DIFFERENCE OF POSTURES ON THERMAL INSULATION OF CLOTHING ENSEMBLES

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ABSTRACT

When we feel cold, we take off clothing. When we feel warm, we put on clothing. Change of clothing is a means to thermo regulate. Thickness of the air layer of under clothing influences the thermal insulation performance, and it is depends on posture. But Thickness of the air layer for each postures were unknown. The purpose of this paper is to clarify the differences of thermal insulation of clothing ensembles in terms of posture. The thermal insulation of clothing in four typical postures (standing, chair sitting, leg-out sitting, lying) was measured by using a thermal manikin. Clothing area factor was measured using the photograph method, and the differences of clothing area factor in terms of posture were investigated. Differences of clothing area factor according to these four postures factors were observed. Although it has been supposed that the measurement of some human body was sufficient for calculating the clothing area factor, it was clearly shown that it was measured from all the directions of the human body. In the condition of this paper, differences expressed by these postures weren't seen in the thermal insulation of clothing ensembles. It is necessary to measure the thermal insulation of women's clothing by posture in a wide range of temperatures including high temperatures. When the thermal insulation of clothing ensembles by the gravimetric method is applied to the thermal environment evaluation, it will be necessary to consider the design and the material of the clothing thoroughly.

Keywords: clothing area factor, clothing ensemble, posture, thermal environment, thermal insulations of clothing ensembles

1. INTRODUCTION

Our sense of hot and cold is caused by the balance of metabolic heat production and heat losses. We can adjust our thermal sensation by regulating heat losses from the body. Changing clothing is one method of adjusting heat discharge.

Clothes act as a thermal insulator, which suppresses thermal diffusivity outside of the body. The thermal insulation of clothing is very important in the evaluation of the thermal environment of our living spaces.

Formulas for the computation of the thermal insulation of clothing (CLO value) based on clothing weight have been proposed. These formulas were derived from experiments made on a thermal mannequin. In Japan, the formulas, proposed by Hanada et al. (1981, 1983), are most commonly used. These formulas were created from experiments using a thermal mannequin in the standing position.

In Japan, even in a western style house it is still common to have, a Japanese-style Tatami-floored room. In the Tatami-floored room, Japanese people often sit or lie on the floor. Even in a western-style room it is common to sit on the floor, even if chairs are available (Yamato et al., 2005a). Kurazumi et al (2008) classified the difference of the heat transfer area of the human body in terms of postures; therefore it is necessary to take a resident's posture into consideration when evaluating their thermal environment.

But, their formulas for CLO value, don't take a persons posture into account. Because the experiments were done on a standing thermal mannequin.

CLO value depends upon not only the thickness of clothes, but also the thickness of the layer of air within the clothing. The thickness of the air layer within clothing depends on a person's posture. So, it is thought that CLO value is also different depending on a person's posture. Some researchers have measured CLO value in different postures, and clarified the influence of posture on CLO value (e.g. Olesen et al. 1982, Hanada 1979a, Hanada 1979b). Authors also clarified the difference in thermal insulation of clothing ensembles in terms of posture using men's clothing (Yamato et al., 2003). However, there is still not enough accumulated data, especially using women's clothing.

The purpose of this paper is to investigate the differences in thermal insulation in clothing ensembles in terms of posture using woman's clothes. CLO values in four postures (standing position, chair sitting position, leg-out sitting position, lying position) were measured. In addition, the validity of the thermal insulation of clothing by the gravimetric method to clothes that diversified the design and the material was examined from the comparison with measurements of the clothes thermal insulation.

2. THE DIFFERENCES OF POSTURES ON THE CLOTHING AREA FACTORS

2.1. The Measurement of the clothing area factors

The clothing area factors (Fcl) were measured using a thermal mannequin, which has joints in the shoulders, hips and knees so it can assume various postures. Table 1 shows the profile of a thermal mannequin. With the surface area of $1.525m^2$.

The type of clothing that was used in these measurements was everyday women's indoor winter clothing in Japan (Yamato et al., 2005b). Table 2 shows the garments used for in the measurements. The mannequin was dressed in the standing position and special attention was paid not to smooth the natural clothing wrinkles. The wrinkles on the surface of the clothes were also left alone as the mannequin was changed to each of the different postures.

Table 1 Profile of manikin.

Region of body	(mm)
Height	1,767
Chest	871
Breadth of shoulders	505
Thickness of chest	232
Thickness of abdomen	210
Inseam	840

Table 2 Characteristics of the garments

Garment	Material (%)	Weight (g)
Brassiere	Polyester (-), Polyurethane (-)	92.0
Camisole	Cellulose (51), Nylon (40), Polyurethane (9)	61.0
Sweat shirt	Cotton (100)	445.0
Shorts	Nylon (62), Polyurethane (38)	24.0
Jersey	Polyester (100)	311.0
Socks	Cotton (81), Nylon (16), Polyurethane (2), Polyester (1)	31.0
	Total	964.0

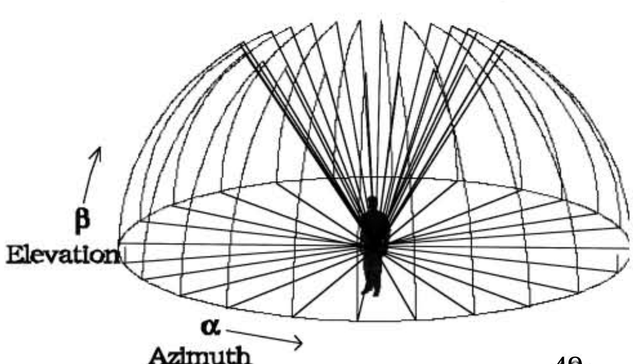

Fig. 1 The hemispherical coordinate system for measuring Fcl.

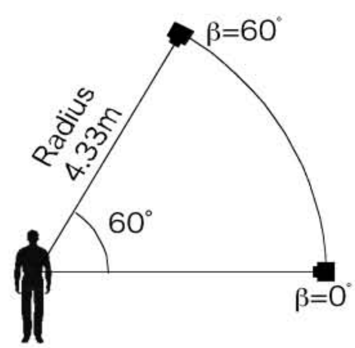

Fig. 2 The scale and elevation for the measurement of Fcl.

A photographic method (Seppanen et al., 1972) was used to determine Fcl. Fig. 1 shows the hemispherical coordinate system for measuring Fcl. Fig. 2 shows the scale and elevation for the measurement of Fcl. The photographs were taken from all azimuth angle directions surrounding the thermal mannequin. In this paper, the projected area for two altitude (b =0°, 60°) and 24 azimuth angle directions (a = 0° – 345°), from 48 directions were measured.

2.2. The Difference of postures on Fcl

The clothing area factors in Standing, Chair sitting, Leg-out sitting and Lying postures were measured by a photographic method. Table 3, Table 4, Table 5, and Table 6 show the result in each posture. Table 7, Table 8, Table 9, and Table 10 shows the mean values of Fcl for each posture.

Standing Fcl was 1.16, Chair sitting was 1.12, Leg out-sitting was 1.11, and Lying was 1.14. The differences in Fcl using the same clothing ensembles, in terms of posture were observed. The shape of the mannequin in the Standing and Lying positions were almost columnar. And the Legout-sitting position was almost "L" shaped when viewed from the side. The Chair sitting pose was like that of a crank when viewed from the side. It is thought that the standard deviation of Fcl is different because there is a difference in the complexity of shape in four postures. The Fcl of the four postures were measured from all azimuth angle directions. Fcl and the standard deviation of Fcl were different depending on posture. Therefore, it is necessary to measure Fcl of each posture when the thermal insulation of clothing is calculated.

Table 3 Measured Clothing area factor(fcl) for Standing

Elevation	Azimuth (α)																							
(β)	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
0°	1.29	1.23	1.18	1.08	1.04	1.00	1.13	1.30	1.19	1.17	1.14	1.12	1.19	1.19	1.18	1.12	1.07	1.03	1.14	1.34	1.24	1.28	1.25	1.20
60°	1.24	1.22	1.16	1.20	1.25	1.24	1.14	1.07	1.05	1.04	1.08	1.16	1.14	1.18	1.14	1.07	1.16	1.15	1.14	1.12	1.11	1.15	1.16	1.25

Table 4 Measured Clothing area factor(fcl) for Chair sitting

Elevation	Azimuth (α)																							
(β)	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
0°	1.15	1.13	1.13	1.12	1.11	1.14	1.24	1.20	1.16	1.13	1.10	1.07	1.07	1.07	1.06	1.07	1.08	1.12	1.19	1.24	1.15	1.15	1.14	1.10
60°	1.13	1.15	1.14	1.15	1.11	1.12	1.15	1.17	1.12	1.07	1.02	1.05	1.02	1.00	0.98	1.04	1.06	1.09	1.12	1.18	1.18	1.15	1.13	1.11

Table 5 Measured Clothing area factor(fcl) for Leg-out sitting

Elevation	Azimuth (α)																							
(β)	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
0°	1.15	1.12	1.11	1.13	1.09	1.12	1.11	1.14	1.11	1.13	1.10	1.05	1.06	1.06	1.07	1.08	1.09	1.13	1.15	1.14	1.24	1.13	1.12	1.13
60°	1.19	1.21	1.13	1.02	1.03	1.04	1.04	1.06	1.16	1.17	1.16	1.22	1.18	1.17	1.16	1.16	1.11	1.05	1.06	1.07	1.04	1.03	1.01	1.02

Table 6 Measured Clothing area factor(fcl) for Lying

Elevation	Azimuth (α)																							
(β)	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
0°	1.18	1.27	1.20	1.14	1.16	1.11	1.13	1.11	1.09	1.05	0.99	1.06	1.28	1.15	1.12	1.16	1.13	1.14	1.13	1.13	1.14	1.09	1.07	1.03
60°	1.21	1.17	1.17	1.17	1.18	1.15	1.14	1.14	1.14	1.12	1.16	1.16	1.10	1.12	1.06	1.12	1.13	1.11	1.11	1.09	1.13	1.15	1.18	1.18

Table 7 Mean values of clothing area factor (fcl) for Standing

Elevation	Azimuth (α)				
(β)	0°-90°	90°-180°	180°-270°	270°-360°	0°-360°
0°	1.14±0.10	1.19±0.06	1.12±0.06	1.26±0.05	1.17±0.09
60°	1.21±0.04	1.09±0.05	1.14±0.04	1.16±0.05	1.15±0.06
0°–60°	1.17±0.08	1.14±0.07	1.13±0.05	1.21±0.07	1.16±0.08
0°–60°	1.16±0.08		1.17±0.07		1.16±0.08

Table 9 Mean values of clothing area factor (fcl) for Leg-out sitting

Elevation	Azimuth (α)				
(β)	0°-90°	90°-180°	180°-270°	270°-360°	0°-360°
0°	1.12±0.02	1.10±0.04	1.10±0.03	1.15±0.05	1.11±0.04
60°	1.09±0.08	1.16±0.06	1.12±0.05	1.03±0.02	1.10±0.07
0°–60°	1.11±0.06	1.13±0.06	1.11±0.04	1.09±0.07	1.11±0.06
0°–60°	1.12±0.06		1.10±0.06		1.11±0.06

Table 8 Mean values of clothing area factor (fcl) for Chair sitting

Elevation	Azimuth (α)				
(β)	0°-90°	90°-180°	180°-270°	270°-360°	0°-360°
0°	1.15±0.04	1.12±0.05	1.10±0.05	1.16±0.05	1.13±0.05
60°	1.14±0.02	1.07±0.06	1.05±0.05	1.15±0.03	1.10±0.06
0°–60°	1.14±0.03	1.10±0.06	1.07±0.06	1.15±0.04	1.12±0.06
0°–60°	1.12±0.05		1.11±0.06		1.12±0.06

Table 10 Mean values of clothing area factor (fcl) for Lying

Elevation	Azimuth (α)				
(β)	0°-90°	90°-180°	180°-270°	270°-360°	0°-360°
0°	1.17±0.05	1.10±0.10	1.14±0.01	1.09±0.05	1.13±0.07
60°	1.17±0.02	1.14±0.02	1.11±0.02	1.15±0.04	1.14±0.03
0°–60°	1.17±0.04	1.12±0.07	1.12±0.02	1.12±0.05	1.14±0.05
0°–60°	1.15±0.06		1.12±0.04		1.14±0.05

The difference of Fcl by coordinates was examined. In every posture except the Legout-sitting, the difference in Fcl between the measurements from forward and the measurements from the rear side were seen. It was shown that the measurement from all azimuth angle directions and 2 directions of height where a thermal mannequin was surrounded were necessary in the measurement of Fcl. The difference in Fcl according to the direction of taking a picture was seen. Thus, it is necessary to take a photograph from all azimuths and 2 elevations like enclosing a thermal mannequin.

3. THE DIFFERENCE OF POSTURES IN CLO VALUE

3.1. The Measurement of CLO value

In this study, CLO values in four postures were measured based on Seppanenn's theory (Seppanen et al., 1972). The procedure of the measurement of CLO value is shown below.

The procedure of the measurement of CLO value

$$I_t = (t_s - t_a)\ 0.155 \cdot Q_t$$
$$I_a = (t_n - t_a)\ 0.155 \cdot Q_n$$
$$I_{cl} = I_t - I_a\ f_{cl}$$

I_t : Thermal insulating value for clothed manikin (

I_a : Thermal insulating value for nude manikin (cl

I_{cl} : Thermal insulating value for clothing ensembl

t_s : Mean surface temperature of clothed manikin (°C)

t_n : Mean surface temperature of nude manikin (°C)

t_a : Air temperature (°C)

Q_t : Heat loss from clothed manikin (W/m^2)

Q_n : Heat loss from nude manikin (W/m^2)

f_{cl} : Clothing area factor (N. D.)

The thermal mannequin, which was used to measure CLO value, was the same as the thermal mannequin that was used to measure Fcl.

The body of the thermal mannequin was divided into 17 segments. Table 11 shows the profile of the thermal mannequin. Each segments of the thermal mannequin is heated to maintain skin temperature at a constant 33°C. Experiments to measure the CLO value were conducted in a climatic chamber.

In most past studies, CLO value has been measured at about 24°C or so (Olesen et al. 1982, Nishimura et al. 1994). However, the temperature of residential living rooms in Japan vary widely, especially in winter, It should be noted that there are many residential living spaces with a considerably low temperature (Matsubara and Sawashima, 1996). Therefore, in this study, CLO value was measured at 18°C. Table 12 shows the experimental conditions.

3.2. The Difference of postures in CLO value

Table 13 shows the measurements made by Kurazumi et al. (2006) using the same thermal mannequin and a climatic chamber as in the present study. Table 14 shows all thermal resistance in clothes (It) Table 15 shows the thermal insulating of clothing (Icl).

Table 11 Profile of thermal manikin.

Region of Body	Surface area (m^2)	Surface area rate(%)
Head	0.119	7.82
Breast	0.168	11.02
Back	0.190	12.45
Abdomen	0.062	4.08
Lumbar	0.093	6.11
Upper arm-R	0.074	4.85
Upper arm-L	0.074	4.85
Lower arm-R	0.052	3.39
Lower arm-L	0.052	3.39
Hand-R	0.037	2.39
Hand-L	0.037	2.39
Thigh-R	0.108	7.05
Thigh-L	0.108	7.05
Leg-R	0.115	7.54
Leg-L	0.115	7.54
Foot-R	0.062	4.03
Foot-L	0.062	4.03
Total	1.525	100.00

R: Right, L: Left

Table 12 Experimental condition

Air temperature (Ta) (℃)	18
Mean radient temperature (MRT) (℃)	MRT=Ta
Relative humidity (RH) (%)	50
Air velocity (Va) (m/s)	< 0.2

Table 13 Measured all thermal insulating value for nude manikin (Kurazumi et al.)

Posture	Thermal insulation (I_a) (clo)
Standing	0.69
Chair-sitting	0.64
Leg-out sitting	0.65
Lying	0.74

Table 14 Measured al thermal insulating value for clothed manikin.

Posture	Thermal insulation (I_t) (clo)
Standing	1.00
Chair-sitting	1.00
Leg-out sitting	1.01
Lying	1.04

Table 15 Measured the thermal insulating of clothing ensemble (Icl)

Posture	Thermal insulation (Icl) (clo)
Standing	0.41
Chair-sitting	0.43
Leg-out sitting	0.43
Lying	0.39

The Measured total thermal insulation for the nude mannequin in each posture was about 1.4clo. The Measured total thermal insulation for the clothed mannequin in each posture was about 1.0clo. The Measured thermal insulation for the clothing in each postures (Icl) were about 0.4clo.

The Differences expressed by these postures weren't seen in this study's experimental condition. However, according to Kurazumi et al. (2006), the differences of thermal insulation of clothing in terms of postures tended to increase with the rising of the operative temperature (OT). A similar tendency was also seen in author's measurement of men's clothing (Yamato et al., 2003). The measurement temperature of this study was comparatively low; Thus, it is necessary to measure the thermal insulation of women's clothing by posture in a wide range of temperatures including high temperatures.

4. COMPARISON OF CLO VALUE USING THE GRAVIMETRIC METHOD

CLO value is based on clothing weight and is most commonly used in the evaluation of the thermal environment today. When the thermal environment is evaluated, this method is usually used because CLO value can be easily calculated. The CLO value of clothes used in this study is 0.97clo in the gravimetric method of Hanada et al (1981, 1983). However, the measurement in the Standing study was 0.41clo. The CLO value in this study by measurement was 0.56 clo lower than the calculated value using the gravimetric method.

It is thought that the shape of the jersey on the lower half of the body used in this study caused this difference. The bottom of the jersey used in this study was voluminous; therefore, there was a comparatively wide opening between the leg of the mannequin and the bottom of the jersey. The jersey used in this study is on the market, and the features of this design are common in today's jersey fashion. It seems that the thermal insulation of clothing shrank because a wide air layer, which formed in a space at the bottom between the surface of the leg of the thermal mannequin and the jersey, and convection, was generated in the air layer.

There are now many different designs of clothing, which are made from many different kinds of material, therefore, design and the material, probably influence CLO value. Because form-fitting clothes made from thing material do not contain a lot of air that acts as a thermal insulator, Moreover CLO value is low in clothes with a large composure of sleeve and breast. It is not appropriate to examine the validity of the thermal insulation of clothing using the gravimetric method using only the results from this study. However, it was suggested that CLO value using the gravimetric method would likely be different from the actual CLO value of the present clothes in the results of this study. Thus, when CLO value by the gravimetric method is applied to the thermal environment evaluation, it will be necessary to consider the design and the material of the clothing thoroughly.

5. CONCLUSION

Fcl and the standard deviation of Fcl were different depending on posture. Therefore, it is necessary to measure Fcl of each posture when the thermal insulation of clothing is calculated.

The difference in Fcl between the measurements from forward and the measurements from the rear side were seen. It was shown that the measurement from all azimuth angle directions and 2 directions of height where a thermal mannequin was surrounded were necessary in the measurement of Fcl. The difference in Fcl according to the direction of taking a picture was seen. Thus, it is necessary to take a photograph from all azimuths and 2 elevations like enclosing a thermal mannequin.

The Differences expressed by these postures weren’t seen in this study’s experimental condition. However, the differences of thermal insulation of clothing in terms of postures tended to increase with the rising of the operative temperature (OT). The measurement temperature of this study was comparatively low; Thus, it is necessary to measure the thermal insulation of women's clothing by posture in a wide range of temperatures including high temperatures.

The CLO value in this study by measurement was 0.56 clo lower than the calculated value using the gravimetric method. It is thought that the shape of the jersey on the lower half of the body used in this study caused this difference. The bottom of the jersey used in this study was voluminous; therefore, there was a comparatively wide opening between the leg of the mannequin and the bottom of the jersey. There are now many different designs of clothing, which are made from many different kinds of material, therefore, design and the material, probably influence CLO value. Thus, when CLO value by the gravimetric method is applied to the thermal environment evaluation, it will be necessary to consider the design and the material of the clothing thoroughly.

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