Operative temperature and globe temperature

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Abstract Thermal comfort is defined as the mental condition that expresses satisfaction with the thermal environment. It is easy to understand this definition but it is difficult to express it by mathematical equations, because it is needed to take into account many of environmental and personal parameters. The Czech standards contain the equations which describe the thermal comfort through PMV, PPD indexes and the thermal state through the operative temperature. In this paper, a comparison between the operative temperature and globe temperature has been presented and it is shown that it is possible to use the globe temperature instead of operative temperature.

1 Introduction

Air temperature, radiant temperature, humidity and air velocity are the four basic environmental variables which define the thermal state of environment. Combined with the metabolic heat generated by human activity and clothing worn by a person, they provide the six fundamental factors that define human thermal environments [1]. Many instruments have been designed which give the effects of air temperature, mean radiant temperature and air velocity on the thermal state of environment. One such instrument is the globe thermometer. In this paper we have shown the possibility of using the globe temperature for describing thermal state by comparing between it and operative temperature.

2 Thermal comfort

The Thermal comfort has been defined by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as the condition of the mind in which satisfaction is expressed with the thermal environment'' [2]. The thermal comfort describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. When we want determination what will make someone feels comfortable we need to take into account a range of environmental and personal parameters which make very difficult to definition thermal comfort.

3 Operative temperature t_o

The operative temperature is defined as a uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non uniform environment. According to ČSN EN ISO 7726 [3] is

$$t_o = t_a + (1 - A)(t_r - t_a) \tag{1}$$

$$A = \frac{\alpha_c}{\alpha_c + \alpha_r} \tag{2}$$

Where:

α_c, α_r [W/m^2.K] are the coefficients of heat transfer by convection and radiation, respectively, on the body surface.
t_a, t_r [^{o}C] is air and mean radiant temperature.
For low air velocity w < 0.2 m/s it is possible to replace operative temperature with globe temperature [4].

$$t_g = t_o \quad , \qquad T_g = T_o \tag{3}$$

Where:
T_g,t_g is globe temperature in unite of [K],[°C] respectively.
T_o,t_o is operative temperature in unite of [K],[°C] respectively
Other reference [3] considers for low air velocity w < 0.2 m/s and small difference of temperature | $t_a - t_r$ | < 4 K, it is possible assess the operative temperature as arithmetic mean of air and mean radiant temperature

$$t_o = \frac{t_a + t_r}{2} \tag{4}$$

When the air velocity increases then the coefficient of heat transfer by convection α_c increase, and the change of coefficient of heat transfer by radiation α_r can be neglect. Then the coefficient A depends on air velocity w, see **Tab. 1**.

Tab. 1 Dependence of coefficient A on the air velocity w [3].

w [m/s]	< 0.2	0.2 to 0.6			> 0.6 to 1	
A [3]	0.5	0.6			0.7	
w [m/s]	< 0.2	0.3	0.4	0.6	0.8	1

It is possible to calculate the coefficient A from the following equation [3]:

$$A = 0.73w^{0.2} \tag{5}$$

4 Globe temperature t_g

The globe temperature is quantity, which measures directly by globe thermometer. The globe thermometer is one of the most common radiant temperature measurement tool, introduced by Vernon (1930). It consists of a hollow copper sphere of diameter 150 mm (in Czech Republic used also diameter 100 mm), coated with matt black paint and containing an ordinary thermometer with its bulb fixed at the center of the sphere, without source of heat. In steady state the radiant heat flux from the environment into the sphere is in balance with the convective heat flux from the surface of sphere to the environment. The globe thermometer reaches thermal equilibrium when the heat gain by radiation equals the heat loss by convection

$$q_c = q_r \tag{6}$$

By Stefan – Boltzmann's law, the radiation gain may be expressed by the equation

$$q_r = \sigma \cdot \varepsilon\left(T_r^4 - T_g^4\right) \tag{7}$$

Where
ε is a numerical constant depending on the emissivity of the sphere, for a surface painted matt black the value of ε is about 0 95;
$\sigma = 5.67 \cdot 10^{-8}$ is Stefan – Boltzmann's constant [W/m^2.K^4];
T_r is mean radiant temperature of the surrounding surfaces [K];
T_g is temperature of the sphere surface [K];

The convection heat transfer between air space and the sphere is given by the equation

$$q_c = \alpha_{cg}(T_g - T_a) \tag{8}$$

T_a is air temperature [K];
α_{cg} is the convection heat transfer coefficient [W/m^2.K];
In case of forced flow; according to ISO 7726

$$\alpha_{cg} = 6.3\frac{w^{0.6}}{D^{0.4}} \tag{9}$$

D is diameter of sphere [m];
w is air velocity [m/s];

The thermal equilibrium equation is written

$$\alpha_{cg}\left(T_g - T_a\right) = \sigma \cdot \varepsilon\left(T_r^4 - T_g^4\right) \tag{10}$$

From last equation can be found the globe temperature as function of velocity, mean radiant temperature and air temperature

$$\alpha_{cg}.T_g + \sigma \cdot \varepsilon \cdot T_g^4 = \alpha_{cg} \cdot T_a + \sigma \cdot \varepsilon \cdot T_r^4 \tag{11}$$

Fig. 1 shows the globe temperature as function of velocity, mean radiant temperature and air temperature (two viewpoints).

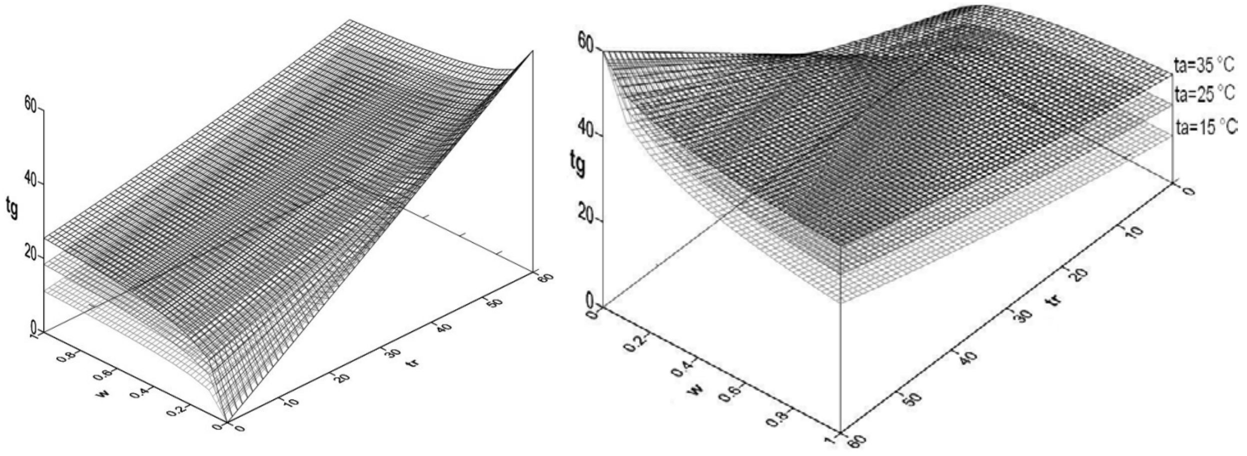

Fig. 1 Globe temperature $t_g = f(w, t_{r,} t_a)$.

From the equations (1) and (5) can be found the operative temperature as function of air velocity, mean radiant temperature and air temperature $t_o = f(w, t_{r,} t_a)$.

Fig. 2 shows the relation of operative temperature with air velocity, mean radiant temperature and air temperature (two viewpoints).

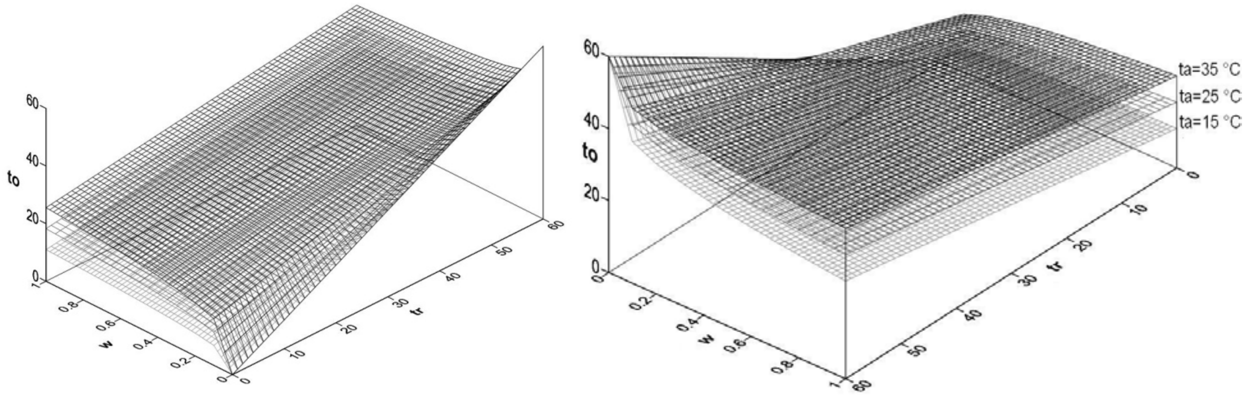

Fig. 2 Operative temperature $t_o = f(w, t_r, t_a)$.

The relation between operative temperature and globe temperature is given by likeness of heat transfer on the surface of human body and the heat transfer on the surface of globe thermometer, and because of globe temperature is easily obtained by reading it directly from the globe thermometer.

Fig. 3 shows a comparison between the operative temperature and globe temperature, the right one for range of mean radiant temperature 40 ^{o}C ≥ t_r ≥ *0* ^{o}C and air velocity 1 m/s ≥ *w* ≥ 0.2 m/s.

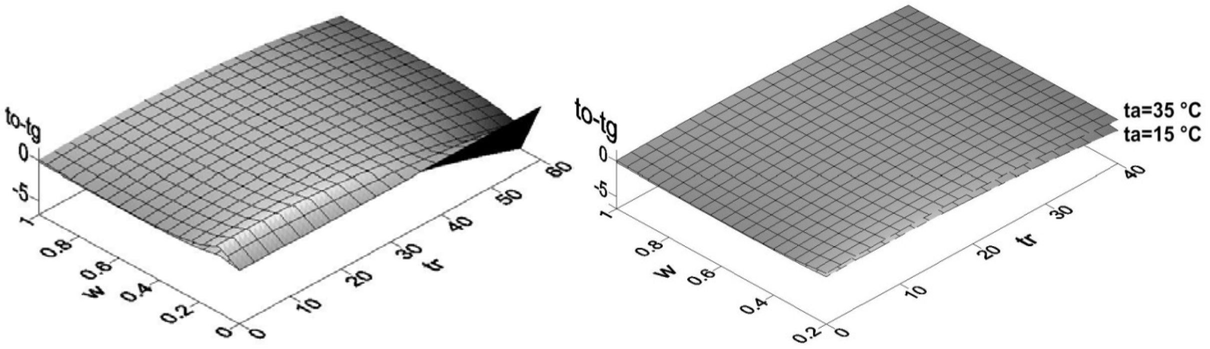

Fig. 3 Deference of operative and globe temperature $t_o - t_g = f(w, t_r, t_a)$.

5 Conclusion

The results show that the difference of operative and globe temperature is small $|t_o - t_g| < 1$ K in the range of velocity *w* (0.2 ÷ 1) m/s and mean radiant temperature t_r (0 ÷ 40) ^{o}C, so it is possible to use the globe temperature instead of operative temperature in previous range.

Reference

[1] PARSONS, K. Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance. 2nd ed. London: Taylor, 2003, 527 s. ISBN 04-152-3793-9.
[2] ANSI/ASHRAE Standard 55. Thermal Environment Conditions for Human Occupancy; 2004.
[3] ČSN ISO 7726. Thermal environments: Instruments and methods for measuring physical quantities. Prague: Czech Standards Institute, 1993, (original in Czech).
[4] Statute-book No. 523/2002 Sb., CZ, Year 2002, (original in Czech).