Investigation of Clothing Insulation and Thermal Comfort in Japanese Houses

KOUKI WATANABE[1], HOM BAHADUR RIJAL[1], TAKASHI NAKAYA[2]

[1]Graduate school of Environmental & Information Studies, Tokyo City University, Yokohama, Japan
[2]Department of Architecture, Gifu National College of Technology, Gifu, Japan

ABSTRACT: People choose and wear the most comfortable clothing to suit to various thermal situations. In the recent times, we can find the research on the cool biz and warm biz as a potential energy saving measure. However, some researches are conducted only for a short period of time, and some offer only a few samples. In order to clarify the clothing insulation, the thermal measurements and thermal comfort survey were conducted in 30 houses during one year period in Gifu Prefecture of Japan. The subjects numbered 40 males and 38 females. The survey was conducted several times a day. The number of samples collected was more than 21,000. We found the following results.

1. *Both in summer and winter, the average clothing insulation of women is greater than that of the men.*
2. *The clothing insulation is correlated with the indoor or outdoor air temperature. The regression equations can be used to predict the clothing insulation in residential building.*
3. *The maximum seasonal difference of clothing insulation is 0.36 clo which corresponds to the difference of about 2.1 K in the comfort temperature. The results showed that the clothing insulation is effective for the energy saving.*

Keywords: clothing, thermal environment, thermal sensation, air temperature, seasonal difference.

INTRODUCTION

Thermal comfort is one of the most important factors in creating the most comfortable homes. People choose and wear the most comfortable clothing to suit to various thermal situations. An understanding of the clothing can be useful for the thermal adjustment, so as to reduce excessive use of air conditioning.

Changing clothing is one of the important behavioural adaptations. Residents more freely choose the clothes and adjust the indoor thermal environment at home, as there are fewer constraints on the clothing at home than one might encounter in an office building. In office buildings the indoor thermal environment is often controlled using air conditioning to improve the thermal comfort and productivity. In contrast, the same is achieved at home more often through changing clothing, as the use of air conditioning has a direct financial implication for the household. Changing clothing reduces the environmental impact of the building by reducing the use of air conditioning for heating and cooling.

In the recent times, we can find the research on the cool biz and warm biz as a potential energy saving measure. [1]. Till date, there are many researches about the clothing of the houses in Japan [2-9]. However, some researchers are conducted for a short period of time, while some collected only a few samples. The clothing may also vary according to the month and season, which is not investigated in the existing research using year-round data.

In order to clarify the seasonal or monthly difference of clothing insulation, to predict the clothing insulation by temperature, to clarify the relation between the clothing and thermal comfort, the thermal measurements and thermal comfort survey were conducted in 30 houses for a year in Gifu Prefecture of Japan.

METHOD OF INVESTIGATION

A thermal comfort survey and thermal measurement were conducted in 30 houses in the Gifu region of Japan from 13 May 2010 to 31 May 2011. The indoor air temperature, the globe temperature and the relative humidity were measured in the living room, avoiding the direct sunlight, at 10-minute intervals using a data logger (Fig. 1).

The number of subjects included 40 male (mean age 40.5 years) and 38 female (mean age 41.3 years). The thermal comfort survey was conducted several times a day using a 9-point thermal sensation scale (Fig. 2).
We measured the clothing weight and the clo value was estimated by the equation of Hanada et al. [10, 11]. We also asked the residents to guess the indoor temperature (cognitive temperature).

We collected more than 21,000 data samples. Outdoor air temperature and relative humidity were obtained from the nearest meteorological station.

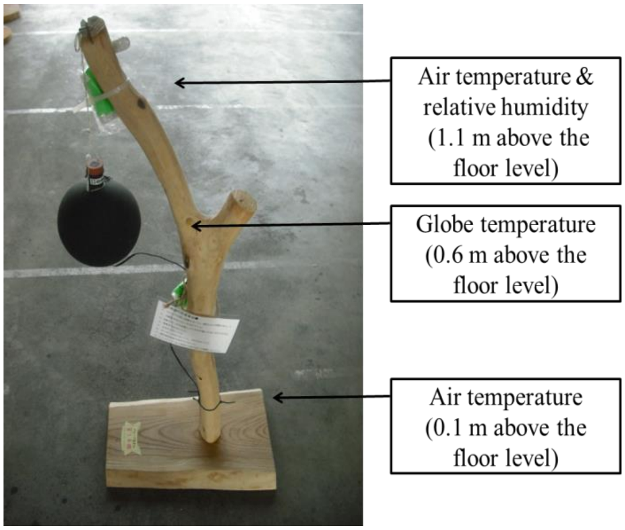

Figure 1: Details of the thermal measurement.

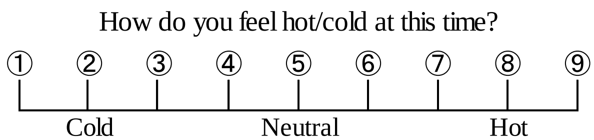

Figure 2: Thermal sensation scale.

RESULT AND DISCUSION

The data were divided into three groups: the NV mode (naturally ventilated), AC mode (cooling by air conditioning) and HT mode (heating). First, we have determined the AC and HT modes based on actual cooling and heating used. The AC and HT modes are two distinct groups of data (generally AC used in summer and HT is used in winter) that need to be analyzed separately.

VARIATION OF TEMPERATURES

Fig. 3 shows the monthly mean outdoor air temperature, indoor air temperature and indoor globe temperature during voting. The temperatures do not vary much within the winter or summer seasons. However, it is quite variable in spring and autumn. The results showed that the temperatures change with the season. In NV mode, the mean temperatures are highest in summer, medium in autumn, spring, and lowest in winter (Table 1).

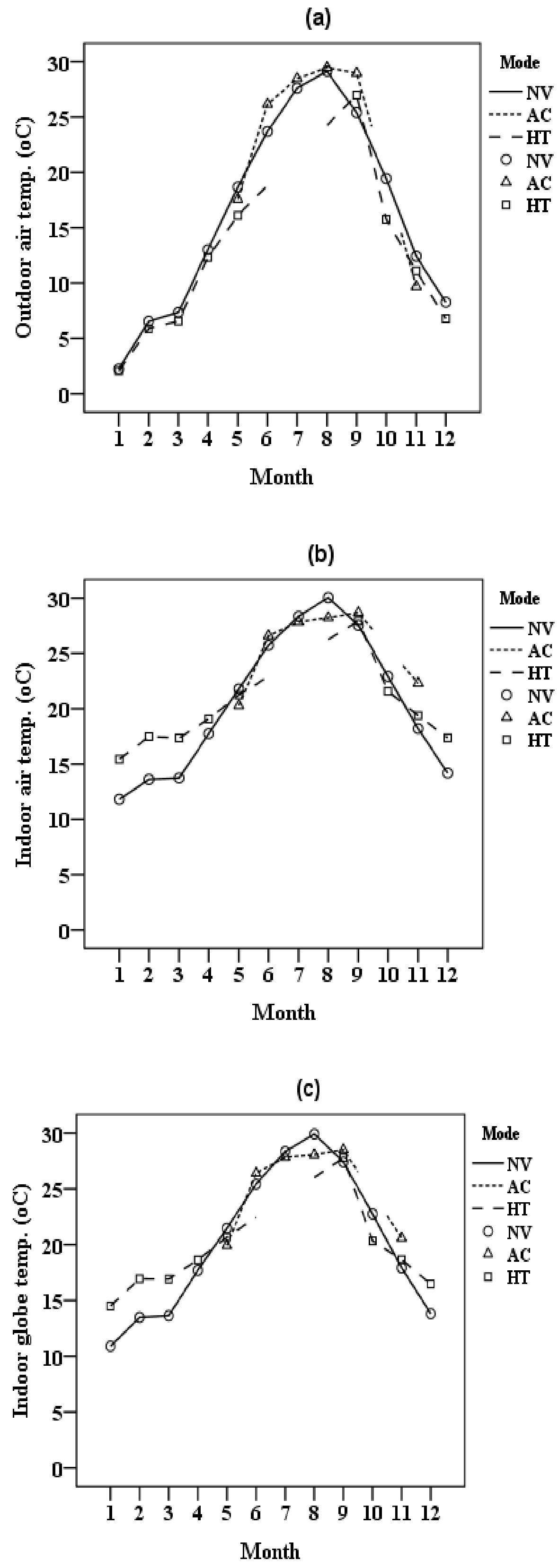

Figure 3: Monthly mean temperatures during the voting.

Table 1: Air temperature and globe temperature during voting.

Mode	Season	Mean temperature (°C)		
		Outdoor	Indoor	Globe
NV	Summer	25.4	27.4	27.2
	Autumn	19.4	23.3	23.2
	Spring	15.9	20.1	19.9
	Winter	5.4	13.4	12.9
AC	Summer	28.8	27.9	27.9
	Autumn	29.1	28.6	28.5
	Spring	17.9	20.3	19.9
HT	Autumn	11.2	19.8	18.8
	Spring	8.5	18.4	17.8
	Winter	4.3	16.7	15.9

DISTRIBUTION OF THERMAL SENSATION

Fig. 4 shows the percentage of the thermal sensation vote. Mean thermal sensation vote was 5.0 in NV mode, 5.6 in AC mode and 4.2 in HT mode. Residents sometimes felt hot (>5) in the AC mode and sometimes felt cold (<5) in the HT mode. Even though residents used the heating or cooling, they sometimes felt 'cold' or 'hot'. Moreover, the percentage of "5 neutral" vote was 45.1% in NV mode, 45.0 % in AC mode, and 37.6% in HT mode (Fig. 4). There is many '5 neutral' votes in the NV mode, it can be said that residents were generally satisfied in the thermal environment of the houses. This may be due to the thermal adaptation of the residents to the local climate and culture.

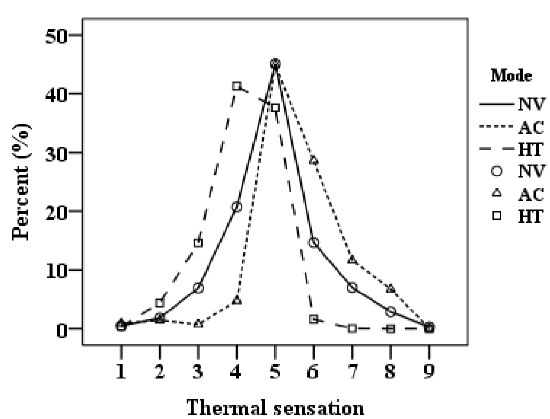

Figure 4: Percentage of the thermal sensation in each mode.

DISTRIBUTION OF CLOTHING

Table 2 shows the clothing during the voting. In NV mode, mean clothing is highest in winter, medium in spring, autumn and lowest in summer. When the mean clothing is analysed by mode, the difference between the NV and AC mode is small in summer, and difference between the NV and HT mode is small in winter (Table 2).

The mean clothing was lowest in August at 0.43 clo and highest in January at 0.79 clo. The maximum seasonal difference in clothing insulation is 0.36 clo which corresponds to the difference of about 2.1 K in the comfort temperature (0.57 K/ 0.1 clo) [12]. The results showed that the clothing insulation is effective for the energy saving. Although the residents are adjusting the body temperature by clothing as much as possible, there is a limitation to the body temperature adjustment by clothing, and thus people used the heating and cooling.

Table 2: Clothing and air temperature in each mode.

Season	Mode	Clothing (clo)		
		N	Mean	SD
Summer	NV	4247	0.47	0.20
	AC	1761	0.45	0.19
Autumn	NV	4143	0.54	0.28
	AC	321	0.45	0.18
	HT	812	0.69	0.30
Spring	NV	3985	0.66	0.32
	AC	4	0.55	0.31
	HT	1558	0.79	0.31
Winter	NV	1255	0.74	0.34
	HT	2887	0.77	0.31

N, number of samples; SD, standard deviation.

DISTRIBUTION OF CLOTHING IN SUMMER

Fig. 5 shows the mean clothing in NV and AC modes in summer. The mean clothing is 0.47 clo in NV mode and 0.45 clo in AC mode. The results showed that people reduce the clothing as much as possible in both modes, and thus there is almost no difference in mean clothing.

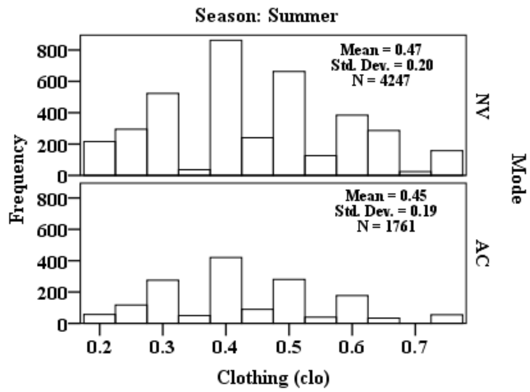

Figure 5: Distribution of clothing in NV and AC modes in summer.

DISTRIBUTION OF CLOTHING IN WINTER

Fig. 6 shows the mean clothing in NV and HT modes in winter. The mean clothing is 0.74 clo in NV mode and 0.77 clo in HT mode. The results showed that people increase the clothing as much as possible in both modes, and thus there is almost no difference in mean clothing.

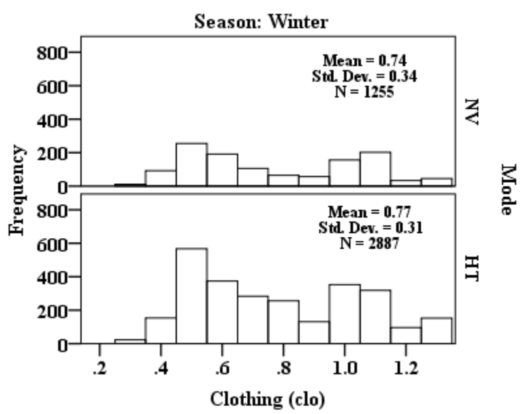

Figure 6: Distribution of clothing in NV and HT modes in winter.

CLOTHING OF MALES AND FEMALES

The mean clothing of males and females is compared. Fig. 7 shows the monthly mean clothing of males and females in NV mode. Monthly mean clothing of females is higher than males. We found a similar trend in the most of existing research (Table 3). The reason might be that this difference is due to the morphological and physiological differences between the organisms of human males and females.

In summer, the mean clothing is 0.39 clo for males and 0.54 clo for females. In winter, the mean clothing is 0.58 clo for males and 0.96 clo for females. The results showed that difference between the males and females clothing is small in summer and big in winter. The reason might be that they are trying to reduce the clothing as much as possible in summer. As for winter, it might be that females felt colder than males.

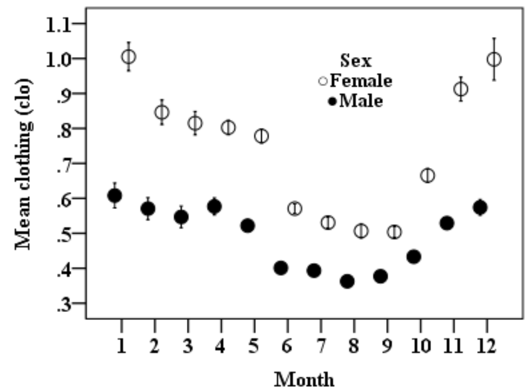

Figure 7: Monthly mean clothing of males and females with 95% confidence intervals in NV mode.

Table 3: Comparison of clothing with existing research.

		Clothing (clo)			
		Males		Females	
Area	Reference	Summer	Winter	Summer	Winter
Gifu	This study (NV)	0.39	0.58	0.54	0.96
Okinawa	[6]	0.39	0.72	0.43	0.85
Kyoto	[7]	0.25	0.71	0.3	0.73
Tokyo	[9]	—	0.92	—	0.93
Tokyo	[3]	0.54	—	0.52	—
Tyubu region	[8]	0.26	0.77	0.25	0.74
Major 8 cities	[13]	Male is higher than female.			

RELATIONSHIP BETWEEN THE CLOTHING AND THERMAL SENSATION

In order to clarify the relation between the clothing and thermal sensation, regression analysis is conducted. Fig. 8 shows the relation between the clothing and thermal sensation with 95% confidence interval in NV mode. The following regression equation was obtained between the clothing insulation (I_{cl}) and thermal sensation (C).

$$I_{cl} = -0.043C+0.785 \quad (n=13575, R^2=0.031, p<0.001) \quad (1)$$

Where n is number of sample; R^2 is coefficient of determination; p is significant level of regression coefficient. The clothing and thermal sensation are correlated. People wear more clothing when they felt cold and they wear less clothing when they felt hot.

When we substitute the "5. neutral" in equation (1), the clothing would be 0.57 clo.

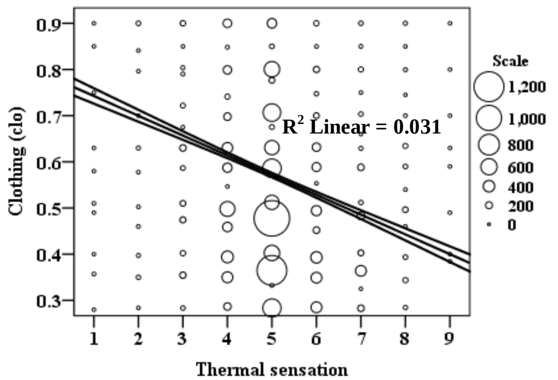

Figure 8: Relation between the clothing and thermal sensation in NV mode.

RELATIONSHIP BETWEEN THE CLOTHING AND TEMPERATURE

In order to predict the clothing insulation, we regressed clothing with temperature. Fig. 9 shows the relation between the clothing and outdoor air temperature (T_o) or indoor air temperature (T_i) or indoor globe temperature (T_g) or cognitive temperature (T_c) with 95% confidence interval in NV mode. The following regression equations were obtained between the clothing insulation (I_{cl}) and temperature (°C).

$I_{cl} = -0.010T_o + 0.762$ (n=13563, R^2=0.067, p<0.001) (2)
$I_{cl} = -0.015T_i + 0.924$ (n=13194, R^2=0.084, p<0.001) (3)
$I_{cl} = -0.015T_g + 0.912$ (n=12934, R^2=0.085, p<0.001) (4)
$I_{cl} = -0.013T_c + 0.851$ (n=13563, R^2=0.061, p<0.001) (5)

Where, n is number of samples; R^2 is coefficient of determination; p is the level of significance for the regression coefficient. The regression coefficients are negative for all equations. It shows that the clothing decreases when temperature is increased. The correlation coefficient of clothing and temperatures are similar (r = 0.25 ~ 0.29).

Table 4 shows the comparison of regression equation with existing research. The regression coefficient of the clothing and outdoor air temperature of this research is smaller than the existing research. The reason might be that the existing research conducted not only indoors but also outdoors and the semi-open areas. The clothing is also related with other environmental factors (humidity, window opening, fan use etc.) and human body elements (activity, posture etc.). It is also necessary to analyze about these factors in future studies.

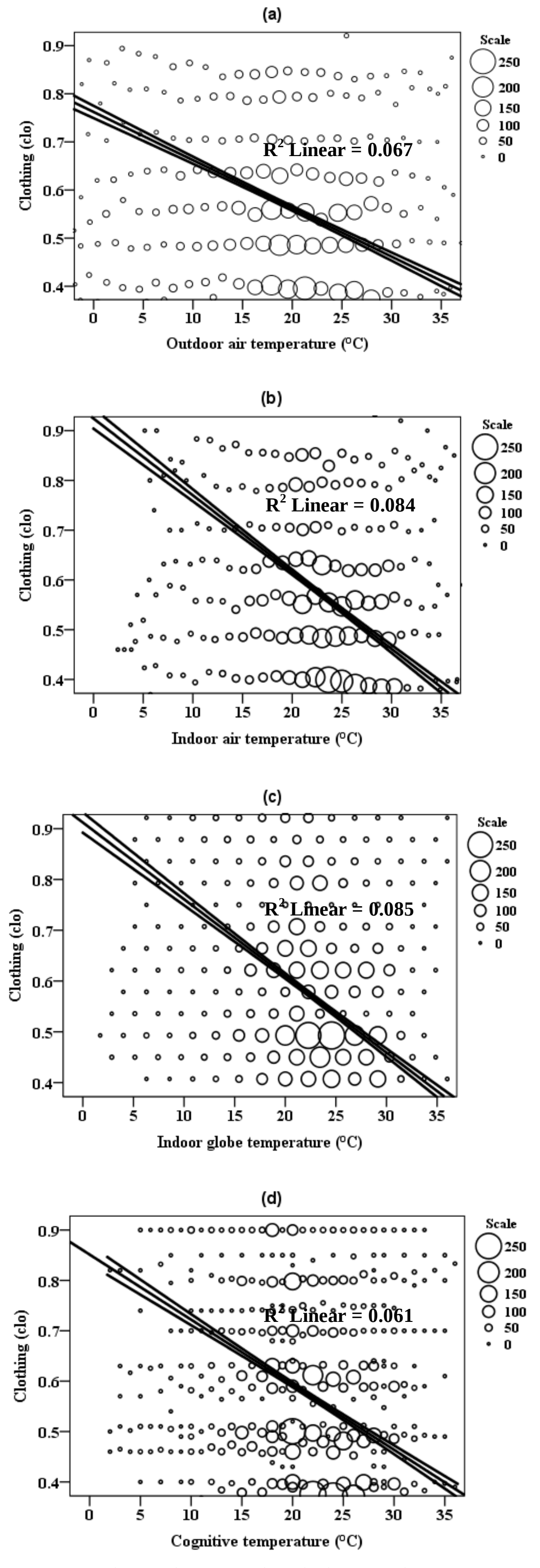

Figure 9: Relation between the clothing and temperatures in NV mode.

Table 4: Comparison of regression equation with existing research.

Area	Reference	Investigated Space	Classification	Equation
Gifu	This study	Houses	NV	I_{cl} =-0.010T_o+0.762
Okinawa	[6]	University, Outdoor	Male	I_{cl} =−0.029T_o+1.217
			Female	I_{cl} =−0.034T_o+1.385
Tokyo	[14]	Houses, Semi-open	-	I_{cl} =−0.037T_o+1.49

I_{cl}, clothing (clo); T_o, outdoor air temperature (°C).

CONCLUSIONS

A thermal comfort survey of the residents of the Gifu region of Japan was conducted over an entire year. The clothing and corresponding thermal environment in their living rooms were investigated. The following results were found:

1. In NV mode, the mean clothing is highest in winter, medium in spring, autumn and lowest in summer.
2. The mean clothing difference between the NV and AC mode is small in summer. As for winter, the difference between the NV and HT mode is small.
3. The monthly difference of clothing insulation is 0.36 clo which corresponds to the difference of about 2.1 K in the comfort temperature. The results showed that the clothing insulation is effective for the energy saving.
4. Monthly mean clothing of females is higher than males. In summer, the mean clothing is 0.39 clo for males and 0.54 clo for females. In winter, the mean clothing is 0.58 clo for males and 0.96 clo for females.
5. The clothing and thermal sensation are correlated. People wear more clothing when they felt cold and they wear less clothing when they felt hot.
6. The clothing and temperatures are correlated. The clothing insulation can be predicted by the proposed regression equations.

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