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Measurements of clo value using heat flux sensors and human body

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Abstract

The purpose of this research is to develop a simple new clo value measuring method, which use a human body and heat flux sensor.

For the purpose of this study, the clo value measurement experiment using a human body and a heat flux sensor is conducted, and comparison and examination with the clo value in the thermal manikin were performed.

Clo value measured by the heat flux was smaller than the thermal manikin measurement.

Because human body equip thermoregulatory function, it maybe inevitable that clo value measured by using a human body is smaller than that of by using a thermal manikin who maintained the skin temperature fixedly.

Consideration of clo value measurement method that premised on a thermoregulatory function of a human body may be needed.

Keywords - clo value; Heat flux sensor; Thermal manikin; Thermal environment; Japanese house

1. Introduction

The balance of metabolic heat production and heat loss causes our thermal sensation. We can adjust our thermal sensation by regulating heat loss from our body.

Changing clothes is one of the methods of adjusting heat loss. Clothes act as a thermal insulator, which suppress heat loss outside of the body. The thermal insulation of clothing (clo value) is very important when evaluating the thermal environment of our living spaces. Therefore, it is necessary to measure a clo value for every clothing ensemble of residents.

A clo value is not a peculiar value for every clothes. For example, even if it is the same clothes, clo value changes with differences in the posture of those who wear. And so, it is indispensable to measure clo value with various postures. However, compared with the variety of Japanese housing resident's posture, the clo value data measured by previous research is still few. The reason with few measurement data of the clo value is because the special, expensive device such as the thermal manikin is necessary for the measurement. An easier new clo value measuring method than before needs to be developed, without needing special and expensive equipment, such as a thermal manikin.

ISO 9920 [1] standardizes the clo value measuring method using a thermal manikin. However, thermal manikin is very expensive equipment. Moreover, thermal manikin cannot change into the posture which Japanese people often take in their home such as AGURA (sit cross-legged).

A clo value measuring method using a human body is also shown in ISO 9920. Human body can be changed into any postures. According to the measurement theory shown in ISO, clo value is calculated by heat loss from a human body, average skin temperature, and air temperature. However, there are many measurement items, some of these items are difficult to measure, are required. It is desirable that the clo value in the posture can be measured without using special equipment like a thermal manikin to evaluate thermal environment in Japanese house accurately.

A clo value may be able to be more simply measured by measuring the amount of heat loss from a human body directly with a heat flux sensor. A heat flux sensor measures the heat flux that passes the sensor stuck on the measuring object part. It is widely used in various fields including mechanical engineering and electrical engineering. In order to correspond to various measuring objects, the form of the sensor of a heat flux transducer and improvement of sensitivity has been progressing. And heat flux sensor that can measure the heat flux from the surface of a complicated and soft human body is increasing too.

The purpose of this research is to develop a simple new clo value measuring method, which use a human body and heat flux sensor. For the purpose of this study, the clo value measurement experiment using a human body and a heat flux sensor is conducted, and comparison and examination with the clo value in the thermal manikin were performed.

2. Method

Temperature in the laboratory, since the temperature in the Japanese residential winter is comparatively low, was set at 22℃, 24℃, 26℃. Relative humidity in the laboratory was set at 50%.

The clothes used for measurement are the most typical combination of clothes of male in their home in winter revealed by a questionnaire survey [2] (Table 1).

clo value was calculated by equation (1).

$$\textit{clo value } I_{cl} = \textit{Thermal insulation value of "clothed" body } I_t - \frac{\textit{Thermal insulation value of "nude" body } I_a}{\textit{Clothing area factor } f_{cl}} \quad \text{- (1)}$$

Table 1 The clothes used for measurements

Garment	Material (%)	Weight (g)
Shorts	Cotton (78.0), Polyurethaner (22.0)	145
Sweatshirt	Polyurethaner (100.0)	494
Pants	Cotton (100.0)	72
Sweatpants	Polyurethaner (100.0)	391
Socks	Polyester (56.8), Cotton(40.8), Polyurethane (1.8), Nylon	54

Thermal manikin that was used in the measurement was divided into 17 sections (such as the head, chest, abdomen, forearm, upper arm), could be set the surface temperature for each section, could be measured the amount of heat loss from the surface. Surface temperature of the thermal manikin was set to 33℃.

A subject used in heat flow measurement was a 20-year-old adult male, height 177.0cm and weight 66.1kg.

The size of the probe portion of the heat flux sensor had a thickness of 0.6mm by 10mm square.

Heat flux sensors were attached to the same 17 points as the measurement point of thermal manikin. Measured 17 points and the area ratio of the part are shown in Table 2.

The surface of the body area and the area percentage of each part were calculated using a formula which fits in with the physique of the Japanese [3]. Thermal manikin and subject that was used in the experiment were shown in Fig. 1.

Clo values of 2 postures (Standing, Sitting on chair) were measured. Before starting the measurement, thermal manikin and subject were exposed to laboratory maintained at a set temperature to heat exchange with the thermal environment reaches a steady state. Each measurement item was measured for at least more than 30 minutes. An average of the measure of the last 30 minutes was used for calculating clo value.

a) Clothed manikin b) Nude manikin c) Clothed subject d) Nude subject

Fig. 1 Manikin and subject that was used in the experiment

Table 2 Measured 17 points and the area ratio of the part

Body part	Thermal manikin		Subject	
	Ratio (%)	Area (m^2)	Ratio (%)	Area (m^2)
Head	7.82	0.119	11.40	0.206
Chest	11.02	0.168	6.20	0.112
Back	12.45	0.190	7.20	0.130
Abdomen	4.08	0.062	6.30	0.114
Lower back	6.11	0.093	3.10	0.056
Upper arm - R	4.85	0.074	5.00	0.090
Forearm - R	3.39	0.052	2.95	0.053
Hand - R	2.39	0.036	2.50	0.045
Upper arm - L	4.85	0.074	5.00	0.090
Forearm - L	3.39	0.052	2.95	0.053
Hand - L	2.39	0.036	2.50	0.045
Thigh - R	7.05	0.108	12.55	0.226
Lower leg - R	7.55	0.115	6.35	0.115
Foot - R	4.03	0.061	3.55	0.064
Thigh - L	7.05	0.108	12.55	0.226
Lower leg - L	7.55	0.115	6.35	0.115
Foot - L	4.03	0.061	3.55	0.064
Total	100.00	1.525	100.00	1.805

3. Results

Clothing area factor f_{cl} that was measured by the photography method were 1.2.

The laboratory temperature was maintained around the preset temperature (22℃, 24℃, 26℃) by all experiments.

Results of measurements of clo values were shown in Fig. 2.

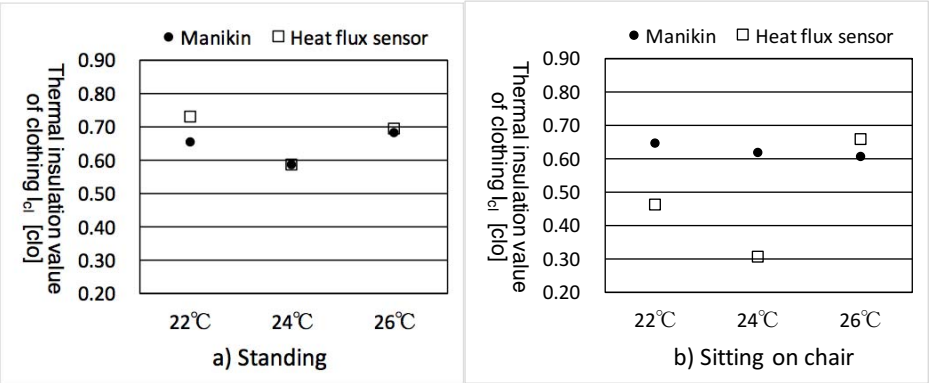


Fig. 2 Results of measurements of clo values

Clo value of thermal manikin experiments was 0.68 clo of the largest "Standing at 26℃" and 0.58 clo of the smallest " Standing at 24℃".

On the other hand, clo value of the heat flux sensor measurements were 0.73 clo of the largest "Standing at 22℃" from 0.30clo of the smallest "Sitting on chair at 24℃".

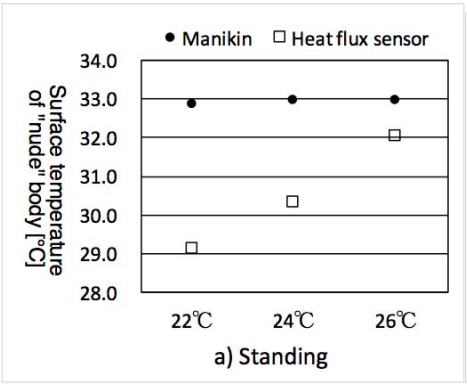
In most conditions, clo values of the heat flux sensor measurements were smaller than the thermal manikin measurements. Especially in "Sitting on chair" measurements, the difference in the clo value by the difference in the temperature became conspicuous. Though measured clothes were long sleeve and trousers, clo value (0.3 clo) by "Sitting on chair at 24℃" was quite small than expectation.

To explore why clo value by the heat flux sensor measurements were small, the measurement results of each item used to clo value calculated were compared.

3-1. Comparison of the surface temperature

Fig. 3 shows surface temperature of “nude” body. Fig. 4 shows surface temperature of “clothed” body.

The thermal manikin measurements, the surface temperature were maintained at about 33℃ regardless of the “clothed” and “nude”. But, in heat flux sensor measurement, the differences were seen in average surface temperature between the "nude" and the "clothed". The skin temperature of "nude" was low. In addition to, while a decline of the skin temperature with the decline of the temperature was about 1℃ in "clothed", it was big at about 3℃ in "nude".



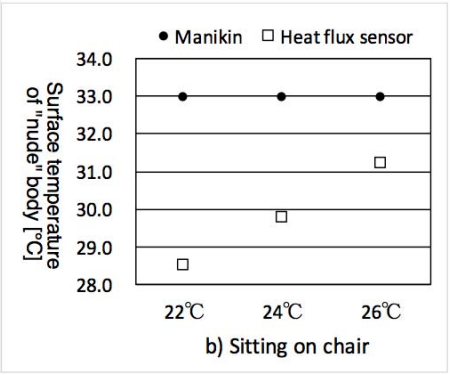
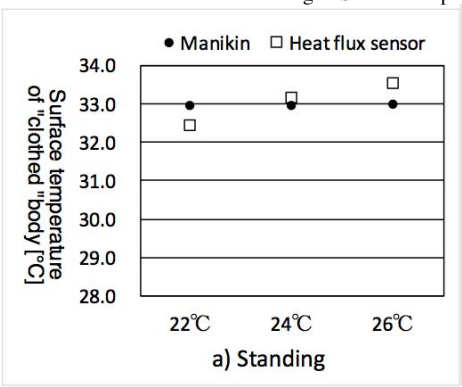


Fig. 3 Surface temperature of "nude" body



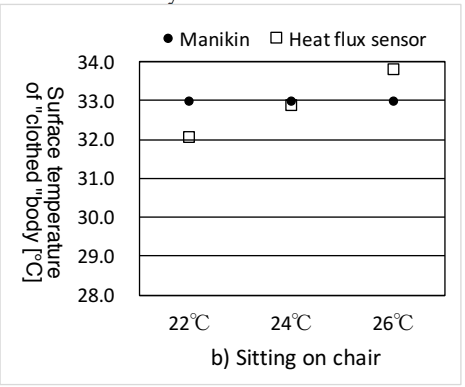


Fig. 4 Surface temperature of "clothed" body

3-2. Comparison of the heat loss from body

1) "clothed" measurements.

Fig. 5 shows heat loss from "clothed" body.

In heat flux sensor measurement, the heat loss from a subject was about 40-60 [W/m^2] regardless of the temperature and the posture.

In thermal manikin measurement, heat loss from a thermal manikin was different according to the temperature. In both posture, heat loss from a thermal manikin was about 60[W/m^2] at 22℃, but 55[W/m^2] at 24℃, and 45[W/m^2] at 26℃. Inverse proportion was observed during the temperature and heat loss.

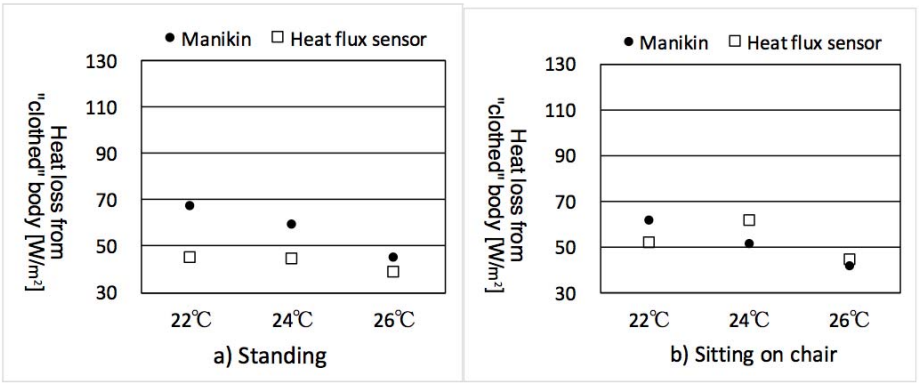


Fig. 5 Heat loss from "clothed" body

2) “nude” measurements.

Fig. 6 shows heat loss from "nude" body.

In the "nude" measurements, heat loss in the heat flux sensor measurements was less than that of the thermal manikin measurements.

In heat flux sensor measurement, the heat loss from a subject was about 50 [W/m^2] regardless of the temperature and the posture.

In thermal manikin measurement, heat loss from a thermal manikin was different according to the temperature. In both posture, heat loss from a thermal manikin was about 120[W/m^2] at 22℃, but 100[W/m^2] at 24℃, and 80[W/m^2] at 26℃. Inverse proportion was also observed during the temperature and heat loss.

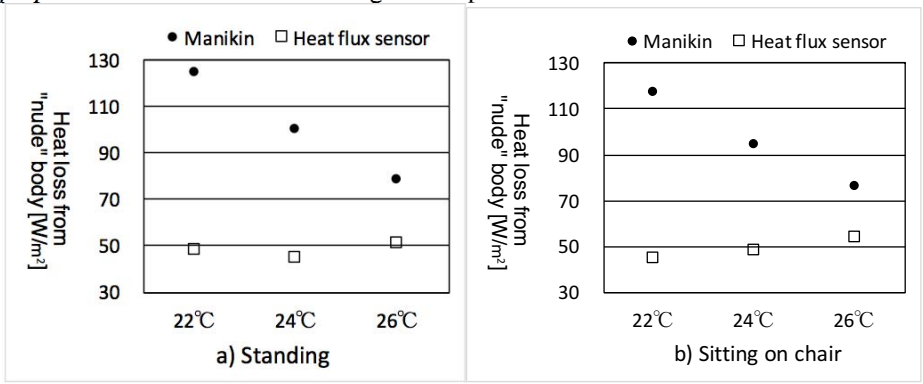


Fig. 6 Heat loss from "nude" body

3-3. Comparison of I_t and I_a

Fig. 7 shows measurement results of thermal insulation value of “clothed” body I_t. Fig. 8 shows measurement results of thermal insulation value of “nude” body I_a.

Either of I_a and I_t, the thermal resistance of the thermal manikin measurement was greater than that of the heat flux sensor measurement.

I_t of a thermal manikin measurements were almost the same (1.1 clo), but I_t of a heat flux sensor measurements varied widely with posture and temperature (about 0.9 - 1.5 clo).

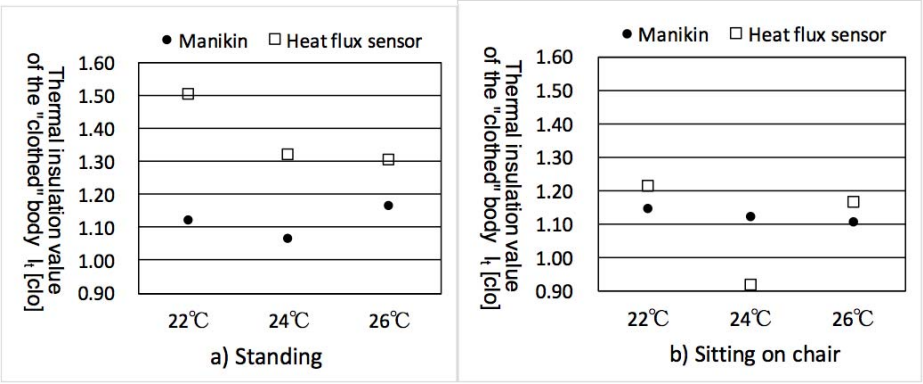


Fig. 7 Mesurement results of thermal insulation value of "clothed" body I_t

While I_a of thermal manikin measurements were roughly the same (0.60 clo) even if the position and the temperature are different, that of heat flux sensor measurements were irregular (about 0.6 – 0.95 clo).

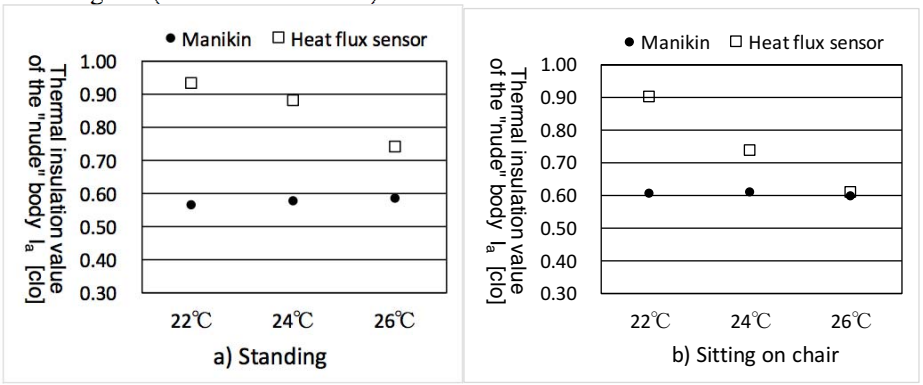


Fig.8 Mesurement results of thermal insulation value of "nude" body I_a

Difference in I_t and I_a in heat flux sensor measurements were smaller than that of thermal manikin measurements, especially in "Sitting on chair" at lower tempetature.

4. CONSIDERATION

clo value measured by the heat flux was smaller than the thermal manikin measurement. Smaller clo value of the heat flux measurement was thought to be caused by smaller gaps between I_t and I_a of the heat flow sensor measurement. Smaller gaps in I_t and I_a of the heat flow sensor measurement are thought to be caused by the following two.

1) In "nude" conditions, heat loss in the heat flow sensor measurements was greater than that of in the thermal manikin measurements.

2) In "clothed" conditions, heat loss in the heat flow sensor measurements was smaller than that of thermal manikin measurements.

The reason is considered as follows. To respond to a change of the temperature and the position, thermal manikin made heat loss change while maintaining the skin temperature fixedly because he was set to maintain his surface temperature 33℃. On the other hand, a subject tried to maintain heat loss fixedly by changing the skin temperature because of his thermoregulatory function.

Because human body equip thermoregulatory function, it maybe inevitable that clo value measured by using a human body is smaller than that of by using a thermal manikin who maintained the skin temperature fixedly.

Consideration of clo value measurement method that premised on a thermoregulatory function of a human body may be needed.

Acknowledgment

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