Bulletin of the Faculty of Engineering,
Hokkaido University, No. 85 (1977)

Mean Skin Temperature Weighted with Both Ratios of Heat Transfer Coefficient and Body Surface Area

Tohru MOCHIDA*

(Received March 28, 1977)

Abstract

The purpose of the present paper is to present a calculation formula for mean skin temperature, weighted with ratios of heat transfer coefficient and body surface area and also to run a comparison againt ordinary mean skin temperature formulas previously proposed.

Although various mean skin temperatures weighted with body area ratio alone has been generally used, if derived by considering the heat balance between man and his immediate environment, the mean skin temperature should include both convective and radiative heat transfer coefficients in addition to the skin area ratios. In the present study, a general equation for calculating mean skin temperature weighted with the heat transfer coefficient and skin area is derived and a concrete calculating formula in the case of dividing the entire human body into six main parts is proposed by substituting definite values into the weighting factors in the general equation.

List of Symbols

F_n : Weighting factor for calculating mean skin temperature, N. D.
T_s : Mean skin temperature, °C
T_{sn} : Skin temperature at a specific site n on the body, °C
T_i : Surface temperature of the wall i, °C
T_r : Mean radiant temperature, °C
T_a : Air temperature (assumed to be equal to the radiant temperature in this paper), °C
P_s : Mean skin vapor pressure, mmHg
P_{sn} : Skin vapor pressure at a specific site n of the body, mmHg
P_a : Ambient vapor pressure, mmHg
A_s : Total body surface area (assumed to be equal to the areas of convection, radiation and evaporation heat transfer, respectively), m^2
A_{sn} : Skin segment area at a specific site n on the body, m^2
S_i : Surface area of the wall i, m^2
h_c : Mean convective heat transfer coefficient of the human body, Kcal/m^2h°C
h_{cn} : Local convective heat transfer coefficient at the site n of the body, Kcal/m^2h°C

* Department of Sanitary Engineering, Faculty of Engineering, Hokkaido University, Sapporo, 060, Japan.

h_r : Mean radiative heat transfer coefficient of the body, Kcal/m^{2}h°C
h_{rn} : Local radiative heat transfer coefficient at the site n of the body (h_{rn} is treated to be equal to h_r in the present paper), Kcal/m^{2}h°C
κ : Modified Lewis relation, °C/mmHg
V : Air movement, m/s
b_{si} : Absorption factor between the human body and the wall i, N. D.
ε_s : Emissivity of the human body, N. D.
σ : Stefan-Boltzmann Constant, Kcal/m^{2}h°K^4
k : Temperature factor on radiation heat transfer ($=[(273+T_s)^2+(273+T_i)^2]\,[(273+T_s)+(273+T_i)]$), °K^3
Q : Net rate of metabolic heat, Kcal/h
Q_c : Convection heat loss, Kcal/h
Q_{cn} : Local convection heat loss, Kcal/h
Q_r : Radiation heat loss, Kcal/h
Q_{rn} : Local radiation heat loss, Kcal/h
Q_e : Evaporation heat loss, Kcal/h
Q_{en} : Local evaporation heat loss, Kcal/h
Q_n : Respiration heat loss, Kcal/h
Q_v : Heat loss by clothing ventilation, Kcal/h
Q_w : Rate of accomplished work, Kcal/h
Q_t : Rate of storage of body heat, Kcal/h
Pr : Prandtl number, N. D.
Gr : Grashof number, N. D.
Nu : Nusselt number (mixed = natural and forced convection), N. D.
$\mathrm{Nu_{for}}$: Nusselt number (forced), N. D.

Subscripts ;

s : Human body,
n : Segment of the body,
i and j : Wall.

1. Introduction

Skin temperature is said to be one of the indices useful for estimating thermal environments. This is a physiological value arising as a result of heat exchange between the human body and the environment. In hot environments, although there is a shade of difference between the skin temperatures on the body surface, each site usually shows different values of skin temperature, especially when the air temperature is low, since the blood to the extremities such as hands, legs and so on, is limited in order to maintain the core temperature at constant. Thus, a great difference among these skin temperatures occurs.

When a mean value of skin temperatures which have different values at each site is calculated, the average value weighted with the skin area ratio or the arithmetic mean of their temperatures has generally been used. Numerous concrete formulas regarding the former have been proposed by physiologists. But it is expected that if derived from the heat balance equation between man and his environment, an averaging formula should include convective and radiative heat transfer coefficients in addition to skin surface areas.

Based on the heat transfer theory, the author intends to derive a calculating formula for mean skin temperature weighted with the ratios of heat transfer coefficient and skin surface area, and to run a comparison against typical averaging formulas weighted by skin area ratios alone.

2. Mean Skin Temperature Weighted with Skin Area Ratios

In general skin temperatures on each site of the body surface are different. As an averaging method, mean skin temperature weighted with the ratios of local skin area to total skin area has been widely used. Although the weighting factors and the number of sites measured in concrete calculating formulas proposed are various, such formulas are all given by the following general form.

$$T_s = \Sigma F_n T_{sn} = \Sigma \frac{A_{sn}}{A_s} T_{sn} \qquad (1)$$

The typical formulas (2)~(8) for calculating the mean skin temperature have been proposed according to the site notation of Fig. 1.[1)]

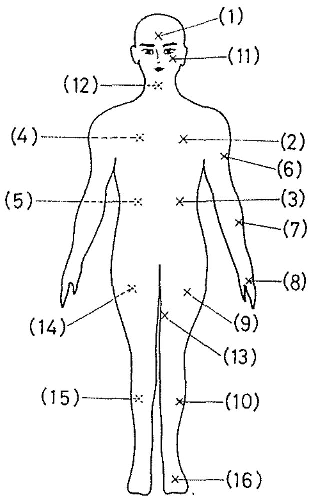

Fig. 1. Sites of skin temperature measurement.

Hardy-DuBois : $$T_s = 0.07\,T_{(1)} + 0.35\,T_{(3)} + 0.14\,T_{(7)} + 0.05\,T_{(8)} + 0.19\,T_{(9)} + 0.13\,T_{(10)} + 0.07\,T_{(16)} \qquad (2)$$

Hardy-DuBois : $$T_s = 0.07\,T_{(1)} + 0.35\,(T_{(2)} + T_{(3)} + T_{(4)} + T_{(5)})/4 + 0.14\,T_{(7)} + 0.05\,T_{(8)} + 0.19\,(T_{(9)} + T_{(14)})/2 + 0.13\,(T_{(10)} + T_{(15)})/2 + 0.07\,T_{(16)} \qquad (3)$$

QREC : $$T_s = 0.125\,T_{(2)} + 0.125\,T_{(5)} + 0.07\,T_{(6)} + 0.07\,T_{(7)} + 0.06\,T_{(8)} + 0.125\,T_{(9)} + 0.15\,T_{(10)} + 0.10\,T_{(11)} + 0.125\,T_{(13)} + 0.05\,T_{(16)} \qquad (4)$$

Teichner : $$T_s = 0.186\,T_{(2)} + 0.186\,T_{(5)} + 0.107\,T_{(6)} + 0.186\,T_{(9)} + 0.149\,T_{(11)} + 0.186\,T_{(13)} \qquad (5)$$

Palmes-Park : $$T_s = 0.19\,T_{(2)} + 0.19\,T_{(5)} + 0.11\,T_{(7)} + 0.05\,T_{(8)} + 0.32\,T_{(9)} + 0.14\,T_{(11)} \qquad (6)$$

Ramanathan : $$T_s = 0.3\,(T_{(2)} + T_{(6)}) + 0.2\,(T_{(9)} + T_{(10)}) \qquad (7)$$

Burton : $$T_s = 0.5\,T_{(2)} + 0.14\,T_{(7)} + 0.36\,T_{(10)} \qquad (8)$$

Eq (1), namely, all concrete equations (2)~(8) for calculating the mean values have a characteristic in that the sum total of the weighting factors makes unity, since the total skin area is unity. This shows that each equation exhibits its special character in cold environments better than in hot.

3. Mean Skin Temperature Weighted with Heat Transfer Coefficient and Skin Surface Area

3-1 Basic theory

The relation between the metabolic energy produced in the body and released heat to the environment is written by the following equation.

$$Q=Q_c+Q_r+Q_e+Q_n+Q_v+Q_w+Q_t \tag{9}$$

As heat losses by respiration Q_n, clothing ventilation Q_v and rate of external mechanical work Q_w are generally regarded as negligible in comparison with heat quantities by convection Q_c, radiation Q_r and evaporation Q_e, in a steady state Eq (9) may be transformed to Eq (10) when man is unclothed in uniform temperature environments where the air temperature is equal to the radiant.

$$Q \fallingdotseq (Q_c+Q_r)+Q_e=(h_c+h_r)(T_s-T_a)A_s+\kappa h_c(P_s-P_a)A_s \tag{10}$$

In Eq (10), the skin temperature T_s, the convective heat transfer coefficient h_c, the radiative h_r and the vapor pressure P_s at the skin surface show "mean values" respectively. It is now assumed that the quantity of heat by convection, radiation and evaporation from the body surface is released through the total skin area.

Let us examine each part of the body and imagine the heat balance between a given part and the environment.

The sum total of heat losses from each segment is nearly equal to the metabolic rate, if a small quantity of heat by respiration and so on is neglected.

$$\begin{aligned} Q &\fallingdotseq (\Sigma Q_{cn}+\Sigma Q_{rn})+\Sigma Q_{en} \\ &=\Sigma(h_{cn}+h_{rn})(T_{sn}-T_a)A_{sn}+\Sigma \kappa h_{cn}(P_{sn}-P_a)A_{sn} \end{aligned} \tag{11}$$

From Eqs (10) and (11),

$$\begin{aligned} &(h_c+h_r)(T_s-T_a)A_s+\kappa h_c(P_s-P_a)A_s \\ &=\Sigma(h_{cn}+h_{rn})(T_{sn}-T_a)A_{sn}+\Sigma \kappa h_{cn}(P_{sn}-P_a)A_{sn} \end{aligned} \tag{12}$$

Mean skin temperature T_s, mean convective heat transfer coefficient h_c, mean radiative h_r and mean skin vapor pressure P_s are obtained as follows by solving the identical equation (12).

$$T_s=\Sigma\left(\frac{h_{cn}+h_{rn}}{h_c+h_r}\right)\left(\frac{A_{sn}}{A_s}\right)T_{sn} \tag{13}$$

$$h_c=\Sigma h_{cn}\frac{A_{sn}}{A_s} \tag{14}$$

$$h_r=\Sigma h_{rn}\frac{A_{sn}}{A_s} \tag{15}$$

$$P_s=\Sigma\left(\frac{h_{cn}}{h_c}\right)\left(\frac{A_{sn}}{A_s}\right)P_{sn} \tag{16}$$

The mean skin temperature T_s[2)3)] shown by Eq (13) is weighted with the ratios of both skin area and heat transfer coefficient. This differs in content from the ordinary mean skin temperature weighted with skin area ratios alone. The question is what values for local and mean convective coefficients for the human body should be used in addition to values radiative coefficient and skin area ratio, when a general equation (13) derived for mean skin temperature is calculated for practical purposes.

3-2 Convective heat transfer coefficient and skin area of the human body

Values and equations for the mean convective heat transfer coefficient of the body have been proposed by physiologists and biological engineers. But a considerable difference among these coefficients is seen even when the experimental conditions are taken into consideration. On the other hand, although Nishi and Gagge[2] have set forth concrete values of local heat transfer coefficients obtained by analyses and experiments, in the present paper, values and equations for the coefficients[4] derived from a man-equivalent thermal cylinder model based on heat transfer theory will be used. The outline is given as follows.

Since the form of a human body is so complicated that it is difficult to determine the exact value of convective heat transfer coefficient, a cylinder model dividing the entire body into several parts will be taken as one of the methods for determination. The human body will be considered to be an assembly of several cylinder segments. The cylinder model of a human body by Parker *et al*[5] was consulted in the present

Table 1. Typical diameters and skin areas of body segments

	Head	Trunk	Upper arms	Forearms	Thighs	Legs
Diameter [m]	0.2	0.3	0.1	0.1	0.2	0.1
Sikn area [m²]	0.2	0.6	0.1	0.2*	0.4	0.3

* That the skin area of forearms is twice as wide as that of upper arms is the reason why it includes that of fingers and why the fractions of the number by Parker et al are counted and over as a whole number.

paper and the whole body is divided into six parts—head (including neck), trunk, upper arms, forearms (with fingers), thighs and legs—and each value of the typical diameter of those cylinders and skin areas is used in round numbers with reference to the numbers by Parker *et al* and are listed in Table 1. Further, using Hilpert's dimensionless equation[6] for forced convective heat transfer and Oosthuizen-Madan's dimensionless equation[7] for mixed convection (natural and forced), local convective heat transfer coefficients according to Table 1 are calculated. As an approximate equation which gives mean convective coefficient for the human body, Eq (18) taking into consideration natural convection especially in low velocity regions was proposed. The

Table 2. Hilpert's dimensionless equation (forced convective heat transmission)

$Nu_{for} = m\ Re^{n}$ (Prandtl number $Pr = 0.72$)		
Re	m	n
40～4000	0.615	0.466
4000～40000	0.174	0.618

effects[8] of the cylinder length and flow direction of air were also taken into account.

Oosthuizen-Madan's dimensionless equation for mixed (natural and forced) convection* ;

$$\frac{\mathrm{Nu}}{\mathrm{Nu}_{for}}=1+0.18\left(\frac{\mathrm{Gr}}{\mathrm{Re}^2}\right)-0.011\left(\frac{\mathrm{Gr}}{\mathrm{Re}^2}\right)^2 \tag{17}$$

* Since only Eq (17) has been formulated as a dimensionless equation for mixed convective heat transmission, in this paper Eq (17) is used.

Mean convective heat transfer coefficient for the body[4] ;

$$h_c=\sqrt[3]{270\,V^2+23} \qquad (0.1\leqq V\leqq 3.0) \tag{18}$$

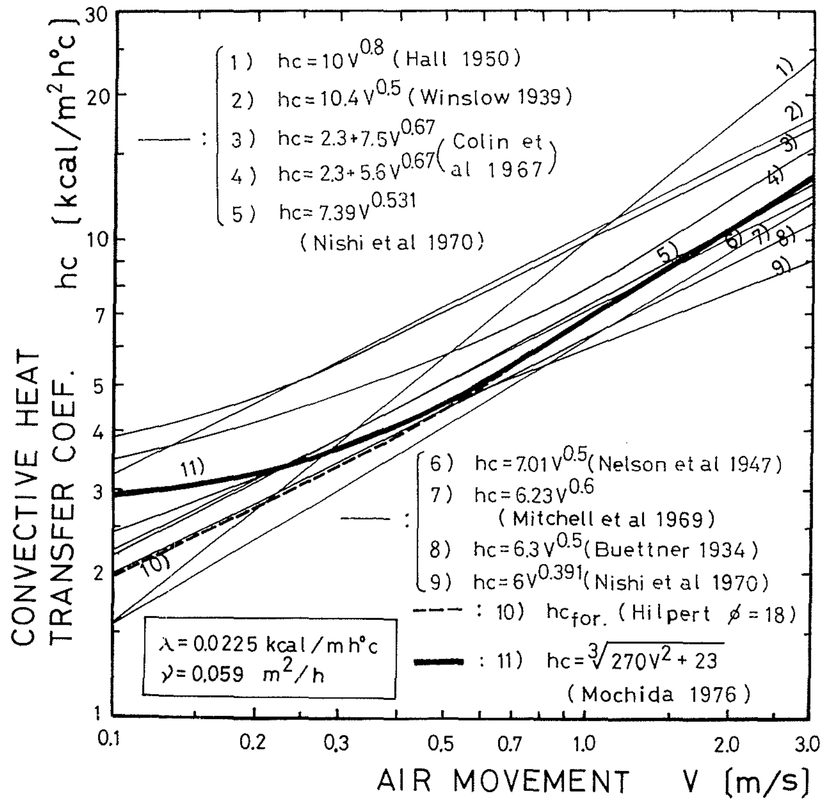

Fig. 2. Comparison of convective heat transfer coefficients for the human body[4].

3-3 Radiative heat transfer coefficient for the human body

As the radiative heat transfer coefficient[9] for the body, the author derived Eq (19) by extending Gebhart's absorption factor method and applying it to the space between the body and the surrounding walls and linearizing from raising the radiation to the fourth power of absolute temperature.

$$Q_r=\varepsilon_s\sigma k(\Sigma b_{si}T_s-\Sigma b_{si}T_i)\,A_s\equiv h_r(T_s-T_r)\,A_s \tag{19}$$

The linear radiation exchange coefficient h_r as shown in Eq (19) is defined by the following equation which includes only the emissivity of the human surface and does not contain that of the surrounding walls.

$$h_r = \varepsilon_s \sigma k \tag{20}$$

Since the change of the temperature factor k in Eq (20) as shown in Fig. 3 is gradual, if the temperature range is limited, it becomes possible to regard it as constant. Further, when radiation heat exchange in an ordinary room is considered, since long waves are mainly involved, objects generally seen in the room may be considered as gray bodies and in addition the human skin and clothing surface would have an emissivity close to that of a black body. Therefore, when the temperature range is assumed and if $\varepsilon_s \sigma k$ in Eq (20) is collectively treated as a constant, the radiative heat transfer coefficient $h_r \fallingdotseq 4.8$ Kcal/m² h °C can be obtained, if emissivity for the body $\varepsilon_s = 0.95$, the temperature factor $k = 1.05 \times 10^8$ °K³ and Stefan-Boltzmann Constant $\sigma = 4.88 \times 10^{-8}$ Kcal/m² h °K⁴ are substituted into Eq (20) as concrete values in daily life. Further, when emissivity ε_s or the temperature range is remarkably different from the above, the value of the coefficient h_r would naturally be a value in accordance with the circumstances. In addition, the mean radiant temperature $T_r (= \Sigma b_{si} T_i)$[9] of Eq (19) is weighted with the absorption factors between the human body and the surrounding walls and is different in content from mean radiant temperatures weighted by usual wall area ratios or angle factors between man and his surrounding walls.

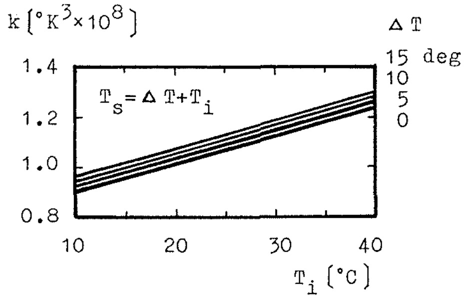

Fig. 3. Variation of temperature factor k on radiation heat transmission.

3-4 Mean skin temperature weighted with heat transfer coefficient and skin surface area ratios

Using Eqs (17), (18), Table 1 and Table 2, when the local convective heat transfer coefficient h_{cn}, mean convective h_c for the body, radiative coefficient $h_r = h_{rn} = 4.8$ Kcal/m²h °C and skin area ratio A_{sn}/A_s calculated in still air movement $V = 0.1$ m/s are substituted into the weighting factors of Eq (13), a calculating formula (21) for mean skin temperature is obtained. In addition, the values of a property of matter consisting of dimensionless numbers were set on the basis of those at 30°C.

$$T_s = 0.106\, T_{(\text{Head})} + 0.284\, T_{(\text{Trunk})} + 0.067\, T_{(\text{Upper arms})} + 0.133\, T_{(\text{Forearms})} + 0.213\, T_{(\text{Thighs})} + 0.202\, T_{(\text{Legs})} \tag{21}$$

In the above equation, the weighting factor amounted to $\sum_1^6 F_n = (h_{cn} + h_{rn})/(h_c + h_r)\,(A_{sn}/A_s) = 1.005$ in all.

Next, by repetition in the same manner regarding the cases of another wind velocity and by arranging the results calculated, Fig. 4[10] was produced. Since Fig. 4 indicates that the weighting factor at each segment of the body has but a small fluctuation against any air motion and may be regarded as constant respectively, a calculating formula for mean skin temperature is newly defined by counting one fraction of more

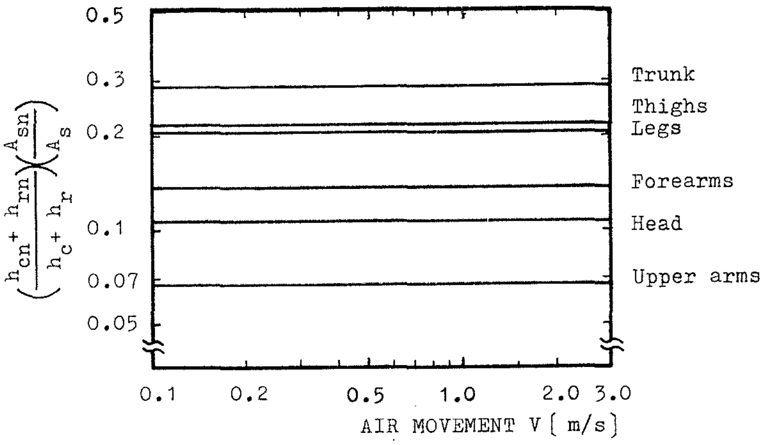

Fig. 4. Relation between weighting factors and air movement.

than 0.5 inclusive and cutting away the rest in thousandth's place of each weighting factor in Eq (21).

$$T_s=\sum_1^6\left(\frac{h_{cn}+h_{rn}}{h_c+h_r}\right)\left(\frac{A_{sn}}{A_s}\right)T_{sn}$$
$$=0.11\,T_{(\mathrm{Head})}+0.28\,T_{(\mathrm{Trunk})}+0.07\,T_{(\mathrm{Upper\ arms})}$$
$$+\,0.13\,T_{(\mathrm{Forearms})}+0.21\,T_{(\mathrm{Thighs})}+0.20\,T_{(\mathrm{Legs})} \tag{22}$$

It is quite accidental that the whole amount of the weighting factors in Eq (22) is calculated to be $\sum_1^6 F_n=\sum_1^6 (h_{cn}+h_{rn})/(h_c+h_r)\ (A_{sn}/A_s)=1.00$.

This shows that mean skin temperature calculated by Eq (22) using data observed in high temperature environments is hardly different from that by Eqs (2)~(8). Therefore, Eq (22) shows its characteristic feature when the ambient temperature is low in the same manner for a calculating formula weighted with body surface area ratios alone.

When a whole body is not divided into six parts and the typical diameters of model cylinders are not different from the case in Table 1 or when local heat transfer coefficients are obtained from one method or another, the actual numbers of weighting factors and the number of terms can be decided by returning to the basic equation (13).

4. Comparison of Calculating Formulas for Mean Skin Temperature

4-1 Experiments

For the purpose of obtaining data to compare the calculating formula (22) for mean skin temperature weighted by the ratios of heat transfer coefficient and skin area with ordinary averaging formulas weighted by mere skin area ratios, the experiments of skin temperature measurement were performed as follows.

Experiment environment;

The experiments were performed in a cloth-made chamber (2.4 m × 2.4 m × 2.0 m) constructed in the laboratory and in the test chamber the air temperature was equal to the radiant temperature. The air temperatures were held approximately by 17°C, 24°C, 26°C and 28°C dry bulbs and the relative humidity was about 50～60% and it was still with the air movement at about 0.1 m/s. The length of resting-sitting tests was 1～1.5 hours at a time. However, during each experimental period, the ambient temperature and the humidity were maintained at nearly constant.

Subjects ;

Eight healthy young men clothed in shorts alone were used and they were ordered to sit on a stool for about 1～1.5 hours and only one subject stayed in the test chamber at one time. The total number subjects observed was fifteen persons.

Skin temperature measurement ;

Skin temperatures were measured at the ten locations corresponding to No. (1)～(10) in Fig. 1 with copper-constantan thermocouples and were recorded continuously during the experiment.

4-2 Comparison of various mean skin temperatures and discussions

Four typical results of skin temperature measurement are demonstrated in Fig. 5～ Fig. 8. When various mean skin temperatures were calculated, modifications listed in Table 3 were made on the skin temperatures substituted except for the above ten locations measured. Therefore, the values of mean skin temperatures associated with these in Fig. 5～ Fig. 8 may differ somewhat.

The difference between the maximum value of mean skin temperature by Burton and the minimum one by QREC is 0.5 deg (°C) in Fig. 5 in a hot environment, on the other hand, Fig. 8 in a cold environment indicates that the difference between the maximum and minimum values is 1 deg (°C). It may safely be said that each calculating formula shows a special character quite of its own in low temperature environments better than in high. It can be read off Fig. 6 that the values calculated from Eq (3) by Hardy-DuBois, Eq (4) by QREC and Eq (22) by the present study are nearly equal. On the other hand, it can be seen from Fig. 8 that the value calculated with Eq (22) is hardly different from those by Eqs (3) and (6). But the deviation between Eq (22) and Eq (7) by Ramanathan or Eq (8) by Burton which have few measurement points is occasionally great. As a result Eq (3) by Hardy-DuBois and Eq (22) weighted with ratios of heat transfer coefficient and body surface area generally show approximate values in the present studies. The main reason why the mean skin temperature of Eq (22) is nearly equal to that of Eq (3) is that the sum of the weighting factors for the trunk and the upper arms which have high skin temperature in Eq (22) is equal to the weighting factor for the trunk in Eq (3). And moreover there is a shade of difference between the weighting factors of Eq (3) and Eq (22) except the trunk. Further, the value of heat transfer coefficient ratio $(h_{cn}+h_{rn})/(h_c+h_r)$ is calculated to lie between 0.85～1.20 in the present paper and therefore there is hardly difference between the weighting factor of Eq (22) which multiplies the above ratio close to 1.00 by skin area ratio A_{sn}/A_s and that of skin area ratio alone.

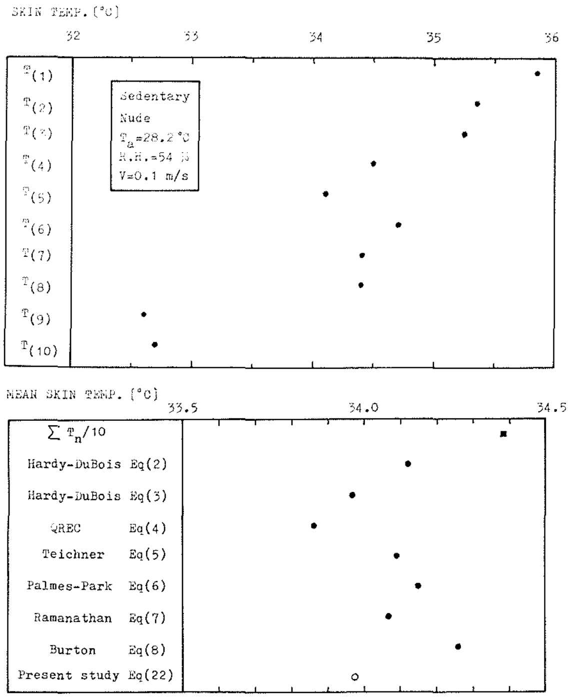

Fig. 5. Results of skin temperature measurement ($T_a = 28.2$°C) and comparison of various mean skin temperatures calculated.

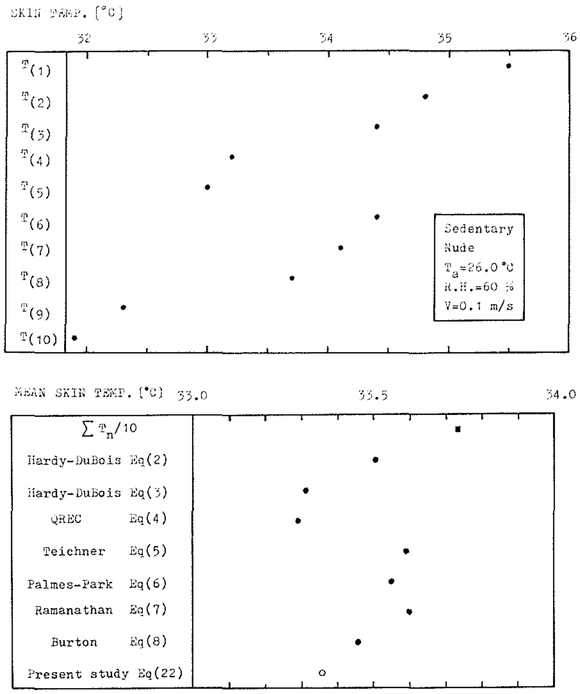

Fig. 6. Results of skin temperature measurement ($T_a = 26.0$°C) and comparison of various mean skin temperatures calculated.

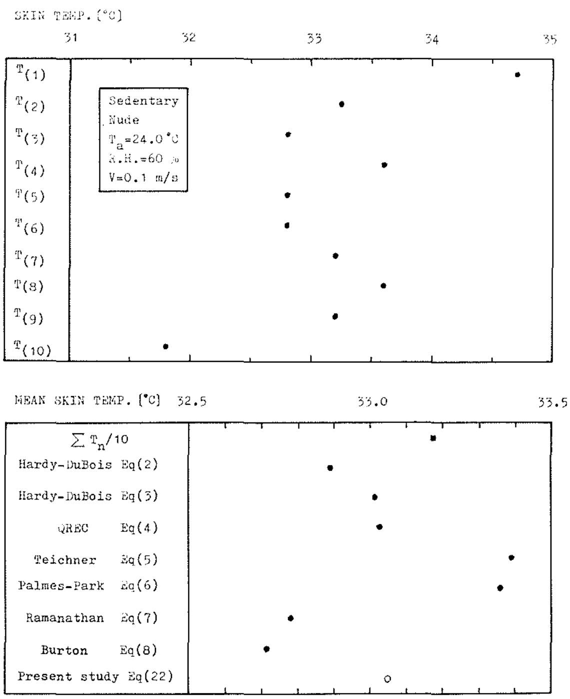

Fig. 7. Results of skin temperature measurement ($T_a = 24.0$°C) and comparison of various mean skin temperatures calculated.

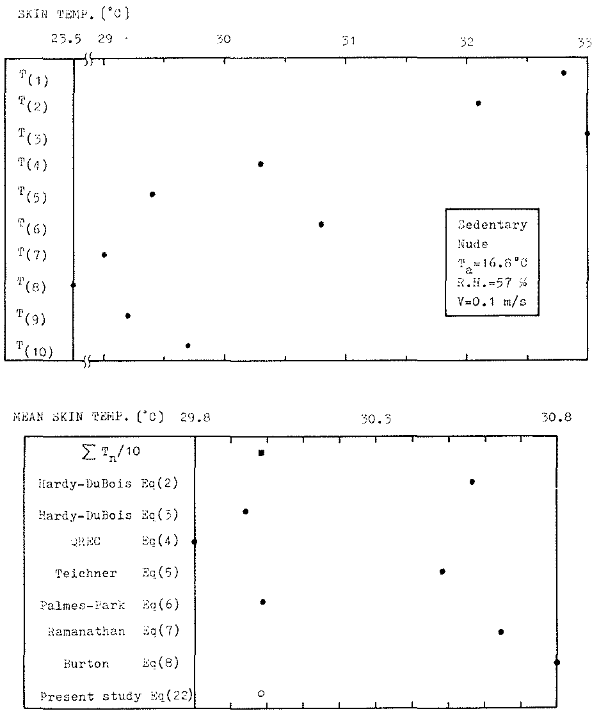

Fig. 8. Results of skin temperature measurement ($T_a = 16.8$°C) and comparison of various mean skin temperatures calculated.

Table 3. List of skin temperatures modified and substituted for calculating mean skin temperature

		Defined Skin Temp. $T_{(n)}$	Substituted Skin Temp. $T_{(n)}$
Hardy-DuBois	Eq (2)	$T_{(16)}$	$T_{(10)}$
Hardy-DuBois	Eq (3)	$T_{(14)}$ $T_{(15)}$ $T_{(16)}$	$T_{(9)}$ $T_{(10)}$ $T_{(10)}$
QREC	Eq (4)	$T_{(11)}$ $T_{(13)}$ $T_{(16)}$	$T_{(1)}$ $T_{(9)}$ $T_{(10)}$
Teichner	Eq (5)	$T_{(11)}$ $T_{(13)}$	$T_{(1)}$ $T_{(9)}$
Palmes-Park	Eq (6)	$T_{(11)}$	$T_{(1)}$
Present study	Eq (22)	$\frac{T_{(2)}+T_{(3)}+T_{(4)}+T_{(5)}}{4}$ $\frac{T_{(7)}+T_{(8)}}{2}$	$T_{(\mathrm{Trunk})}$ $T_{(\mathrm{Forearm})}$

5. Conclusions

As one of the indices for evaluating thermal environments, various mean skin temperatures weighted with body surface area ratio alone have been used. The weighting factors for calculating the mean, for instance, by distribution density of sense receptor or of nerve can be envisaged besides skin area ratio.

The author derived a general calculating formula (13) for mean skin temperature weighted with both ratios of heat transfer coefficient and body surface area from the heat balance equation between man and the environment based on the heat transfer theory.

$$T_s=\sum_1^n\left(\frac{h_{cn}+h_{rn}}{h_c+h_r}\right)\left(\frac{A_{sn}}{A_s}\right)T_{sn} \tag{13}$$

In the next place, from both theoretical analyses and experimental data, the actual numbers were substituted into local and mean convective heat transfer coefficients, h_{cn}, h_c, radiative coefficient $h_{rn}\,(\equiv h_r)$ and local and total skin areas A_{sn}, A_s which are composed of the weighting factors in Eq (13).

As a result, although a formula (22) for calculating mean skin temperature was proposed, quite accidentally the weighting factor amounted to 1.00 in this case.

$$\begin{aligned} T_s &= \sum_1^6\left(\frac{h_{cn}+h_{rn}}{h_c+h_r}\right)\left(\frac{A_{sn}}{A_s}\right)T_{sn} \\ &= 0.11\,T_{(\mathrm{Head})}+0.28\,T_{(\mathrm{Trunk})}+0.07\,T_{(\mathrm{Upper\ arms})} \\ &\quad +0.13\,T_{(\mathrm{Forearms})}+0.21\,T_{(\mathrm{Thighs})}+0.20\,T_{(\mathrm{Legs})} \end{aligned} \tag{22}$$

For the purpose of obtaining skin temperature data, experiments using subjects were performed. With the data measured, Eq (22) was compared with previously proposed mean skin temperatures weighted by mere area ratio and a general conclusion is that good agreement is obtained between Eq (22) and Eq (3) by Hardy-DuBois which has many measurement sites of skin temperatures and that poor agreement is occasionally seen between Eq (22) and averaging formulas with few measurement points in the present studies.

References

1) D. Mitchell and C. H. Wyndham: Comparison of weighting formulas for calculating mean skin temperature, J. Appl. Physiol., Vol. 26, No. 5, 1969, P. 616.

2) Y. Nishi and A. P. Gagge: Direct evaluation of convective heat transfer coefficient by naphthalene sublimation, J. Appl. Physiol., Vol. 29, No. 6, 1970, P. 830.

3) T. Mochida and Y. Nishi: Calculating method for mean skin temperature weighted with local heat transfer coefficient and skin area, SHASE annual meeting, 1971, P. 95.

4) T. Mochida: Convective and radiative heat transfer coefficients for the human body, Bulletin of the Faculty of Engineering, Hokkaido Univ., No. 84, 1977, P. 1.

5) A. Parker *et al*: Atmosphere selection and control for manned space stations, General Electric Co., Missile and Space Div., Valley Forge, Pa., Presented at the International Symposium for Manned Space Stations in Munch, 1965, (Cited by Ningen-Kankyokei, Ningen To Gijutsusha, 1972, P. 185, Written in Japanese).

6) W. H. McAdams: Heat transmission, McGraw-Hill, Kogakusha, 1962, P. 260.

7) P. H. Oosthuizen and S. Madan: Combined convective heat transfer from horizontal cylinders in air, ASME Trans., 1970, P. 194.

8) K. Ibamoto and Y. Nishi: Thermal sensation analysis and its application to air-conditioning, Bulletin of the Faculty of Engineering, Hokkaido Univ., No. 46, 1968, P. 73.

9) T. Mochida and K. Ibamoto: A study on evaluation of the thermal rediation effect—Mean rediant temperature weighted with the absorption factor—, Memoirs of the Faculty of Engineering, Hokkaido Univ., No. 64, 1976, P. 1.

10) T. Mochida: An examination on mean skin temperature from an engineering method, SHASE winter meeting, 1972, P. 5.