THE EVALUATION OF THERMAL COMFORT AFFECTED BY CONDUCTION FROM WATER HEATED FLOOR TO CONTACTED BODY SURFACE

熱伝導を考慮した床暖房の快適性評価に関する研究

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ABSTRACT

The purpose of this paper is to clarify the effect of air temperature and floor temperature on the occupants' comfort sensation in the hot water floor heating system. This paper also considers the contact areas between floor and human body to quantitatively determine the heat conduction between the floor and the subjects. The present study deals with the effect of heat conduction with regard to modified mean skin temperature. The subjects (7 female college students) were exposed to the following conditions: combinations of air temperatures (18°C, 23°C) and water temperatures (25°C, 30°C, 35°C, 40°C, 45°C) in still air and RH 40%. The subjects were exposed to these conditions while sitting on the floor, sitting on a chair and lying on the floor. The following results were obtained: The skin temperature of the body parts in contact with the floor was affected by the floor temperature. The thermal sensation vote was neutral at a mean skin temperature of 33°C. Levels of thermal comfort and acceptability of the floor temperature was rated as 'satisfactory' at globe temperatures above 20°C. The permissible comfort level of the floor temperature was found to be approximately 25°C at globe temperature 20°C. New weighting coefficients to calculate mean skin temperature are derived on the basis of Hardy & DuBois formula.

Keywords: floor heating system, heat conduction, thermal sensation, modified mean skin temperature

床暖房、熱伝導、温冷感、伝導修正平均皮膚温

1. INTRODUCTION

Floor heating system has a significant influence on the mean radiant temperature in a space. It is regarded as an economical and comfortable heating system because of the radiant heat. Reasons like free use of space, no cleaning, no noise, no draft, no ducts, uniform temperature distribution and a low temperature heating system have made many people choose floor heating.(4)

Several studies have proved the comfort of floor heating system. [ASHRAE55,(1981); ISO-7730(1984); Nevins,(1964,1966); Olesen, B.W., (1977,1997); Kim,(1990); Choi,(1996) etc.](1-8)Although a large number of studies have been made on floor heating system during winter conditions, only few studies have so far been made with different postures of the exposed subjects.

The purpose of this paper is to consider the effects of air and floor temperature upon the human body, at different body postures. Even more important is to clarify the effect on parts of the body(i.e. scapula, lower back, posterior thigh, calf, and buttocks) in contact with air temperature and floor temperature using the water based floor heating system. The paper also considers the area of contact between the floor and the human body to quantitatively determine the heat conduction between the floor and a subject. The present study will deal with the effect of heat conduction mean skin temperature(MSTd) by the floor heating system. In addition, the present paper recommends the permissible comfort range of air and floor temperature for the human body.

2. METHOD

2.1 EXPERIMENTAL FACILITIES

The experiment was carried out using a floor heating system (W3.7m × D3.55m) in climate chambers A(W4.5m × 5m, H2.5m) and B(W3m × D3m, H2.5m) at Nara Women's University. Fig. 1 shows the plan of the climate chamber. The floor heating system was installed in the floor panels

(thickness 12mm). A 7mm pipe was inserted into the panels, which were 7.5cm wide. Hot water was circulating through the pipes.

2.2 EXPERIMENTAL CONDITIONS

The subjects (7 female college students) were exposed to the following conditions: combinations of air temperatures ($T_a=18^\circ\text{C}, 23^\circ\text{C}$) and water temperatures ($T_w=25^\circ\text{C}, 30^\circ\text{C}, 35^\circ\text{C}, 40^\circ\text{C}, 45^\circ\text{C}$) air velocity less than 0.1m/s and relative humidity 40%. In the case of air temperature at 18°C, water temperature at 30°C (floor temperature=22.5°C), 35°C (24.3°C), 40°C (26.3°C), 45°C (28.2°C) and in the case of air temperature at 23°C, water temperature at 25°C ($T_f=23.7^\circ\text{C}$), 30°C (25.6°C), 35°C (27.5°C), 40°C (29.4°C).

Fig.1 Plan of the Climate Chamber

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The maximum vertical temperature difference was 1.4°C (Ta1.1m-0.1m) when Ta18°C and Tw45°C and below 0.5°C when Ta23°C. Table 1 shows the experimental conditions.

2.3 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. 2 shows the different postures to which the subjects were exposed. 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. Table 2 shows physical condition and characteristics of subjects.

2.4. THE MEASUREMENT OF FLOOR CONTACT AREA

The floor area and contact areas were measured by Miyamoto on a transparent acryl board(2000mm×1000mm×25mm) by 1mm tape fixed in a 100mm lattice. (15) The subjects were positioned on the board, and pictures were taken from the other side of the board. A 100mm lattice was used to calculate the contact area through the photographs, for which the error was found to be less than 0.1%. One position took less than 15 seconds to measure. Two young college females subjects were measured by a subcutaneous fat measuring instrument. The subjects were exposed to the above conditions while sitting on the floor, sitting on a chair and lying on the floor. Figure 2 shows the different postures to which the subjects were exposed. The subjects, who were all female were clothed in winter attire including: long sleeve shirts, training shirt, training trousers, socks and their own panties and brassieres. The present study considered a clothing suit which adheres closely to the body. In this way the contact area is more clear than with other attires. Table 3 shows the characteristics of subjects used in the contact area measurements.

2.5. MEASUREMENTS

Air temperature was measured at the center of the experimental room at 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 0.1mm ϕ . 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(0.1mm ϕ). Skin temperature was measured by a 30 point hybrid recorder and 0.1mm ϕ thermocouple. The rectal temperature was measured by a 30 point hybrid recorder of which the sensor was inserted about 10cm into the anus of the subject. Body weight were obtained by weighting the subjects immediately before and after the experiment. The blood pressure and heart rate were obtained immediately before and after the experiment. The body surface area was calculated by Hardy & DuBois equation and Kurazumi's equation adjusted for the shape of Japanese body.(13) Mean skin temperature was calculated by the weighted mean formula at 12 point surface area by Hardy & DuBois.(9) The mean skin temperature was also calculated by Modified formula, which considers the effect of the parts of the body in contact with the floor. Table 5 shows the weighting coefficients for the calculation of mean skin temperature and modified mean skin temperature from this 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]. Table 4 shows the time schedule of the experiment. The experiment was done between February and March 1997.

3. RESULTS

3.1. SKIN TEMPERATURE AND RECTAL TEMPERATURE

The following results were obtained; Fig. 3 shows the changes in skin temperature with different exposures of air and water temperature.

Generally, skin temperature of the trunk gradually increased as the environmental temperature increased. The skin temperature of peripheral parts of hands and feet had a wide range, and in the case of low environmental temperatures, the skin temperature dramatically dropped to a lower temperature. The skin temperatures of parts of the body in contact with the floor continued to rise. In the case of sitting on a chair, posterior thigh showed higher temperature due to the contact with the chair, and except peripheral parts of the hand, temperatures instead, and soles of the feet decreased. Skin temperatures at the forearm and the back of the hand decreased and skin temperatures of thigh(p.), calf, buttock increased by sitting on the floor.

In the case of lying on the floor, body temperature was significantly affected by the floor temperature. In particular, the skin temperature of parts of the body in contact with the floor was affected by the floor temperature, for example, the scapula, lower back, thigh(p.), calf and

Table 1 Experimental Conditions

Environmental Conditions	Air Temp. (°C)	Water Temp. (°C)	Floor Temp. (°C)	Globe Temp. (°C)	Relative Humidity (%)	Air Velocity (m/s)
Environmental Conditions (Pretest Room Ta=23°C, RH=60%)	18°C	30°C	22.6°C	18.2°C	40%	less than 0.1
		36°C	24.3°C	19.7°C		
		40°C	26.3°C	20.2°C		
		46°C	28.2°C	20.7°C		
	23°C	25°C	23.7°C	23.1°C		
		30°C	26.6°C	23.6°C		
		36°C	27.6°C	24.1°C		
		40°C	29.4°C	24.6°C		

Table 2 Physical Condition and Characteristics of Subjects

Activity	Sedentary					
Clothing	0.92clo					
7 Female	Age(yr.)	Height(cm)	Weight(kg)	BMI(kg/m ²)	As(m ²) ^a	Ac(m ²) ^b
AVG	21.5	163.3	54	22.1	1.83	1.82
STD	±0.84	±4.88	±5.66	±1.33	±0.09	±0.10

Table 3 Characteristics of Subjects Used for the Contact Area Measurements

2 Female	Age(yr.)	Height(cm)	Weight(kg)	BMI(kg/m ²)	As(m ²) ^a	Ac(m ²) ^b
AVG	24	160	63	20.69	1.63	1.64
STD	±6.24	±7.07	±4.24	±0.17	±0.03	±0.10

As(m²)^a=Kurazumi's formula

Ac(m²)^b=Hardy & DuBois's formula

Table 4 Time Schedule of Experiment

Time	-30min	0min	30min	60min	90min
Situation	Pre-test room	Test Room			
	Recess	Exposure			
		↔ sitting on the floor or ↔ lying on the floor ↔ sitting on a chair after sitting on a chair			
Skin Temp.		Interval 30second			
Weight loss		▽		▽▽	▽
Votes	▽	▽	▽	▽	▽

Fig. 2 The Different Positions to Which the Subjects were Exposed

Table 5 Weighting Coefficients for the 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	0.07	0.07		0.07		0.07	
upper chest	0.0875	0.0875		0.0875		0.1603(A)	
scapula	0.0875	0.0875		0.0875			0.0147(A1)
abdomen	0.0875	0.0875		0.0875		0.0875	
lower back	0.0875	0.0875		0.0875		0.0875	
forearm	0.14	0.14		0.14		0.14	
back of hand	0.05	0.05		0.05		0.05	
thigh(a.)	0.095	0.095		0.0950		0.1495(B)	
thigh(p.)	0.095	0.095		0.0798			0.0071(B1)
shin	0.065	0.065		0.065		0.1185(C)	
calf	0.065	0.065		0.065			0.0115(C1)
instep	0.07	0.0616		0.0607		0.0589(D)	
buttock					0.0152		0.0334(B2)
sole			0.0084		0.0093		
heel							0.0011(D1)
Total	1		1		1		1

buttock. In the case of water temperature at 45°C , a marked increase in temperatures were observed at the buttock and the scapula, to about 36°C . The skin temperature of the soles of the feet when lying decreased compared with sitting on the floor and sitting on a chair. The mean skin temperature ranged from 31.3°C to 33.8°C . The modified mean skin temperature was valued higher than the mean skin temperature in the same manner as Choi's result in the case of sitting on the floor. It can be explained by the heat conduction. Especially modified mean skin temperature was valued lower than the mean skin temperature in the case of lying on the floor at a higher floor temperature. The rectal temperature of the subject was stable at a temperature of about 37.5°C . Minimal effects from the environment were found at the rectal temperature.

Fig. 5 shows the relation between globe temperature and mean skin temperature. The coefficient of correlation was higher valued between globe temperature and MST & MSTd exceeded 0.9. The coefficient of correlation of modified mean skin temperature was slightly higher than the mean skin temperature in the case of lying on the floor, which can be explained by heat conduction.

3.2. THERMAL SENSATION VOTE

Fig. 4 shows the changes in thermal sensation votes with different postures at different air and water temperatures. When sitting on a chair the thermal sensation was affected by air temperature. In particular, the

upper part was significantly affected by air temperature. The instep was lower than the temperature of the sole, when sitting on a chair. Based on the above, we have grounds for thinking that subjects wish for a higher air temperature. When sitting on the floor, all parts of the body was affected by the air and floor temperatures. When lying on the floor, the peripheral parts had lower temperatures at lower ambient temperatures. Especially, the feet were lower when lying on the floor. It can be assured that the feet was not in contact with the floor.

3.3. GLOBE TEMPERATURE AND PSYCHOLOGICAL VALUATION

Fig. 6 shows the relation between globe temperature, thermal comfort and thermal sensation vote. The thermal sensation votes were rated as 'slightly cool' or 'cool' at $T_a=18^{\circ}\text{C}$, and 'neutral' or 'slightly warm' at $T_a=23^{\circ}\text{C}$ when sitting on a chair and sitting on the floor. When sitting on a chair, the thermal sensation vote was nearly the same for higher a lower floor temperature. When sitting on the floor, thermal sensation vote gradually changed with floor temperature at $T_a=18^{\circ}\text{C}$ in comparison with the case of $T_a=23^{\circ}\text{C}$ for which there were nearly no change. Thermal sensation was affected by air temperature rather than floor temperature. When lying on the floor the thermal sensation was dramatically affected by floor and air temperatures.

The comfort levels were rated as 'comfortable' at all conditions with air

Fig. 3 Changes in Skin Temperature with Different Postures, Air and Floor Temperature

Fig. 4 Changes in Thermal Sensation Vote at Different Postures, Air and Water Temperature

Fig. 5 Relation Between Globe Temperature and Mean Skin Temperature

Fig. 6 Relation Between Globe Temperature, Thermal Comfort and Thermal Sensation Vote

Fig. 7 Relation Between Globe Temperature and Preferred Room Temperature Change

Fig. 8 Relation Between Globe Temperature and Satisfaction with the Floor Temperature

temperature 23°C . Uncomfortable condition is found at air temperature 18°C . Especially, when sitting on the floor levels of comfort were rated as highly comfortable at $T_w = 40^{\circ}\text{C}$ and 45°C , $T_a = 18^{\circ}\text{C}$. When sitting on a chair, the thermal sensation was not much influenced by the floor temperature. When lying on the floor, the comfort level was rated as highly comfortable as the air and floor temperature increased. Judging from the above, it seems the subjects prefer a higher floor temperature at $T_a = 18^{\circ}\text{C}$. This experiment has shown that the floor temperature is an effective parameter in increasing the comfort level.

Fig. 7 shows the relation between globe temperature and preferred room temperature change. When sitting on a chair a $1-2^{\circ}\text{C}$ higher air temperature was preferred at $T_a = 18^{\circ}\text{C}$. When sitting on the floor the higher satisfied at higher floor temperature by $T_a = 18^{\circ}\text{C}$. When $T_a = 23^{\circ}\text{C}$ was evaluated as 'comfortable' at all conditions. In general, when sitting on a chair thermal sensation was affected by air temperature and when lying on the floor it was also influenced by floor temperature.

Fig. 8 shows the relation between globe temperature and satisfaction with the floor temperature. Levels of satisfaction with the floor temperature were evaluated as 'satisfactory' at globe temperature above 20°C when sitting on a chair and sitting on the floor. Levels of satisfaction with the floor temperature were rated as 'satisfactory' at $T_w = 35^{\circ}\text{C}$, 40°C and 45°C and $T_a = 18^{\circ}\text{C}$ when lying on the floor. The recommended comfort level of floor temperature is found to be about 25°C with globe temperature 20°C .

Fig. 9 shows the relation between modified mean skin temperature, thermal sensation vote and thermal comfort vote. Thermal sensation was neutral at a mean skin temperature of 33°C . The thermal comfort vote is obtained when the mean skin temperature is above 32°C when sitting on a chair and sitting on the floor, and above 32.5°C when lying on the floor in this experiment.

3.4. HEAT LOSS

Fig. 10 shows the relation between globe temperature and total body heat loss, conductive heat loss.

The heat loss by conduction was affected by the floor temperature significantly when lying on the floor. when sitting on a chair, the conductive heat loss was not affected by the value of the conductive heat loss. The coefficient of correlation was higher valued between globe temperature and heat loss.

The difference of the heat loss by each postures, and the heat loss were effected by floor temperature and air temperature. Especially, in the case of lying on the floor was higher valued than another positions.

4. CONCLUSION

These results lead to the following conclusions:

- (1) The skin temperature of body parts in contact with the floor was affected by the floor temperature. When sitting on the floor, the buttocks and soles of the feet were affected. When sitting on a chair only the soles of the feet were affected. When lying on the floor, the scapula, lower back, posterior thigh, calf, and buttocks were affected.
- (2) The mean skin temperature ranged from 31.3°C to 33.8°C .
- (3) The thermal sensation vote was neutral at a modified mean skin temperature of 33°C .
- (4) Levels of thermal comfort and satisfaction with the floor temperature was rated as 'satisfactory' at globe temperature above 20°C .
- (5) The body parts in contact and the contact surface area between a floor and the human body were measured quantitatively.
- (6) New weighting coefficients to calculate mean skin temperature are derived on the basis of Hardy & DuBois formula.
- (7) The correlation coefficient between globe temperature and mean skin temperature & modified mean skin temperature exceeded 0.9.
- (8) The heat loss by conduction was significantly affected by the floor temperature when lying on the floor.
- (9) The recommended permissible comfort level of floor temperature was about 25°C with globe temperature 20°C .

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[ANNEX1]

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

$$\begin{aligned}
 A1 &= \text{scapula's contact area} / A_s \\
 A &= 0.875 + (0.875 - A1) \\
 B1 &= \text{posterior thigh's contact area} / A_s \\
 B &= 0.095 + (0.095 - (B1 + B2)) \\
 C1 &= \text{calf's contact area} / A_s \\
 C &= 0.095 + (0.095 - C1) \\
 D1 &= \text{heel's contact area} / A_s \\
 D &= 0.07 + (0.07 - D1)
 \end{aligned}$$

Fig. 9 Relation Between Modified Mean Skin Temperature and Thermal Sensation Vote, Thermal Comfort Vote

Fig. 10 Relation Between Globe Temperature and Heat Loss

[ANNEX2]

On this study, we calculated by HIRAYAMA's equation about Heat Loss.
 $M = C + R + Cd$ [W/m²] — by hirayama's equation (1984)

In addition to the present paper calculated by heat conduction from the contacted point skin temperature and water temperature of floor heating system.

$$\begin{aligned}
 C + R &= h(T_{sd} - T_o) / (1 + 0.18h \cdot I_{clo}) \\
 Cd &= \lambda / (Tw - Tcs) \cdot f \\
 h &= hc + hr \\
 To &= (hr \cdot Tr + hc \cdot Ta) / (hr + hc)
 \end{aligned}$$

[SYMBOLS]

M : rate of metabolic heat production [W/m²]
 C : convective heat loss [W/m²] R : radiative heat loss [W/m²]
 Cd : conductive heat loss [W/m²]
 hc : convective heat transfer coefficient [W/m²°C]
 hr : radiative heat transfer coefficient [W/m²°C]
 T_{sd} : modified skin temperature [°C] T_a : air temperature [°C]
 T_o : operative temperature [°C] T_r : mean radiant temperature [°C]
 I_{clo} : thermal resistance in clo units [clo]
 λ : floor material thickness [m]
 λ : flooring material heat transfer coefficient [W/m k]
 Tw : water temperature of floor heating system [°C]
 Tcs : contacted point skin temperature [°C]
 f : contacted body surface area / body surface area [m²/m²]
 A_s : body surface area [m²]

[NOTES] A part of this study was presented at Annual Meeting Architectural Institute of Japan 97, 98 and INDOOR AIR'99 Edinburgh, Scotland.

【和文要約】

1. はじめに

床暖房時の気温と床温の人体影響および快適温度範囲に関する研究は多くの研究が見られるが、姿勢の違いによる床接触部位に及ぼす床温の影響に関する研究は少ない。また、快適温度範囲の提案ではかなり高い温度であり、実験室での気流の影響が含まれていることも考えられる。そこで、本研究では温水循環式床暖房を用いて、床座、椅子座、仰臥の姿勢の違いによる生理的、心理的反応に及ぼす影響を把握する。また、床暖房の場合は伝導による熱授受が存在する環境であるため、伝導修正平均皮膚温を考慮する必要があることから伝導修正平均皮膚温を求め、従来の平均皮膚温と比較し、伝導熱の影響を考慮する。さらに、人体影響を考慮した許容温度範囲を気温と床温との関連で検討する。

2. 実験方法

実験はFig. 1に示すように奈良女子大学人工気候室で、床暖房は水循環式床暖房装置を床に敷いて、冷温水循環装置から温水を流した。設定条件はTable 1に示すように気温（18、23℃）と水温（25、30、35、40、45℃）の組み合わせで8条件、相対湿度は40%、気流速度は0.1m/s以下とした。なお、前室は気温23℃相対湿度40%とし、椅子座安静を保った。

床面との接触面積の測定は、透明なアクリル板上の100mmの格子状に1mm幅のテープを貼り、その上に被験者を位置させ、下方より写真撮影を行った。像の歪みを確認したところ、誤差は約1%であった。着衣は実験時と同様な着衣で測定を行い、接触面が鮮明に写るように、下着のように密着する薄手の計測着でも測定を行った。Table 2に被験者の特徴を示す。温熱環境要素としては気温、黒球温度、床温、相対湿度を測定し、赤外線放射温度計でも観測した。人体反応として皮膚温は皮膚表面14点を測定し、血圧・心拍数、体重を実験前後に測定した。平均皮膚温はHardy & DuBoisの12点体表面積重み平均で算出し、尚、本研究では姿勢により床との接触面積が異なることで、本研究から求めた各姿勢による伝導修正平均皮膚温算出法により計算した。心理反応としては温冷感、快適感などの申告を受けた。暴露姿勢はFig. 2に示した床座・椅子座・仰臥の姿勢で実験を行った。なお、被験者は青年女子7名とし、被験者の特徴、着衣はTable 3に示したとおりである。Table 4に実験手順を示す。被験者は前室に入室させ設定着衣を着用し、測定装置を取り付け、椅子座安静を保ち、約30分後に人工気候室に入室し、設定条件下に床座・椅子座は60分間、仰臥は椅子座の後に30分間暴露させた。Table 5に本研究から求めた各姿勢による伝導修正平均皮膚温の重みを示す。

3. 測定結果および考察

3.1 皮膚温への影響

Fig. 3に姿勢別・温度条件別の部位別皮膚温の平均分布を示す。全体的に軀幹部は高くなり、手部和足部の末梢部は低く、温度差も大きくなる傾向が見られる。また、接触部位皮膚温は上昇する傾向が見られる。椅子座の場合、椅子に接触している大腿後、臀部の皮膚温が高くなり、手背、足背、足底の末梢部を除き分布は小さくなる。床座の場合は全体的に気温と床温の上昇と共に皮膚温も徐々に上昇し、環境の影響を受けていることが分かる。手部和足部の抹消部で皮膚温の変動が大きく、大腿前の部位で高い皮膚温を示しているが、軀幹部と接近しているため、軀幹部からの影響であると考えられる。仰臥の場合は、床面に接触している部位で床温の影響を顕著に受け、床からの伝導による影響が考えられる。特に水温が45℃の場合は臀部の皮膚温で約36℃とかなり高い皮膚温となっている。全体の平均皮膚温は31.3℃～33.8℃の範囲にある。直腸温はほぼ37.5℃にあり、環境の影響がほとんど見られない。伝導修正平均皮膚温は床座の場合は平均皮膚温よりも高い値を示し、接触伝導による影響を示すことが出来た。しかし、仰臥の姿勢の場合は床温が高

い場合、従来の平均皮膚温よりもやや低い温度を示している。Fig. 5に黒球温度と平均皮膚温との関係を示す。黒球温度と平均皮膚温、伝導修正平均皮膚温とも0.9以上の高い相関が得られた。特に、仰臥の姿勢で、伝導修正平均皮膚温の場合が高い相関が得られ伝導の影響をより受けていることと考えられる。

3.2 各部位の温冷感評価

Fig. 4に姿勢別・温度条件別の部位別温冷感の平均分布を示す。椅子座の場合は、軀幹部で気温の影響が大きく見られ、仰臥の姿勢の場合は末梢部で、低い環境で低い温冷感評価が得られた。特に、足部は床に接触してないため、低い評価を示した。

3.3 黒球温度と心理的評価との関係

Fig. 6に黒球温度と全身温冷感および快適感申告の関係を示す。全身温冷感申告で椅子座、床座の場合は気温が18℃の場合「やや涼しい」「涼しい」の評価を示し、気温23℃では「どちらとも言えない」「やや暖かい」の申告となっている。仰臥の申告の場合は気温と床温の影響が顕著にみられ、床温が高くなることによって申告の評価も暖かい側の評価となる。また、気温18℃床温22.5℃の場合に寒い側の評価を示し、仰臥の姿勢の場合はある程度高い床温が望ましいと考えられる。快適感申告では気温23℃の場合には全条件で快適側の評価となっている。気温18℃の場合にはグローブ温度20℃で快適側の申告となる。

Fig. 7にグローブ温度と室温評価との関係を示す。椅子座の場合は気温18℃では「やや（1～2℃）上げたい」、気温23℃では「ちょうど良い」と評価されている。これに対し、床座の場合は気温が18℃では床温が高いほど「ちょうど良い」側の評価となり、床温が高いと低い気温でもある程度快適な環境を創り出せることを示していると考えられる。気温23℃ではほとんど「ちょうど良い」側の評価である。

Fig. 8に黒球温度と床温の満足感申告との関係を示す。椅子座、床座の場合はグローブ温度20℃以上で床温に対して満足側の評価となっている。仰臥の場合は全条件の平均値で床温に対して満足している。

Fig. 9に平均皮膚温と全身温冷感・快適感との関係を示す。平均皮膚温は約33℃で温熱的中性の「どちらとも言えない」の評価となり、快適感評価では椅子座・床座は約32℃で、仰臥は約32.5℃で快適側の評価となっている。

3.6 黒球温度と放熱量との関係

Fig. 10にグローブ温度と放熱量との関係を示す。仰臥の姿勢の場合、伝導による放熱量は床温の影響を顕著に受けている。椅子座の場合は伝導による影響はほとんど受けていない。グローブ温度と放熱量の場合、高い相関が得られた。

4. まとめ

本研究では、以下の結果が得られた。

- (1)床接触部位は床温の影響を大きく受け、床座の場合は「臀部」と「足部」、椅子座の場合は「足部」のみ、仰臥の場合は「背中」、「腰」、「大腿後」、「下腿後」、「臀部」で床温の影響を顕著に受けていた。(2)平均皮膚温は約31.3℃～33.8℃の範囲にあった。(3)平均皮膚温約33℃で温熱的中性評価となっていた。(4)グローブ温度20℃で快適感、床温に対して満足という評価が得られた。(5)本研究では、各姿勢の床面と人体の床接触面積を求めた。(6)既往のHardy & DuBoisの平均皮膚温算出法を修正した伝導修正平均皮膚温を求めた。(7)黒球温度と平均皮膚温、伝導修正平均皮膚温との間に0.9以上の高い相関が得られた。(8)仰臥の姿勢の場合、伝導による放熱量は床温の影響を顕著に受けていた。(9)本研究では床暖房の許容範囲として、グローブ温度20、床温25℃提案する。

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