THERMAL COMFORT FOR HUMANS : FROM OUTDOOR TO INDOOR

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ABSTRACT

The purpose of this paper is to provide the thermal comfort for humans using physiological principles of heat transfer and thermoregulation, heat exchange between the human body and its enclosure, and heat exchange between the inside enclosure and the outside environment.

INTRODUCTION

For many centuries, survival was a far more important and a critical factor to humans than was their comfort. However, as human beings became more sophisticated, the growth of cities brought them together to create a better life. This high density concentration of people in manufacturing plants and buildings created new problems to both health and comfort.

In recent years, considerable attention has been given to the thermal comfort for humans. The purpose of this paper is to provide the thermal comfort for humans using physiological principles of heat transfer and thermoregulation, heat exchange between the human body and its enclosure, and heat exchange between the inside enclosure and the outside environment.

DESCRIPTION OF METHODS AND PRINCIPLES

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following methods and principles are described.

1. PHYSIOLOGICAL PRINCIPLES[2],[5],[9],[25],[30]

A basic understanding of the physiological principles of heat transfer is essential to the person who works with environmental systems used for thermal comfort and health of the human occupants of a building. An in-depth study of the subject is complex, including such elements as a study of how the body reacts to extreme cold or heat under various conditions and with different clothing. There are many considerations to be made when a controlled artificial environment is to be provided to the building occupants who depend on the surrounding air to sustain their lives.

The human body through its process of metabolism, breathing and perspiring, produces varying amounts of heat and moisture. Persons in good health normally maintain a body temperature of 98.6 ^{O}F as long as a reasonable equilibrium with the surroundings is controlled. The body exchanges heat with external sources by radiation from the sun or other hot objects and by conduction and convection from surrounding air. Mean skin temperatures vary, but average near 90 ^{O}F for the majority of people that are feeling comfortable.

The body loses heat by:

a) Conduction when the body temperature is higher than that of the surrounding air. The type and amount of clothing can greatly influence this conduction loss.

b) Convection to the layer of air immediately adjacent to the skin. If air is circulated past the body, the convective heat transfer process is accelerated, causing the person to feel cooler even though the surrounding temperature does not change.

c) Radiation to surrounding surfaces such as walls, ceiling, floor, windows, and panels.

d) Evaporation of perspiration from the skin. If the surrounding air and surfaces are warmer than the skin temperature, evaporation is the only method the body has left to lose heat, because it can only be gaining heat from conduction, convection, and radiation.

The evaporation of perspiration increases as the relative humidity of the air decreases. The final analysis of human comfort, then, is based on the condition of the air surrounding the body and the temperatures of the nearby surfaces. The goal of system designer is to provide a system that can maintain that comfort in an artificial environment while people are engaged in selected activities.

2. PHYSIOLOGY OF THERMOREGULATION[2],[5],[25],[30]

Although a human being is bounded by the laws of thermodynamics, it is not sufficient to regard the body as a purely passive system. The body takes an active part in controlling its own temperature and any change in the external environment will produce some compensatory adjustment in the thermal state of the body.

2.1 METABOLIC HEAT PRODUCTION

Heat is continually being produced in the body. This heat comes from food and the calorific value of a quantity of food is simply the heat and work that will be produced by its assimilation and utilization as a source of energy.

a) HEAT PRODUCTION

The heat output resulting from the oxidation of food per liter of oxygen varies slightly with the composition of the food. The actual heat production takes place at various sites of the human body, and the heat is rapidly circulated around the body by the bloodstream. The total rate of heat production is directly controlled by the activity level of a person. The measurement of oxygen of an active person gives the metabolic rate M. Metabolic rate depends mainly on the intensity of the physical activities performed by the human body. The unit of metabolic rate is called Met. One Met is defined as 18.4 Btu/hr-ft^2, which is equal to the energy produced per unit surface area of a seated person at rest.

b) EXTERNAL MECHANICAL WORK

In some activities the person may be performing external work such as climbing a hill and acquiring potential energy, or doing a mechanical task such as sawing wood. Thus, the energy released from the oxidative processes within the body core can be partly transformed into external mechanical work through the action of the muscles. Mechanical work W is usually expressed as a fraction of the metabolic rate, M, and can be calculated as

$$W = \eta M$$

where η = mechanical efficiency.

For most office work, mechanical efficiency η is less than 0.05. Only when there is a large amount of physical activity such as bicycling, lifting and carring, or walking on a slope may η increase to a value of 0.2 to 0.24.

2.2 BODY CORE, AND SKIN TEMPERATURE

The effect of homeothermy is to keep the central regions of the body, which contain the vital organs, within the rather narrow range of temperature essential for their proper functioning. This central temperature is termed the core temperature.

While core temperature is held constant over a wide range of ambient temperature, skin temperature changes in response to changes in external temperature. Skin temperature varies from place to place over the body.

3. ENVIRONMENTAL INDICES[2],[5],[25],[30]

In order to evaluate the sensation of comfort for the human body environmental indices are used. This paper deals with the prediction and use of the following environmental indices: (a) air temperature, (b) humidity, (c) mean radiant temperature, (d) relative air velocity, (e) activity level, and (f) insulation value of clothing.

a) dry bulb temperature

The dry bulb temperature, which is the single most important index of comfort, is especially important for comfort in colder regions.

b) relative humidity

Relative humidity has no real meaning in terms of comfort unless the accompanying dry bulb temperature is also known. Relative humidity is the ratio of the mole fraction of the water vapor in a mixture to the mole fraction of water vapor in a saturated mixture at the same temperature and pressure. Very high or very low relative humidity is generally associated with discomfort.

c) mean radiant temperature

The uniform surface temperature of a radiantly black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non uniform space.

d) relative air velocity

The relative air velocity is the most difficult of the direct indices to describe. The convective heat transfer from the body depends on the velocity of the air moving over it.

e) activity level

The metabolic rate M is the rate of energy released per unit area of skin surface as a result of the oxidative processes in the living cells. The activity level can be measured using metabolic rate.

f) insulation value of clothing

Clothing insulation can be determined through measurements on a heated mannequin. Clothing insulation value can be expressed either as hr-ft^2-deg F/Btu or in a new unit called clo, where 1 clo = 0.88 hr-ft^2-deg F/Btu.

4. HEAT EXCHANGE BETWEEN HUMAN BODY AND INSIDE ENVIRONMENT (ENCLOSURE)[2],[5],[25]

Most models of thermal exchange between the body and environment, and the subsequent measures of the associated physiological strain or thermal sensations are similar in that they use classical heat transfer theory as a rational starting basis and introduce empirical equations describing the effects of known physiological regulatory controls. Sensible and latent heat losses from the skin are expressed in terms of environmental factors, skin temperature and skin wetness. The expressions also incorporate factors that account for the thermal insulation and moisture permeability of clothing. The independent environmental variables can be summarized as: air temperature, mean radiant temperature, relative air velocity, and ambient water vapor pressure. The independent personal variables that influence thermal comfort are activity and clothing.

Three commonly used models are the two node model, multinode model, and steady state energy balance model.

4.1 TWO NODE MODEL OF THERMAL INTERACTION[13]

In 1971, Gagge et al. recommended a two node model of human thermal interaction. In this model, the human body is composed of two components: an inner body core including skeleton, muscle and internal organs, and an outer shell of skin surface. The temperatures of the body core and the surface skin are each assumed to be uniform and independent. Metabolic heat production, external mechanical work, and respiratory losses occur only in the body core. Heat exchange between the body core and the skin surface depends on heat conduction from direct contact and peripheral blood flow of the thermoregulatory mechanism of the human body.

Gagge developed a thermal comfort model in an attempt to improve the effective temperature equation. He developed a physiological model based on body heat generation and regulatory sweating, suitable for low and medium activity levels. For the purposes of evaluating thermal comfort, the model considers that the human body is composed of two thermal compartments; the skin and the core. All metabolic heat (M) produced by the person is generated in the core. Shivering and muscle tension creates additional metabolic heat. Energy is lost from the core by the muscles doing work on the environment and by respiratory heat loss (Qres). Heat is transported from the core to the skin by conduction (K) and peripheral blood flow (Vb). The peripheral blood flow occurs as warm blood is pumped from the core to the skin in an attempt to cool the person off, then returns to the core at a cooler temperature. Heat is dissipated from the skin by convection (Qc), radiation (Qradiation), regulatory sweating (Eresw), and diffusion of water vapor (Ediff).

Heat transfer in the Gagge model consists of heat balances on the core and skin.

Heat balance on the core is as follows:

metabolic + shivering = work + respiration + conduction + convection by blood +

rate of increase in internal energy of the core

Heat balance on the skin is as follows:

heat from core = radiation + convection + diffusion + evaporation +

rate of increase in internal energy of the skin

The Gagge model predicts thermal sensation. The predictive thermal sensation (TSENS) equation is as follows:

$$TSENS = 0.245SET + 0.0165Pset - 6.741$$

where SET : given environment temperature

Pset : corresponding water vapor pressure

Gagge's two node model is based on steady state experimental measurements on people. However, reaching steady state takes at least an hour when a person is exposed to a constant room condition. Gagge's model is mostly used to study the effect of clothing in humans.

4.2 Multinode Models[29]

Multinode models are useful when people are exposed to nonuniform environments. Stolwijk's multinode model divides each part of the body into four segments: skin, muscle, fat, and core component. A comparison of the Stolwijk model to experimental measurements on human subjects has been made, and the skin temperature and evaporative weight loss predictions of the model are in close agreement to the measurements. However, this model does not predict comfort, or incorporate the effects of clothing.

4.3 STEADY STATE ENERGY BALANCE[9]

A steady state model developed by Fanger assumes that the body is in a state of thermal equilibrium with negligible heat storage. That is the heat stored in the body core and skin surface is approximately equal to zero. The body is assumed to be near thermal neutrality, there is no shivering, and vaso-regulation is not considered since the core and skin are modeled as one compartment.

Fanger has developed a thermal comfort equation which consists of the following six variables: a) air temperature, b) humidity, c) mean radiant temperature, d) relative air velocity, e) activity level, and f) insulation value of clothing. Fanger's model is based on the linear relationships of mean skin temperature and evaporative heat loss required for comfort at different activity levels. Fanger's comfort equation is a result of a heat balance. Since the purpose of the thermoregulatory system of the body is to maintain an essentially constant internal body temperature, it can be assumed that for long exposures to a constant thermal environment with a constant metabolic rate, heat balance will exist for the human body, i.e., the heat production will equal the heat dissipation, and there will be no significant excess heat stored within the body. The heat balance for this condition is:

$$H - Ed - Esw - Ere - L = K = R + C$$

where H = internal heat production in the human body

Ed = heat loss by water vapor diffusion through the skin

Esw = heat loss by evaporation of sweat from surface of the skin

Ere = latent respiration heat loss

L = dry respiration heat loss

K = heat transfer from the skin to the outer surface of the clothed body (conduction through the clothing)

R = heat loss by radiation from the outer surface of clothed body

C = heat loss by convection from the outer surface of clothed body

The energy balance equation states that the internal heat production H minus the heat loss by evaporation from the skin (Ed + Esw) and by respiration (Ere + L) is equal to the heat conducted through clothing (K) and dissipated at the outer surface of the clothing by radiation and convection (R + C). It is assumed that the evaporation corresponding to Esw and Ed takes place at (or underneath) the skin surface. If the heat production (H) is less than the heat dissipation, the person feels cold. If the heat production is greater than the heat dissipation, the person feels hot.

Radiant heat exchange takes place between the human body and its surroundings. The heat loss by radiation from the outer surface of the clothed body can be expressed by the Stefan-Boltzmann law. An expression for R in the energy balance equation is as follows:

$$R = A_{eff}\,\varepsilon_{body}\,\sigma[(t_{cl}+273)^4-(t_{mrt}+273)^4]$$

where A_{eff} : the effective radiation area of clothed body

ε = emittance of the outer surface of the clothed body

σ = Stefan-Boltzmann constant

t_{mrt} = mean radiant temperature

t_{cl} = outside clothing temperature

The body partially radiates to itself; therefore, the surface area used in R the equation is not be the actual body surface area but a reduced effective radiation area. The bracketed term indicates the difference between the the fourth powers of the absolute temperature of the clothed body and the mean absolute radiant temperature.

Fanger used his thermal comfort equation to develop an expression which predicted thermal sensation. This expression is known as the predicted mean vote (PMV). The PMV is as follows:

$$PMV = (0.352e^{-0.042(M/A_{DU})} + 0.032)\{\frac{M}{A_{DU}} - 0.35\{43.0 - 0.061\frac{M}{A_{DU}} - P_a\} -$$
$$0.42\{\frac{M}{A_{DU}} - 50.0\} - 0.023\frac{M}{A_{DU}}(44.0 - P_a) - 0.0014\frac{M}{A_{DU}}(34.0 - t_a) -$$
$$3.4(10^{-8})f_{cl}\{(t_{cl} + 273.0)^4 - (t_{mrt} + 273.0)^4\} - f_{cl}h_c(t_{cl} - t_a)\}$$

$$h_c = 10.4\sqrt{V} for 2.05(t_{cl} - t_a)^{0.25} \leq 10.4\sqrt{V}$$
$$2.05(t_{cl} - t_a)^{0.25} for 2.05(t_{cl} - t_a)^{0.25} \geq 10.4\sqrt{V}$$

where M = metabolic rate (Kcal/hr)

A_{DU} = nude area of human body (m^2)

P_a = vapor press in ambient air (mm Hg)

I_{cl} = thermal resistance of cloth (clo)

V = relative air velocity (m/sec)

f_{cl} = ratio of surface area of clothed body to surface area of nude body

h_c = convective heating transfer coefficient (Kcal/hr-m^2-^oC)

t_{cl} = outside clothing temperature (^oC)

t_a = inside air temperature (^oC)

Fanger's comfort model also predicts the percentage of adult persons dissatisfied (PPD) with a particular environment. Predicted mean vote and PPD are used extensively today in analyzing thermal sensations.

This paper used Fanger's model of heat exchange between the human body and its environment since the multinode model, although potentially highly accurate, does not predict comfort or incorporate the effects of clothing. The Gagge two node model requires a detailed clothing model which is beyond the scope of this thesis. The Fanger model, which has been used by the ASHRAE Standard 55-1981[1] produces an accurate and validated picture of thermal exchange between an adult body and the internal environment.

5. HEAT EXCHANGE BETWEEN ENCLOSURE SURFACES INCLUDING ROOM AIR TEMPERATURE AND OUTSIDE ENVIRONMENT

The heat exchange between enclosure surfaces and the outside environment depends on conduction, convection, and radiation.

5.1 MRT Method[14]

In 1980 George Walton proposed an algorithm for improving the accuracy of the BLAST and NBSLD computer programs by using mean radiant temperature. He accomplished this by proposing that the radiant interchange in a room could be adequately modeled by assuming that each surface in a volume radiate to a fictitious surface which has an area, emissivity, and temperature giving about the same heat transfer from the surface as in the real multi surface case. The radiant heat exchange between two parallel gray surfaces is i and the other fictitious surface, f, yields the general form of the MRT equation:

$$q_{radi,mrt} = \sigma F_{if} (T_i^4 - T_{fi}^{\ 4}) + q_{\mathrm{int}\,i} + q_{soli} \qquad \text{--- (1)}$$
$$i = 1, N$$

Where the area of the fictitious surface is the sum of the area of all other surfaces in the room:

$$A_{fi} = \sum_{j \neq i}^{n} A_j$$

The emissivity is an area-weighted average of all surface emissivities:

$$\varepsilon_{fi} = \sum_{j \neq i}^{n} A_j \varepsilon_j / \sum_{j \neq i}^{n} A_j$$

The temperature is an area x emissivity-weighted average of all inside temperatures:

$$T_{fi} = \sum_{j \neq i}^{n} A_j \varepsilon_j T_j / \sum_{j \neq i}^{n} A_j \varepsilon_j$$

T_{fi} is the mean radiant temperature (MRT) seen by surface i. The radiation interchange factor is given by:

$$F_{if} = 1/((1-\varepsilon_i)/\varepsilon_i + 1 + A_i(1-\varepsilon_{fi})/A_{fi}\varepsilon_{fi}) \qquad \text{--- (2)}$$

Equation (2) is the expression for the radiant interchange between surface i and f where a) no part of i can view itself, b) f may view itself, c) f completely encloses i (or i and f form a complete enclosure), or d) diffuse reflections from gray surfaces are accounted for.

An approximation is made that:

$$(T_i^4 - T_{fi}^4) = 4T^3_{avgi}(T_i - T_f)$$
$$\textit{where} \qquad \text{--- (3)}$$
$$T_{avgi} = \frac{(T_i + T_f)}{2}$$

Lastly, a radiation balance term is required that accounts for the net imbalance of the method, which is:

$$q_{bali} = (\sum_{j=1}^{N} 4\sigma F_{if} T^3_{avgi}(T_j - T_{fi})A_i) / \sum_{j=1}^{N} A_j \qquad \text{--- (4)}$$

Substituting equation (3) and adding term equation (4) into equation (1) yields the MRT/Balance equation:

$$q_{radi,mrt/bal} = 4\sigma F_{if} T^3{}_{avgi}(T_i - T_{fi}) + q_{int\,i} + q_{soli} + q_{bali} \qquad \text{--- (5)}$$

This is the final form of the MRT method radiation flux term, and it can be substituted directly into the following general surface boundary equation:

$$q_{condi} + q_{convi} + q_{radi} = 0$$
$$i = 1, N$$

There can be significant errors in the MRT equation since the F_{if} term does not involve exact angle factors.

5.2 MRT Correction Method in Enclosured Environment[28]

Summers, Steinman, and Kalisperis proposed a new method of radiant heat exchange which produces significantly improved accuracies over the BLAST and NBSLD load program. It incorporates the mean radiant (MRT) method, which is currently employed by the BLAST load program. It is proposed that with error analysis and numerical methods a correction can be applied to the MRT algorithms. The correction components account for an enclosed environment's surface to surface exact angle factor, which are lacking in the MRT method. The MRT correction method improves the accuracy of the MRT method while maintaining the computational speed, so inherently advantageous to the MRT method. This leads to more accurate determination of building loads and human comfort conditions. The MRT correction method is most applicable to complex geometries and geometries with large surface temperature variations.

5.3 Measurement of Mean Radiant Temperature [3]

Summers, Olesen,Steinman, Kalisperis, and Rosendahl proposed the following methods for calculation and measurement of mean radiant temperature:

a) use of a weighted mean value of the plane radiant temperature in six directions,

b) use of a spherical globe sensor, and c) use of an ellipsoidal globe sensor. For enclosures with uniform surface temperatures, differences between the three methods are small. Using an ellipsoidal sensor gives a much better approximation than the other two choices. The tests also show that when measuring the effect of sunlight as a radiant source on a person, both the color of the sensor and direction of the sun greatly influence the measurement.

6. Explicit Method

To find the inside surface temperature of each surface, the explicit method will be used. There are three different cases which cover the: a) outside convection boundary, b) inside convection and radiation boundary, and c) an interior node.

a) for the outside boundary convection

$$T_m^{p+1} = 2F_0(T_2^p + B_i T_{o,\infty}{}^p) + (1 - 2F_0(1 + B_i))T_m^p$$

b) for the inside boundary convection, and radiation

$$T_m^{p+1} = 2F_0(T_{10}^p + B_i T_{i,\infty}{}^p + \frac{\Delta x}{k} q_{rinm}{}^p) + (1 - 2F_0(1 + B_i))T_m^p$$

c) for an interior node

$$T_m^{p+1} = F_0(T_{m+1}^p + T_{m-1}{}^p) + (1 - 2F_0)T_m^p$$

where B_i = Biot number of inside and outside surface

$B_i inside = \frac{h_i \Delta x}{k}$ for inside surface

q_{rinm} = outgoing radiation - incoming radiation of the inside surface

$B_i outside = \frac{h_o \Delta x}{k}$ for outside surface

Fourier number $F_0 = \frac{\alpha \Delta t}{\Delta x^2}$

Thermal diffusivity $\alpha = \frac{k}{\rho c_p}$

Time step Δt

Step distance Δx

Specific heat c_p

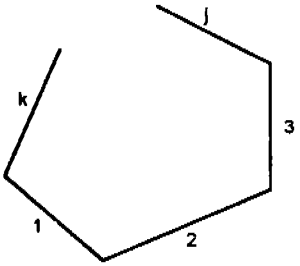
Density ρ

$T_{o,\infty}$ = outside air temperature for outside convection boundary

$T_{i,\infty}$ = inside room air temperature for inside convection and radiation boundary

7. Net Radiation Method[20]

Using the net radiation method, the radiosity of each surface can be found.



Net radiation method

If A_k is the inside surface of a wall of finite thickness, the q could be the heat conducted through the wall A_k. The energy balance at the surface provide the relation.

$$Q_k = q_k A_k = (q_{out,k} - q_{in,k}) A_k \qquad \text{--- (1)}$$

$$q_{out,k} = \varepsilon_k \sigma T_k^4 + \rho_k q_{in,k} = \varepsilon_k \sigma T_k^4 + (1-\varepsilon_k) q_{in,k} \qquad \text{--- (2)}$$

where $\rho_k = 1 - \varepsilon_k$ for opaque gray surface

$$A_k q_{in,k} = A_1 q_{out,1} F_{1k} + A_2 q_{out,2} F_{2k} + \cdots + A_n q_{out,n} F_{nk} \qquad \text{--- (3)}$$

from form factor reciprocity relation

$$\begin{aligned} A_1 F_{1k} &= A_k F_{k1} \\ A_2 F_{2k} &= A_k F_{k2} \\ &\text{-------} \\ A_n F_{nk} &= A_k F_{kn} \end{aligned} \qquad \text{--- (4)}$$

substitute equation (4) into equation (3):

$$A_k q_{in,k} = A_k q_{out,1} F_{k1} + A_k q_{out,2} F_{k2} + \cdots + A_k q_{out,n} F_{kn}$$

$$\text{or, } q_{in,k} = \sum_{j=1}^{n} F_{kj} q_{out,j} \qquad \text{--- (5)}$$

substitute equation (2) into equation (1):

$$\begin{aligned} Q_k &= (q_{out,k} - q_{in,k}) A_k = \\ &\left\{\frac{q_{out,k} - (q_{out,k} - \varepsilon_k \sigma T_k^4)}{1-\varepsilon_k}\right\} A_k = \\ &A_k \frac{\varepsilon_k}{1-\varepsilon_k} (\sigma T_k^4 - q_{out,k}) \end{aligned} \qquad \text{--- (6)}$$

substitute equation (5) into equation (1):

$$\begin{aligned} Q_k &= (q_{out,k} - q_{in,k}) A_k \\ &= (q_{out,k} - \sum_{j=1}^{n} F_{kj} q_{out,j}) A_k \end{aligned} \qquad \text{--- (7)}$$

Using equation (6) and equation (7), system of equations relating surface heating Q and surface temperature T can be found.

from equation (6):

$$q_{out,k} = \sigma T_k^4 - \frac{1-\varepsilon_k}{\varepsilon_k} \frac{Q_k}{A_k} \qquad \text{--- (8)}$$

from equation (7):

$$Q_k = (q_{out,k} - q_{in,k}) A_k = (q_{out,k} - \sum_{j=1}^{n} F_{kj} q_{out,j}) A_k \qquad \text{--- (9)}$$

from equation (8):

$$q_{out,j} = \sigma T_j^4 - \frac{1-\varepsilon_j}{\varepsilon_j} \frac{Q_j}{A_j} \qquad \text{--- (10)}$$

substitute equation (8) and equation (10) into equation (9):

$$\frac{1}{\varepsilon_k}\frac{Q_k}{A_k} = \sigma T_k^4 - \sum_{j=1}^{n}\{F_{kj}(\sigma T_j^4 - \frac{1-\varepsilon_j}{\varepsilon_j}\frac{Q_j}{A_j})\} \qquad \text{--- (11)}$$

from equation (11):

$$\sum_{j=1}^{n}\{(\frac{\delta_{kj}}{\varepsilon_j} - F_{kj}\frac{1-\varepsilon_j}{\varepsilon_j})\frac{Q_j}{A_j}\} = \sum_{j=1}^{n}\{(\delta_{kj} - F_{kj})\sigma T_j^4\} \qquad \text{--- (12)}$$

where δ_{kj} = kronecker delta

$\delta_{kj} = 1$, when $(k = j)$

$\delta_{kj} = 0$, when $(k \neq j)$

from equation (6) and equation (7), eliminating Q_k's:

$$q_{out,k} - (1-\varepsilon_k)\sum_{j=1}^{n} F_{kj} q_{out,j} = \varepsilon_k \sigma T_k^4 \qquad \text{--- (13)}$$

from equation (13):

$$\sum_{j=1}^{n}\{\delta_{kj} - (1-\varepsilon_k)F_{kj}\}q_{out,j} = \varepsilon_k \sigma T_k^4 \qquad \text{--- (14)}$$

using equation (14), $q_{out,j}$ can be found if the T_k are known.

In this paper, the explicit method to find the inside surface temperatures and net radiation method to find the inside room air temperature are used.

RESULT AND DISCUSSION

People respond to their environment in many ways, and many factors affect their health and attitude: the size of the space in which they work and live, the colors and furnishings, openings to the outdoors, air quality (heat, humidity, air movement), noise, light, proximity of other people, etc.

Of the many human comfort factors and principles the ones that can be controlled or at least affected by environmental systems are temperature, radiation, humidity, air movement and some noise. The important personal factors are clothing and activity. In the ASHRAE Standard 55-1981[1], the basic aim is to specify conditions that are thermally acceptable to 80% or more of the occupants. This standard includes adjustments that can be made for clothing, activity, air movement and temperature range that give greater flexibility for comfort adjustment and often have energy saving potential.

CONCLUSIONS

In order to understand thermal comfort for humans, the following heat exchange processes must be understood and modeled.

a) Physiological principles of heat transfer and thermoregulation

b) Heat exchange between the human body and its enclosure

c) Heat exchange between the inside enclosure and the outside environment

More research must be needed for heat exchange between Korean and their enclosures.

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