PHYSIOLOGICAL DETERMINANTS OF THERMONEUTRALITY IN THE COLD

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INTRODUCTION

Man responds to climatic stress by a series of physiological and behavioural reactions. Peripheral vasomotor activity and sweating are the two most important means of adjustment. It has been proposed that both factors also are important determinants of thermal sensation [2]. Indeed, it has been postulated that a certain amount of sweating is required for the experience of thermal comfort irrespective of thermoregulatory requirements [3]. However, the basis for this assumption are experiments in moderate and warm thermal environments. It can be readily questioned whether such criteria also apply to cold environments (subzero conditions) [7, 8].

Thermal neutrality can be well maintained also at very low temperatures by proper combination of adequate clothing insulation and physical activity [1, 8]. However, increased clothing insulation decreases the potential for evaporative heat loss. High levels of sweating may rapidly saturate clothing microclimate. Progressive absorption and build-up of moisture in clothing layers, impair the insulative properties and may endanger thermal balance. From a survival point of view it is not likely that conditions defining a sensation of thermal neutrality ("comfort"), are similar to those, that may present a thermal hazard.

This paper examines the relevance of existing physiological comfort criteria for exposure to cold environments.

METHODS AND MATERIALS

During the last decade several studies have been undertaken in our institute to investigate human responses to cold exposure with special emphasis on the development of criteria for acceptable exposures to cold environment in occupational work. A total of more than 150 individual experiments has been undertaken. Some of the results have also been reported previously [4, 5, 6, 7].

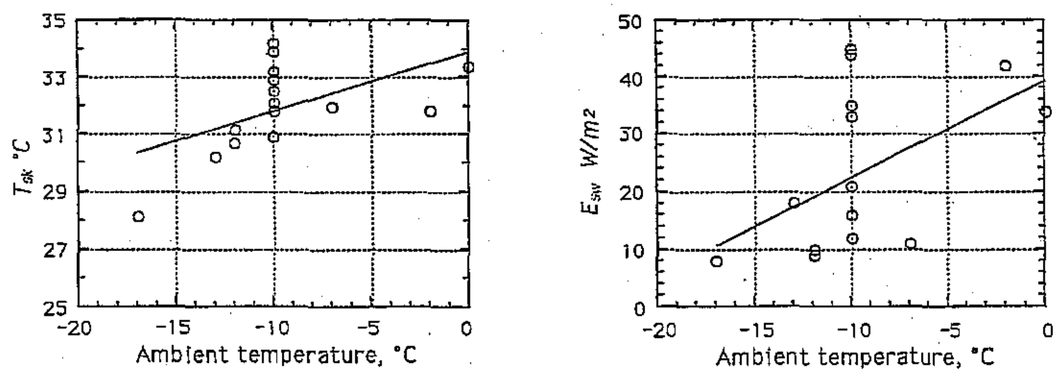
Fanger [2] has proposed a set of physiological comfort criteria that has been widely used for the assessment of moderate thermal environments and, occasionally, for the evaluation of more extreme environments. The hypothesis is that with increased activity level (M), the sensation of thermal neutrality is associated with a lower mean skin temperature (T_{sk}=35.7–0.028 M) and a higher sweat rate (E_{sk}=0.42 (M–58)) [2].

In the present analysis measured values for mean skin temperature and evaporative heat loss during steady-state conditions were compared with predicted values for thermoneutral sensation.

RESULTS AND DISCUSSION

Measured values for T_{sk} and E_{sw} obtained at different environmental conditions and activity levels are given in the figures. A general trend is that both T_{sk} and E_{sw} decrease with colder conditions. This is anticipated at equal levels of clothing insulation and activity. However, all conditions analyzed here are not directly comparable, since they vary in these two aspects. This is particularly true for –10 °C, where several different types of cold weather clothing (at different insulation levels) were tested. In other words, the maintenance of heat balance was accomplished by different degrees of thermoregulatory strain. Some of the conditions were rated by subjects as equal or close to thermoneutrality. Other conditions were rated warmer. Of all conditions only two were rated slightly cool.

Mean skin temperature of subjects at thermoneutral ratings (PMV≈0) were of the same magnitude as predicted by the comfort criteria, e.g. at –10°C (30.8 versus 30.7 °C). The narrow interval of activity levels in which thermoneutral conditions were established, does not justify a regression analysis of T_{sk} on M. It seems logical, however, that increased metabolic heat production (and core temperature) in the cold requires progressive vasoconstriction to restore heat content and thermoneutral sensation [3].



Measured evaporative heat loss for the actual conditions never exceeded 45 W/m^2. Predicted comfort sweating was 30-71 W/m^2 higher than measured E_{SW}, despite the fact that most of the conditions were rated by subjects as slightly warm or warm. It seems clear that predicted levels of E_{SW} (comfort levels) for thermoneutrality are too high.The comfort equation in its original (Fanger) or modified form [3] significantly overestimates the warmth of a cold environment. Apparently, the concept of comfort sweating does not apply to subzero environments. Man in the cold should maintain heat balance by regulation of sensible heat exchange (clothing), rather than provoke sweating by overdressing [9].

CONCLUSIONS

Low levels of evaporative heat exchange was required for thermoneutral or warm sensations during light to moderate activity in cold environments.

Established sweating criteria for thermoneutrality (comfort sweating) cannot be applied to models predicting responses to very cold climates.

Further studies are required to elucidate the important determinants of subjective thermal responses to cold exposure.

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