.

Long-wave length thermal radiation from concrete walls of buildings and stone walls of revetments with high heat capacity becomes strong, and the amount of long-wave length thermal radiation heat gain in the human body increases. Paddy fields, in which the water that has received short-wave length solar radiation does not flow, have a high heat capacity, which works to increase the long-wave length thermal radiation in the time period when the accumulated amount of short-wave length solar radiation increases. A ground surface feature with a high heat capacity may promote the sensation of hot and deteriorate the thermal sensation.

A landscape of thick vegetation with a high green factor may have a strong feeling of confinement, which can make it somewhat hot and somewhat uncomfortable thermal environment due to the sense of stagnation.

The ETFe that gives a neither hot nor cold, thermally neutral thermal sensation was 30.6°C. The ETFe that gives neither comfortable nor uncomfortable thermal comfort was 35.5°C. The mean skin temperature that gives a neither hot nor cold, thermally neutral thermal sensation was 33.0°C. The mean skin temperature that gives neither comfortable nor uncomfortable thermal comfort was 34.0°C. The sense of expectation for the degree of comfort in outdoor spaces is low to begin with and they are not judged to be comfortable thermal environments, so it is conceivable that even thermal environments with a high ETFe or in which mean skin temperature becomes high were permitted.

The thermal sensation that gives neither comfortable nor uncomfortable thermal comfort was a neither hot nor cold thermally neutral 56.0. When a comfortable ETFe is obtained from the relationship between ETFe and thermal sensation according to this condition, ETFe is obtained as 35.2°C. Compared with the urban environment, it is conceivable that the difference in the perceptual environment, whereby it is subconsciously assumed to be a comfortable thermal environment, had an effect on the rural and suburban regional environment, resulting in an ETFe lower than the upper limit of comfort in a summer urban environment.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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