

Effects of Visual Stimuli upon Thermal Sense under Air Conditioning in Summer

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Abstract

Human thermal sense is not expressed only by simple heat equilibrium. The influence of visual and auditory stimuli causes differences in overall thermal sense arrived at by sophisticated sensory processing by the cerebrum. If it can be clearly shown that a thermal environment considered slightly uncomfortable could be ameliorated using visual stimuli, the cost effectiveness of such an initiative would be highly significant, particularly in terms of air conditioning system running costs. Focusing on the visual stimuli provided by greenery, experiments were conducted in a thermal environment deemed slightly uncomfortable, where the temperature was set at a base point of 28°C. Experiments were conducted in a temperature-controlled room. Thermal environmental conditions were set at three different temperatures: 25°C, 28°C and 31°C. Wall surface temperatures were set to equal these temperatures. Air velocity (calm air currents of 0.2 m/s or less) and relative humidity (60% RH) were set the same throughout. Subjects were asked to sit quietly for the test. The visual stimuli consisted of ten different types of scenery, including that of leafy vegetation. The influence of overall stimuli of the cerebrum on the indoor thermal environmental index ETF was determined to prove the significance of actively placing visual stimuli in spaces. Thermal stimuli influence the human body on mean skin temperatures, while visual stimuli do not affect mean skin temperatures. In ETF deemed fairly uncomfortable, that is at a range of hotter than 28-29°C, clear improvements were observed in thermal sense due to the influence of visual stimuli such as natural elements including vegetation like greenery. Visual stimuli were appropriate at a level of up to 69% greenery, where a dynamic effect on warmer environmental conditions can be felt and where the depth of fuller vegetation cover can be perceived.

Keywords: ETF; Green; Thermal sensation; Thermal comfort; Visual stimuli

Introduction

The Japanese people have long been attached to a way of life where they derive satisfaction from comfort obtained through subtle changes in their surroundings brought about by economizing. However, changes such as the emergence of super-insulated housing and rising summer temperatures have resulted in higher indoor temperatures that cannot be addressed by these traditional cultural lifestyle values. In Japan, it is a commonly held belief that air conditioning systems should be set at 28°C in order to save energy. This may be highly beneficial and effective in private buildings where costs are paid for by the occupants. On the other hand, keeping the temperature at this setting is far less beneficial in public places and can even be a cause of complaints. The temperature of 28°C enables the maintenance of the neutral body temperature of an unclothed individual who is sitting quietly. In private buildings, individuals can achieve heat balance by behavioral thermoregulation, for example by adjusting their clothing or positions. However, in public buildings, where behavioral thermoregulation is more difficult, this temperature setting can be inappropriate, potentially contributing to concentration problems and negatively influencing health.

The instance of heat stroke or death by heat has climbed for indoor environments [1,2]. Though the trend in Japan for school buildings is now to encourage the active use of air conditioning systems, it is clear that the setting of 28°C does not allow people to concentrate sufficiently enough to do even light tasks [3]. Steps toward fostering an environmentally friendly, energy-saving environment are easily accepted, but what is really needed is cost-effective climate control.

In general, hot or cold sensations felt by humans are measured by air temperature. However, during the summer, rays of sunlight coming through a window can make one feel hot, while a breeze can make one

feel cool; high temperatures can make one feel it is humid outside, while floors can feel cooler to the touch. Therefore, it is important to consider not only air temperature but also environmental factors, such as heat emission, convection, humidity and heat conduction, when assessing thermal senses. Further, this particular sensation is not only about physical heat equilibrium; it is important to note that overall thermal sense happens through high-level sensory processing of the cerebrum, which be affected by visual, auditory and other sensory input.

According to Rohles et al. [4], wall color and the color temperature of lighting results in differences in perceived ambient temperature, indicative of an individual's neutral thermal sensation. Research implemented by Matsubara et al. [5] clearly indicates that the mitigating effects of psychological thermal load by means of orange or light blue colors in uncomfortable thermal environmental conditions are strongly influenced by cool colors on the high temperature side and by warm colors on the low temperature side. Matsubara et al. [6] also add that visual or auditory factors, including green tones and water, clearly influence perception of thermal sensation as well as

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perception of comfort levels regarding heat. According to Murakami and Shimomura [7], improvements in thermal senses accomplished by rooftop gardening are bolstered by a fuller vegetation cover. Fukagawa et al. [8] show that visual stimuli created by water scenes serve to lower hot thermal sense by engendering a sense of depth. However, because these research projects do not utilize the thermal environmental index as the evaluation axis, they can only address relative differences.

According to Kurazumi et al. [9], thermal sensation based on the heat-balanced based outdoor thermal environmental index (ETFe) is affected by physical barriers to short wave solar radiation, such as leaves, and by a visually-induced psychological influence. In their study, the visual stimuli engendered by nature scenes comprised of vegetation and other greenery led to a perceived temperature that was 3.5°C lower than that of man-made scenes comprised of such elements as buildings and pavement, serving to alleviate perceived heat levels. The visual stimuli of greenery and other factors served to ameliorate perceptions of high heat and high body temperature.

The research also indicates that non-thermal factors such as the visual and auditory senses have an influence on thermal sensation as well as on the perception of thermal comfort level. Research conducted in laboratories on environmental factors and human body responses has yielded preliminary results showing that visual and auditory factors such as greenery and water influence thermal sensation and the perception of thermal comfort level. However, the work is limited to the absence or presence of sensory stimuli; sensational and physiological temperatures are not assessed. In other words, quantitative research has not been conducted.

We cannot expect an ameliorative effect on sensational and physiological temperatures of auditory stimuli, but we can expect such an effect from visual stimuli using wall surfaces, etc. By placing visual stimuli featuring greenery on walls and thereby improving sensational and physiological temperatures, we can devise a scenario where a slightly hotter space (levels where people feel they are forced to endure the heat) can be rendered comfortable. We can additionally expect to see improvements in learning efficiency and labor efficiency.

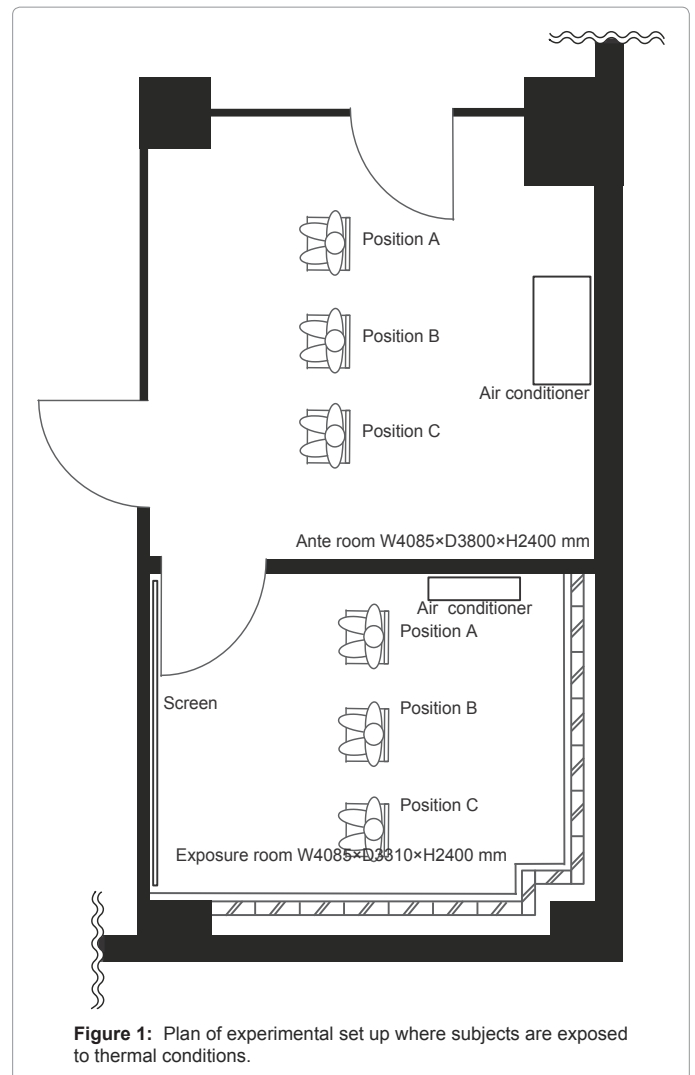
Under these circumstances, the purpose of this study is to clarify the effects of greenery visual factors to the perception of thermal sensation and thermal comfort, by means of the quantitative research based on ETF. This research is to test subjects placed in a thermal environment deemed slightly uncomfortable, where the temperature is set at a base point of 28°C, to determine the influence of overall stimuli of the cerebrum on the indoor thermal environmental index ETF and to prove the significance of actively placing visual stimuli in spaces. Focusing on the visual stimuli provided by greenery and quantifying discrepancies in thermal perception on the human body, we will develop strategies to render the 28°C setting an effective one during the summer season.

The Japanese people have long lived a lifestyle that is slightly restrictive. If an influence on sensory perception of stimuli via sensory processing by the cerebrum can be shown, it would facilitate the creation of environmentally friendly spaces.

Experimental Design

Experimental procedure

Testing was conducted in a temperature-controlled room as shown in Figure 1. Because of the need to minimize the influence on visual stimuli, the testing room was done in white. Visual stimuli



were implemented by placing visuals on a screen situated in the temperature-controlled room. Thermal environmental conditions were set at three different temperatures: 25°C, 28°C and 31°C. Wall surface temperatures were set to equal these temperatures. Air velocity (calm air currents of 0.2 m/s or less) and relative humidity (60%RH) were set the same throughout.

The subjects were asked to wear light white clothing in order to minimize as much as possible the influence of visual stimuli and to further clarify the influence on the human body. They were asked to sit quietly for the test.

The subjects stayed in a relaxed position for 45 minutes or more in an anteroom, with settings equally controlled for the initial environmental conditions and relative humidity as well as for wall temperatures and ambient temperatures. Subsequently, the subjects were promptly transferred to the exposure room, where they were exposed to the predetermined thermal environmental conditions for duration of 60 minutes for each different condition.

The visual stimuli consisted of 10 different types of scenery including leafy vegetation, the characteristics of which are described below. Each type of visual stimuli was presented for 180 seconds. Thirty

seconds later, the subjects were asked to describe their psychological reactions. The presentation of visual stimuli was conducted randomly.

Visual stimuli

Kurazumi et al. [9] indicate that, in outdoor spaces, visual stimuli comprised of natural elements such as greenery including leafy vegetation has a positive influence on the perception of heat levels and the perception of comfort levels, in comparison to visual stimuli comprised of man-made elements including buildings, asphalt, etc. In addition, the influence was found to be greater in tandem with greater solid angle ratios. For visual stimuli, the researchers chose landscape scenes with differing percentages of greenery including leafy vegetation, characteristics of which are described in Table 1. The solid angle ratio of visual stimuli was measured in the direction of the line of sight of each subject to the center of a screen at Position A (0.09), Position B (0.10) and Position C (0.09). The discrepancy of the solid angle ratio of the visual stimuli on the positioning of the subjects was 0.01, indicating minimal discrepancy.

In cases of visual stimuli featuring scenes comprised of man-made elements, the scenes themselves may have perceptual significance.

Point	Visual stimuli scene	Greenery	Green factor
1	Building	Lawn	0.29
2	Building side	Grass & Tree	0.27
3	Building side	Hedge	0.32
4	Copse	Grass & Tree	0.46
5	Slope face	Grass & Tree	0.71
6	Thicket	Grass & Tree	0.54
7	Mountain path	Grass & Tree	0.56
8	Open space	Lawn & Tree	0.73
9	Mountain path	Bamboo	0.81
10	Clump of bushes	Tree	0.69

Green factor is green covering factor. Green covering factor is defined as the ratio of green surface areas to a picture area

Table 1: Summary of visual stimuli.

In addition, the retouching process may bring about an “unnatural” effect. For control stimuli, it may be necessary to add visual stimuli of man-made elements with a greenery ratio of 0.00. Instead, during the testing, we added visual stimuli with a low percentage of greenery, such as buildings.

This research focuses on the greenery ratio of the visual stimuli. The visuals presented were divided into three groups: Nos. 1, 2 and 3 had a ratio of 20–39%; Nos. 4, 6, 7 and 10 fell in the range of 40–69% and Nos. 5, 8 and 9 fell into the 70–89% range. Visual No. 1 is comprised primarily of green ground cover. Nos. 2, 4, 5, 6, 7 and 8 are comprised primarily of ground cover and forest. Nos. 3 and 10 consist of mostly forest, while No. 9 largely features bamboo.

Subjects

The study subjects consisted of a group of 19 people who were healthy young male and female university students as described in Table 2. The 12 male subjects stood on average 168.0 ± 3.0 cm, while their weight fell in the range of 57.75 ± 4.68 kg. The seven female subjects stood on average 158.4 ± 5.5 cm, while their weight fell in the range of 49.70 ± 6.76 kg. There was nothing unusual about the physical state of any of the subjects. In accordance with rules stated in the Helsinki Convention [10], the testing conditions were sufficiently explained to the subjects prior to the testing phase, and the subjects agreed to the conditions.

Measured parameters

We assessed the conditions of the thermal environment, including air temperature, humidity, air velocity and wall temperature. Air temperature and humidity were assessed using a small temperature/humidity logger (ESPEC MIC: RS-13, temperature measure in range of 0–50°C, precision=0.3°C, humidity measurement=10–95%, precision=5%) at a loading height of 0.6 m. Air velocity was measured with a hot bulb omnidirectional wind speedometer (Kanomax Japan: 6533, measurement range=0.05–5.00 m/s, precision=2%). The surface temperature of the indoor surface was measured with a 0.3 mmφT thermocouple. The solid angles of the visual stimuli were measured

Subject	Sex	Age	Height(cm)	Weight(kg)	B-area(m ²)	RohrerIndex	Native place
YC	female	21	159.0	47.45	1.48	118.0	Aichi
UM	female	21	160.6	58.81	1.61	142.0	Aichi
KS	female	21	147.2	39.91	1.31	125.1	Aichi
NM	female	22	156.5	40.89	1.38	106.7	Aichi
SN	female	21	166.8	56.08	1.63	120.8	Kagawa
SK	female	21	159.0	51.04	1.52	127.0	Aichi
YK	female	21	160.3	53.73	1.56	130.4	Fukui
MH	male	22	169.9	49.56	1.57	101.1	Fukuoka
AK	male	21	164.1	58.29	1.63	131.9	Fukuoka
TA	male	22	168.5	58.59	1.67	122.5	Fukuoka
YT	male	21	165.6	56.55	1.62	124.5	Fukuoka
HT	male	22	174.5	66.76	1.79	125.6	Fukuoka
NN	male	20	163.8	57.72	1.62	131.3	Fukuoka
ST	male	21	167.8	61.15	1.69	129.4	Miyazaki
YN	male	22	166.6	58.88	1.66	127.3	Fukuoka
MS	male	22	170.2	54.45	1.63	110.4	Fukuoka
TK	male	21	166.9	59.71	1.67	128.4	Ooita
AT	male	21	170.2	53.58	1.62	108.7	Kumamoto
YK	male	21	164.1	49.21	1.53	111.4	Fukuoka

B-area is the calculated body surface area by Kurazumi's formula. $S=100.315W^{0.383}H^{0.693} \times 10^{-4}$ (Kurazumi et al., 1994)
 S: Body surface area [m²], W: Weight [kg], H: Height [cm] Native place is life region from birth to 2.5 years old time>

Table 2: Physical characteristics of subjects.

using photography, specifically a fisheye lens (Olympus: Fisheye Zuiko 8 mm f/2.8) and a 35 mm digital single-lens reflex (Canon: EOS 5D). Projections were made in the line of sight of the visual at the expected loading height of 1.1 m, the height assumed to be the eye height of the seated subjects.

Human physiological data, specifically sublingual temperature and skin temperature, were measured with a 0.2 mm ϕ T thermocouple. The eight areas of the skin measured were the forehead, abdomen, forearm, back of hand, anterior thigh, shin, instep and sole of the foot.

The female subjects wore light clothing consisting of a T-shirt, shorts, panties, bra and camisole. The male subjects also dressed lightly, wearing only T-shirts, knee-length underpants and underpants. Details of the clothing are shown in Table 3. Since panties, bras and camisoles were difficult to render uniform, the study subjects brought their own. Clo values were calculated from the weight of the clothing in a formula devised by Hanada et al. [11,12].

Using discrete rating scales, this research focused on psychological conditions of the human body as follows: thermal sensation (seven levels), cool/warm sensation (seven levels) and thermal comfort (seven levels). Psychological reaction was measured 30 seconds after visual stimuli were presented. The extreme points of cold/hot, cool/warm and uncomfortable/comfortable were given for the three categories. The extreme points of cold, cool and uncomfortable were assigned -3, while the extreme points of hot, warm and comfortable were assigned +3. Values were allocated at equal distances.

Observed Results on Thermal Environments

The temperature was set within the range of $\pm 0.5^{\circ}\text{C}$ with wall surface temperature set within $\pm 0.3^{\circ}\text{C}$ of this range. Relative humidity was set within the range of $\pm 7.9\%$ of the parameters. Though the changes in relative humidity fluctuated in a more significant range, the standard deviation stood at 2.6%. Air velocity was 0.2 m/s according to previous measurements. Figures remained essentially stable throughout the entire period of testing, and it is believed that, in essence, environmental conditions were met.ETF is an indoor thermal environmental index based on human body heat balance. Therefore, to assess the heat balance of the human body, we utilized the weight coefficient [13] of the sitting position, taking heat transfer by convection into consideration in calculating mean skin temperature. In addition, the weight coefficient corresponding to the sitting position, also taking heat convection into consideration, was used to calculate mean skin temperature in the context of physiological reaction of the

human body [14]. We used values obtained by Kurazumi et al. [15] for the convective heat transfer area ratio, radiant heat transfer area ratio and the conductive heat transfer area ratio [15].

For the human body in the sitting position, we used the configuration factor values for sitting position provided by Tsuchikawa et al. [16], the radiative heat transfer coefficient and the convection heat transfer coefficient [17]. For the emissivity on the human body, we used 0.98, derived from the degree of reflection on the skin of electromagnetic waves of 3 μm and above [18]. Because perspiration was difficult to ascertain, we used the thermoregulation model of Kurazumi et al. [19] to arrive at these values. We then calculated ETF as theorized and validated by Kurazumi et al. [20,21] based on thermal environment measures as well as skin temperature and amount of clothing.

The statistical test was used a statistical packages JMP. The statistical analyses were carried out with a significance probability of 0.05.

Discussion

ETF and mean skin temperature

The relationship between ETF and mean skin temperature is show in Figure 2. This indicates that as ETF rises, the mean skin temperature also tends to rise. Examining similar ETF levels, distribution is slightly narrower at temperatures of over 28°C , compared to temperatures around 25°C .

Examining the regression line, the group leaning toward 20-39% tended to be higher. However, no significant difference manifests in grouping by greenery ratios, and ETF intersects at the 30°C mark. Testing for homogeneity of the regression line led to a result of $p < 0.05$ ($F = 5.518$, $p = 0.004$), indicating a significant degree of parallelism on the regression line. According to multiple comparisons performed by Tukey-Kramer HSD, no significant differential was found between greenery percentages of 20–39% and 40–69% ($n = 562$, $t = -1.94$, $p = 0.129$), 20–39% and 70–89% ($n = 562$, $t = -2.29$, $p = 0.058$) and 40–69% and 70–89% ($n = 562$, $t = -0.46$, $p = 0.888$). Therefore, the ETF results of testing do not indicate a significant influence of the greenery percentage as visual stimuli on mean skin temperature.

ETF and thermal sensation

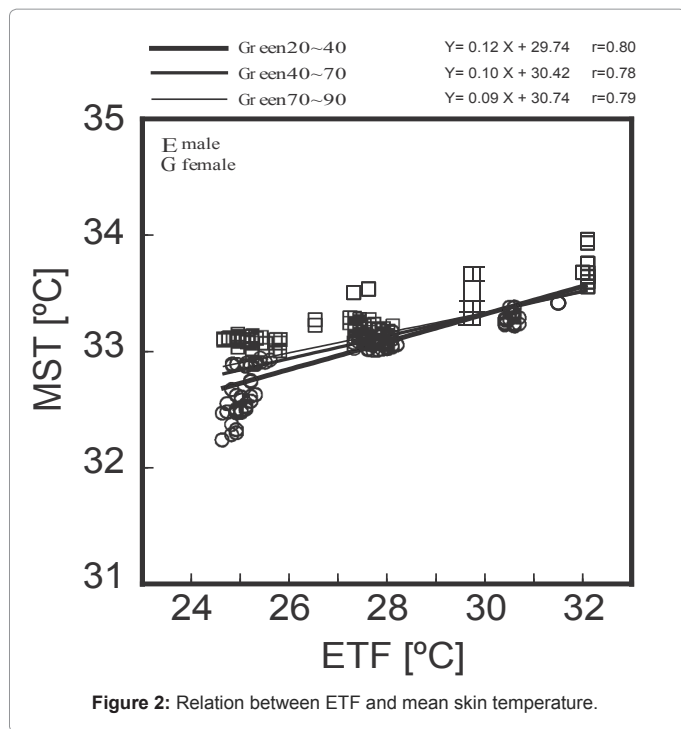
Figure 3 shows the relationship between ETF and the description of thermal sensation. The scope of ETF is small, primarily around 28°C in the range of $\pm 4^{\circ}\text{C}$, the range considered slightly uncomfortable, from slightly cool to slightly warm. The values given by subjects in describing thermal sensation were distributed widely over a range from cold to hot, indicating great individual differences. Judging from distribution density, with a peak ETF in the range of $28\text{--}29^{\circ}\text{C}$, the tendency was for subjects to describe conditions as “cold” in the lower ranges. At higher ETF, subjects tended to give a neutral description regarding heat levels, neither hot nor cold. At ETF of over $28\text{--}29^{\circ}\text{C}$, the research indicates a departure from the tendency for greater thermal sensation with regard to ETF of up to 28°C .

However, the 70-89% greenery group indicated less of an alleviating effect on heat than did the other two groups. The group with the highest percentage of greenery on visual stimuli, at 70–89%, is believed to have been negatively influenced by a “stagnant” impression caused by excessive forest cover. According to Fukagawa et al. [8], water-scene photographs with great depth perception tend to result in subjects perceiving the photographs as “cold;” yet, visuals featuring water surfaces alone tend to have less of such an effect. Considering the

Subject	Description	Material [%]	Weight [g]
Male	Pantie	- Cotton Cotton	21~27
	Short-sleeved shirt		114~118
	Kee-length underpants		84
Female	Pantie	-	24~34
	Brassiere	-	56~64
	Camisole	-	42~52
	Short-sleeved shirt	Cotton Cotton 98%, PU 2%	114~118
	Short pants		181

PU is polyurethane

Table 3: Clothing ensembles of subjects.



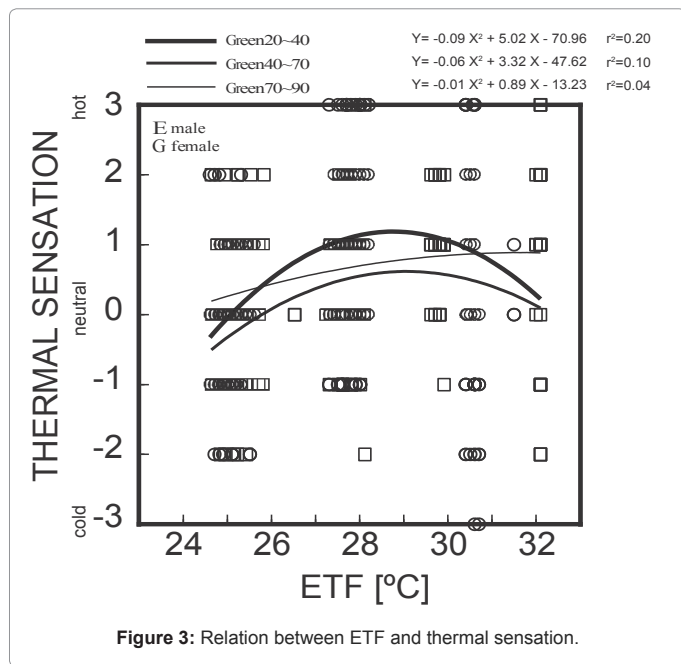
assessment on building rooftop settings indicates the possibility of visual elements engendering thermal senses due to rooftop greenery. Fuller coverage, as opposed to ground cover only, engendered an effect of visual stimuli. In addition, research on heat balance by Kurazumi et al. [9] in outdoor urban spaces shows that descriptions provided by subjects on thermal sensation were influenced both by the physical barrier provided by shade, which blocks short wave solar radiation, and the psychological influence of visuals.

The elements present in greenery percentages of less than 70%, which are perceived to have a dynamic effect on thermal environment conditions by visual stimuli, are believed to have influenced the thermal sensation given by the subjects in light of visual stimuli involving plants.

ETF and cool/warm sensation

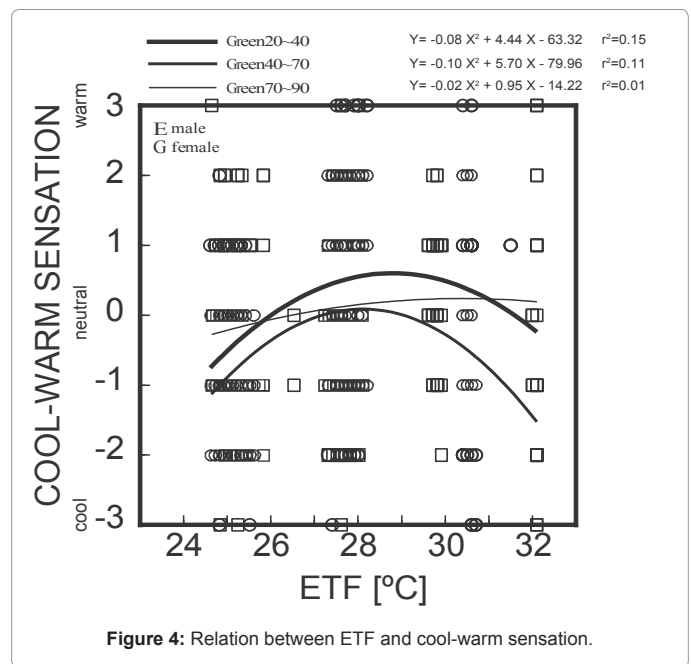
Figure 4 shows the relationship between ETF and warm/cool sensation. Similar to descriptions of thermal sensation provided by the subjects, the cool/warm values were distributed over a wide range from cool to warm, again clearly indicating significant individual differences. Based on the distribution density in ranges where ETF exceeded 28-29°C, the research shows results that depart from the tendency for greater warm/cool perception with regard to ETF of up to 28°C. Examining the regression line, as is the case with the relationship between ETF and thermal sensation descriptions given by the subjects, those descriptions given by grouping greenery percentages ameliorated perceptions of high temperature levels where ETF exceeded the 28-29°C range. As is true with thermal sensation descriptions, visual stimuli provided by the group with the highest percentage of greenery, at 79-89%, are believed to have led to improvements in warmth perception due to an image of stagnation caused by the forest cover.

Examining the distribution of the regression line and comparing descriptions given by the subjects of thermal sensation and cool/warm sensation, there is a shift to lower values on the regression line as compared to the relationship between ETF and thermal sensation. In addition, the research shows a clear inclination toward lower values once the ETF peak of 28-29°C is exceeded. Research by Matsubara et al. [5], focusing primarily on psychological assessment, shows that,



idea that the visuals for the 70-89% group, the group with the highest percentage of greenery, were also “crowded” by forest and ground cover, we see that, as in Fukagawa et al. [8], it is important to create a sense of openness in the space.

In a study by Matsubara et al. [5] focusing on psychological assessment in an indoor setting in a slightly uncomfortable thermal environment, the researchers show that lessening the psychological perception of higher temperatures was more greatly influenced by cooling colors in hot spaces and by warming colors in cooler spaces. In addition, research by Murakami and Shimomura [7] on psychological



in slightly uncomfortable, warmer environmental conditions, an ameliorative effect on high thermal sensation was shown in the cool/warm category as opposed to in the thermal sensation category in indoor settings. In addition, in research by Shimada et al. [22], also focusing primarily on psychological assessment in indoor settings, the gradient of the regression coefficient was smaller for non-singular cool/warm impressions as opposed to singular thermal sensation impressions of heat. The present research also shows greater improvement in terms of cool/warm sensation as opposed to thermal sensation.

As is true with the relationship between ETF and thermal sensation, the elements involved in visual stimuli that are expected to have a dynamic influence on thermal environmental conditions of 69% or less are believed to have an influence on cold/warm sensation engendered by forest and greenery visuals.

ETF and thermal comfort

The correlation between ETF and thermal comfort is shown in Figure 5. As is the case with thermal sensation and cool/warm sensation, distribution fell over a broad range from uncomfortable to comfortable, and, again, there were significant differences between individuals. Examining the distribution density, there was a trend for subjects to describe lower temperature ranges as comfortable with ETF at a peak of around 28–29°C. In ranges of higher ETF, there was a tendency for the subjects to describe their perceptions as natural with regard to the heat, that is, as neither comfortable nor uncomfortable. Where ETF was higher than the 28–29°C degree range, results indicated tendencies that differed from descriptions where subjects indicated that they were comfortable in the ETF range of up to 28°C.

Examining the regression line, subjects described thermal sensation on greenery percentages; all descriptions indicated an increase in the perception of discomfort at an ETF of 28–29°C. However, comparing the 70–89% group, that with the highest percentage of greenery, with the other two groups, amelioration of the perception of heat was low. As was the case with thermal sensation and cold/warm sensation, visual stimuli of the 79–89% greenery group influenced thermal comfort

levels negatively due to a sense of stagnation created by over-crowded greenery.

Aerial currents are believed to be a significant fluctuating factor among hot outdoor environmental factors. Kuwasawa et al. [23] show that fluctuating air currents, more so than static air currents, contributed to a lower perception of discomfort in environments deemed “hot.” As above, the impression of “stagnation” led to less dynamic impressions of the thermal environment. This means that improvements in thermal comfort levels were relatively insignificant.

The elements present in greenery percentages of less than 70%, which are perceived to have dynamic effects on thermal environment conditions by visual stimuli, are believed to have influenced the warm/cold sensation given by the subjects in light of visual stimuli involving plants.

Visual stimuli and influence on the human body

The relationship between ETF and mean skin temperature indicates that thermal stimuli influence mean skin temperatures, but that visual stimuli do not influence mean skin temperatures. On the other hand, with regard to the relationship of ETF and thermal senses, in the ETF range of higher than 28–29°C, improvements in thermal senses resulting from visual stimuli were indicated. These results were primarily present in visual stimuli elements featuring a greenery percentage of 69% or less, the range expected to have a dynamic influence on thermal environment conditions.

In qualitative visual stimuli testing conducted by Matsubara et al. [5], amelioration of the psychological influence (perceived high temperatures) was significant in relation to both hot and cold environments deemed slightly uncomfortable. The level of improvement engendered by fuller vegetation with regard to thermal environments was greater than that yielded by flatter vegetation cover [7]. In turn, visual stimuli offering depth perception had the effect of lowering thermal sensation [8]. The results of this research were also clearly shown qualitatively using ETF as the evaluation axis. Presenting visual stimuli incorporating natural elements such as vegetation, even in indoor settings where ETF is set in the slightly uncomfortable range of higher than 28°C, clearly had ameliorative results on feelings of discomfort caused by the heat.

Conclusion

Human thermal sense is not expressed only by simple heat equilibrium. The influence of visual and auditory stimuli causes differences in overall thermal sense arrived at by sophisticated sensory processing by the cerebrum. This means that extreme temperature settings are not necessary in indoor air-conditioned spaces, and that a space may be deemed slightly hot or uncomfortable and still be acceptable. If it can be clearly shown that the effects of a thermal environment considered slightly uncomfortable could be ameliorated using visual stimuli, the cost effectiveness of such an initiative would be highly significant, particularly in terms of air conditioning system running costs.

In this context, the objective of this research was to test subjects placed in a thermal environment deemed slightly uncomfortable, where the temperature is set at a base point of 28°C, to determine the influence of overall stimuli on the cerebrum on assessing an indoor thermal environment, and to prove the significance of actively placing visual stimuli in spaces.

The results indicate that:

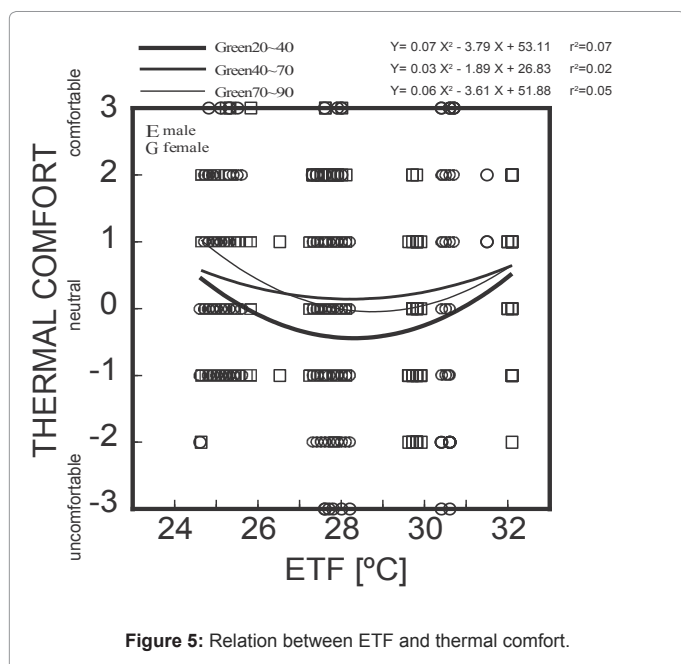


Figure 5: Relation between ETF and thermal comfort.

- 1) Thermal stimuli influence the human body in terms of physiological dose on mean skin temperatures, while visual stimuli do not affect mean skin temperatures.
- 2) In ETF deemed fairly uncomfortable, that is at a range of hotter than 28-29°C, clear improvements were observed in thermal sense due to the influence of visual stimuli such as natural elements including vegetation like greenery.
- 3) Visual stimuli are shown to be appropriate at a level of up to 69% greenery, where a dynamic effect on warmer environmental conditions can be felt and where the depth of fuller vegetation cover can be perceived.

The Japanese people have long loved a lifestyle that is slightly restrictive. In a thermal environment where it is possible for the occupants to endure mild heat, visual stimuli including vegetation could lead to the creation of environmentally friendly spaces.

More research is needed to clarify the influence of age bracket, exposure time, and environmental stimuli other than thermal environmental factors and so on.

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