Assessment of method for measuring clo value using human body – Assessment of method for measuring clo value that assumes human body temperature adjustment

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Abstract. In order to make it possible to measure the clo value in various postures, we are studying the measurement method using the human body. Our previous researches showed that clo value measured with the human body is less than that measured with a “constant temperature control”-type thermal manikin. In our previous experiments, human body changes its skin temperature in response to the amount of clothing or changes in the temperature to maintain heat loss, while a “constant temperature control”-type thermal manikin changes its heat loss in response to the temperature or amount of clothing. Human body reaction is similar to "constant heat dissipation" -type thermal manikin. In order to improve the clo value measurement method using the human body, clo value of same clothing by thermal manikin which changed control method to "constant temperature" and "constant heat dissipation" were measured. Relational expressions of thermal insulation of clothes measured by different control methods were shown.

1 Background and purpose of study

1.1 Necessity of clo value of different posture

Clo value is one of the six factors of thermal environment, along with air temperature, humidity, airflow, radiation and metabolic rate, and it is very important for thermal environment assessment. Clo value is largely determined by heat resistance of the air among the fibers of clothes and the air beneath clothes. The thickness of the air layer underneath the clothes changes depending on the posture. Our previous studies [1-3] have reported that clo value also differs depending on the posture. Moreover, Japanese people do not only sit on chairs at home but adopt various postures such as sitting cross-legged on the floor. Thus, the knowledge of clo value for different postures is essential for the assessment of thermal environment of Japanese houses.

1.2 Existing methods of measuring clo value and their problems

1.2.1 Method using thermal manikin

Thermal manikin was developed and has been used to measure clo value. The control methods of a thermal manikin include “constant temperature control,” “constant heat loss control”. While the ISO 9920 method for measuring clo value defines the recommended range of the surface temperature and of the heat loss from the surface of thermal manikin, it does not specify, for instance, which control method should be used. Therefore, the measurer is compelled to choose one of the two abovementioned methods arbitrarily. In addition, the thermal manikin is very expensive and has a problem that it can only take a limited posture, such as standing or sitting on a chair. Thus, thermal manikin cannot be used to measure clo value for various postures, such as sitting cross-legged on the floor that is often taken in Japanese house.

1.2.2 Method using representative clothing combinations

In ISO 9920, clo value of hundreds or more representative clothing and clo value of clothing combination of hundreds or more types is listed. The aim is to substitute the clo value of a desired clothing combination with that

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of the closest combination in the list. The values in ISO 9920 were obtained using a thermal manikin in a standing position. Therefore, it is doubtful whether these can be applied to clo value for other postures.

1.3 Necessity of new assessing method for measuring clo value that assumes human body temperature adjustment

We have been assessing a measurement method using the human body to enable measurement of clo values for various postures without using a special device, such as a thermal manikin. Previous our research [4] showed that clo values measured with the human body are less than that measured with a thermal manikin. The human body changes its skin temperature by 2°C–3°C in response to the amount of clothing or changes in the temperature to maintain heat loss at nearly 50 W/m^2, while a "constant temperature control"-type thermal manikin changes its heat loss by up to 50 W/m^2 (nearly 120 - 70 W/m^2) in response to the temperature or amount of clothing. This is deemed to be the cause of the difference in the measured clo value. Thus, it is inevitable that clo values measured using a human body exhibiting body temperature adjustment are lower than those measured using a "constant temperature control"-type thermal manikin. Therefore, when examining a method for measuring clo value using the human body, it is necessary to assume human body temperature adjustment.

To assess a method for measuring clo value that assumes human body temperature adjustment, it is necessary to understand the relationship between the clo value measured using a "constant temperature control" thermal manikin and that measured using a "constant heat loss control" thermal manikin.

In the preliminary experiment we measured clo value with the same combination of male clothes using same thermal manikin but with different control methods. By comparing their measurements, the relationship between the clo value using a "constant temperature" manikin and that using a "constant heat loss" manikin, as well as the relationship between the clo value using the human body and that using a "constant temperature" manikin was obtained. The accumulation of data and improvement in the measurement device accuracy were identified as issues that need to be examined to assess the reproducibility and understand general tendencies.

1.4 Purpose of this study

1. To improve the accuracy of the method for measuring clothing insulation with the human body using a cordless button-type temperature logger and to accumulate data, the clothing insulation of women's wear was measured with female test subjects and a high-resolution button-type temperature logger.

2. To accumulate data for the method for measuring clothing insulation that assumes human body temperature adjustment, clothing insulation values using a constant temperature thermal manikin and a constant heat loss thermal manikin with the same combination of women's wear were measured. The relationship between these measurements was determined.

2 Method

2.1 Thermal resistance experiment with thermal manikin using different control methods and the same clothing

Clothing insulation values for the same clothing were measured using a thermal manikin with different control methods. By comparing the measurements, the relationship between the clo values using a constant temperature manikin and a constant heat loss manikin were obtained.

The body of the thermal manikin used in this experiment was divided into 17 parts. In this experiment, the surface temperature of each part was set at 33°C for the constant temperature control measurement and the heat loss from each part was set at 50 W/m^2 for the constant heat loss control measurement.

The temperature of the climatic chamber was set at 22°C, 24°C, and 26°C. The humidity was set at 50% under any temperature condition. The posture of the manikin was set as standing position.

The four clothing combinations from light clothes of short sleeves and shorts to thick clothes wearing a coat were used for the experiment. The four clothing combinations were shown in Table 1.

Table 1 clothing combinations

Garment	Material (%)	Weight (g)	Nude	Ensemble			
				A	B	C	D
Socks	Cotton(40), Acryl(28) Rayon(19), Nylon(9) Polyester(2), Polyurethane(2)	26			●	●	●
Brassiere	Nylon(55), cupra(37) Polyurethane(8)	75	●	●	●	●	●
Shorts	Wool(95), Polyurethane(5)	37	●	●	●	●	●
T-shirt	Wool(100)	190		●			
Short pants	Polyester(60), Rayon(40)	37		●			
Blouse	Rayon(76), Polyester(24)	191			●	●	●
Pants	Polyester(48), Rayon(48) Polyurethane(4)	422			●	●	●
Cardigan	Acryl(55), Wool(27) Nylon(18)	601				●	●
Court	Liner: Polyester(100) Court]Main: cotton(100)	1160					●

First, the temperature of the climatic chamber was set as the experimental temperature. The designated clothes were then put on the thermal manikin, which was activated and set in the designated state. Once the room temperature became constant, the thermal manikin was acclimatized for one hour. Measurements were then taken

for more than 30 min. The data collected from up to 30 min to before the end of the experiment were used.

2.2 Measurement of clothing insulation values using a button-type temperature data logger, a metabolic analyzer and a human body

Clo values were measured using a human body. The skin surface temperature of the subject was measured with "Hygrochron" (KN laboratories) that is a small-button battery type temperature measurement logger, and the heat flow from the subject's body surface was measured with a metabolism analyzer (Quark CPET). Metabolic analyzer is a device for measuring the energy metabolic rate. In this study, we assumed that all metabolic fever produced in the body was dissipated from the body surface. The clothing insulation values measured using human body and the values measured using thermal manikin were compared.

Five healthy females were selected as test subjects. The profiles of the subjects are shown in Table 2.

Table 2. Subjects profile

Subject	Age	Height [cm]	Weight [kg]	Rohrer index	Body surface area [m²]
Ave.±SD	19	161.0 ± 4.3	53.8 ± 4.3	129 ± 12.2	1.57 ± 0.79

The temperature of the climatic chamber was set at 22°C, 24°C, and 26°C. The humidity was set at 50% under any temperature condition. The posture was set as standing position. The combination of clothes used for this measurement were the same as those for Nude, Ensemble B and Ensemble D used for the measurement experiment with the thermal manikin with different control methods.

First, the temperature of the climatic chamber was set as the experimental temperature. When the room temperature became constant, the test subjects were acclimatized for more than 60 min wearing the designated clothing. Measurement was conducted for more than 30 min. The data collected from up to 30 min to before the end of the experiment were used.

3 Results

3.1. Comparison of the clo value with thermal manikin and with human body

Fig. 1 shows the average surface temperatures measured in the button-type temperature data logger experiment. The surface temperature of the constant temperature thermal manikin remained almost constant at the set temperature of 33°C, regardless of the amount of clothing and the room temperature. Meanwhile, the average surface temperatures of the five test subjects decreased at lower temperatures and increased at higher temperatures. When dressed, the impact of room temperature on the average surface temperature was less than when naked due to the thermal insulation performance of the clothes. Similarly, the surface temperature of the constant heat loss thermal manikin decreased when naked or lightly dressed and increased when warmly dressed; further, it decreased at low room temperature and increased at high room temperature, thus changing depending on the amount of clothing and the room temperature. The variation in the skin surface temperature of the human body with room temperature was less pronounced than that for the constant heat loss thermal manikin.

Fig. 2 shows the measurements of the heat loss from the body in the temperature logger experiment. The heat loss from the constant temperature thermal manikin was high at low temperature and low at high temperature. Conversely, the heat loss from the test subjects tended to be almost constant, regardless of the amount of clothing and the room temperature, although there were differences between individuals. The heat loss from the constant heat loss thermal manikin remained at 50 W/m^2, regardless of the amount of clothing or the room temperature. The heat loss from the human body was ~30 W/m^2 higher than that from the constant heat loss thermal manikin.

Fig. 3 shows the measurements of the clo value in the temperature logger experiment. The clo value by the human body was lower than the clo value by the thermal manikin. Contrary to prior expectations, the difference between the clo value by a human body with a small difference in heat release from the body surface due to temperature and clothes, and the clo value of constant heat flow thermal manikin, which resembles a human

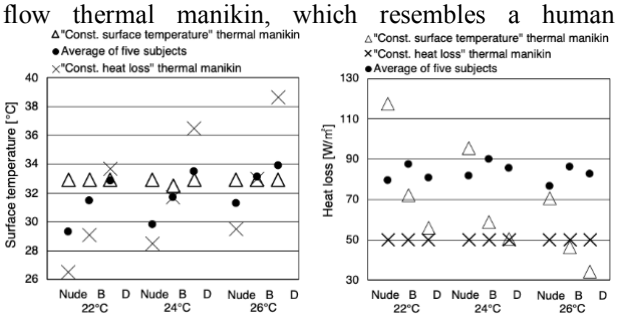

Fig. 1 Measurements of average surface temperature (left)

Fig. 2 Measurements of heat loss from the body (right)

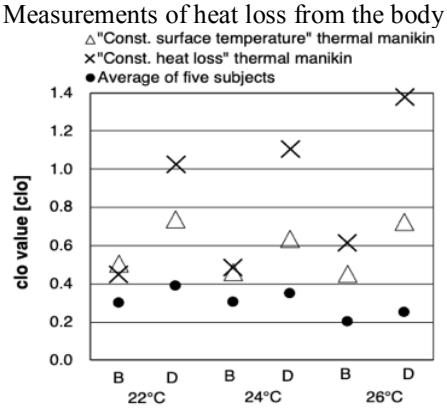

Fig. 3 Measurements of clo value

body, was large. In particular, the tendency of the clo value in the constant heat flow thermal manikin to become large under conditions of thick clothing and high temperature was remarkable.

3.2 Relationship Between the Constant Temperature Thermal Manikin and the Constant Heat Loss Thermal Manikin

The surface temperature of the constant temperature thermal manikin remained at the set temperature of 33°C regardless of the amount of clothing or the room temperature. Conversely, the average surface temperature of the constant heat loss thermal manikin decreased when "nude" or was lightly dressed and it increased when it more clothes were donned on it. Furthermore, it decreased at low room temperature and increased at high room temperature.

The heat loss from the constant temperature thermal manikin tended to increase when "nude" or when it was lightly dressed and decrease when more clothes were donned on it. Furthermore, it tended to increase at a low room temperature and decrease at a high room temperature. Meanwhile, the heat loss from the constant heat loss thermal manikin remained around the set value of 50 W/m^2, regardless of the amount of clothes and the room temperature.

Fig. 4 shows the relationship between the clo values under constant temperature control and those under constant heat loss control. The clo values measured with the constant temperature manikin were smaller than those measured with the constant heat loss manikin by an almost constant ratio. Furthermore, this ratio was almost independent of room temperature. Prior to the experiment, it was predicted that the clothing insulation measurements with the constant temperature manikin would be higher than those with the constant heat loss manikin. However, the results contradicted this prediction. The relations between the clo value measured with constant heat loss control, (y), and the clo value measured with constant temperature control, (x), were as follows:

y = 0.6631x + 0.1265 at 22°C, y = 0.4762x + 0.212 at 24°C, and y = 0.4793x + 0.126 at 26°C.

4 Conclusion

Since the response of the surface temperature and the heat loss of the human body due to the difference in temperature and clothing is similar to constant heat loss thermal manikin, the clo value of constant heat loss thermal manikin was expected to be lower than that of constant temperature thermal manikin, but in reality it was the opposite. Probably because the mean surface temperature of the dressed constant temperature manikin was low and the heat loss was high.

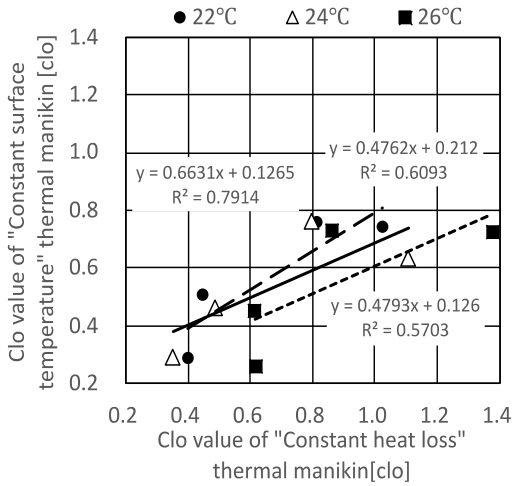

Fig. 4. Relationship between clo values in "constant temperature" and in "constant heat loss"

Contrary to expectation, conversion of the clothing insulation of women's wear measured with the human body using the equation obtained from the experimental results showed that it is usually even smaller than the clothing insulation measured using the constant temperature control type thermal manikin.

The surface temperature of the constant temperature thermal manikin was set as 33°C throughout its body, and the heat loss from the constant heat loss thermal manikin was set at 50 W/m^2 throughout its body. However, the future direction of research to assess the clo value measurement method using the human body, which assumes body temperature adjustment, is to conduct measurements under conditions that are closer to those of actual human skin, where surface temperature and heat loss distributions exist.

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