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Weighting coefficients for calculation of mean skin temperature: A review

Chhaya R Kavitkar, A.K. Mehta, Anvesha and Prachi Sharma

Abstract
Mean skin temperature is a physiological parameter of interest for the evaluation of thermal balance in human. Many different models for calculating the mean skin temperature have been proposed incorporating from one to fifteen local skin temperatures based on the different form of weighting coefficients. This article reviews the different form of weighting coefficient used in mean skin temperature models and conclusion.The crucial role of calculating mean skin temperature in the evaluation of thermal comfort has resulted several attempts to develop models being made, in order to estimate mean skin temperatures with various logics. Among the various methods employed, weighting coefficients i.e., based on the skin surface area ratio to the total body surface area has been most widely accepted and this system of weightings more faithfully represents the definition of mean skin temperature. (Lee *et al,* 2010)

Keywords: Weighting coefficients, calculation, mean skin temperature

Introduction
Skin temperature is said to be one of the indices useful for estimating thermal environments. The temperature of the skin is crucial for effective thermoregulation, together with the temperature of inner organs and the brain. The skin temperature, which is closely related to the thermal sensation, is a physiological value regulated by both the conditions of man and his working environment. Mean skin temperature (MST) is an average skin temperature of human body and important physiological parameter reflecting human response to heat or thermal stimulus and states of heat exchange between human body and a thermal environment. Many formulae for calculating the mean skin temperature have been proposed.
As there are several calculation methods of skin temperature, the variations in these methods lead to differences in the calculation results. This has been studied previously by several researchers. Mitchell *et al*. and Choi *et al*. studied 18 methods for calculating mean skin temperature. Lian *et al*. comprehensively compared 26 methods for calculating skin temperature. The mean skin temperature calculated by each method is obtained by multiplying a limited number of local skin temperatures and the corresponding weighting coefficients, and then summing them. The corresponding weighting coefficients are mostly calculated by the area of each part. All existing calculation methods use the area weighting method to calculate the mean skin temperature. The main difference is the number of skin temperature measurement points. With existing techniques, mean skin temperature is determined by weighting the skin temperature of certain body surface sections by the total body surface area. All the formulae can be described by a general form the sum of the product of both the regional skin temperature and the weighting coefficient concerned with the region. The purpose of the present paper is to present a different weighting coefficient for calculation of mean skin temperature.

Weighting Coefficients for Calculating Mean Skin Temperature
The calculation formula of mean skin temperature T_s is expressed using skin temperature T_{sn} and the weighting coefficient F_i of each region of the body as follows:

$$T_s = \sum F_i * T_{sn}$$

Where,
T_s- Mean skin temperature, ˚C
F_i- Weighting coefficient for calculating mean skin temperature
T_{sn}- Skin temperature at a specific site, n on the body, ˚C
Weighting coefficient F_i proposed by some researchers is classified into six categories as follows:

1. Simple average
2. One point
3. Skin surface area ratio
4. Skin surface area ratio and thermal sensitivity of the skin
5. Skin surface area ratio and heat transfer coefficients ratio
6. Skin surface area ratio and heat transfer coefficients ratio and sensitivity of the skin

Simple average

Based on the simple average group of weighting coefficients, Kurata and Funazu (two point) mean skin temperature model, Teichner (Ten point) mean skin temperature model, Stolwik and Hardy (Ten point) mean skin temperature model, and Mitchell and Wyndham (Fifteen point) mean skin temperature model developed mean skin temperature calculation models. Form of their weighting factor is as follow:

$$F_i = \frac{1}{n}$$

Where, F_i = Weighting factor
A simple average method exists from two point average by Kurata & Funazu (1954) [5] to fifteen point average by Mitchell & Wyndham (1969) [3]. Teichner (1958) [18] proposed a one point method by measuring only the medial thigh temperature.
Teichner (1958) [18], and Lund and Gisolfi (1974) [7] developed one point mean skin temperature model however it is not being used by the researchers. The general form of their weighting factor is as follow:

$$F_i = 1$$

Where, F_i = Weighting coefficient

Skin surface area ratio

Mean skin temperature is calculated based on the ratio of body surface sections to the total body surface area by Burton, 1934 [1]; Winslow *et al*., 1936 [19]; Hardy and DuBois, 1938 [4]; Palmes and Park, 1947 [13]; Teichner, 1958 [18]; Ramanthan, 1964 [14]; Stolwijk and Hardy, 1966 [17]; Mitchell and Wyndham, 1969 [3]; Nadel *et al*., 1971 [12]; Roberts *et al*., 1977 [16]; Research committee on physiological reaction to climatic seasonal change, the 7th division of Scientific Research Aid Board, Department of Education, Japan, 1952 [15]; Kurata and Funazu, 1954 [5]; Miura *et al*., 1960 [8], etc. With this technique, the distribution of skin temperature on the body surface is divided into different sections. The number of sections and the selection of representative sectional skin temperatures vary amongst these studies.
The general form of their weighting factor is as follow:

$$F_i = \frac{Ai}{A}$$

Where,
Fi = Weighting factor
Ai = Skin segment area at a specific site of the body, m^2
A = Total body surface area, m^2

Based on the skin surface area ratio, Burton (1934) [1] developed three point mean skin temperature model, based on the skin surface area ratio. Burton studied about the temperature of the surface of the human body is 4° or 5° lower than the interior temperature, which is not reached until a depth of several centimetres. A theoretical estimate is made of how the rectal and surface temperatures should be combined to give the true average. From the results of forty hour periods with the respiration calorimeter upon a group of subjects in basal and absorptive condition, the formula giving the least average discrepancy between direct and indirect heats is found experimentally fit. It agrees closely with that deduced theoretically, and is average temperature equals 0.65 X rectal temperature plus 0.35 X average surface temperatures. Based on the observations, the model was given with three sites as follows:

0.5 T_{sk} left upper chest + 0.36 T_{sk} left anterior calf + 0.14 T_{sk} left forearm

Hardy and DuBois (1938) [4] developed seven point mean skin temperature model based on the skin surface area ratio. The proportions of surface contributed by head, trunk, arms, legs, hands and feet are calculated from the linear formula and the average radiation per square centimetre from each of these is then multiplied by the percentage of the total area contributed by that part of the body. The model for calculation of mean skin temperature is: 0.07 T_{sk} Forehead + 0.14 T_{sk} Left forearm + 0.05 T_{sk} Left hand + 0.07 T_{sk} Left foot + 0.13 T_{sk} Left anterior calf + 0.19 T_{sk} Left anterior thigh + 0.35 T_{sk} Left abdomen
Hardy and DuBois (1938) [4] also developed twelve point mean skin temperature model based on the skin surface area ratio. The model for calculation of mean skin temperature is as follows:

0.07 T_{sk} Forehead + 0.0875 T_{sk} Chest + 0.0875 T_{sk} Abdomen + 0.14 T_{sk} Forearm + 0.05T_{sk} Lower arm + 0.095 T_{sk} Anterior thigh + 0.065 T_{sk} Shin + 0.07 T_{sk} Lower leg + 0.0875 T_{sk} Back + 0.0875 T_{sk} Lumbar + 0.095 T_{sk} Posterior thigh + 0.065 T_{sk} Calf

Newburgh and Spealman (1943) [20] proposed four point model for mean skin temperature measurement. They divided the human body areas in terms of whole limbs and weightages are in single digits, and making computations quite simple. Proposed four point mean skin temperature model is as follows:

0.34 $_{sk}$ Chest +0.33 T_{sk} thigh + 0.18 T_{sk} leg + 0.15 T_{sk} lower arm.

Ramanathan used nude, resting subjects, under various experimental conditions. He used a Tsk calculated by the 7-point formula of Hardy and Du-Bois (1938a) as a reference, and found a high correlation of Tsk. Based on an analysis of skin temperature data from three resting human subjects from 112 studies, a basic weighting system for calculating the mean skin temperature from measurements on four areas of the body namely chest, arms, thighs and legs have been proposed.

The proposed mean skin temperature model is as follow:

0.3 T_{sk} (Left upper chest + T_{sk} Left upper arm) + 0.2 (T_{sk} Left anterior thigh + T_{sk} Left anterior calf)

Winslow (1936) [19] developed fifteen point mean skin temperature model. An area weighted reference mean skin temperature was calculated from the temperatures measured at all 15 points according to the following equation.

$T_{skref} = C_{head}(T_1+T_2+T_3)/3 + C_{ant\ trunk}(T_4+T_5)/2 + C_{post\ trunk}(T_6+T_7)/2 + C_{upperarm}.T_8 + C_{forearm}\ T_9 + C_{hand}\ T_{10} + C_{thigh}(T_{11}+T_{12})/2 + C_{leg}(T_{13}+T_{14})/2 + C_{foot}\ T_{15}$

Where the weighting coefficients (C) correspond to the fractions of the total body surface area to which the temperature measurements correspond.

Skin surface area ratio and thermal sensitivity of the skin

Mean skin temperature is calculated based on the ratio of body surface sections to the total body surface area and thermal sensation (Nadel *et al*., 1973) [11]. This technique takes advantage of the relationship between temperature sensation and skin temperature. With this technique, temperature sensation is assessed in terms of evaporation ratios. This technique is suitable for calculating mean skin temperature at higher temperatures, but not at lower temperatures. The general form of their equation is as follow:

$$F_i = \frac{Ai}{A} * S$$

Where, Fi = Weighting factor
Ai = Skin segment area at a specific site of the body, m^2
A = Total body surface area, m^2
S = Thermal sensitivity

Nadel (1973) [11] conducted the study on differential thermal sensitivity of human skin. They concluded that face has a relatively greater thermal sensitivity than other skin areas. Thermal irradiation was applied to selected skin areas to determine whether particular areas demonstrate a greater thermal sensitivity than others in determination of a physiological thermoregulatory response. Based on the thermal sensitivity they suggested the weighing factors for calculation of mean skin temperature.

0.21 T_{sk} Forehead + 0.21 T_{sk} Chest + 0.12 T_{sk} Upper arm + 0.17 T_{sk} Abdomen + 0.06 T_{sk} Forearm+ 0.15 T_{sk} Thigh + 0.08 T_{sk} Lower leg

Skin surface area ratio and heat transfer coefficients ratio

Mean skin temperature is calculated based on the ratio of body surface sections to the total body surface area and the convective heat transfer coefficient for each section (Mochida and Nishi, 1971 [12]; Mochida, 1977 [9]; etc.). In other words, mean skin temperature is calculated using a formula for the heat balance between the human body and the surrounding environment. The convective heat transfer coefficient for each body surface section is calculated using a cylinder model or thermal mannequin. A heat balance formula is derived on the assumption that the total body surface area is involved in heat exchange through convection, radiation and evaporation. However, even in a relatively open standing position, there are some areas of body surface contact, but body surface contact is not involved in heat exchange between the body and the surrounding environment. Kurazumi *et al*. (2003) [21] reported a marked difference between the estimated and actual temperatures for postures involving substantial body surface contact, such as lying and sitting on the floor.

The general form of their equation is

$$F_i = \frac{Ai}{A} * \frac{hci + hri}{hc + hr}$$

Where, Fi = Weighting factor
Ai = Skin segment area at a specific site of the body, m^2
A = Total body surface area, m^2
h_{ci} = Local convective heat transfer coefficient at the site of human body, kcal/m^2h˚C
h_{ri}=Local radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C
h_c= Mean convective heat transfer coefficient at the site of human body, kcal/m^2h˚C
hr = Mean radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C

Nishi and Gagge (1970) [22] developed eight point mean skin temperature model based on the skin surface area ratio and heat transfer coefficients ratio. Nishi and Gagge (1970) [22] conducted the study on direct evaluation of convective heat transfer coefficient by naphthalene sublimation. They measured the convective heat transfer coefficient (h_c) directly by observing the sublimation rate of ten 3cm diameter naphthalene balls located evenly over and 3 cm off the body surface. Observations were made on subjects while sitting-resting, treadmill and free walking at 2, 3, and 4 mph, and bicycling on an ergometer at 50 and 60 rpm allin normally ventilated environments (approx. 30 ft/min). They found that results agree with comparable values from partitional calorimetry for sitting-resting and a man-sized calorimetric manikin but are less so for bicycle exercise. Equations, prediction, as a function of treadmill or free walking speed, are developed. They used the results to measure more accurately total and regional dry heat losses, for calculating average skin temperature by convective heat transfer coefficient. They presented the formula for calculation of mean skin temperature-

0.07 T_{sk} Forehead + 0.16 T_{sk}Chest + 0.08 T_{sk} Upper arm + 0.08 T_{sk} Forearm + 0.18 T_{sk} Thigh + 0.21 T_{sk} Lower leg + 0.16 T_{sk} Back + 0.06 T_{sk} Palm

Mochida (1983) [10] developed seven point mean skin temperature model based on the Skin surface area ratio and heat transfer coefficients ratio. The researcher derived a general calculating formula for mean skin temperature calculation weighted with ratios of heat transfer coefficient and body surface area from heat balance equation between man and the environment based on the heat transfer theory. Developed seven point mean skin temperature model based on the Skin surface area ratio and heat transfer coefficients ratio as follow:

0.11 T_{sk} Head + 0.28 T_{sk} Trunk + 0.07 T_{sk} Upper arm + 0.13 T_{sk} Forearm + 0.21 T_{sk} Thigh + 0.20 T_{sk} Leg

Skin surface area ratio and heat transfer coefficients ratio and sensitivity of the skin

Mean skin temperature is calculated based on the ratio of body surface sections to the total body surface area, the convective heat transfer coefficient for each section, and thermal sensation (Mochida, 1983) [10]. With this technique, the weighting coefficients proposed by Nadel *et al*. (1973) [11] are combined with local convective heat transfer coefficients derived from a heat balance formula. With this technique, caution should be exercised when calculating mean skin temperature for postures with substantial body surface contact and at lower temperatures.

The general form of their equation is follow:

$$F_i = \frac{Ai}{A} * \frac{hci + hri}{hc + hr} * S$$

Where, Fi = Weighting factor

Ai = Skin segment area at a specific site of the body, m^2

A = Total body surface area, m^2

S = Thermal sensitivity

h_{ci} = Local convective heat transfer coefficient at the site of human body, kcal/m^2h˚C

h_{ri}=Local radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C

h_c= Mean convective heat transfer coefficient at the site of human body, kcal/m^2h˚C

hr = Mean radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C

Mochida (1983) [10] developed seven mean skin temperature model based on the Skin surface area ratio and heat transfer coefficients ratio and sensitivity of the skin. Based on the heat equilibrium between man and his environment, the author newly derived a mean skin temperature model weighted by the skin areas and heat transfer coefficients. With reference to the thermal sensitivity coefficients given by Nadel *et al*, a new formula, which is weighted by three important factors, the skin area, the heat transfer coefficients and the thermal sensitivity was proposed. The derived mean skin temperature model weighted by skin area, the transfer coeffients and the thermal sensitivity as follow:

0.198 T_{sk} Face + 0.179 T_{sk} Chest and back + 0.145 T_{sk} Abdomen + 0.153 T_{sk} Upper legs + 0.092 T_{sk} Lower legs + 0.138 T_{sk} Upper arms + 0.076T_{sk} Lower arms

Conclusions

Many sets of weighting coefficients have been published, differing mainly in the number of skin sites used. One has to choose between the available formulae or construct an independent set. The best weighted mean skin temperature will be derived by measuring the temperature at large number of sites and actually determining the area represented by each temperature, Mitchell and Wyndham (1969) [3]. Weighting coefficients are determined according to the relative influence of the particular skin areas on the temperature centre rather than from their significance in heat exchange.

The initial interest in mean skin temperature originated from discussions concerning the estimation of mean body temperature (Burton, 1934; Hardy DuBois, 1938) [1, 4]. The change in mean body temperature reflects body heat storage, which is necessary term to quantify heat exchange between the human body and the surrounding environment. The crucial role of calculating mean skin temperature in the evaluation of thermal comfort, has resulted in a number of attempts to develop models being made, in order to estimate mean skin temperatures with various logics i.e. simple average, one point, skin surface area ratio, skin surface area ratio and sensitivity of the skin, skin surface area and heat transfer coefficient ratio as discussed above. Among the various methods employed, weighting coefficients, i.e. based on the skin surface area ratio to the total body surface area has been most widely accepted and this system of weightings more faithfully represents the definition of mean skin temperature. (Lee *et al*, 2010) [6]

From the perspective of the heat exchange between the human body and the surrounding environment, taking convective heat transfer as an example, the total heat exchange is the product of the heat transfer coefficient (heat exchange per unit area and unit temperature difference) and the temperature difference and the heat exchange area. In this case, it is reasonable to use the area weighting method to calculate the mean skin temperature. However, various parts of the human skin have different sensitivity to temperature changes. This variation in sensitivity to temperature changes must also be considered when predicting the thermal sensation of the human body.

References

1. Burton AC. The average temperature of the tissues of the body, Journal of Human calorimetry. Department of vital economics, University of Rochester, Rochester New York; c1934.
2. Du-Bois BS. The Measurement of the surface area of man. Clinical calorimetry, New York; c1915.
3. Duncan M, Wyndham CH. Comparison of weighting formula for calculating mean skin temperature. Journal of Applied Physiology, 1969, 26(5).
4. Hardy JD, Du-Bois EF. The technic of measuring radiation and convection. Journal of Nutrition. 1938;15:461-475.
5. Kurata M, Funazu Y. A practical method of evaluating mean skin temperature Journal of Sci. Labour. 1954;30(5):332-337.
6. Lee JY, Nakao K, Tochihara K. Chest, abdomen, or back: selecting an optimum trunk region for Hardy and Du-Bois weighted mean skin temperature formula. Journal of the Human Environment system. 2010;13(1):7-14.
7. Lund DL, Gisolfi CV. Estimation of skin temperature during exercise. Journal of applied physiology. 1974;36(5):625-628.
8. Miura T, Morioka M, Kimura K, Akutsu A, Hyodo S, Osawa H, *et al*. Experimental studies on the optimum temperature of room cooling in summer in relation to the outdoor temperature J. Sci. Labour. 1960;36(6):283-336.
9. Mochida T. Mean skin temperature weighted with both ratios of heat transfer coefficient and body surface area., Bulletin of the Faculty of Engineering, Hokkaido University. 1977;85:15-26.
10. Mochida T. Mean skin temperature weighted by skin area, heat transfer coefficients and thermal sensitivity, Bulletin of the Faculty of Engineering, Hokkaido University. 1983;115:1-10.
11. Nadel ER, Mitchell JW, Stolwijk AJ. Differential thermal sensitivity in the human skin John B Pierce foundation laboratory and Yele University School of Medicine, New

Haven, Connecticut. 1973;340:71-76.
12. Nadel ER, Bullard RW, Stolwijk AJ. Importance of skin temperature in the regulation of sweating. Journal of applied physiology, 1971, 31(1).
13. Palmes ED, Park CR. Thermal regulation during early acclimatization to work in a hot dry environment.United state army medical department. Field research laboratory; c1947.
14. Ramanathan NL. A new weighting system for mean surface temperature of the human body. Industrial Health Research Unit, Section of Physiological and industrial Hygiene. All India institute of Hygiene and Public health Calcutta, India; c1964.
15. Research Committee on physiological reaction to climatic seasonal change, the 7th division of Scientific Research Aid Board, Department of Education, Japan Seasonal variations of skin temperature distribution of Japanese male adults. Nisshin Igaku. 1952;39(3):121-136.
16. Roberts MF, Wenger CB, Stolwijk JAJ, Nadel ER. Skin blood flow and sweating changes following exercise training and heat acclimation. Journal of Applied Physiology. 1977;43(1):133-137.
17. Stolwijk JAJ, Hardy JD. Partitional calorimetric studies of responses of man to thermal transients. Journal of Applied Physiology. 1966;21(3):967-977.
18. Teichner WH. Assessment of mean body surface temperature. Journal of Physiology. American physiological society; c1958.
19. Winslow CEA, Herringtone LP, Gagge AP. A new method of partitional calorimetry. American Journal of Physiology. 1936;116(3):641-655.
20. Newburgh LH, Spealman CR. Acclimation to cold. CAM Report, 1943, 241.
21. Kaita S, Hou Z, Nishiura M, Doi Y, Kurazumi J, Horiuchi AC, *et al*. Ultimately Specific 1, 4-cis Polymerization of 1, 3-Butadiene with a Novel Gadolinium Catalyst. Macromolecular rapid communications. 2003 Feb;24(2):179-184.
22. Nishi Y, Gagge AP. Direct evaluation of convective heat transfer coefficient by naphthalene sublimation. Journal of applied physiology. 1970 Dec 1;29(6):830-838.