MEASUREMENT OF THERMAL AND WATER VAPOR RESISTANCE OF PROTECTIVE GARMENTS WITH A MOVABLE MANIKIN

Karl H. Umbach
Bekleidungsphysiologisches Institut Hohenstein e.V.
Bönnigheim, Federal Republic of Germany

INTRODUCTION

In order to evaluate the physiological performance of protective garments and to determine their temperature range of utility a predictive model can be applied, based on man's energy balance (1). As an input this model uses the resultant thermal and water vapor resistance of the clothing worn. Consequently, the accuracy of the prediction depends on the precision of these garment resistances. For their determination we have developed an evaluation technique using a movable thermal manikin ("Charlie") and a sweating hot plate (Skin Model) (1, 2).

However, in a recent publication (3) the validity of our evaluation method has been doubted, argueing with water vapor resistance values determined with a manikin sweating by means of a cotton knit "skin" sprayed with water to simulate skin saturated with sweat. These values are about 60% higher compared to the results of our evaluation technique. In this paper results of wear trials with subjects with 2 garment ensembles are presented which are in good agreement with the physiological performance of the clothing predicted by our evaluation model, proving its validity.

METHOD

The resultant thermal resistance R_c of the garment ensemble is directly measured with the electrically heated sectional manikin Charlie, distinguishing between a value $R_c(1)$ for the manikin standing and a value $R_c(3)$ for the manikin moving which includes the pumping effect (2). From these R_c-values the thermal resistance R_{cT} intrinsic to the fabric combinations in the ensemble (measured separately with the dry Skin Model) is subtracted, yielding the effective thermal insulation R_{cL} of the air layers within the garment ensemble and adhering to its outer surface (1).

By a basic physical relation out of R_{cL} the equivalent water vapor resistance R_{eL} of these air layers is calculated. By adding the intrinsic evaporative resistance R_{eT} of the ensemble's fabric combinations measured with the sweating Skin Model the resultant water vapor resistances $R_e(1)$ and $R_e(3)$ of the clothing are gained with the wearer either standing or moving, respectively.

The resultant R_c- and R_e-values, thus determined, are used in a thermophysiological model (1, 2) predicting the ensemble's range of utility, limited by a minimum ambient temperature T_{amin} at which the wearer is just not feeling too cold, and a maximum ambient temperature T_{amax} at which he is just not suffering from hyperthermia. Vice versa, with a given climate and activity condition, as an indication for the wearer's physiological strain, the model predicts his skin and rectal temperature, heart rate and microclimate humidity as well as his subjective comfort sensation.

RESULTS

Two clothing ensembles (shorts and sports-shirt; jeans and shirt) have been tested in controlled wear trials with 4 subjects in a climatic chamber performed under warm climate conditions near the ensembles' upper limit of the range of utility with medium and heavy physical activity. Sensors on the subjects' body registered relevant physiological data out of which the effective thermal and water vapor resistance of the garments could be determined. Additionally the test persons' subjective comfort sensation was registered by multi-step scale votes.

All these data collected in the wear trials were in close agreement with the results of our evaluation technique with the manikin "Charlie" and the Skin Model as well as of our predictive model applied. Examples are given in Figures 1 and 2. In contrast the published data from the manikin sweating with a water-sprayed cotton skin (3) largely disagreed with the results from the wear trials.

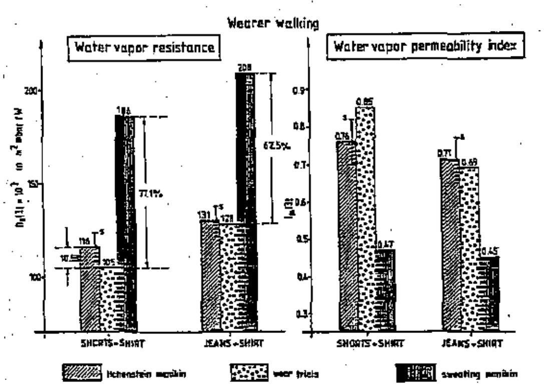

Figure 1

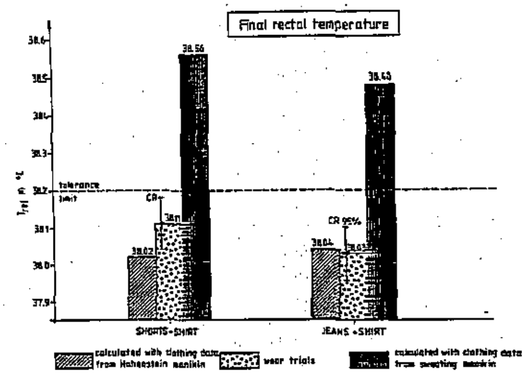

Figure 2

CONCLUSIONS

The Hohenstein measurement and evaluation technique with the movable thermal manikin "Charlie" and the sweating Skin Model yields the thermal and water vapor resistance of a garment ensemble as they are effective in use. With these clothing data applied in a predictive model the physiological performance of protective garments and their wearability in specific climate and activity conditions can be determined in good agreement with practical results.

REFERENCES

1. Mecheels, J. and Umbach, K.H., The psychrometric range of clothing systems. In Clothing Comfort, edited by N.R.S. Hollies and R.F. Goldman, pp 133-151, Ann Arbor, Ann Arbor Science Publishers Inc., 1977.

2. Umbach, K.H., Physiological tests and evaluation models for the optimization of the performance of protective clothing. In Environmental Ergonomics, edited by I.B. Mekjavic et al., pp 139-161, New York/London, Taylor & Francis, 1988.

3. McCullough, E.A. et al., A data base for determining the evaporative resistance of clothing. ASHRAE TRANSACTIONS, 95, Pt. 2, 1989.