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Investigation of the outdoor thermal comfort and clothing insulation in Hachiko Square in Tokyo

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Abstract
In order to clarify the outdoor thermal comfort and clothing, the thermal measurements (air temperature) and thermal comfort survey were conducted in Hachiko Square which is located in the Shibuya station, Tokyo. (Hachiko is a famous statue of a dog which is a popular meeting place.) The survey was conducted every two weeks and the number of people investigated was 224. The results showed that the average clothing insulation of the females is greater than that of the men. The clothing insulation is highly correlated with the outdoor air temperature. The equation can be used to predict the degree of clothing insulation in outdoor spaces.

Keywords: Clothing insulation; Outdoor air temperature; Outdoor thermal comfort

1. Introduction
People use outdoor spaces for various activities, such as relaxing, meeting people, taking short breaks and playing. If the outdoor environment is well-designed and thermally comfortable, people use it regularly in their daily life. However, we often encounter uncomfortable outdoor environments which need improving by optimizing shading, greenery, open spaces etc. Because of seasonal and regional adaptation, people may have different thermal expectations of the outdoor environment, which might be an important factor in explaining outdoor thermal comfort. How people adapt to various outdoor conditions is not yet fully understood. Generally, people feel comfortable in outdoor space by adjusting their clothing. They choose and wear the most comfortable clothing to suit their various thermal situations. People are free to adjust the clothing outdoors, and thus they might be adapting well compared to within the office buildings context. Up to date, there are many research papers on clothing in indoor environments [1-8]. However, there is only a limited amount of research on clothing in outdoor environments and conducted only for a short period of time [12, 13, 17].

In order to clarify the outdoor thermal comfort and clothing, thermal measurements and a thermal comfort survey (thermal sensation, thermal preference and clothing insulation) were conducted in Hachiko Square in Tokyo.

2. Research methods
The survey was conducted in the Hachiko square which is located by Shibuya station, Tokyo. The survey was conducted every two weeks and the number of investigated people was 224

(male = 162, female = 62). The mean age of these participants was 31 years old (male = 33 years, female = 30 years).

The Investigation period was 29th September to 2nd December 2013 and the investigative time was 12:00 to 20:00. The outdoor air temperature was measured by a compact measuring device around the people. In the thermal comfort survey, thermal sensation (7 point scale), thermal preference (5 point scale) and clothing insulation were included (Table 1).

The clothing insulation was recorded by two methods: summation method and illustration method. The summation method is the conventional method where the clothing insulation was summed up by recording each items of clothing. In the "illustration method", the clothing insulation was chosen from the nearest figure (Figure 1).

Table 1: Thermal sensation and thermal preference scale.

No.	Thermal sensation How do you feel the temperature of the now?	Thermal preference Do you want how the temperature of the now?
1	Very cold	Much warmer
2	Cold	A bit warmer
3	Slightly cold	No change
4	Neutral (neither hot nor cold)	A bit cold
5	Slightly hot	Much cold
6	Hot	
7	Very hot	

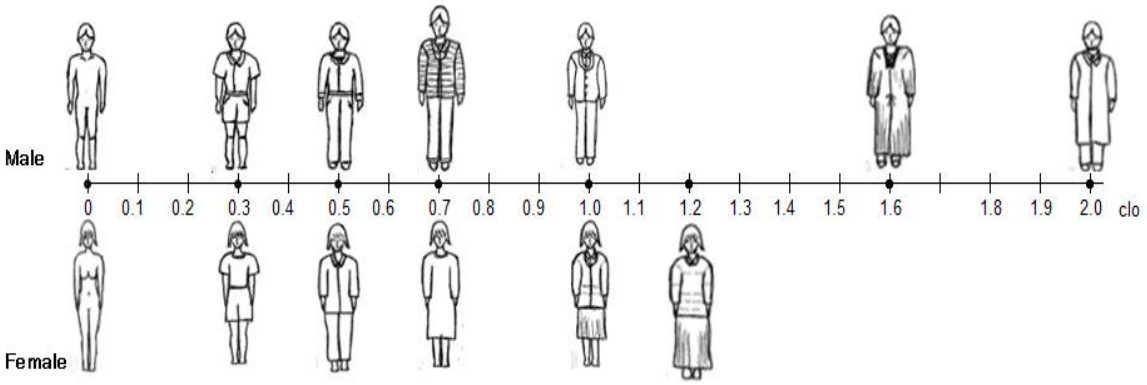

Figure 1: Scale of the clothing insulation for illustration method.

3. Results and discussion

3.1 Outdoor air temperature

The daily mean outdoor temperature during the voting is shown in Table 2. The mean outdoor temperature in autumn is about 10 ºC higher than in winter.

Table 2: Average outdoor temperature of the day.

Date	Season	Number of data	Outdoor air temperature (℃)		Thermal sensation		Thermal preference	
			Mean	SD	Mean	SD	Mean	SD
2013/9/29	Autumn	39	22.6	1.3	3.8	0.7	2.9	0.6
2013/10/8	Autumn	65	27.5	1.2	4.8	0.8	3.6	0.7
2013/11/11	Autumn	18	15.2	3.0	2.6	1.2	1.9	1.1
2013/11/28	Autumn	41	14.5	2.2	2.6	0.9	2.2	1.0
2013/12/2	Winter	61	14.6	0.5	3.0	0.9	2.7	0.6

SD : Standard deviation

3.2 Distribution of thermal sensation

The mean thermal sensation vote is shown in Table 2. The percentage of thermal sensation is shown in Table 3. The most common thermal sensation vote is “4 neutral” (33.5%). The proportion of thermal sensation in cold side (1 very cold to “3 slightly cold”) is 45%. This might be due to the low outdoor air temperature in winter.

Table 3: Percentage of the thermal sensation.

Scale	Number of data	Percentage (%)
1	7	3.1
2	46	20.5
3	48	21.4
4	75	33.5
5	33	14.7
6	14	6.3
7	1	0.4
Total	224	100.0

3.3 Distribution of thermal preference

The mean thermal preference vote is shown in Table 2. The percentage of thermal preference is shown in Table 4. The most common thermal preference is “3 no change” (53.1%). If we count the vote “1 much warmer” and “2 a bit warmer”, it would be 27.7%.

Table 4: Percentage of the thermal preference.

Scale	Number of data	Percentage (%)
1	25	11.2
2	37	16.5
3	119	53.1
4	34	15.2
5	9	4.0
Total	224	100.0

3.4 Relation between the thermal preference and thermal sensation

Figure 2 show the relation between the thermal preference and thermal sensation. They are highly correlated, and thus two scales are well matched.

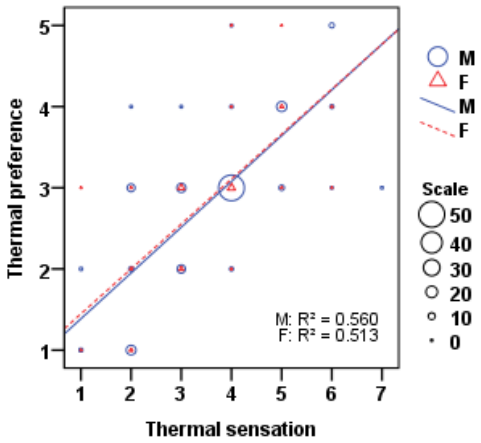

Figure 2: Relation between the thermal preference and thermal sensation.

3.5 Relation between the outdoor air temperature and thermal sensation

Figure 3 shows the relation between the thermal sensation and outdoor air temperature. They are highly correlated. We have found the following regression equation to predict the outdoor comfort temperature.

All: $C = 0.157T_o + 0.462$ (n=224, R^2=0.56, p<0.001) (1)

M: $C = 0.160T_o + 0.435$ (n=162, R^2=0.55, p<0.001) (2)

F: $C = 0.149T_o + 0.521$ (n=62, R^2=0.58, p<0.001) (3)

C : thermal sensation, T_o : outdoor air temperature (ºC), n: number of samples, R^2: coefficient of determination, p: significance level.

When the comfort temperature is predicted by substituting "4 neutral" in the equations (1) to (3), the comfort temperature would be 22.5ºC (male = 22.2ºC, female = 23.3ºC). The comfort temperature of the female is slightly higher than the male.

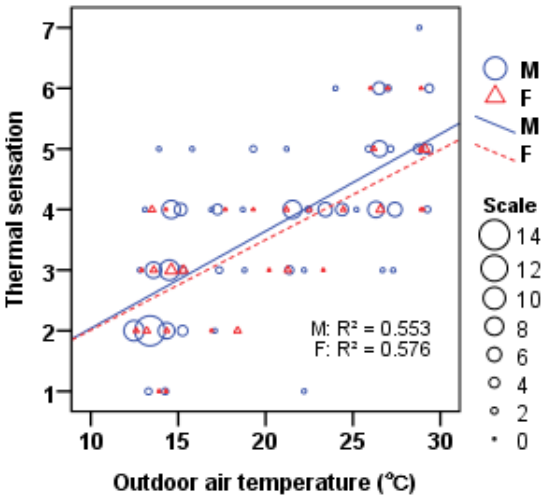

Figure 3: Relation between the thermal sensation and the outdoor air temperature.

3.6 Distribution of clothing insulation

Table 5 shows the mean clothing insulation. The clothing insulation of the "summation method" is slightly higher than that of the "illustration method". Table 6 shows the comparison of the clothing insulation with the previous research. The clothing insulation of this research is comparable to the previous research. In most research, the clothing insulation of female is higher than male. The reason might be that female are more sensitive to temperature changes than male.

Table 5: Daily mean clothing insulation.

Date	Number of data	Illustration method (clo)		Summation method (clo)	
		Mean	SD	Mean	SD
2013/9/29	39	0.6	0.30	0.7	0.20
2013/10/8	65	0.5	0.19	0.6	0.13
2013/11/11	18	0.7	0.17	1.0	0.27
2013/11/28	41	0.9	0.31	1.3	0.26
2013/12/2	61	0.9	0.33	1.4	0.34

SD : Standard deviation

Table 6: Comparison with the previous research.

No.	Reference	Region	Place	Year	Month	Method	Clothing insulation (clo)		
							Mean	Male	Female
1	This research	Tokyo	Outdoor	2013	10～12	Illustrations method	0.63	0.62	0.69
						Summation method	0.83	0.83	0.85
2	Ooi et al. [10]	Fukuoka	Outdoor	1998	11	Summation method	1.03	-	-
3	Ooi et al. [11]	Fukuoka	Outdoor	1998	11	Summation method	1.08	1.11	1.06
4	Shirono et al. [12]	Fukuoka	Outdoor	1999	11	Summation method	-	0.98	0.90
5	Shirono et al. [13]	Fukuoka	Outdoor	1999	11	Summation method	0.98	0.90	0.95
6	Yasui et al. [14]	Okinawa	Outdoor	2000	10～12	Summation method	-	0.59	0.61
7	Yasui et al. [15]	Okinawa	Outdoor	2000	10～12	Summation method	-	0.59	0.60
8	Yasui et al. [16]	Okinawa	Outdoor	2000･2001	10～12	Summation method	0.67	-	-
9	Nakamatsu et al. [17]	Okinawa	Outdoor	2000･2001	10～12	Summation method	-	0.60	0.70
10	Nakamatsu et al. [18]	Okinawa	Outdoor	2000･2001	10～12	Summation method	-	0.57	0.67
11	Suzuki et al. [19]	Aichi	Outdoor	2002	10～12	Summation method	1.41	-	-
12	Noguchi et al. [20]	Tokyo	Semi	2002～2003	10～1	Summation method	1.00	-	-

3.7 Relation between the "illustration method" and the "summation method"

Figure 4 shows the relation between "illustration method" and "summation method". The clothing insulation of the "summation method" is greater than that of the "illustration method".

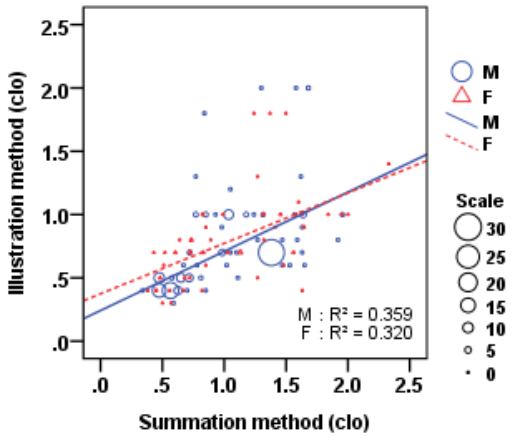

Figure 4: Relation between the "illustration method" and "summation method".

3.8 Relation between the clothing insulation and the thermal sensation

Figure 5 shows the relation between the clothing insulation and thermal sensation. They are negatively correlated. The results showed that people adapt to outdoor environments by changing their clothing.

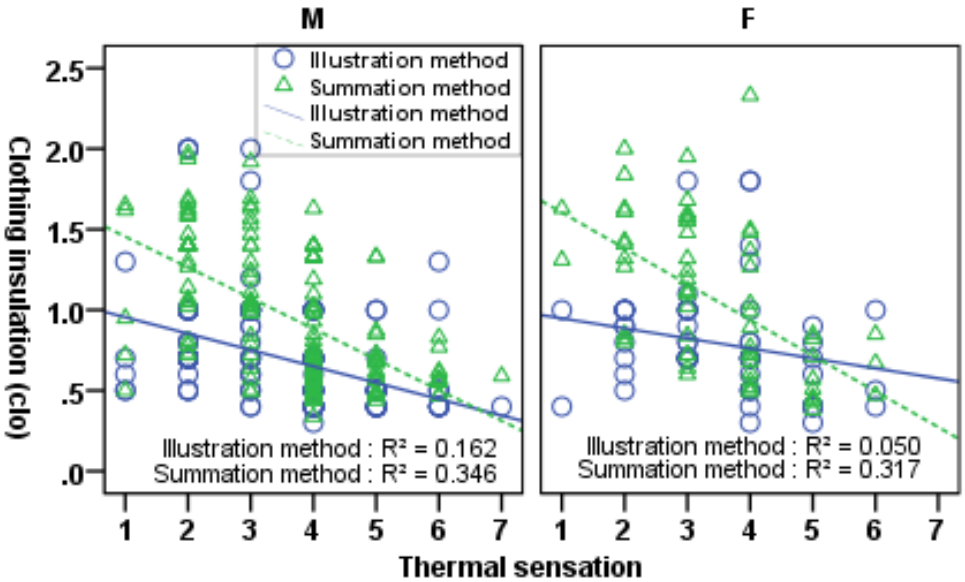

Figure 5: Relation between the clothing insulation and thermal sensation.

3.9 Relation between the clothing insulation and the outdoor air temperature

To predict the clothing insulation, figure 6 shows the relation between the clothing insulation and the outdoor air temperature. They are negatively correlated. We have the following regression equation.

Illustration method

All: I_{cl} = -0.028T_o+1.268 (n=224, R^2=0.26, p<0.001) (4)

M: I_{cl} = -0.027T_o+1.227 (n=162, R^2=0.25, p<0.001) (5)

F: I_{cl} = -0.030T_o+1.384 (n=62, R^2=0.30, p<0.001) (6)

Summation method

All: I_{cl} = -0.055T_o+2.072 (n=224, R^2=0.58, p<0.001) (7)

M: I_{cl} = -0.054T_o+2.026 (n=162, R^2=0.60, p<0.001) (8)

F: I_{cl} = -0.058T_o+2.200 (n=62, R^2=0.56, p<0.001) (9)

I_{cl} is the clothing insulation. If we substitute the 15 ºC in in these equations, the clothing insulation for "illustration method" is 0.85 clo (male = 0.72 clo, female = 0.93 clo). Similarly, as for the "summation method", it would be 1.25 clo (male = 1.22 clo, female = 1.33 clo).

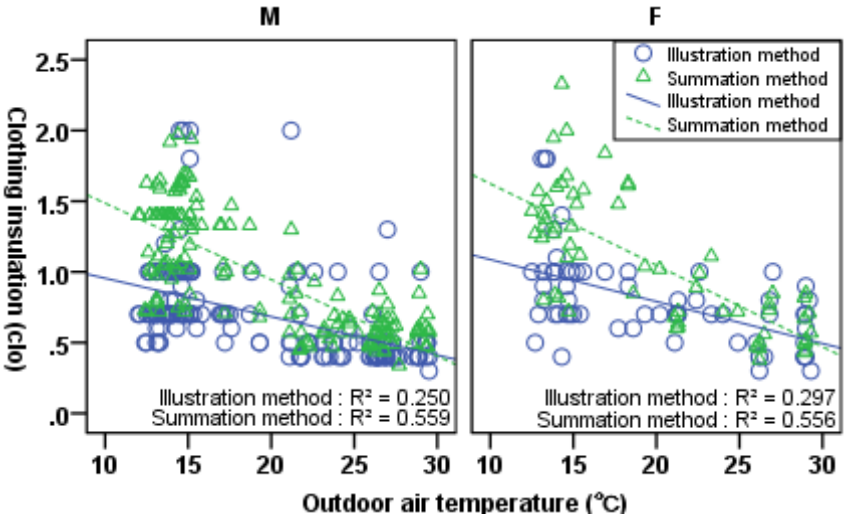

Figure 6: Relation between the clothing insulation and the outdoor air temperature.

To investigate the regression coefficient and coefficient of determination of the raw data, figure 7 shows the relation between the mean clothing insulation and the mean outdoor air temperature. Each point is the daily mean value. The regression lines of the average data are very similar to the raw data (Figs. 6 and 7). However, the coefficient of determination is significantly higher in the averaged data.

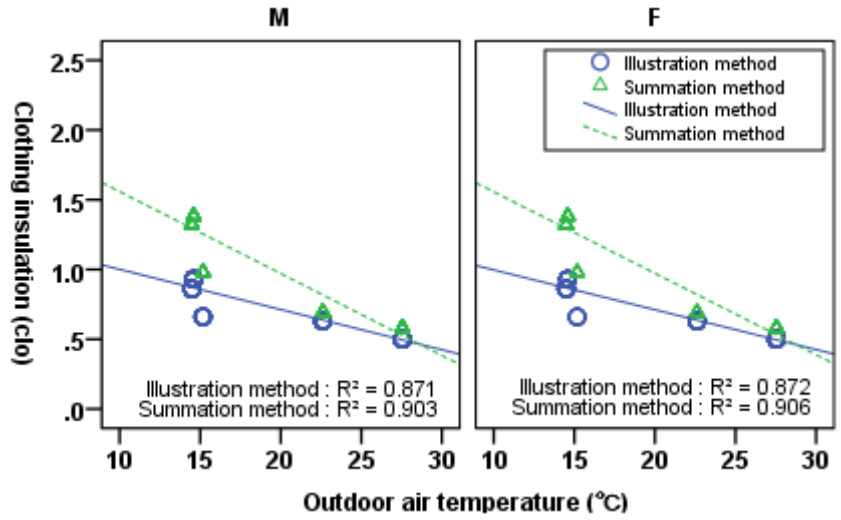

Figure 7: Relation between the clothing insulation and the outdoor air temperature.

4 Conclusions

In this research, we have conducted the thermal measurements and thermal comfort survey in Hachiko Square in Tokyo, and the following results were obtained.

1. The clothing insulation of the female is higher than the male.
2. The clothing insulation of the "summation method" is higher than the "illustration method".
3. The relation between the clothing insulation and the thermal sensation is negatively correlated. The results showed that people adapt to outdoor environments by changing their clothing.
4. The relation between the clothing insulation and the outdoor air temperature is negatively correlated, and thus the clothing insulation can be predicted by outdoor temperature.

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