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TEMPERATURE VARIATION IN SKIN AND SUBCUTANEOUS LAYERS UNDER DIFFERENT ENVIRONMENTAL CONDITIONS—A TWO DIMENSIONAL STUDY

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Attempt has been made to study temperature variation in skin and subcutaneous tissues of human body for various values of environmental temperatures, wind velocity and rate of sweat evaporation. The mathematical model incorporates the effect of blood mass flow and metabolic heat generation. The outer surface of the skin is assumed to be exposed to the environment and the heat loss from the skin caused by convection, radiation and sweat evaporation. The rates of blood mass flow, metabolic, heat generation and thermal conductivity have been assigned different values in each layer of the region. The formulation for two dimensional steady state case is presented. Variational finite element analysis has been used to obtain nodal temperatures for different values of skin thickness. It has been observed that the environmental changes effect mainly outer layer of the skin and inner layers are influenced by body core temperature.

INTRODUCTION

Heat generation within the body and its dissipation from the body are continuous processes. Most of the heat produced in the body is transported to the skin through which it is dissipated to the environment. The human body constantly endeavours to maintain a state of balance between the heat generated in it and that rejected from it. This physiological thermoregulatory activity of the body depends to a large extent on the prevailing environmental conditions. The skin being the surface of interaction between the body and environment plays an important role in the temperature regulation in human body and the heat balance of it with the surroundings.

The skin and subcutaneous tissues (SST) region of the human body consists of dead tissues in the from of stratum corneum on one side and cells with continuous metabolic activity and dense blood vessels with connective nerve fibers on the other side. In between lie fibrous tissues, fat cells, lymphatics, blood vessels and sweat ducts (Fig. 1). All these components help in maintaining a uniform body core temperature and

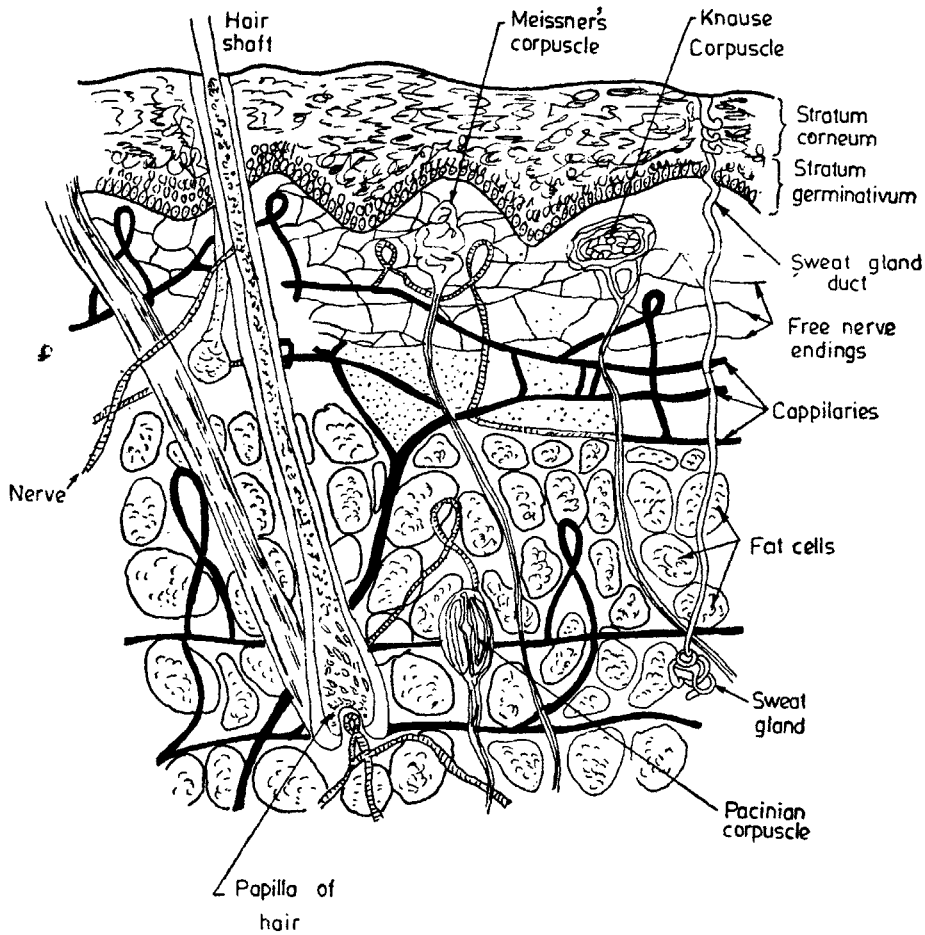

FIG. 1. Section through the skin showing the structures in epidermis and dermis.

regulate the effect of environmental variations. The important processes which account for this regulation are metabolism, blood flow and perspiration.

Due to the complexity of structure of the region and involvement of many physical parameters, a theoretical study regarding temperature distribution is useful in many studies concerning physiology and allied sciences. Attempts have been made earlier by Patterson[5,6] for experimental determination of temperature profiles in the SST region. Saxena[7], Saxena and Arya[8-10] have obtained temperature distribution in the region by using analytic and numerical methods. All these studies are confined to one dimensional cases and do not give any idea about the effect of different environmental factors on the temperature distribution in the region.

The present study deals with two dimensional steady state case of temperature distribution in SST under various environmental conditions. A rectangular area of the

region has been considered with outer surface exposed to the environment. It is assumed that the loss of heat is due to convection, radiation and evaporation of sweat. The three natural layers namely, epidermis, dermis and subcutaneous, of the region have been considered. Each layer has been divided into eight triangular elements. The quantitative details available from the experimental investigations by Hodgson[3] have been used to obtain the results. Average values of rate of blood mass flow (rbmf), metabolic heat generation (rmhg) and thermal conductivity have been considered for each layer. Variational finite element analysis has been used to obtain nodal temperatures. Firstly, the mathematical formulation has been done for a particular element (Fig. 2) and then this formulation has been used to obtain the matrix for the whole region (Fig. 3).

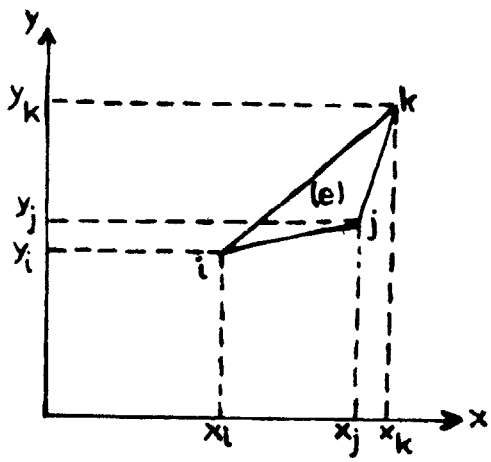

FIG. 2. Finite element triargular element.

MATHEMATICAL FORMULATION

If Q denotes quantity of heat in a tissue element at time t then $\frac{\partial Q}{\partial t}$ is sum of the rates of charges due to diffusion (d), perfusion (p) and metabolic heat generation (m). Accordingly, we have

$$\frac{\partial Q}{\partial t} = \left.\frac{\partial Q}{\partial t}\right|_d + \left.\frac{\partial Q}{\partial t}\right|_p + \left.\frac{\partial Q}{\partial t}\right|_m . \qquad \ldots(1)$$

The first term on the right hand side of eqn. (1) can be defined with the help of Fourier's Law and third term can be denoted by S, the rate of metabolic heat generation. The middle term which accounts for the heat supplied or removed through perfusion can be described with the help of Fick's Principle. Consequently we arrive at the following differential equation :

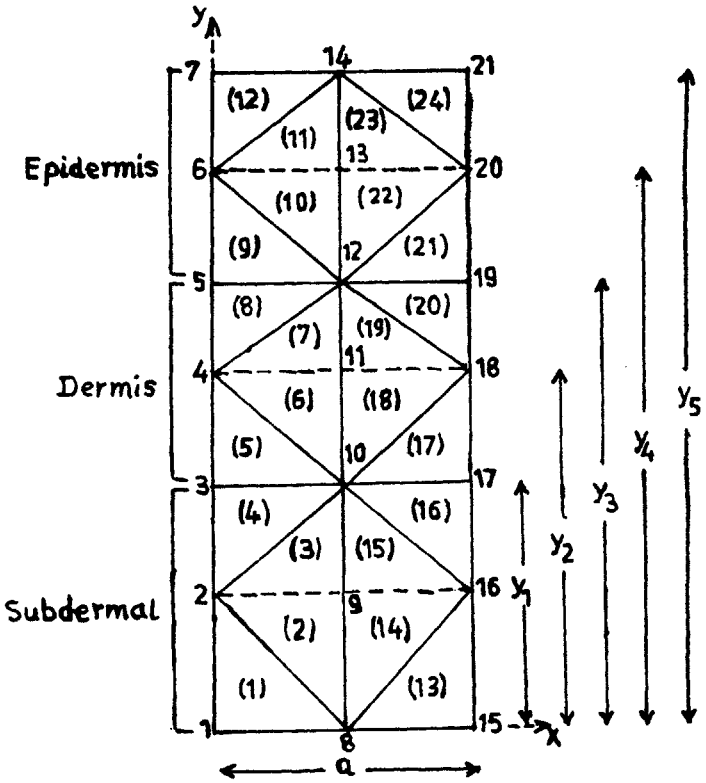

FIG. 3. Finite element arrangement for the whole region,

$$\rho \bar{c} \frac{\partial \theta}{\partial t} = \text{div}\,(K \text{ grad } \theta) + mc_b (\theta_b - \theta) + S. \qquad \ldots(2)$$

Assuming heat loss at the outer boundary due to convection-radiation and evaporation, we have

$$K \frac{\partial \theta}{\partial n} = h (\theta - \theta_a) + L E \qquad \ldots(3)$$

where first term on the right-hand side shows the loss of heat due to convection-radiation and second term determines heat loss due to sweat evaporation from the skin surface. The other boundary conditions are as follows :

$$\left.\frac{\partial \theta}{\partial x}\right|_{x=0} = 0, \quad \left.\frac{\partial \theta}{\partial x}\right|_{x=a} = 0, \quad \theta (X, 0) = \theta_b. \qquad \ldots(4)$$

Here ρ, $\bar{c}$, K, n, h, θ_a, L and E are respectively tissue density, tissue specific heat, tissue thermal conductivity, normal to the outer surface, heat transfer coefficient, atmospheric temperature, latent heat of evaporation and rate of sweat evaporation.

The partial differential equation (2) coupled with boundary condition (3) written in two dimensional steady state case and compared with Euler-Lagrange equation (Myers[4]) is transformed into the following variational form :

$$I = \frac{1}{2}\int_{y=0}^{y_5}\int_{x=0}^{a}\left[K\left(\frac{\partial\theta}{\partial x}\right)^2 + K\left(\frac{\partial\theta}{\partial y}\right)^2 + mc_b(\theta_b - \theta)^2 - 2S\theta\right] dx\,dy + \frac{1}{2}\int_s\left[h(\theta - \theta_a)^2 + 2LE\theta\right] ds \qquad ...(5)$$

here A denotes the region under consideration and s the surface of the region where a convective transfer boundary condition is given. Integral I may be divided into following parts :

$$I = I_k + I_h - I_g + I_q \qquad ...(6)$$

where

$$I_k = \frac{1}{2}\int\int_A\left[K\left(\frac{\partial\theta}{\partial x}\right)^2 + K\left(\frac{\partial\theta}{\partial y}\right)^2\right] dx\,dy \qquad ...(7)$$

$$I_h = \frac{1}{2}\int\int_A mc_b(\theta_b - \theta)^2\,dx\,dy \qquad ...(8)$$

$$I_g = \int\int_A S\theta\,dx\,dy \qquad ...(9)$$

$$I_q = \frac{1}{2}\int_s\left[h(\theta - \theta_a)^2 + 2LE\theta\right] ds. \qquad ...(10)$$

I, the integral to be minimized, will be a function of the nodal temperatures. To minimise I, it is differentiated with respect to each nodal temperature and each derivative be set equal to zero. That is :

$$I = I(\Theta) \qquad ...(11)$$

where

$$\Theta = [\theta_1, \theta_2, \ldots, \theta_M]^T \qquad ...(12)$$

$$\frac{dI}{d\Theta} = \left[\frac{\partial I}{\partial\theta_1}, \frac{\partial I}{\partial\theta_2}, \ldots, \frac{\partial I}{\partial\theta_M}\right]^T = 0 \qquad ...(13)$$

where 0 is a column matrix of M zeros. The region contains twenty four elements (Fig. 3) so equation (6), with the help of equation (13), may be written as :

$$\frac{dI}{d\Theta} = \frac{d}{d\Theta}\sum_{e=1}^{24} I^{(e)} = \sum_{e=1}^{24} \frac{dI^{(e)}}{d\Theta} = 0 \qquad \ldots(14)$$

here (e) denotes a particular element (Fig. 2). The derivative of $I^{(e)}$ with respect to Θ is a column matrix of mostly zero elements because $I^{(e)}$ depends only on θ_i, θ_j and θ_k and not on the other nodal temperatures. That is

$$\frac{dI^{(e)}}{d\Theta} = \left[0, 0, \ldots, \frac{\partial I^{(e)}}{\partial \theta_i}, \frac{\partial I^{(e)}}{\partial \theta_j}, \frac{\partial I^{(e)}}{\partial \theta_k}, \ldots, 0, 0\right]^T . \qquad \ldots(15)$$

To avoid working with all these zeros, we consider matrix (15) to be the product of an 21×3 matrix and a 3×1 column matrix. That is we can write now :

$$\frac{dI^{(e)}}{d\Theta} = M^{(e)} \frac{dI^{(e)}}{d\Theta^{(e)}} \qquad \ldots(16)$$

where

$$M^{(e)} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ \leftarrow i\text{th row} \\ \leftarrow j\text{th row} \\ \leftarrow k\text{th row} \\ \\ \end{matrix} \qquad \ldots(17)$$

$$\frac{dI^{(e)}}{d\Theta^{(e)}} = \begin{bmatrix} \dfrac{\partial I^{(e)}}{\partial \theta_i} \\ \dfrac{\partial I^{(e)}}{\partial \theta_j} \\ \dfrac{\partial I^{(e)}}{\partial \theta_k} \end{bmatrix} . \qquad \ldots(18)$$

Within each element we assume that the temperature varies linearly between the three corner temperatures. This may be expressed as follows :

$$\theta^{(e)} = C_1^{(e)} + C_2^{(e)}\, x + C_3^{(e)}\, y \qquad \ldots(19)$$

or

$$\theta^{(e)} = p^T\, C^{(e)} \qquad \ldots(20)$$

where

$$p^T = [1 \quad x \quad y] \qquad \ldots(21)$$

and

$$C^{(e)} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix}^{(e)}. \qquad \ldots(22)$$

The coefficients C_1, C_2 and C_3 may be evaluated as $\theta^{(e)}$ is equal to θ_i, θ_j and θ_k at the corners of the element. Thus we have

$$\Theta^{(e)} = P^{(e)} C^{(e)} \qquad \ldots(23)$$

where

$$\Theta^{(e)} = \begin{bmatrix} \theta_i \\ \theta_j \\ \theta_k \end{bmatrix}, \quad P^{(e)} = \begin{bmatrix} 1 & x_i & y_i \\ 1 & x_j & y_j \\ 1 & x_k & y_k \end{bmatrix}$$

from eqn. (23) we get

$$C^{(e)} = P^{(e)-1} \Theta^{(e)} = R^{(e)} \Theta^{(e)}$$

where

$$R^{(e)} = P^{(e)-1} = \frac{1}{x_{ij}y_{jk} - x_{jk}y_{ij}} \begin{bmatrix} x_j y_k - x_k y_j & x_k y_i - x_i y_k & x_i y_j - x_j y_i \\ -y_{jk} & y_{ik} & -y_{ij} \\ x_{jk} & -x_{ik} & x_{ij} \end{bmatrix}$$

here $x_{ij} = x_j - x_i$ and $y_{ij} = y_j - y_i$

substitution of this result in equation (20) gives

$$\theta^{(e)} = p^T R^{(e)} \Theta^{(e)}. \qquad \ldots(24)$$

Now, we take up the function $I_k^{(e)}$, which from eqn. (7), may be written for the element (e) as :

$$I_k^{(e)} = \frac{K^{(e)}}{2} \int_{A^{(e)}} \int \left[\left(\frac{\partial \theta^{(e)}}{\partial x} \right)^2 + \left(\frac{\partial \theta^{(e)}}{\partial y} \right)^2 \right] dx\, dy. \qquad \ldots(25)$$

Differentiation of equation (24) and substitution of the results in eqn. (25) gives :

$$I_k^{(e)} = \frac{K^{(e)}}{2} \int_{A^{(e)}} \int \left[\left(p_x^T \; R^{(e)} \; \Theta^{(e)} \right)^2 + \left(p_y^T \; R^{(e)} \; \Theta^{(e)} \right)^2 \right] dx \; dy. \qquad \ldots(26)$$

Equation (26) is differentiated with respect to each of the threee corner temperatures at the same time. Thus

$$\frac{dI_k^{(e)}}{d\Theta^{(e)}} = \frac{K^{(e)}}{2} \int_{A^{(e)}} \int \left[2 \left(p_x^T \; R^{(e)} \; \Theta^{(e)} \right) \left(p_x^T \; R^{(e)} \right)^T + 2 \left(p_y^T \; R^{(e)} \; \Theta^{(e)} \right) \left(p_y^T \; R^{(e)} \right)^T \right] dx \; dy$$

$$= K^{(e)} \; R^{(e)T} \int_{A^{(e)}} \int \left(p_x \; p_x^T + p_y \; p_y^T \right) dx \; dy \; R^{(e)} \; \Theta^{(e)}. \qquad \ldots(27)$$

Simplification of eqn. (27) gives

$$\frac{dI_k^{(e)}}{d\Theta^{(e)}} = B^{(e)} \; \Theta^{(e)} \qquad \ldots(28)$$

where

$$B^{(e)} = \frac{K^{(e)} \; A^{(e)}}{(x_{ij} y_{jk} - x_{jk} y_{ij})^2} \begin{bmatrix} x_{jk}^2 + y_{jk}^2 & -(x_{ik} x_{jk} + y_{ik} y_{jk}) & (x_{ij} x_{jk} + y_{ij} y_{jk}) \\ & x_{ik}^2 + y_{ik}^2 & -(x_{ij} x_{ik} + y_{ij} y_{ik}) \\ \text{(symmetry)} & & x_{ij}^2 + y_{ij}^2 \end{bmatrix} \qquad \ldots(29)$$

and

$$A^{(e)} = \frac{1}{2} \mid x_{ij} \; y_{jk} - x_{jk} \; y_{ij} \mid .$$

Equation (28) is now substituted in eqn. (16) and the result for all elements is expressed as follows :

$$\frac{dI_k}{d\Theta} = \sum_{e=1}^{24} M^{(e)} \; B^{(e)} \; \Theta^{(e)} = \sum_{e=1}^{24} M^{(e)} \; B^{(e)} \; M^{(e)T} \; \Theta = B \; \Theta \qquad \ldots(30)$$

where

$$\Theta^{(e)} = M^{(e)T}\,\Theta \text{ and } B = \sum_{e=1}^{24} M^{(e)}\,B^{(e)}\,M^{(e)T}.$$

Similarly we obtain the values for other integrals in the following form :

$$\frac{dI_g}{d\Theta} = g \sum_{e=1}^{24} S^{(e)} \qquad \ldots(31)$$

$$\frac{dI_h}{d\Theta} = (H - g\,\theta_b) \sum_{e=1}^{24} (mc_b)^{(e)} \qquad \ldots(32)$$

where

$$g = \sum_{e=1}^{24} M^{(e)}\,g^{(e)};\; g^{(e)} = A^{(e)}\,[1\ 1\ 1]^T/3;\; H = \sum_{e=1}^{24} M^{(e)}\,H^{(e)}$$

$$H^{(e)} = R^{(e)T}\,A^{(e)}\,Q_c^{(e)}\,R^{(e)};\quad Q_c^{(e)} = \begin{bmatrix} 1 & x_c & y_c \\ x_c & A^{(e)}x_c^2 & A^{(e)}x_c y_c \\ y_c & A^{(e)}x_c y_c & A^{(e)}y_c^2 \end{bmatrix}$$

$$x_c = (x_i + x_j + x_k)/3;\; y_c = (y_i + y_j + y_k)/3.$$

Now, corresponding to eqn. (16) and (17) we can write a similar expression for the boundary condition terms. That is

$$\frac{dI_q^{(e)}}{d\Theta} = D^{(e)} \frac{dI_q^{(e)}}{d\Theta_x^{(e)}} \qquad \ldots(33)$$

where

$$D^{(e)} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{matrix} \\ i\text{.h row} \\ j\text{th row.} \\ \\ \end{matrix} \qquad \ldots(34)$$

Here we are considering only one side of element (e), between nodes i and j, to have a convection conditions. The linear temperature distribution along the boundary may be expressed as follows :

$$\theta_x^{(e)} = x^T X^{(e)} \Theta_x^{(e)} \qquad \ldots(35)$$

where

$$x^T = [1 \quad x] \text{ and } X^{(e)} = \frac{1}{x_{ij}} \begin{bmatrix} x_j & -x_i \\ -1 & 1 \end{bmatrix}. \qquad \ldots(36)$$

Now,

$$I_q^{(e)} = \frac{h^{(e)}}{2} \int_{xi}^{xj} \left(\theta_x^{(e)} - \theta_a \right)^2 dx + LE \int_{xi}^{xj} \theta_x^{(e)} \, dx$$

$$= \frac{h^{(e)}}{2} \int_{xi}^{xj} \left(x^T X^{(e)} \Theta_x^{(e)} - \theta_a \right)^2 dx + LE \int_{xi}^{xj} x^T X^{(e)} \Theta_x^{(e)} \, dx \qquad \ldots(37)$$

differentiation of this equation with respect to $\Theta_x^{(e)}$ gives :

$$\frac{dI_q^{(e)}}{d\Theta_x^{(e)}} = \frac{h^{(e)}}{2} \int_{xi}^{xj} 2 \left(x^T X^{(e)} \Theta_x^{(e)} - \theta_a \right) (x^T X^{(e)})^T dx + LE \int_{xi}^{xj} (x^T X^{(e)})^T dx$$

$$= \frac{h^{(e)}}{2} X^{(e)T} \int_{xi}^{xj} \left[x \, x^T X^{(e)} \Theta_x^{(e)} - \theta_a \, x \right] dx + LE \, X^{(e)T} \int_{xi}^{xj} x \, dx. \qquad \ldots(38)$$

Matrix integration is now carried out to obtain the following result :

$$\frac{dI_q^{(e)}}{d\Theta_x^{(e)}} = H_x^{(e)} \Theta_x^{(e)} - N_x^{(e)} + U_x^{(e)} \qquad \ldots(39)$$

where

$$H_x^{(e)} = h^{(e)} x_{ij} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \Big/ 6; \; N_x^{(e)} = \frac{h^{(e)}}{2} x_{ij} \theta_a \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$U_x^{(e)} = \frac{1}{2} LE\, X^{(e)T} \begin{bmatrix} 1 \\ 1 \end{bmatrix}.$$

Equation (39) is now substituted in equation (33) to obtain the results for all the elements which have convective boundary condition. Thus we obtain:

$$\frac{dI_q}{d\Theta} = \sum D^{(e)} \left(H_x^{(e)}\, \Theta_x^{(e)} - N_x^{(e)} + U_x^{(e)} \right)$$

$$= \sum D^{(e)}\, H_x^{(e)}\, D^{(e)T} - \sum D^{(e)} \left(N_x^{(e)} - U_x^{(e)} \right). \qquad \ldots(40)$$

These summations may be replaced by global matrices defined below :

$$H_x = \sum D^{(e)}\, H_x^{(e)}\, D^{(e)T} \;,\; W_x = \sum D^{(e)} \left(N_x^{(e)} - U_x^{(e)} \right).$$

Thus eqn. (40) may be stated as follows :

$$\frac{dI_q}{d\Theta} = H_x\, \Theta - W_x. \qquad \ldots(41)$$

Substituting the results of eqns. (30), (31), (32) and (41) in eqn. (14) we obtain;

$$\frac{dI}{d\Theta} = B\,\Theta + (H\,\Theta - g\,\theta_b) \sum_{e=1}^{24} (mc_b)^{(e)} - g \sum_{e=1}^{24} S^{(e)} + H_x\Theta - W_x = 0$$

or

$$\left[B + H \sum_{e=1}^{24} (mc_b)^{(e)} + H_x \right] \Theta = \sum_{e=1}^{24} (mc_b\, \theta_b + S)^{(e)} + W_x. \qquad \ldots(42)$$

Equation (42) gives a matrix of order 21 × 21. This matrix reduces to order 18 × 18 on the application of the condition that the body core temperature is prescribed (37°C). Solution of this final matrix gives the values of nodal temperatures of the region.

Numerical Results

From the geometry of the skin (Fig. 1) it appears that interfaces of different layers are not smooth. Some part of the dermis is projected into epidermis layer thus this portion may have some blood flow. Also the population density of the blood vessels increases gradually and becomes uniform in the subdermal layer. The dermis layer has more variation in the population density of the blood vessels. Due to these

reasons small values of m and S have been assigned to the elements (9) and (21) which are situated at the interface of epidermis and dermis. These values are taken zero for all other elements of epidermis. Two different set of these values have been considered for the elements of dermis layer. All elements of subcutaneous layer have same values of m and S. Constant but different values of thermal conductivity have been assigned to each layer. Details about these values and other physical constants are given in Table I (Chao *et al.*[1], Guyton[2]). The values of environmental conditions namely,

TABLE I

Values of physical constants

	Epidermis	Dermis	Subcutaneous tissues
K (cal/cm.min.degC)	0.03	0.045	0.06
mc_b (cal/cm^{3}min.degC)	0.0066	0.0198	0.0264
	(for elements 9,21)	(elements 5,6,17,18)	
		0.0132	
		(elements 7,8,19,20)	
S (cal/cm^2.min)	0.0176	0.0526	0.0702
	(elements 9,21)	(elements 5,6,17,18)	
		(elements 5,6,17,18)	
		0.0348	
		(elements 7,8,19,20)	

h = 0.009 cal/cm^{2}min.degC. at 0.5 m/sec. wind speed,
= 0.045 cal/cm^{2}min.degC. at 5.0 m/sec. wind speed.
L = 579 cal/gm.
θ_b = 37 deg. C.

humidity, atmospheric temperature, wind speed and rate of sweat evaporation are listed in Table II (Hodgson[3]). The values of nodal temperatures for three sets of skin thickness (Table III) are shown in Table IV. The three sections of this table correspond to set-I, II and III of skin thickness respectively. Also, the values are in the same order of environmental conditional (E_1, E_2,...,E_7) as shown in Table II.

DISCUSSION

(A) *Discussion of the Method*

The complexity in the structure of the SST region prevents the use of well known analytic and numerical methods in obtaining a useful solution for the study of heat

TABLE II

Values of environmental conditions

	E_1	E_2	E_3	E_4	E_5	E_6	E_7
Humidity (%)	22	39	72	72	39	22	72
Rate of sweat evaporation (gm/cm^{2}min)	1.41×10^{-3}	1.08×10^{-3}	0.82×10^{-3}	0.42×10^{-3}	0.516×10^{-3}	0.60×10^{-3}	0.51×10^{-3}
atmospheric temperature (θ_a deg. C.)	35	25	15	15	25	35	35
wind speed (m/sec.)	5.0	5.0	5.0	0.5	0.5	0.5	5.0

TABLE III

Skin layers thickness in cm

set	y_1	y_2	y_3	y_4	y_5	a
I	0.06	0.11	0.16	0.18	0.20	0.10
II	0.16	0.24	0.32	0.36	0.40	0.10
III	0.20	0.30	0.40	0.45	0.50	0.10

migration in the region. Skin is a layered medium and each layer has different physical properties. These layers are neither smooth nor distinct from each other. Sometimes the geometry of each layer is also irregular. Variational finite element analysis provides a guideline to divide the whole region into number of finite elements and then assemble the result for the whole region. Such type of division provides us flexibility in assigning suitable and independent values to quantities like thermal conductivity, density, rbmf and rmhg etc.

Another most important merit of variational finite element method is that all matrices obtained in the analysis are symmetric which is a computational advantage. Also, finite element solution approaches the exact solution as the number of nodal points increase.

(B) Discussion of the Results

(i) The temperature of the outer surface of the skin changes markedly with the change in the environmental conditions without an equal change in the temperature of the deeper layers.

(ii) The fall in the temperature with the rise in the value of E is considerably more for thick skin layers than thin layers. In latter case influence of θ_b (body core temperature) is easily seen on the temperature distribution.

(iii) The nodes situated at the same depth from the surface have almost equal temperature showing the uniform effect of the environmental changes.

(iv) Effect of wind velocity on the temperature distribution may be noticed from the nodal temperatures for the values E_2 and E_5 (or E_3 and E_4). There is considerable difference in the nodal temperatures for these values as the wind velocity changes the rate of sweat evaporation. The wind speed in the former case (E_2 or E_3) is ten times more than later case (E_5 or E_4).

(v) The results elaborate the fact that the atmospheric humidity constitute a barrier for heat dissipation to the atmosphere. In case of higher values of humidity skin temperature is high due to lack of ease with which heat is transferred to the

TABLE IV

Values of nodal temperatures in degree centigrade

θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_9	θ_{10}	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}	θ_{21}
36.26	35.43	34.44	34.07	33.16	32.90	36.19	35.40	34.45	33.92	33.12	32.76	35.92	35.48	34.21	34.06	33.18	32.92
36.46	35.66	34.65	34.50	33.64	33.44	36.39	35.63	34.69	34.35	33.60	33.30	35.81	35.70	34.46	34.49	33.66	33.46
36.62	35.92	35.08	34.83	33.92	33.70	36.55	35.81	35.11	34.68	33.88	33.54	35.67	35.82	34.88	34.82	33.93	34.71
36.75	36.41	35.69	35.62	34.83	35.03	36.68	36.32	35.72	35.46	34.79	34.89	36.14	36.06	35.49	35.60	34.85	34.05
36.80	36.54	35.85	35.80	34.98	35.25	36.74	36.44	35.89	36.65	34.95	35.12	36.27	36.48	35.67	35.80	34.99	34.29
36.89	36.63	35.98	35.97	35.19	35.51	36.83	36.53	36.02	35.83	35.16	35.38	36.46	36.57	35.80	35.98	35.20	34.55
36.95	36.82	36.02	36.24	35.49	35.86	36.89	36.72	36.25	36.10	35.45	35.73	36.52	36.66	35.94	36.25	35.52	34.90
36.01	35.02	34.05	31.87	31.56	30.07	35.85	35.03	34.07	31.84	31.58	29.16	35.67	35.07	34.05	31.89	31.59	30.09
36.17	35.31	34.54	32.56	32.36	30.99	36.01	35.34	34.56	32.51	32.38	30.89	35.83	35.35	34.54	32.58	32.39	31.01
35.25	35.48	34.79	32.93	32.76	31.46	36.10	35.50	34.83	32.88	32.80	31.37	35.90	35.53	34.80	32.96	32.82	31.50
36.58	36.18	35.40	34.52	34.56	33.50	36.43	36.21	35.63	34.47	34.61	33.45	36.26	36.25	35.12	34.55	34.62	33.56
36.64	36.29	35.56	34.75	34.82	33.81	36.49	36.32	35.79	34.71	34.86	33.76	36.31	36.36	35.28	34.80	34.89	33.87
36.70	36.41	35.60	35.01	35.12	34.17	36.55	36.43	35.94	34.97	35.16	34.12	36.37	36.48	35.69	35.06	35.19	34.23
36.78	36.57	35.85	36.17	35.42	34.62	36.63	36.60	36.18	35.30	35.52	34.58	36.48	36.64	35.91	35.43	35.51	34.70
34.82	33.61	30.49	29.09	27.81	26.61	34.80	33.62	30.47	29.06	27.81	26.63	34.83	33.65	30.53	29.16	27.85	26.67
35.23	34.06	31.65	30.14	28.67	27.90	35.21	34.07	31.61	30.11	28.91	27.90	35.23	34.10	31.65	30.15	28.93	27.93
35.51	34.30	31.92	30.69	29.48	28.63	35.50	34.31	31.87	30.65	29.51	28.62	35.53	34.35	31.93	30.72	30.53	28.65
36.07	35.34	32.89	33.09	32.28	31.78	36.07	35.36	32.85	33.06	32.31	31.77	36.09	35.40	32.90	33.15	33.33	31.84
36.63	35.50	33.24	33.43	32.68	32.23	36.62	35.51	33.20	33.41	32.72	32.21	36.63	35.54	33.25	33.50	33.71	32.25
36.69	35.68	33.36	33.86	33.15	32.77	36.67	35.69	33.32	33.83	33.19	32.76	36.70	35.73	33.37	33.92	34.20	32.79
36.76	35.89	33.71	34.36	33.70	33.38	36.74	35.90	33.68	34.32	33.73	33.38	36.77	35.94	33.71	34.45	34.76	33.40

atmosphere thus cooling the surface. With fall in the value of humidity the temperature of epidermis layer falls suddenly. It is not so rapid in other layers.

(vi) The results are almost similar for all the three sets of skin thickness. The skin surface temperature is higher in thinner skins. The difference decreases with the depth. The difference in the surface temperature may be because in thinner skin the body heat reaches to the surface easily due to less fat deposition. So the temperature is nearer to the core temperature. On the other hand in thicker skin the body heat does not reach to the surface so easily due to more fat deposition. Actually, fat deposited in subcutaneous tissues acts as heat insulator to the body. In case of set-III the thickness of subcutaneouse tissue layer is three times more than set-I.

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