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NEW WEIGHTING COEFFICIENTS FOR CALCULATING MEAN SKIN TEMPERATURE IN RELATION TO THE POSTURE WITH CONSIDERATION TO HEAT CONDUCTION

열전도를 고려한 각 자세에 따른 평균 피부온의 산출

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ABSTRACT

This paper is to clarify a thermal physiological index that can account for the effects of local thermal environment. For this purpose two young female subjects exposing themselves to the above while sitting on a chair, sitting on the floor and lying on the floor were measured. These three representative postures accompanied the different contact surface areas, thereby the heat conduction rate between the floor and subject was quantitatively measured for each posture. It made the present study deal with the effect of heat conduction concerning the modified mean skin temperature and finally propose new weighting coefficients for the mean skin temperature calculation based on the Hardy & DuBois' formulas. In order to verify the proposed model, the experiment was carried out using a floor heating system. The comparison between the experimental result and prediction revealed that the proposed model should be about 10% more accurate than the conventional one in the case of lying on the floor which the heat conduction effect becomes important.

Keyword: Modified Mean Skin Temperature, Weighting Coefficients of Mean Skin Temperature, Contacted Surface Area, Heat Conduction, Floor Heating System.

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1. INTRODUCTION

The contact area between floor and human body in case of sitting on the floor and lying on the floor is increased larger compared with that in case of standing and sitting on a chair. Therefore the mean skin temperature, the typical value of physiological meaning, has to consider the effect of the thermally contacted part. In several studies it is proved that the contacted surface areas between floor and subjects differs with each posture, [Miyamoto(1994,1999),Choi(1996), Kurazumi (1997,1998) etc.] and they suggested the weighting coefficients for the mean skin temperature calculation considering the heat conduction effect by the measurement of the contacted surface area between floor and the human body. Although a large number of studies have been made on contacted surface area, only a few studies have so far been made with different postures to which the subjects were exposed. But, even these studies were still lacking in the consideration of the posture lying on the floor. From this point of view this paper will consider the contact areas between floor and human body in case of lying on the floor as well as sitting on a chair and the floor. Kurazumi regarded the different body types, but on this study the experiment was done by using the standard subjects and the body types were not considered. The purpose of this paper is to clarify the contacted surface area between floor and human body to be measured to quantitatively determine the heat conduction between floor and subjects. The present paper adopts the Modified Mean Skin Temperature formula with the conventional method for each postures, which consider the effect of the parts of the body in contact with floor modifying the Hardy & DuBois' equation. In addition, the present paper will consider the effect of heat conduction which should be taken into account to adjust the modified mean skin temperature at each posture of floor heating experiments. (1998,1999)

2. METHOD

2.1 The Physical Characteristics of Subjects

Two young college females subjects were measured by a subcutaneous fat measuring instrument.We employed the subjects of standard body types. The

subjects, who were all female were clothed in winter attire including: long sleeve shirts, sweat shirt, sweat trousers, socks and their own panties and brassieres. The clothing insulation value was estimated as 0.92clo. The subjects, who were all female, were clothed in summer attire including: T-shirts, short trousers, and their own panties and brassieres. The clothing insulation value was estimated as 0.32clo. We also measured with close adhesion to the underwear on the body. In this way the contact area is more clearly figured than with other clothing part. The body surface area was calculated by Hardy & DuBois equation (1938) and Kurazumi's equation (1994) adjusted to the shape of Japanese body. Table 1 shows physical condition and characteristics of subjects used for the contact area measurements. The experiment was done July 1999 at Nogoya Institute of Technology. We explained the survey contents to subjects before the experiment.

2.2 The Measurement of Floor Contact Area

The floor and floor contact areas were measured on the transparent acrylic board(2000mm×1000mm×25mm)by fixing 1mm tape in a 100mm lattice. The subjects were positioned on the board, and pictures from below the board. A 100mm was used to calculate the contact area through the photographs, for 0.1%. One position took less than 15 seconds to measure. It could keep to freeze the subjects in still at a constant position. The subjects were clothed in the same clothing during their experiment. We also measured with adhere closely on the body like underwear.

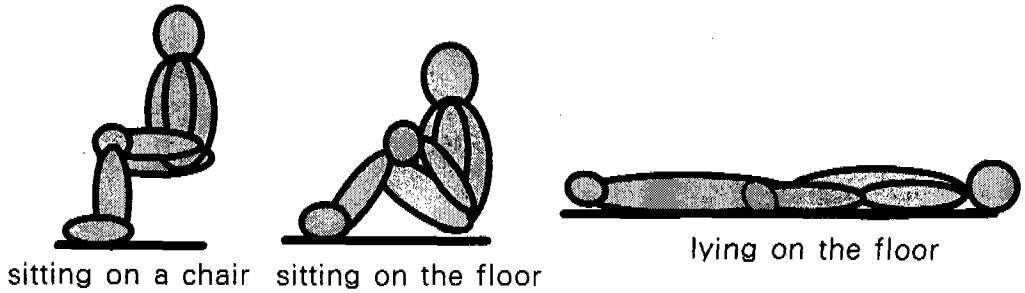


Figure 1 The different positions to which the subjects were exposed

2.3 Positions

The subjects were exposed to set conditions while sitting on the floor, sitting on a chair and lying on the floor. Figure 1 shows the different position to which the subjects were exposed.

Table1 Physical Condition and Characteristics of Subjects Employed for the Contact Area Measurements

2Female	Age(yr.)	Height(cm)	Weight(kg)	BMI(kg/㎡)	As(㎡)*	As(㎡)**
AVG	24	160	53	20.69	1.55	1.54
STD	±4.24	±7.07	±4.24	±0.17	±0.09	±0.10

As(㎡)* =Kurazumi's formula
As(㎡)**=Hardy & DuBois' formula

Table2 In the case of sitting on a chair posture results of contact area

subject	head (㎡)	upper chest (㎡)	scapula (㎡)	abdomen (㎡)	lower back (㎡)	forearm (㎡)	back of hand (㎡)	thigh (㎡)	buttock (㎡)	legs (㎡)	feet (㎡)
YA	-	-	-	-	-	-	-	-	-	-	0.0071
JY	-	-	-	-	-	-	-	-	-	-	0.0098

Table3 In the case of sitting on the floor posture results of contact area

subject	head (㎡)	upper chest (㎡)	scapula (㎡)	abdomen (㎡)	lower back (㎡)	forearm (㎡)	back of hand (㎡)	thigh (㎡)	buttock (㎡)	legs (㎡)	feet (㎡)
YA	-	-	-	-	-	-	-	-	0.0154	-	0.0090
JY	-	-	-	-	-	-	-	-	0.0150	-	0.0095

Table4 In the case of lying on the floor posture results of contact area

subject	head (㎡)	upper chest (㎡)	scapula (㎡)	abdo-men(㎡)	lower back (㎡)	forearm (㎡)	back of hand (㎡)	thigh (㎡)	buttock (㎡)	legs (㎡)	feet (㎡)
YA	0.0050	-	0.0138	-	-	0.0140	0.0024	0.0082	0.0327	0.0097	0.0011
JY	0.0045	-	0.0157	-	-	0.0199	0.0031	0.0060	0.0341	0.0133	0.0011

Table5 Results of contact area

posture	sitting on a chair	sitting on the floor	lying on the floor
head	-	-	0.0047±0.0004
trunk	-	-	0.0147±0.0014
arms	-	-	0.0169±0.0042
hands	-	-	0.0027±0.0005
buttock	-	0.0152±0.0003	0.0334±0.0010
thighs	-	-	0.0071±0.0019
legs	-	-	0.0115±0.0025
feet	0.0084±0.0019	0.0093±0.0004	0.0011±0.00004

2.4 Measurement

The body surface areas were calculated by both Hardy & DuBois equation and Kurazumi's equation adjusted to the shape of Japanese. Mean skin temperature was calculated by the weighted mean formula at 12 point surface area by Hardy & DuBois. The present paper was calculated by Modified Mean Skin Temperature formula with the conventional method, which consider the effect on parts of the body in contact with floor modifying the Hardy & DuBois equation. Two young college females subjects were measured by a subcutaneous fat measuring instrument. We employed the subjects of standard body types. The subjects, who were all female were clothed in winter attire including: long sleeve T-shirts, training shirt, training trousers, socks and their own panties and brassieres.

The clothing insulation value was estimated as 0.92clo. The subjects, who were all female, were clothed in summer attire including: T-shirts, short trousers, and their own panties and brassieres. The clothing insulation value was estimated as 0.32clo. We also measured with close adhesion to the underwear on the body. In this way the contact area is more clearly figured than with other clothing part. The body surface area was calculated by Hardy & DuBois equation and Kurazumi's equation adjusted to the shape of Japanese body. Table 1 shows physical condition and characteristics of subjects used for the contact area measurements. The experiment was done July 1999. We explained the survey contents to subjects before the experiment.

3. RESULTS

Table 2, 3 and 4 shows the results of contact area at each postures (in the case of sitting on a chair, sitting on the floor and lying on the floor). The contacted surface regions between floor and human body were only soles of the feet, when sitting on a chair. In the case of sitting on the floor, the buttocks and soles of the feet were contacted, and when lying on the floor, the head, scapular, forearm, back of hand, buttocks, posterior thighs, calf and feet were contacted.The previous study of Kurazumi's showed that the effect of heat conduction should be considered in case that the considered surface area ratio between floor and human body at each posture is over 2.5% (2.45%).In this experiment we obtained the ratio as 2.45% in the case of sitting on the floor and 9.22% in the case of the lying on the floor. Therefore, the effect of heat conduction in the floor heating and cooling system should be taken into consideration. Table 5 shows the results of contact areas of each part according to different the postures.The bottock part showed the largest contact area when sitting on the floor and lying on

Table 6 Contact area ratio

posture	contact area
sitting on a chair	0.0084±0.0019
sitting on the floor	0.0245±0.00008
lying on the floor	0.0922±0.0076

Table 7 Comparision of contact area ratio in the previous stidies

Investigator	sitting on a chair	sitting on the floor	lying on the floor	Numbers of subject
Miyamoto et al.(1994)	-	0.0339	-	female(3)
Mizuyuki et al.(1996)	0.0105	-	-	male(1)
Kurazumi et al.(1998)	0.0094	0.0219	-	male(15)
Kurazumi et al.(1999)	0.0084	0.0271	-	female(15)
Authors (1999)	0.0084	0.0245	0.0922	female(2)

the floor. Table 6 shows the contact area ratio at each postures.The contacted surface area becomes lager in the order, sitting on a chair, sitting on the floor and lying on the floor. Table 7 shows the comparision of the experimental results with previous results of the contact area. In the sitting on a chair, the values of our results were almost the same results with those of Kurazumi's results in the case of female ones. In the case of sitting on the floor, the values of our results were lower than those of Kurazumi's results. Table 8 shows the suggestion of the new coefficients for calculating the modified mean skin temperature based on the Hardy and DuBois mean skin temperature formular.

3.1 In the case of application to floor heating system

In order to verify the new weighting coffeicient for Modified Mean Skin Temperature, the experimental was carried out using on floor heating system.The experimental results were cpmpared to the propasal prediction model.

3.1.1 Experimental Conditions

The experiment was carried out using a floor heating system (W3.7m×D3.55m) in climate chambers A(W4.5m×D5m, H2.5m) and B(W3m×D3m, H2.5m) at Nara Women's University. The subjects (7 young college females) were exposed to the following conditions: combinations of air temperature (Ta=18℃,23℃) and water temperature (Tw=25℃,30℃,35℃,40℃,45℃) with air velocity less than 0.1m/s and relative humidity 40%. In the case of air temperature 18℃, water temperatures were 30℃(floor temperature=22.5℃), 35℃(24.3℃), 40℃(26.3℃) and 45℃(28.2℃). And in the case of air temperature 23℃, water temperatures were 25℃(Tf=23.7℃), 30℃(25.6℃), 35℃(27.5℃) and 40℃(29.4℃).

3.2 Physical Condition and Characteristic of Subjects

The subjects were exposed to the above conditions while sitting on the floor, sitting on a chair and lying on the floor. Fig. 1 shows the different postures to which the subjects were exposed. The subjects, who were all female were clothed in winter attire including: long sleeve shirt, sweat shirts, sweat trousers, socks and their own panties and brassieres. Table 9 shows physical condition and characteristics of subjects.

Table 8 Weighting coeffients for calculation of mean skin temperature according to Hardy-DuBois

Measuring position	Hardy-DuBois	Modified weighting factors					
		sitting on a chair		sitting on the floor		lying on the floor	
		uncontact	contact	uncontact	contact	uncontact	contact
forehead	0.0700	0.0700		0.0700		0.0700	
upper chest	0.0875	0.0875		0.0875		0.1603(A)	
scapular	0.0875	0.0875		0.0875			0.0616(A1)
abdomen	0.0875	0.0875		0.0875		0.0875	
lower back	0.0875	0.0875		0.0875		0.0875	
forearm	0.1400	0.1400		0.1400		0.1400	
back of hand	0.0500	0.0500		0.0500		0.0500	
thigh(a.)	0.0950	0.0950		0.0950		0.1495(B)	
thigh(p.)	0.0950	0.0950		0.0950			0.0071(B1)
shin	0.0650	0.0650		0.0650		0.1185(C)	
calf	0.0650	0.0650		0.0650			0.0115(C1)
instep	0.0700	0.0616		0.0607		0.0689(D)	
buttock					0.0152		0.0334(B2)
sole			0.0084		0.0093		
heel							0.0011(D1)
Total	1.0000	1.0000		1.0000		1.0000	

Table 9 Physical Condition and Characteristics of Subjects Employed for the Floor Heating System

7Female	Age(yr.)	Height(cm)	Weight(kg)	BMI(kg/㎡)	As(㎡)*	As(㎡)**
AVG	21.5	156.3	54	22.1	1.56	1.52
STD	±0.84	±4.88	±5.56	±1.33	±0.09	±0.10

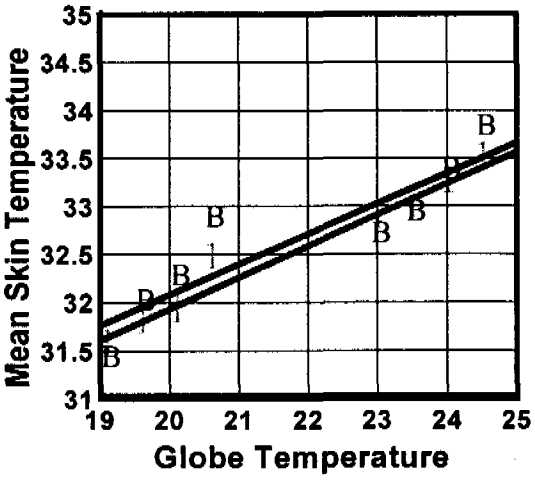
3.3 Measurements

Air temperature was measured at the center of the experimental room with three different levels (H=0.1, 0.6, 1.1m), and Globe Temperature (Tg=in contact with the floor, and at 0.6m) was measured by a 15cm diameter globe thermometer. Floor surface temperature was measured by a thermocouple of diameter 0.1mmϕ. Humidity was measured by an automatic assmann hygrometer. To determine physiological effects, the skin temperatures at 14 points were measured every 5 seconds by thermocouples(0.1mmϕ). Skin tem-

perature was measured by a 30 point hybrid recorder. The rectal temperature was measured by a 30 point hybrid recorder of which the sensor inserted about 10cm into the anus of the subject. Body weights were obtained by weighing the subjects immediately before and after the experiment. The blood pressure and heart rate were obtained immediately before and after the experiment. From 30 minutes before the experiment to 60 minutes after, the subjective psychological evaluation of the whole body and local body of subjects were described at 10 minute intervals based on the traditional nine-point scale for thermal sensation votes [-4: very cold through +4: very hot], and seven-point scale for thermal comfort votes [-3: very uncomfortable through +3: very comfortable]. The experiment was done between February and March 1997.

3.4 Physical Globe Temperature and Mean Skin Temperature

Fig. 2 shows the relation between globe temperature and mean skin temperature. The coefficient of correlation was higher valued between globe temperature and mean skin temperature & modified mean skint emperature exceeded 0.9. The coefficient



●MST Y=0.3x+25.7 R=0.90
×MSTd Y=0.3x+25.3 R=0.98
Figure2 Relation Between Globe Temperature, Mean Skin Temperature and Modified Mean Skin Temperature
-in the case of lying on the floor-

of correlation of modified mean skin temperature was slightly higher than mean skin temperature in the case of lying on the floor, which can be explained by heat conduction.

4. CONCLUSION

These results lead to the following conclusion:

(1) The contacted surface areas between floor and human body were measured to quantitatively determine the heat conduction between floor and subjects.

(2) The contacted surface region was only soles of the feet between floor and

human body, when sitting on a chair. In the case of sitting on the floor, the buttocks and soles of the feet were contacted, and when lying on the floor,the head, scapular, lower back, forearm, back of hand, buttocks, posterior thighs, calf and feet were contacted.

(3) The results of contact area ratio is about 2.45% in the case of sitting on the floor and 9.22% in the case of the lying on the floor.

(4) New weighting coefficients to calculate mean skin temperature are derived on the basis of Hardy & DuBois's formula.

(5) The correlation coefficient was established valued between globe temperature and mean skin temperature, modified mean skin temperature exceeded 0.9 in the case of application to floor heating system.

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[ANNEX1]

This study calculated the weighting coefficients for calculation of mean skin temperature below equation. In order to calculate the contacted surface area, it calculated the contacted area by substracting contacted area from seperated parts of body surface, and the value of uncontacted parts in relation to the opposite parts of the body surface area.

A1=scapula's contact area / As

A=0.875+(0.875-A1)

B1=posterior thigh's contact area / As

B=0.095+(0.095-(B1+B2))

C1=calf's contact area / As

C=0.065+(0.065-C1)

D1=heel's contact area / As

D=0.07-D1

[NOTES]

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저자 소개

◈ 이주연(LEE Ju-Youn)

일본 나라여자대학에서 주거환경학으로 석사학위를 받았으며, 현재 나라여자대학 인간문화연구과 생활 환경학 박사과정에 재학중이면서, L G전자 디지털어플라이언스 연구소 냉열응용팀에서 쾌적공조분야에 관해서 연구하고 있다. 관심분야는 온열환경, 감성공학, 복사·기류냉난방 시스템등이다.

◈ 미야모토 세에치(MIYAMOTO Seiichi)

일본나고야 공업대학에서 공학박사학위를 수여하고, 현재 나고야 공업대학에서 조수에 재직하고 있다. 관심분야는 건축환경공학중에서도 복사환경에 많은 관심을 갖고 연구하고 있다.

◈ 이소다노리오(ISODA Norio)

일본동경공업대학에서 공학박사학위를 수여하고, 현재 나라여자대학 인간문화연구과 교수에 재직하고 있다.주연구분야는 건축환경공학중에서도 온열환경이고, 음환경·공기환경에 대해서도 연구하고 있다.

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