Comfort Ranges Drawn up Based on the PMV Equation as a Tool for Evaluating Thermal Sensation

Ilona Frohner[1] and László Bánhidi[2]

[1]University of Pécs, Pollack Mihály Faculty of Engineering, Hungary
[2]Budapest University and Ergonomics

Corresponding email: frohner@witch.pmmf.hu

SUMMARY

When dimensioning closed rooms according to the thermal sensation solving the relevant equations is necessary for a prediction of the PMV and for the determination of the surface temperature of clothing without using expensive simulation programmes in many cases, since they are not available for every designer.
Thus we considered the drawing up of thermal comfort ranges as necessary plotting the PMV ranges corresponding to the categories *A*, *B* and *C* of the general thermal comfort according to the standard CR 1752.
We have determined the terminating lines on both sides of the comfort range plotted for this purpose by fixing the values PMV = ±0.2, ±0.5 and ±0.7 using Fanger's equation on the t_{lev}-t_{ks} plane. When drawing up comfort ranges for different applications we have considered the changes in relative humidity and air velocity as well.

INTRODUCTION

During the last decades dimensioning methods have been developed enabling an even more exact calculation and evaluation of the temperature sensation of a person staying in a room. A forecast of thermal comfort is already prescribed by standards as well, however they do not determine any simple calculation method of the parameters PVM and PPD. Comfort ranges given depending on air temperature and on the radiant temperature of the surfaces surrounding the room, which could help the dimensioning do not contain references on PVM values being fixed in CR 1752 as preconditions of thermal comfort. Therefore it necessary to develop a comfort range demonstrating the connection between the expected temperature sensation corresponding to the building quality categories A, B and C, the air temperature and surface temperatures.

METHODS

When evaluating the thermal environment the environmental parameters playing the most important role are the air temperature (t_a), mean radiant temperature of the surrounding surfaces (t_{mrt}), relativeair movement (v_r), partial water vapour tension of air (p_a) as a result of relative moisture content (φ) and personal parameters, i.e. thermal insulation ability of clothing (I_{cl}), ratio of body surfaces being naked and covered with cloth (f_{cl}) and activity level (M/F_{Du}).
Criteria related to the general thermal comfort in CR 1752 are determined by the operative temperature (t_{op}) on one side and by the expected values of the temperature sensation (PVM) on the other side.

Local discomfort factors have an important role as well during evaluating the thermal environment, which are the followings: draft (i.e. medium air speed and turbulence intensity), vertical differences in air temperature, radiant temperature asymmetry and surface temperature of the floor.
Forecast of thermal comfort can be numericated by the parameters of the expected temperature sensation (PVM) and PPD. The parameter PPD gives the ratio of those being unsatisfied with the thermal environment, thus it is a characteristic value of evaluating the thermal environment quality.
Numerication of the expected temperature sensation can be determined with the help of the comfort equation written by Fanger. This thermal equilibrium equation written on the basis of thermal equilibrium of the human body is an equation defining the identity of heat produced by the human body and the heat amount transferred to the environment.
Definition of thermal comfort sensation is based on the assumption that a person feel his/her environment - in which he/she stays - as comfortable, if he/she can give over the heat produced by him/her under such conditions being appropriate to evaluate the environment as pleasant. In this case heat production and heat transfer is in equilibrium and PMV = 0.
Temperature sensation depends on thermal load (L_h) being the difference between the internal heat production and the heat amount transferred to the environment.
In case of comfort sensation the value of heat load $L_h = 0$ and the expected temperature sensation PMV = 0 (neutral). Equation determined by Fanger for the expected temperature sensation:

$$PMV = \left(0,352 \cdot e^{-0,042\left(\frac{M}{F_{Du}}\right)} + 0,032\right)\left\{\frac{M}{F_{Du}}(1-\eta) - 0,35\left[43 - 0,061\frac{M}{F_{Du}}\cdot(1-\eta) - p_a\right] - 0,42\left[\frac{M}{F_{Du}}(1-\eta) - 50\right] - 0,0023\frac{M}{F_{Du}}(44 - p_a) - 0,0014\frac{M}{F_{Du}}(34 - t_a) - 3,4\cdot 10^{-8}\cdot f_{cl}\left[(t_{cl}+273)^4 - (t_{mrt}+273)^4\right] - f_{cl}\cdot\alpha_c\cdot(t_{cl}-t_a)\right\} \quad (1)$$

Value η in the equation is the efficiency of mechanical work and t_{cl} the surface temperature of clothing, for which equation (2) is relevant.

$$t_{cl} = 35,7 - 0,032\frac{M}{F_{Du}}(1-\eta) - 0,181\cdot I_{cl}\cdot\left[3,4\cdot 10^{-8}\cdot f_{cl}\cdot\left[(t_{cl}+273)^4 - (t_{mrt}+273)^4\right] + f_{cl}\cdot\alpha_c\cdot(t_{cl}-t_a)\right], \quad (2)$$

Value α_c in the above equation is the heat-transfer coefficient for convection:

$$\alpha_c = \max\left\{2,05(t_{cl}-t_a)^{0,25};\quad or \quad 12,1\sqrt{v_r}\right\}, \quad (3)$$

Air velocity (v_r) is influenced by the activity level and by the air state built up in the room, the relative air speed caused by the ventilation and by the natural air flows arising near to cold or warm surfaces. Equation (1) does not take into consideration the turbulence intensity caused by the air flow, limited by CR 1752 together with air speed depending on the air temperature.
For the forecast of the general temperature sensation equations (1) and (2) related to the calculation of PMV are to be calculated during dimensioning - according to CR 1752 - with the given parameters by the designer for the resting points in the room.
Therefore it is necessary to draw up a thermal comfort range supporting the design demonstrating at the same time the PMV ranges corresponding to the categories A, B and C of the general thermal comfort according to the standard CR 1752.