A CLIMATIC INDEX FOR THE EVALUATION OF RADIANT HEAT LOAD

Alfons Forsthoff and Hortense Neffgen
Institute of Occupational Physiology at the University of Dortmund,
Ardeystr. 67, 44139 Dortmund, FRG

INTRODUCTION

Occupational heat stress is often caused by heat radiation from the surroundings. However, there was a great lack of knowledge about the physiological effects of heat radiation. Experimental studies couldn't be carried out earlier because efficient test rooms were not available. Therefore, a special climatic chamber was constructed and comprehensive experiments were performed to study the physiological strain produced by heat radiation systematically. The results have been published in detail [1, 2]. The findings indicated, that heat stress indices commonly used are less capable to evaluate the thermal effects of heat radiation correctly. The purpose of this paper is to propose a new evaluating method, based on the earlier studies.

METHODS

In about 900 climatic chamber experiments 16 healthy non acclimatized men (19 - 22 years) were exposed to climates with different combinations of air temperature, mean radiant temperature and air velocity. The water vapour pressure was always low. The radiation intensity is given in terms of "Effective radiation (E_{eff})", because it is related to a mean surface temperature of 32 °C (305 K). The E_{eff} was calculated from measuring values of Vernon's globe temperature. The used equations for t_r and E_{eff} are given in ISO 7726 [3].

Table 1: Studied variables

Air temperature	t_a	: (5 ··· 55) °C
Mean radiant temperature	t_r	: (25 ··· 160) °C
Air velocity	v	: (0.5 ··· 2.0) m/s
Water vapourpressure	e	: (5 ··· 15) hPa
Eff. radiation intensity	E_{eff}	: (-40 ··· 1400) W/m²
Globe temperature	t_g	: (25 ··· 76) °C
Radiant direction		: all-sided, one-sided
Air flow direction		: ventral, dorsal
Clothing insulation	I_{cl}	: 0.1 clo; 0.7 clo
Metabolic rate	M	: (100 ··· 200) W/m²

Three types of radiation loads were simulated: 1. the body was radiated symmetrically from all sides, 2. only the frontal side and 3. only the back side. Each situation was combined either with ventral or dorsal direction air flow. The subjects worked on a treadmill at three levels of metabolic heat production (100, 150 and 200 W/m²). They wore either only shorts and footwear (0.1 clo) or a typical work suit (0.7 clo). The studied variables are summarized in Table 1.

Each experiment lasted 3 hours. The subjects worked first at reference climates (air temperature equal to radiant temperature) and then at climates with reduced air temperatures (lower than reference temperature) combined with elevated radiant temperatures (higher than reference temperature). The highest difference was about 140 K. During the exposure time heart rate (HF), rectal temperature (RT) and skin temperature were recorded continuously. The sweat rate (SR) was calculated each half an hour from the weight loss and the O_2-uptake hourly.

PHYSIOLOGICAL EQUIVALENT CLIMATES

For the development of a heat stress index it is necessary to find those combinations of the influencing variables which produced physiologically equal reactions. An example of the procedure is shown in Figure 1. At first the physiological reactions were investigated at a reference climate, e.g. 40 °C. In further experiments the air temperature was reduced in steps of about 10 K and the radiant temperature was elevated stepwise until the physiological reactions were equal to those in the reference climate. As criteria for indicating equal heat stress conditions the mean values of HR, RT and SR occuring in the third hour of exposure time were taken. At this time the values represented mostly steady state conditions. According to a reference climate of 40 °C the equivalent climates were plotted. The slope of the equivalence line depends on air velocity and clothing type but it is independent from the other variables, namely: metabolic rate, radiant and air flow directions.
All physiologically equivalent climates got the same index-value. It seemed practicable to take the temperature of the reference climate. Therefore, in this example the index value is called t_{eq} = 40 °C. The index t_{eq} can be defined as follows: "For any combination of air temperature, radiant temperature and air velocity the t_{eq}-value

indicates the temperature of the physiologically equivalent reference climate. Climates with equal t_{eq}-values produce the same thermal strain".

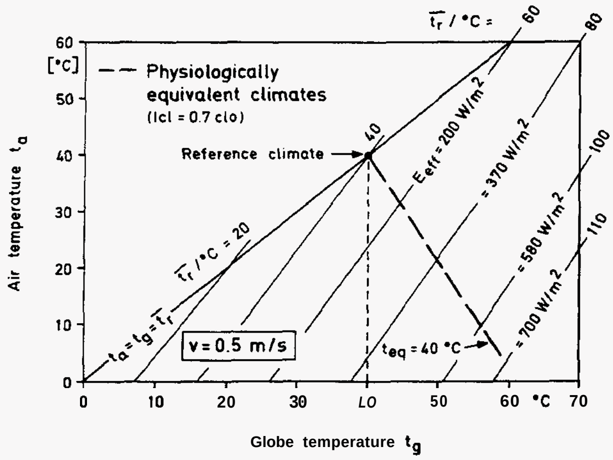

Figure 1: Example for equivalent climates

CALCULATION AND MEASURING OF t_{eq}

The index t_{eq} can be calculated from the basic climatic variables. The general function of the equivalent line as shown in figure 1 is:

$$t_{eq} = (t_g + b \cdot t_a) / (1 + b) \qquad [°C]$$

(t_g = globe temperature, *6* inch, / °C; t_a = *dry* air temperature / °C). The factor b depends on air velocity v_a (m/s) and the clothing type.

$b = 0.34 - 0.02\ v_a$ for nearly nude persons
$b = 0.546 - 0.033\ v_a$ for fully clothed persons.

The equations are valid for t_{eq}-values in the range of 25 "C up to 55 "C and air velocities between 0.5 m/s and 2 m/s.
Furthermore the t_{eq}-value can be measured approximately by using small globe thermometers. The globe size should be 40 mm for fully clothed persons and 65 mm for nearly nude persons. The validity of the instruments was proved in technical and physiological studies [4, 5].

CONCLUSIONS

For the assessment of heat stress different thermal indices have been developed. Actually the Corrective Effective Temperature (CNET), the Wet Bulb Globe Temperature (WBGT, ISO 7243 [6]) and the Index of Required Sweat Rate (E_{eq}, ISO 7933 [7]) are commonly used. **A** comparison with the presented index t_{eq} shows however, that these indices overestimate the effects of heat radiation often extremely, especially at large differences (20 K or more) between air and radiant temperatures. Therefore, it is proposed to integrate the index t_{eq} in the currently used indices.

REFERENCES

1. Wenzel, H.G. and Forsthoff A. 1989, Modification of Vernon's globe thermometer and its calibration in terms of physiological strain. Scand. J. Work Environ. Health 15(suppl.I) 47-51
2. Forsthoff, A.; Wenzel, H.G.; Neffgen, H.; Wenzel, C. und Golka, K. 1990, Ermittlung aquivalenter Klimate fur bekleidete Personen durch ein modifiziertes Globethermometer. Verh. Dt. Ges. Arbeitsmed. 30,371
3. ISO 7726, 1985, Thermal environments; Instruments and methods for measuring physical quantities.
4. Forsthoff, A. und Wenzel, H.G. 1988, Untersuchungen zur Eignung eines neuen Globethermometers als Klimasummenwertgerat. Verh. Dt. Ges. Arbeitsmed. 28,209
5. Forsthoff, A. und Wenzel, H.G. 1986, Modifikation des Globethermometers nach Vernon zur Erfassung physiologisch äquivalenter Wärmestrahlungsbelastungen. Verh. Dt. Ges. Arbeitsmed. 28,303
6. ISO 7243, 1989, Hot environments; Estimation of the heat stress on working man, based on the WBGT-Index (wet bulb globe temperature).
7. ISO 7933, 1989, Hot environments; Analytical determination and interpretation of thermal stress using calculation of required sweat rate.