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EFFECT OF VISUAL STIMULI ON HUMAN THERMAL SENSATION OF SHORT TERM RESIDENTS IN AN OUTDOOR CAMPUS LANDSCAPE IN A TROPICAL CLIMATE

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ABSTRACT: Climate change is one of the most serious issues in the recent world. Climate change is known as caused by the increase of carbon dioxide and many countries are forced to take measures. The first big measure was the Paris Agreement in 2015, and many countries joined the agreement. According to the agreement, many of the countries declared major shifts, such as the shift to electric vehicles in the car industry. The biggest concern about climate change at this moment is the rise of the temperature and it causes more death by heat stroke in summer. It also causes more usage of air conditioning systems and emits more carbon dioxide. It became a serious vicious circle. For that reason, it is important to analyze the mechanism of the human thermal sensation, which can be affected by the environmental history of the person, such as the residential area, the length of stay, and so on. In addition, it is expected that the effect of these histories especially appears strongly outdoors. For that reason, the outdoor experiment targeting short-term residents was carried out in Bangkok. For the experiment, 5 measuring points were selected. As a result, a different tendency was grasped at one of the measuring points with an open sky.

Keywords: Global warming, Thermal sensation, Thermal discomfort, Image evaluation, Visual stimuli

1. INTRODUCTION

In recent years, high temperatures in urban areas have become a serious problem. Higher temperatures in urban areas are generally referred to as the heat island effect, which is caused by increased man-made land surfaces and exhaust heat. In addition, due to global warming, people in some urban areas are forced to live under extremely high temperatures during the summer.

As a countermeasure to this worsening thermal environment, there is an urgent need to curb carbon dioxide emissions on a global scale [The Paris Agreement on Climate Change]. Looking at measures by region, for example, Singapore is promoting greening under the government's initiative [Garden city vision since 1960's]. In addition, Tokyo enacted an ordinance in December 2022 which obligates the installation of solar panels on new detached houses to decrease fossil fuel consumption. However, the clear effects of these measures are still expected to take time.

Focusing on the negative effects of higher temperatures in urban areas, the number of deaths by heat stroke is on the rise and has become a serious problem, especially in Japan, where the number of death by heat stroke was 805 in 2022. Heat stroke occurs when the balance of body temperature is lost, which is mainly affected by the heat transfer between the human body and the air. In addition, the thermal sensation of humans is also an important factor. When the thermal sensation reaches a certain level, the human body starts to sweat to control the body temperature, and the body temperature is adjusted accordingly.

The thermal sensation of the human body is generally said to be influenced by temperature, humidity, airflow, and radiation as physical indicators, and metabolism and the clo-value as indicators on the human side. Physical indicators are strongly affected by the surrounding environment, as they are affected by direct and indirect solar radiation, land use, and surrounding areas. On the other hand, human indicators are even more complicated, and previous research has shown that it is necessary to additionally consider the effect of stay history and visual stimuli on human indicators. Regarding the history of stay, also called environmental history in similar research, it is said that human needs a certain period to adapt to the climate when staying in a different climate classification. Therefore, by studying the thermal sensation of short-term residents in the target climate zone, it will be possible to grasp more accurate measures against heatstroke.

The following are examples of research that deal with physical factors based on land use conditions. Fukagawa et al. [1] had research dealt with the differences in temperature formation due to different ground surface coverage conditions outdoors. In this study, long-term measurements were carried out on multiple ground surfaces in Higashi-Hiroshima City, Hiroshima Prefecture, and the characteristics of temperature formation due to each ground surface cover were clarified. In addition, Tanaka et al. [2] have studied the impact of dam lakes on the surrounding climate as a huge body of water. In this study, Fukutomi Dam, located in Higashi-Hiroshima City, Hiroshima Prefecture, is targeted, and the extent of its impact is shown. According to these studies, temperature formation tendency based on land use was grasped.

Furthermore, to study the mechanism of human thermal sensation, it is necessary to understand the changes under various outdoor environmental stimuli. The following studies deal with human thermal sensation and comfort outdoors. Rahim et al. [3] studied the thermal performance in hot, humid climate areas and showed the importance of the land surface of the outdoors. Zheng et al. [4] researched the outdoor thermal environment of the university campus by using GIS and mentioned the wide temperature gap on the campus by showing the temperature distribution map. Aruninta et al. [5] presented the results of a study on thermal comfort outdoors on a university campus located in Bangkok and showed the tendency of thermal comfort. Kurazumi et al. [6] [7] researched the effect of environmental stimuli, such as artificial and non-artificial visual stimuli, on human thermal sensation and mentioned the effect on human neutral temperature.

In addition, to examine environmental stimuli more deeply, it is necessary to examine the relationship between visual stimuli and thermal sensations. The following studies deal with the effects of visual stimuli, as psychological factors, on human body temperature and cold sensation. Matsubara et al. [8] focused on sight sense as a psychological effect and had an experiment on hue-heat and clarified that the effect of visual stimulus causes a 0.3-degree centigrade difference. Fukagawa et al. [9] analyzed the effect of visual stimuli by water landscape on thermal sensation to grasp the psychological effect. Kurazumi et al. [10] examined the effects of visual stimuli by foliage plants on human body temperature in an artificial weather chamber where the temperature is controlled by an air conditioning system.

2. RESEARCH SIGNIFICANCE

Those studies shed considerable light on the influencing factors of human thermal sensation. However, when considering the improvement of the thermal environment, it is common to consider it from the perspective of long-term residents. In a tourism-oriented country like Thailand, on the other hand, it is difficult to reduce accidents caused by heat stroke without considering the thermal sensation of short-term residents. In addition, when the residents evaluate the outdoor thermal environment, the influence of the environmental history up to that point strongly appears. For that reason, the research significance is to clarify the evaluation tendency of short-term residents on thermal sensation in an outdoor thermal environment in Bangkok.

3. EXPERIMENT OVERVIEW

The research experiment took place on the campus of Chulalongkorn university in 2016 (rainy/wet season) with a group of Japanese university students who had just visited Bangkok for the first time as the subjects. The subjects were 11 males and 5 females, for a total of 16 subjects with a clo-value of between about 0.3 to 0.5. The experiment was performed on August 29th and 30th, which were fine sunny days, during the daytime only from before noon to afternoon. The measuring points were selected on the university premises. 4 points were selected by considering the surrounding environment, such as surface ground condition and sky factors.

The measuring points and route patterns are shown in Tab.1 and Fig.1. The subject moved to these four measuring points and filled out the declaration vote after staying for 10 minutes at each point. A total of four experiments were performed. To analyze the sky factors of each measuring point, all-sky photos are taken at each point. The photos and the sky factors are shown in Fig.2. and Tab.1, and the outline of each measurement point is as follows.

The measuring point No.0 is located in the semi-outdoor space inside the university building and the sky ratio is very low. Point No.1 is located beside a pond where many trees are around, so the sky ratio is low, but the green ratio is high. Point No.2 is on the soccer field, so the sky ratio is high. Point No.3 is located beside the engineering department building so the sky ratio is low. However, many

Table 1 Ratio of sky factors

	Sky	Non Sky	Green	Total
⓪ Building Court	0.14	0.52	0.34	1
① Pond side	0.25	0.09	0.66	1
② North Play Field	0.88	0.03	0.09	1
③ Engineering Bldg side	0.16	0.28	0.56	1
④ Auditorium Plaza	0.42	0.22	0.36	1

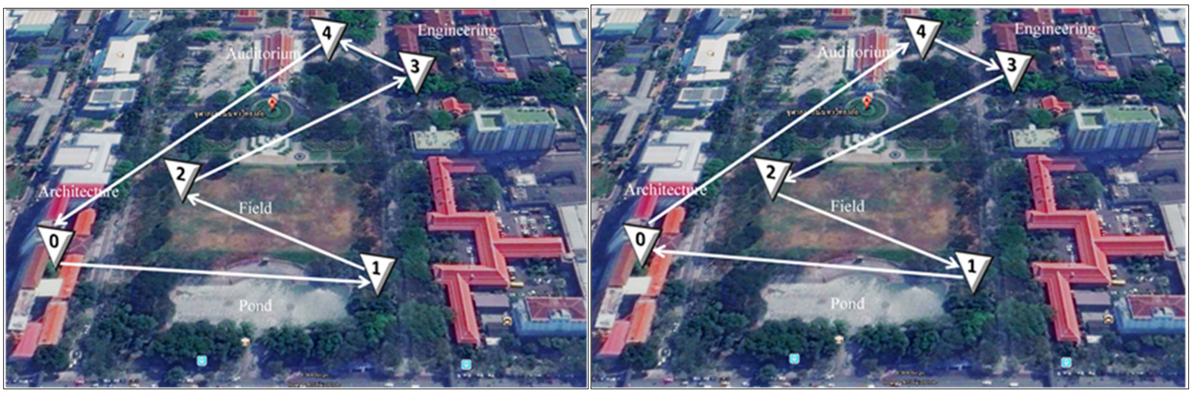


Fig.1 Measuring points

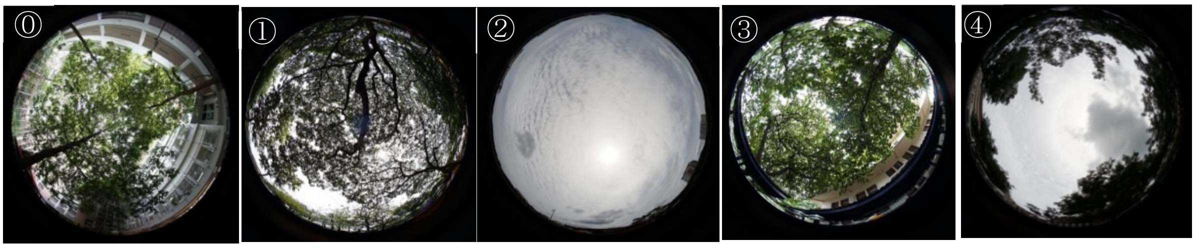


Fig.2 All-sky photos of measuring points

Table 2 30 Adjective pairs in the declaration vote

Ugly	-	Beautiful	Useless	-	Useful	Dry	-	Fresh	Slow	-	Fast	Solemn	-	Casual
Unrelaxing	-	Relaxing	Uncomfortable	-	Confortable	Cramped	-	Majestic	Dark	-	Bright	Noisy	-	Tranquil
Annoying	-	Breezy	Boaring	-	Enjoyable	Cloudy	-	Pure	Mild	-	Active	Invariant	-	Changeable
Disattractive	-	Attractive	Wild	-	Gentle	Artificial	-	Natural	Closed	-	Disclosed	Cold	-	Hot
Unfamiliar	-	Familiar	Strict	-	Graceful	Less Green	-	Fully Green	Dislikable	-	Likable	Far	-	Close
Poor	-	Rich	Mobid	-	Healthful	Old	-	New	Aggressive	-	Passive	Exclusive	-	Coexistence

trees are planted along the building, so the green ratio is quite high. Point No.4 is located near the auditorium which has an artificial square in front. For that reason, the ratio of green is low.

3.1 Experiment Protocol

The declaration vote was utilized for this experiment. The vote is composed of the image evaluation part by using the SD method and the thermal sensation part. SD method part contains 30 adjective pairs with 7-level rating scales giving a score of +3 to -3. The 30 adjective pairs used for this experiment are shown in Tab.2. Line rating scale was utilized for thermal sensation and thermal comfort parts, and for the experiment, temperature, wind speed, humidity, and ground surface temperature were measured as physical factors. All data were measured at 1-minute intervals. Fig.3 shows the average values of each measurement point.

3.2 Thermal Conditions

Looking at the temperature data at the time of the measurement, although the highest value is shown at measurement point 2, the difference between the measurement points is extremely small. Humidity data shows that there is a difference of up to 3% between the measurement points. However, like the temperature, the difference is extremely small.

The wind data of point No. 2 marked the strongest value, where the sky factor was the largest. Looking at the value of the ground surface temperature, measuring point No. 2 was the highest, where the sky factor was the largest. Then followed by the highest value at point No. 4, where located in the center of the artificial square. By the above results, there is no extreme thermal environment at the measuring points selected for this experiment.

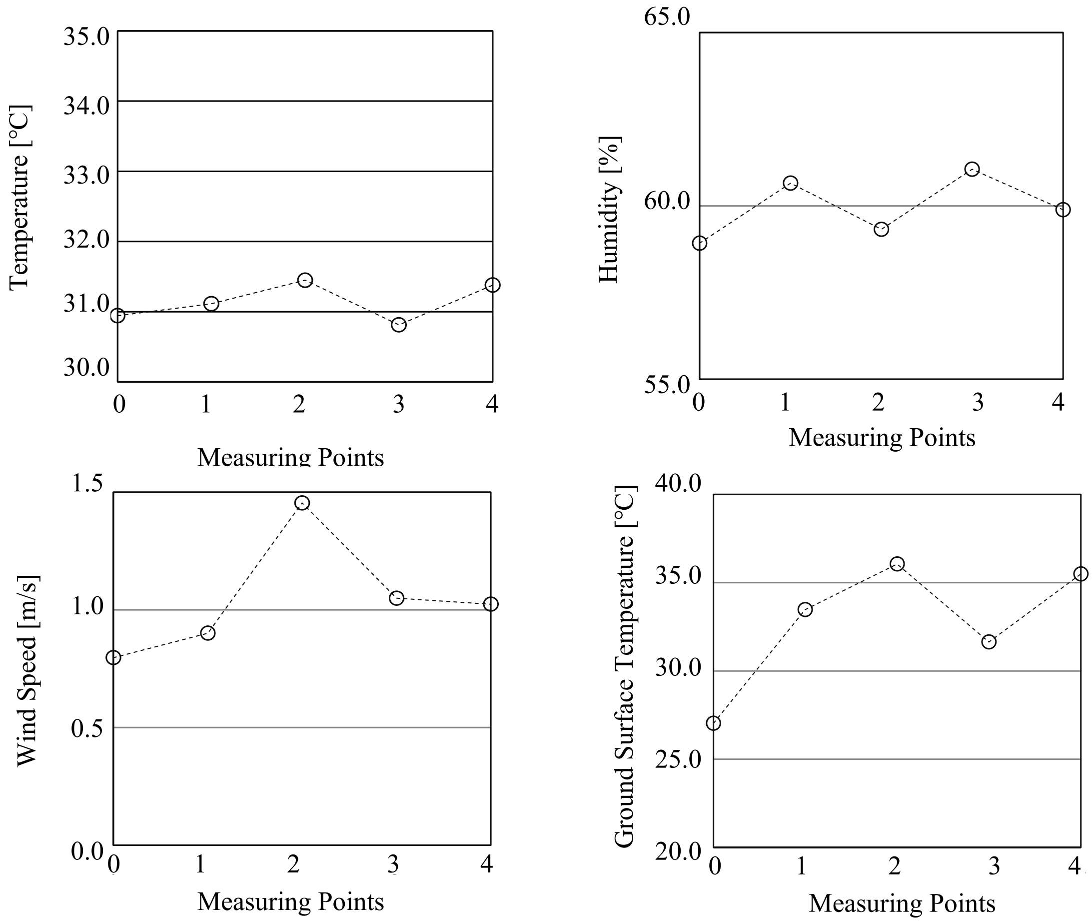


Fig.3 Thermal condition in each measuring points

4. EXPERIMENT RESULTS

In this chapter, the results of image evaluation by the SD method and the evaluation results of thermal sensation and thermal discomfort are analyzed. The result of the image evaluation is shown in Fig.4. The image evaluation scores were aggregated and averaged for each measuring point.

Measuring point No. 2 shows characteristic results, especially for items such as Bright, Disclosed, and Hot that are presumed to affect the feeling of warmth and cold. This is estimated that the influence of the magnitude of the sky ratio, which is the largest at measuring point No.2.

Measuring point No.3 also shows a different tendency from the other measuring points in items such as Cramped, Dark, and Closed, which express a feeling of openness in space. It is considered that this is due to the small sky factor and the low ability in the visual field range at that point. The result of the image evaluation suggests that the sky factor, brightness, and the feeling of openness of the space at the time of evaluation may affect the evaluation results.

4.1 Results of Thermal Sensation and Thermal Discomfort

The result of averaging the declared values of thermal sensation and thermal discomfort by gender and the overall average value is shown in Fig.5. Since the declaration method used in this measurement is the linear rating scale, the fluctuation tendency is more focused rather than the value itself. Looking at the results declared by females, the results of thermal sensation and discomfort are generally similar. However, the difference between those results gets wider at measuring point No.2. Looking at the results declared by males, the tendency of thermal sensation and discomfort is generally similar.

The results of the male showed a similar tendency to the female, except for measuring point No.2. At this point, the thermal comfort deteriorates, but the thermal sensation improves. By the results shown in Fig.3, there is no significant difference found in physical indicators such as temperature at measuring point No. 2 compared to other points. Therefore, it is considered that the difference in the image evaluation results is influenced by psychological factors rather than physical factors.

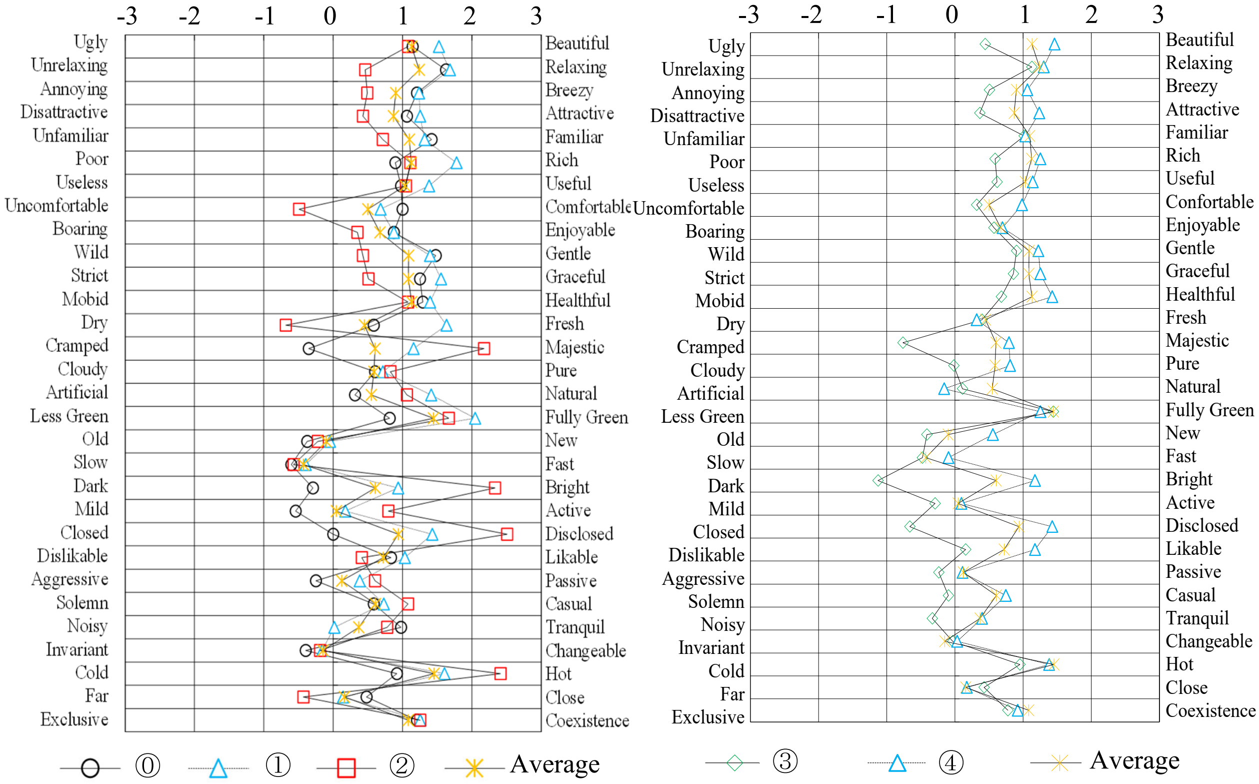
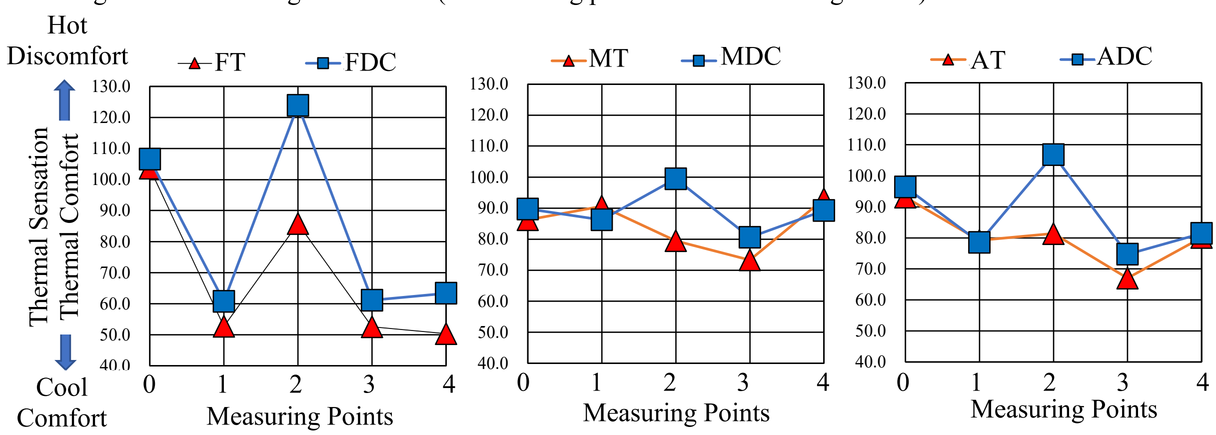


Fig.4 Results of image evaluation (at measuring point 1 to 4 with average score)



※F: Female, M: Male, A: Average, T: Thermal Sensation, DC: Thermal Discomfort

Fig.5 Results of thermal sensation and thermal discomfort vote

5. IMAGE EVALUATION STRUCTURE

To analyze the tendency of the image evaluation results by the subjects, factor analysis was taken. For the factor analysis, the varimax rotation method was taken. Factor analysis was performed based on an eigenvalue of 1.0 or higher, and 7 factors were extracted. Since there was a problem in the interpretation of the 7 factors, the number of factors was fixed at 3 to 6 and the factor analysis was performed again. The most interpreted result was obtained when the factor number was set as 3. The result of setting the factor number as 3 is shown in Tab.3. The factor scores of more than 0.37 are highlighted.

Focusing on the items marked high factor, the first factor is named "Comfort" The items relating to comfort, such as "Unattractive - Attractive", "Strict - Graceful," and "Unrelaxing - Relaxing", are categorized. A total of 18 items were selected for the first factor. The second factor is named "Sensation" The items relating to sensation, such as "Dark - Bright", "Closed – Disclosed," and "Cramped -Majestic" which emphasize human sensation, are categorized. A total of 10 items were selected for the second factor.

The third factor is named "Impression". The items relating to impression, such as "Aggressive - Passive," "Slow – Fast", and "Invariant – Changeable," are categorized. A total of 5 items were selected for the second factor.

5.1 Analysis on the Average Factor Score

To analyze the tendency of each of the extracted factors by measuring point and by gender, the average factor score in each of them were calculated. The plotted diagram of those data is shown in Fig.6.

Table 3 Factor loading matrix

Adjective Pairs \ Factor	1st Comfort	2nd Sensation	3rd Impression
Unattractive - Attractive	0.83	0.18	0.23
Strict - Graceful	0.76	0.10	-0.02
Unrelaxing-Relaxing	0.72	-0.12	0.19
Annoying - Breezy	0.72	0.06	0.24
Unfamiliar - Familiar	0.72	0.12	0.19
Ugly - Beautiful	0.71	0.30	0.07
Poor - Rich	0.71	0.31	0.00
Wild - Gentle	0.70	-0.09	-0.17
Dislikable - Likable	0.68	0.25	0.20
Mobid - Healthful	0.67	0.30	-0.06
Discomfortable - Confortable	0.67	-0.10	0.29
Boaring - Enjoyable	0.63	0.19	0.29
Useless - Useful	0.55	0.39	0.19
Cloudy - Pure	0.51	0.40	0.07
Dry - Fresh	0.50	-0.03	0.08
Exclusive - Coexistent	0.42	0.36	0.19
Old - New	0.36	0.20	0.29
Noisy - Tranquil	0.35	0.07	-0.19
Dark - Bright	0.06	0.85	0.10
Closed - Disclosed	0.09	0.84	0.00
Cramped - Majestic	0.17	0.82	-0.12
Mild - Active	-0.05	0.54	0.41
Aggressive - Passive	0.25	0.51	0.36
Cold - Hot	-0.03	0.51	0.00
Solemn - Casual	0.40	0.49	0.15
Less Green - Fully Green	0.37	0.39	-0.24
Slow - Fast	0.16	0.17	0.53
Invariant - Changeable	0.14	0.11	0.46
Far - Close	0.23	-0.23	0.38
Artificial - Natural	0.22	0.30	-0.37

* Factor scores of higher than 0.37are highlighted.

To this result, measuring point No. 2 tends to be different from the other points. Furthermore, the differences in the tendency of each measuring point are greater than those of the differences by gender. The difference between the factors is more obvious between the 1st factor, "Comfort," and the 2nd d factor, "Sensation," than the 3rd factor, "Impression." In particular, the 2nd factor has a large difference in the tendency.

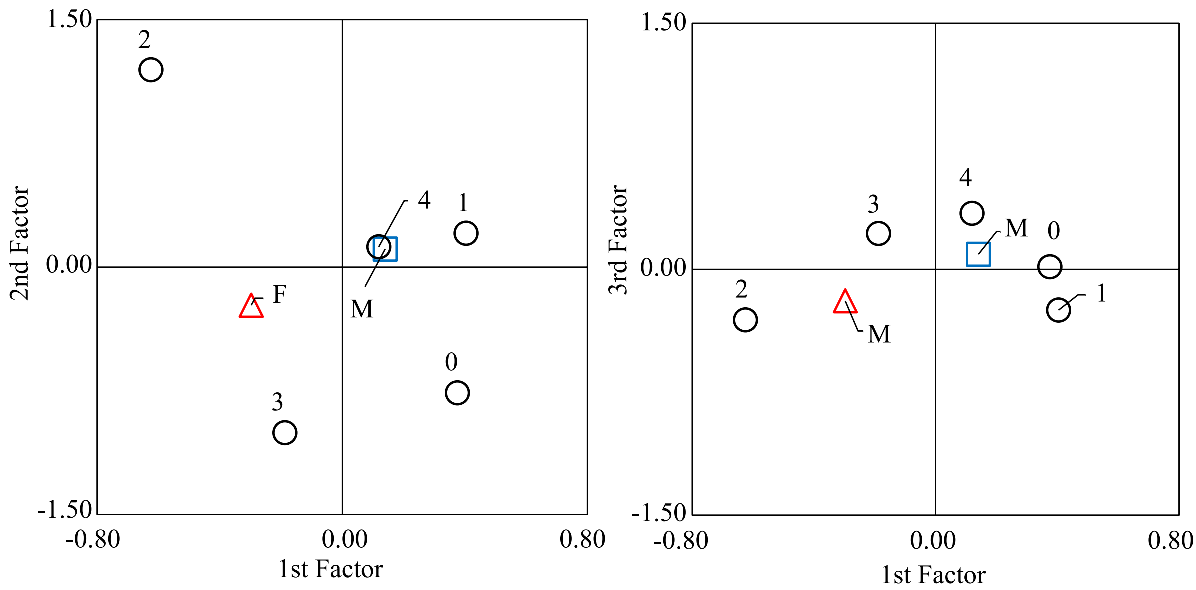
5.2 Analysis of the Correlation of the Image Evaluation Factors and the Thermal Discomfort and Sensation

In the result of the average factor score, the difference at each point was larger than the gender difference. Therefore, in this chapter, the data is not classified by gender but by using all the data to examine the relationship between each factor and thermal discomfort and sensation. The result is shown in Tab.4.

Focusing on Thermal discomfort, the 1st factor showed a significant negative correlation at the 5% level, and the 2nd factor showed a significant positive correlation at the 1% level. The results of Thermal sensation showed significant results at the 1% level for both the 1st factor and the 2nd factor. In addition, the 1st factor showed a positive correlation, and the second factor showed a negative correlation. The 3rd factor did not show a significant correlation with thermal discomfort or thermal sensation.

6. ANALYSIS BY MULTIPLE LINEAR REGRESSION

To examine the relationship between each factor and thermal sensation shown in the



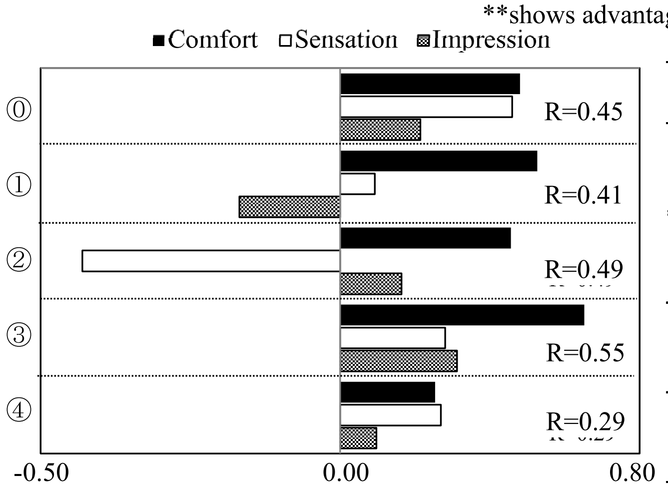
※The number represents the measuring points. ※F: Female, M: Male

Fig.6 Average factor score by gender and measuring points

Table 4 Result of correlation analysis

		Thermal Sensation	1st Factor	2nd Factor	3rd Factor
Thermal Sensation	Pearson Correlation Coefficient		.306**	-.204**	-.002
	Sample Number		193	193	193
1st Factor	Pearson Correlation Coefficient			-.080	-.231**
	Sample Number			201	201
2nd Factor	Pearson Correlation Coefficient				-.057
	Sample Number				201

**shows advantage at 1 % level. * shows advantage at 5% level.



	Measuring Points ⓪	①	②	③	④
Multiple Correlation Coefficient	0.45	0.41	0.49	***0.55***	0.29
Comfort	0.30	0.33	0.29	***0.41***	0.16
Sensation	0.29	0.06	***-0.43***	0.18	0.17
Impression	0.13	-0.17	0.10	***0.19***	0.06

Fig.7 Result of multiple linier regression analysis.

previous chapter in detail, a detailed analysis is performed using the factor scores and thermal sensation reported values. To analyze the definite factor of outdoor thermal sensation, multiple linear regression analysis was taken. For the analysis, the factor score was separated into each measuring point and analyzed. The result is shown in Figure 7.

Focusing on the multiple correlation coefficient, measuring point 3 showed the highest value on the multiple correlation coefficient and then measuring point "2". The measuring point "4" showed the lowest value. Focusing on the tendency of the standard regression coefficient, only measuring point 2 showed an obviously different tendency. The standard regression coefficient of 2nd factor, "Sensation," is a negative value to the thermal sensation. The factor "Sensation" is composed of items including "Dark - Bright", and "Cold - Hot".

For that reason, this factor is can be taken as most likely affecting the thermal sensation. In addition, measuring point "2" is with the highest percentage of sky factor, which means more sunlight than the others. By the deeper analysis of this result, it can be said that the subjects declare the thermal sensation lower than the actual condition of the thermal environment at measuring point "2" which is with a larger sky factor and more sunlight.

7. CONCLUSIONS

In this study, short-term resident was targeted to clarify the evaluation tendency of the thermal environment. The obtained results are as below.

1) Comparing the results of image evaluation of each measuring point, point "2" showed an obviously different tendency.
2) By the factor analysis, 3 factors were obtained. In addition, the averaged factor scores of each measuring point, the measuring point "2" showed the highest value in the 2nd factor. Furthermore, the measuring point showed the lowest value in the 2nd factor.
3) By the correlation analysis among the obtained 3 factors and the thermal discomfort and sensation, the 1^{st} and the 2^{nd} factor showed significant correlation.
4) To analyze the definite factor, multiple regression analysis was taken. As a result, the 2nd factor showed the possibility of lower thermal sensation at the measuring point "2".

In the summary of the above results, it is confirmed that by understanding the elements that affect both 1^{st} and 2^{nd} factors, it is possible to have some influence on the thermal discomfort and thermal sensation of the short-term residents.

In addition, it is confirmed that raising the 2nd factor has the effect of alleviating the thermal sensation of the short-term residents in a space with a high sky factor.

As described above, the results of this research show that short-term residents in Bangkok during the rainy season tend to evaluate their thermal sensations in open, well-ventilated spaces with a high sky rate rather than in spaces where sunlight is blocked. In order to further development of the research, we plan to compare the results of this research with those of long-term residents and conduct similar experiments in the dry season to examine the psychological factors that affect thermal sensations in more detail.

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