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DYNAMIC ANALYSIS OF HUMAN THERMAL COMFORT DEPENDING ON ENVIRONMENT TEMPERATURE AND HUMIDITY

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ABSTRACT
The purpose of the paper is to analyze the thermal sensation of human body from the influence of absolute humidity of the surrounding air. So, depending on environment certain absolute humidity and temperature issued in review the borders of cool and the warm sense of human body. Through analytical expressions derived the diagrams which reflect the dynamics of human clothing temperature in function of the equation of human thermal balance and the environment parameters temperature-humidity.
Key words: temperature, absolute humidity, relative humidity, thermal equilibrium.

1. INTRODUCTION

Metabolic heat is generated during the transformation to the environment from the skin surface via dry (conduction, convection and radiation) and evaporative heat transfer pathways. Parameters within the environment that influence heat exchange include the ambient temperature and water vapor pressure, radiant heat, air movement, and the properties of clothing (insulation and moisture transfer). The data produce the following parameters [1]: Environmental parameters: mean radiant temperature (t_{mr}, ^{o}C), partial water vapor pressure in ambient air ($p_{w,a}$, Pa), the convective heat transfer coefficient (h_c, W/(m^2.K).); Clothing parameters: Clothing area factor (A_D), effective clothing insulation (I_{ve}, cl=0.155m^2K/W); resistant of clothing to heat transfer R_{ve} (=0,155I_{ve}, m^2 ^{0}C/W); Physiological parameters: metabolic heat production (M, W/m^2), internal heat production (E_M, W/m^2), body heat storage (A, W/m^2), heat loss or gain via conduction, convection, radiation and evaporation (H, W/m^2), heat loss by skin diffusion ($E_{l,dif}$, W/m^2), skin wittedness and convective and evaporative heat exchange from the respiratory tract (Q_{res}, W/m^2).

2. HUMAN THERMAL EQUILIBRIUM AND THE INFLUENCE OF MOISTURE

The living body constantly produces heat that must be transferred to the environment. Heat balance (thermal equilibrium) is the balance between the rate of heat production and the rate of heat loss [2]. The rate at which heat is produced depends primarily on our metabolic rate. Mathematically, the relationships between the body's heat production and all its other heat gains and losses are as below:
Rate of storage of heat in the human body is:

$$A=M-W-Q_{lëk}-Q_{res} \tag{1}$$

Where are:

M –metabolic rate, of body surface area, W/m^2;
W –external work, equal to zero for most activities, W/m^2;
$Q_{lëk} = C+R+E_{lëk}$ –heat lost from skin to environment, W/m^2;
C=$f_{ve}\cdot h_c (t_{ve}-t_a)$ –heat losses by convective heat flux, W/m^2;
f_{ve} –factor of clothing, the ratio of a person's surface area while clothed, to the surface area while nude (=A_{ve}/A_D):
f_{ve} =1,0+1,29I_{ve} for I_{ve}≤0,078 m^{2}K/W respectively for I_{ve}≤0,5Ve;
f_{ve} =1,05+0,645I_{ve} for I_{ve}>0,078 m^{2}K/W respectively for I_{ve}>0,5Ve;
I_{ve},, V_e –thermal isolation of clothing, (1V_e=1cl =0,155m^2 K/W);
h_c – convective heat transfer coefficient, W/(m^2 ^{0}C:
h_c =2,38(t_{ve}- t_a) $^{1/4}$ –by natural convection;
h_c =12,1(v_{rel})$^{1/2}$ –by forced convection;
t_{ve} –surface temperature of clothing, ^{0}C;
t_a –air temperature, ^{0}C;
v_{rel} –the average wind velocity, m/s;
R =3,95·10^{-8}f_{ve}[(t_{ve}+273)^4-(t_{mr}+273)^4] –heat loss by radiation from the surface of the clothed body, W/m^2;
$E_{lëk} = E_{l,dj} + E_{l,dif}$ –heat losses by sweat evaporation from the skin surface, W/m^2;
$E_{,dj}$ =0,42(M-W-58,12) –heat transfer by sweat evaporation from the skin surface, W/m^2;
$E_{,dif}$ =3,05·10^{-3}($p_{w,l}$-$p_{w,a}$) –evaporative heat transfer via skin moisture diffusion, W/m^2;
$p_{w,l}$ =256$t_{lëk}$-3373 –vapor saturation pressure at skin temperature, Pa;
$t_{lëk}$=35,7-0,0275(M-W) –skin temperature, ^{0}C;
$p_{w,a}$ – partial water vapor pressure, Pa;
$Q_{res} = C_{res,s}+E_{res,l}$ –heat losses due to respiration, W/m^2;
$C_{res,s}$=0,0014M(34-t_a) –sensible heat lost by **c**onvection, W/m^2;
$E_{res,l}$ =1,72·10^{-5} M(5867-$p_{w,a}$) –latent evaporative heat loss, W/m^2;

Ideally A should equal 0 (A=0) when the body is in heat balance; i.e. heat production = heat loss with no storage. So, from equation (1) achieve the heat balance:

$$P = H \tag{2}$$

Where are:
$P=M-W$ –the rate of heat production (or P = total energy - work energy), W/m^2;
$H=Q_{lëk} + Q_{res}$ – heat losses from the human body, W/m^2;

Heat balance also can express as below:

$$M\text{-}W\text{-}E_{lëk}\text{-}Q_{res} = R+C = P_{ve} \tag{3}$$

Where are:
$K=C+R$ –sensible heat losses from skin to the surfaces clothing, W/m^2;

$$P_{ve} = \frac{t_{lëk} - t_{ve}}{R_{ve}}$$ -conduction to the surfaces through the clothing, W/m^2, (4)

R_{ve} (=0,155 I_{ve}) -resistant of clothing to heat transfer, m^2 ^{0}C/W;

Mechanical efficiency: η=W/M (5)

Human level activity respectively the: E_M = M /A_D (6)

Where are:
E_M – internal heat production, met (1met=58.15 W/m^2);
A_D=0,202m^{0,425}h^{0,725} –body surface area (physiological variable), m^2;
m –body mass, kg;
h –body height, m;

The surface temperature of clothing, ^{0}C, expressed from equations (3) and (4):

$$t_{ve}= t_{lëk}\text{-}0,155I_{ve}(M\text{-}W\text{-} E_{lëk} \text{-}Q_{res})$$

The mean radiant temperature [3], ^{0}C, from equation (2):

$$t_{mr}=\left[\frac{f_{ve}\cdot h_c\cdot(t_{ve}-t_a)+3,96\cdot10^{-8}\cdot f_{ve}\cdot(t_{ve}+273)^4-(M-W-E_{lëk}-Q_{res})}{3,96\cdot10^{-8}\cdot f_{ve}}\right]^{1/4}-273 \tag{7}$$

The relative humidity, %, of ambient air is $\chi = p_{w,a}/p_n$.

In continuity of paper is analyzed the influence of moisture in the conditions of human thermal equilibrium for: human body mass 80kg, human body height 1.8m, external work 10W/m^2, metabolic rate 1met, effective clothing insulation 1cl, average velocity 1.5m/s, air temperature 20^{0}C, and relative humidity χ =0÷100%. The diagrams below on the figures 1, 2, 3 and 4 show the change parameters related to the equation of human thermal equilibrium in connection with temperature, heat and mass transfer respectively depending of relative humidity.

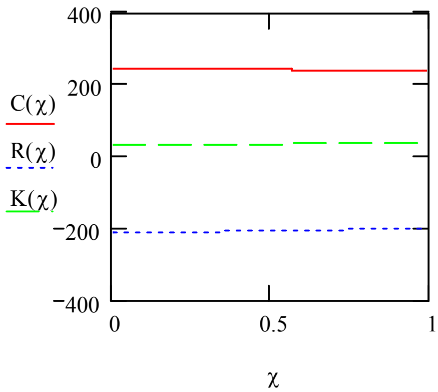


Figure 1. Changing of heat losses by convective heat flux C, heat loss by radiation and sensible heat losses from the skin to the surfaces clothing K, depending of relative humidity χ

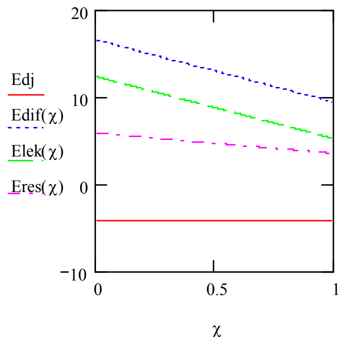


Figure 2. Changing of heat transfer by sweat evaporation from the skin surface E_{dj}, evaporative heat transfer via skin moisture diffusion E_{dif}, heat losses by sweat evaporation from the skin surface E_{lek}, and latent evaporative heat loss E_{res}, depending of relative humidity χ

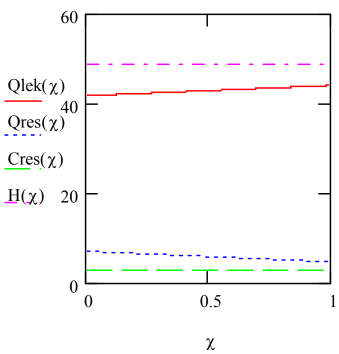


Figure 3. Changing of heat lost from skin to environment Qlek, heat losses due to respiration Qres, heat losses due to respiration Cres, and heat losses from the human body H, depending of relative humidity χ

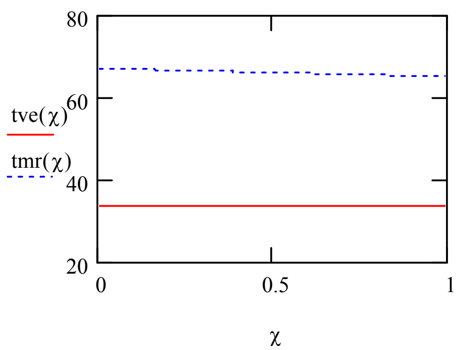
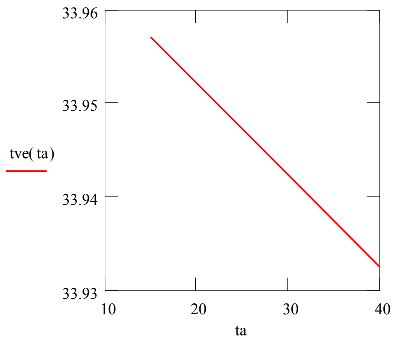


Figure 4. Changing of surface temperature of clothing t_{ve}, and the mean radiant temperature t_{mr}, depending of relative humidity χ.

By I_{ve}=0.5V_e=0,078 m^{2}K/W dhe M=1met (fig. 5):



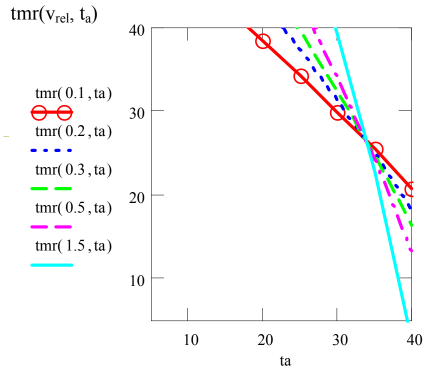


Figure 5. a. surface temperature of clothing (t_{ve}): b. The mean radiant temperature (t_{mr}), depending ambient temperature (t_a)

3. CONCLUSION

In order to protect the thermal equilibrium, as shown in above equations and diagrams, we can conclude that change of relative humidity causes change of almost all other parameters. Increase of the relative humidity has to be accompanied with increase of Q_{lek}, K, and R and decrease of C, t_{ve}, t_{mr}, Q_{res}, C_{res}, H, E_{dif}, E_{lek} and E_{res}. Therefore the humidity control is also important, because the high humidity can retard human heat loss by evaporative (sweating and respiration) and the law humidity tends to dry throat and nasal passages.

4. REFERENCES

[1] Holland, M. et al,: Thermal environmental conditions for human occupancy, ASHRAE, Atlanta, Inc, 1992;
[2] Parsons, K., Human Thermal Environments, Taylor & Francis, London, 1993;
[3] Fanger, P., Thermal Comfort, 1st edn. McGraw-Hill Book Co, New York, 1970;