THE TOLERANCE INTERVAL WITH REGARD TO DIFFERENT ENVIRONMENTAL CONDITIONS

Danilo Jakšić

University of Ljubljana, Slovenia

INTRODUCTION

The system human being - clothing - environment is very unstable by its nature. A human being changes his or her activities and their intensity often. From this reason, changes in quantity of heat emission appear. Under certain circumstances extreme perspiration may take place. Part of sweat remains in clothing, changing its performance. Thermoisolation value decreases and convenience of clothing diminishes. The environment is unstable by itself, also. Paying regard to the air as the component of the environment only, a temperature, humidity (precipitation) and wind velocity are of the greatest interest. All three parameters influence changes of a thermoisolation value of clothing and velocity of heat emission to environment, respectively.

MATERIALS and METHODS

The equation (1) defines thermal resistance of warmth conductivity through layers of clothing, R_c:

$$R_c = \sum d_i/\lambda_i = d/\lambda \qquad (1)$$

where: d - thickness of i layers of clothing; *hi*- coefficient of thermal conductivity; d - total thickness of clothing; λ - average mean of coefficients of thermal conductivity of all layers of clothing.

A layer of stable air exists at a clothing surface, that provides resistance to heat conductivity R_a. The value of R_a, that depends on wind velocity, is calculated by the equation':

$$R_a = 0.0429/(0.4 + 2(v)^{0.5}) \qquad (2)$$

Where: v - wind velocity m/s.

Thermal resistance is expressed in $m^2.h.°C/kJ$. Coefficient of thermal conductivity, λ is expressed in $kJ/m.h.°C$, respectively. Total thermal resistance R_s is sum of thermal resistance R_c and R_a

$$R_s = R_c + R_a \tag{3}$$

Coefficient of thermal conductivity λ is a function of temperature, humidity and wind velocity. In case of water proof and gas permeable clothing (protecting clothing, with layer for poisonous gases absorption), coefficient of thermal conductivity is calculated by the equation[2]:

$$\lambda = \lambda_0(1 + k_1T + k_2W) + bc\gamma Vd \tag{4}$$

Taking into consideration equations (1), (2) and (4), the equation (3) (valid for plain surface) is transformed to[2]:

$$R_s = ad/(\lambda_0(1 + k_1T + k_2W) + bc\gamma Vd) + 0.0429/(0.4 + 2.0(v)^{0.5}) \tag{5}$$

where: λ_0 - coefficient of thermal conductivity at 0 "C; k_1 and k_2 coefficients that have value of approximately 0.0025/°C and 0,04 /% humidity clothing, T-temperature, "C; W - percentage of humidity in clothing; a = **b** = **1** (in the observation); c - specific heat of air, kJ/kg.°C; γ - specific air density, kg/m^3; V - velocity of air flow through clothing at the defined wind velocity, $m^3/m^2.h$; v - wind velocity, m/s.

Velocity of warming up or cooling down of a human body depends on average specific heat of a body. Its value **is** approximately 3.5 kJ/kg.°C. The augmentation of warmth in an organism as well as pulling it out is calculated by the equation:

$$AQ = \gamma G(T_2 - T_1) \tag{6}$$

where: γ - specific body heat, kJ/kg.°C; T_1 - normal average body temperature, approximately, 36.5 *"C;* T2 - actual average body temperature, *"C.*

The equation ***(6)*** points out that value of **AQ** in the process of cooling down is negative $T_1 > T2$ (body emits more heat into environment than produces it). In the case of warming up, its value is positive: $T_1 < T_2$ (body is accumulating heat). If equilibrium is established at the level of comfort temperature, when no disequilibrium in heat exchange exists ($T_2 = T_1$ and $AQ = 0$).
In a process of cooling down body produces certain amount of Q_1, and **emits** into environment heat Q_2, respectively. Yet, $Q_2 > Q_1$. Actual heat deficit AQ, $kJ/m^2.h$, is calculated by the equations:

$$AQ = Q_1 - Q_2 = (T_1 - T_2)/R_{s1} - (T_1 - T_2)/R_{s2} \quad (7)$$

$$AQ = (T_1 - T_2)*(1/R_{s1} - 1/R_{s2}) \quad (8)$$

where:
T_1 - temperature at skin surface, "C; T_2 - temperature of environment, "C; R_{s1} - total resistance to heat conductivity through clothing needed to keep organism in a stage of comfort, m^2.h.°C/kJ; R_{s2} - actual total resistance of clothing to heat conductivity, m^2.h.°C/kJ.

At average body temperature 29,2 °C (stage of overcooling), taking in account the start body temperature **36.3** "C, specific heat, $\gamma = 3.5$ kJ/kg. **°C**, and mass of **an** subject G = 70 kg., heat debalance Q_c of 1.789kJ, is calculated by the equation:

$$Q_c = \Delta T*\gamma*G \quad (9)$$

Heat loss Q_c takes place in a defined period of time. Its duration depends on skin surface from which heat is conducted into environment through, thermoisolation value of clothing, thremoisolation value of body superficiality which increased along with the decreasing temperature of superficiality and depends on temperature difference at skin surface.

To define the exact time period of cooling down or warming up, the functional relation between changes of thermoisolation value of body superficiality and decreasing temperature at skin surface has to be known. **As** temperature difference, i.e., value DT decreases along with decreasing temperature at skin surface, a process of cooling is slowed down.

Under the presumption of constant velocity of heat emission into environment (equation 9) during the cooling process, the minimal time interval of cooling is defined. Still, actual time interval is longer due to decreasing temperature at skin surface and increasing thermoisolation value of body superficiality. Heat debalance $\Delta Q*S*t$ in kJ is equal to heat Q_c. S is skin surface (1.8 m^2) and t, time interval in minutes. The shortest tolerance interval is calculated by the equation:

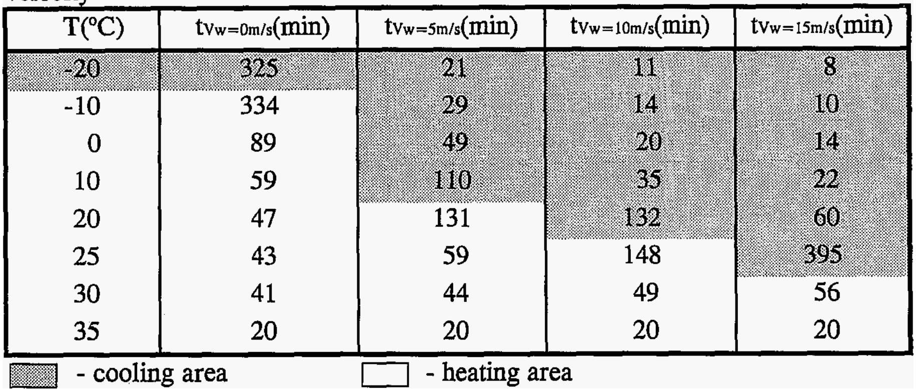
$$t = 60*Q_c/(1.8*\Delta Q) \quad (10)$$

Interval of warming up may be calculated by similar procedure, only that presumed circumstances are opposite. Body is accumulating heat and warms up. Coefficient of heat conductivity increases up to the highest value, clothing is wetting with sweat and its coefficient of heat conductivity increases, sweat evaporates and surplus heat is used in the process of evaporation. The process of warming up to critical temperature is slowed down, respectively.

RESULTS

Table 1 shows minimal tolerance intervals in case of the hard working individual producing 1050 kJ/m^2.h at different wind velocities in clothing, having resistance of heat conductivity 0.044 m^2.h.°C/kJ.

Table 1. Tolerance intervals according to temperature of environment and wind velocity



T(°C)	$t_{Vw=0m/s}$(min)	$t_{Vw=5m/s}$(min)	$t_{Vw=10m/s}$(min)	$t_{Vw=15m/s}$(min)
-20	325	21	11	8
-10	334	29	14	10
0	89	49	20	14
10	59	110	35	22
20	47	131	132	60
25	43	59	148	395
30	41	44	49	56
35	20	20	20	20

▨ - cooling area ☐ - heating area

Legend of the columms: T(°C) - temperature of environment, $t_{Vw=Xm/s}$(min) - time of tolerance in minutes by different wind velocity.

Underlined numbers **mark** limits between stage of warming up and cooling down. Time period of warming up is widened for 20 minutes, i.e., time that is needed to increase average body temperature from 36.5°C up to 39.0°C.

CONCLUSIONS

Methodology that is based on theory of thermoisolation makes calculation of exact values of parameters influencing clothing thermoisolation value under defined conditions possible. It allows pure laboratory experiment, without human being involved. It is also cost effective, as neither expensive climate chamber nor mannequin are needed.

REFERENCES

1. Kerslake D. Mck.: "Textiles for comfort", Shirley Institute, Manchester, 1971.
2. Jaksic D.: "Projektiranje in konstrukcija tekstilij", Univerza v Ljubljani, FNT - Oddelek za tekstilstvo, 1988.