RELIABLE PREDICTION OF CLIMATIC WEARING COMFORT USING IMPROVED SIMULATION TECHNIQUES

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INTRODUCTION

The basic functions of a human-physiological simulation device, known as "Hand-/Foot-Model" (1) or "CYBOR" (for "Cybernetic Body Regulation"), have been enhanced to allow reliable predictions of the climatic wearing comfort of hand- and footwear. Additional phantoms with different shapes (e.g., buttock or square) can be used with the simulation device. Thus, the system can also be applied to car seats or flat specimen like matresses and textiles, respectively.

MATERIALS AND METHODS

The simulation device (Figure 1) consists of a computer-controlled air conditioner, a heated transfer line to avoid condensation of water on the way to the phantom and exchangeable phantoms made of fiber-reinforced plastic.

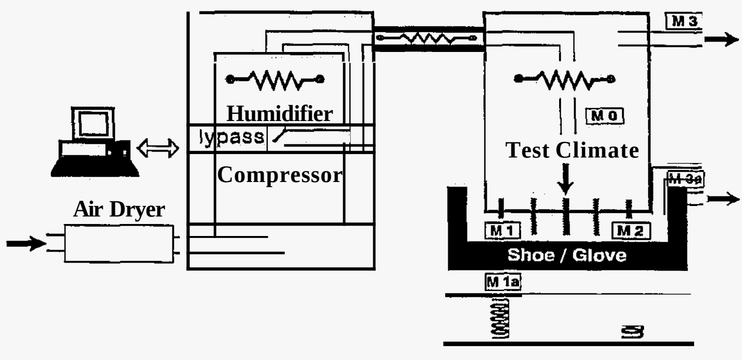

Figure 1. Simulation Device "CYBOR." Model 3a: rh/T-sensors.

The specifically designed perforated surfaces of the phantoms allow the simulation of the sweating process closely related to physiological conditions. The concept of the simulation device provides a *precise* and separate control of *dry* and humid enthalpy streams, which are fed into the phantom and allows various applications of the system for the determination of comfort-related material parameters as well as the judgement of climatic comfort, i.e.,:

• simulation of the dynamic change of temperature and humidity as they occur inside a shoe (glove) during walking (working) at different levels of additional metabolic rate;

• determination of absolute values of the heat and water vapor resistance of hand- and footwear systems;

• simulation of defined enthalpy levels that are separated in dry and humid heat as a function of skin temperature.

The most important features of the simulation device are discussed below.

RESULTS AND DISCUSSION

Dynamic Change of Temperature and Humidity

Dynamic changes of temperature and humidity can be precisely simulated. The precision of the method allows the judgment of the footwear (handwear) system as a whole, as well as all of its components. An example of a comparative test of socks differing only in respect of the applied mixture of fibers is given in Figure 2.

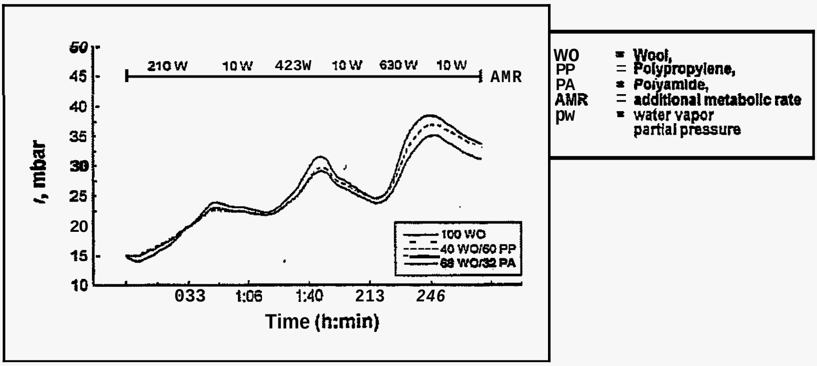

Figure 2. Comparative investigation of the mircoclimatic wearing comfort of socks

The measurement was carried out inside a regular combat boot at 16°C outside temperature. The curves represent the water vapor partial pressure between the (phantom) foot and the sock in the medial section of the foot as a function of time and additional metabolic rate. It can be seen that, by the end of the test, there are obvious differences in the levels of the water vapor pressure. The following conclusions can be drawn from this test:

• From the 3 different fiber mixtures under test mixture 2 (32% PES/68% WO) will provide the most comfortable (driest) microclimate inside the shoe.

• The influence of different fiber mixtures is becoming significantonly after longer times of walking and/or higher levels of additional metabolic rate. **A** short test of several minutes to about one hour would not have shown clear differences. The water vapor transmisson rate in the sole area of the socks, measured according to ISO 11092, is nearly identical. Similar investigations have been made with different kinds of inlay soles.

By registering the in- and outgoing *dry* and humid enthalpy streams, as well as the change of weight of the shoe and sock, the total energy balance of the footwear system can be calculated. The calculation delivers precise and relevant results, because the water is supplied to the phantom in vaporous state, and there are no energy consuming evaporation processes of unknown amount inside the phantom. Thus, information can be obtained about the insulation, water vapor transmission and storage behavior of the footwear system and its components. For defined military applications, footwear systems can be designed to match the desired microclimatic wearing comfort.

Determination of Heat and Water Vapor Resistance Values

In the fixed value mode of the simulation device, absolute values for the heat (R_{ct}) and water vapor resistance (R_{et}) of shoes and gloves, as well as flat samples like fabrics and nonwovens, can be determined depending on the shape of phantom used. In this mode, the device is operated with fixed temperatures for the humidifier, the transfer line and the phantom. Tests carried out on textile samples of different construction and thickness showed a good correlation of R_{ct}- (r = 0.947) as well as R_{et}- (r = 0.909) values to those measured with the standardized ISO 11092 method (Hohenstein Skin Model) (2). The advantage of the hand/foot model, though, can be seen in the fact that both values can be determined at the same time. This is of particular importance, when foot- and handwear systems are investigated: convection caused by temperature and humidity gradients inside the shoe (glove) can significantly influence the measurement of the heat and water vapor resistance values. By measuring both values at the same time, the influence of the fit or of different constructions of socks, inlay soles and shoe-lining materials, respectively, can be quantified.

Simulation of Fixed Enthalpy Levels

Investigations on the microclimatic wearing comfort can be carried out with close relation to physiological control mechanisms. The phantom is fed with a fixed enthalpy stream correlated to a given workload. By means of a built-in *fuzzy* controller **(3)** the initially *dry* enthalpy stream is continually turned to humid enthalpy according to the physiological sweat gland activity. Figure 3 shows an example of the investigation of a membrane-lined trekking shoe.

While the temperature does not exceed 35°C in all three cases, the humidities adjust to different values between 30 and 80% RH with respect to the selected workload (enthalpy). The result has been shown to be reproducible with a precision of 0.5°C for the temperature and 2% for the RH. This control concept can be fine-tuned to precisely represent the human thermoregulation in the hand, foot or buttock region, respectively.

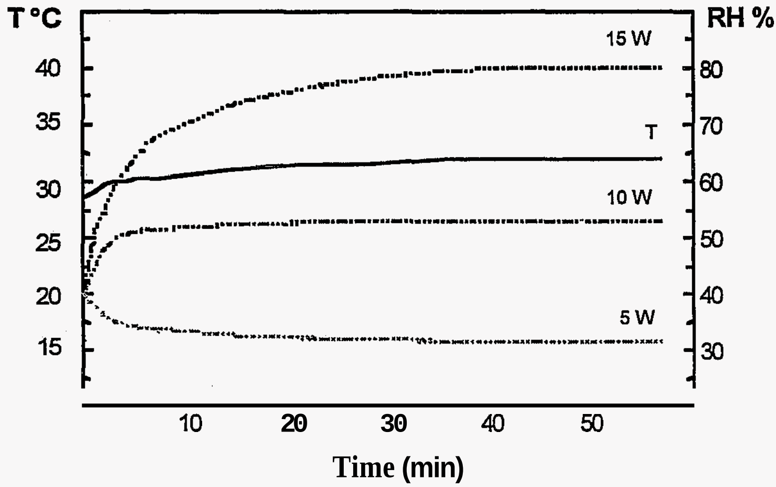

Figure 3. Fuzzy-controlled adjustment of relative humidity (dotted lines) inside a trekking shoe at different levels of workload. The measured temperatures (filled line) are identical at every level of workload (5W/10W/15W).

CONCLUSION

The human simulation device, "CYBOR," has proven to be a powerful tool for the objective determination of physiology-related climatic properties of clothing and other articles, which are in close contact with the surface of the human body.

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