CYBOR CONCEPT FOR THERMOPHYSIOLOGICAL SIMULATION OF DRY AND WET HEATFLOW

B. Kurz[1] and W. Uedelhoven[2]

[1]Institute for Applied Ergonomics (IfaErg), München, Germany
[2]Bundeswehr Institute for Materials, Explosives, Fuel and Lubricants (WIWEB), Erding, Germany

INTRODUCTION

The purpose of this paper is to describe the CYBOR-system, a biophysical simulation device that is used to simulate the dry and wet heat flows in human body segments (i.e., heat amount and perspiration rate) by controlling temperature and humidity in phantoms with permeable surface and adapted body shapes.

MATERIALS AND METHODS

CYBOR Concept

In contrast to comparable devices, the humidity output of the CYBOR-system is derived entirely from water vapor. When determining the interaction between dummy and clothing with respect to humid heat transfer properties, the state of the induced humidity (liquid or vaporous) is of low importance.

The purpose of sweat production, with respect to thermal physiology, is the efficient loss of heat by evaporation. If this is not possible due to the water vapor transport properties of the clothing (e.g., high transmission impedance Re) or partial pressure gradients (e.g., tropic environs), the sweat will stay as liquid on the surface of the skin. This results in an uncomfortable feeling, the clothing system will be overloaded, and wet spots will appear (condensation).

The main advantage of determining the microclimate of the phantom by means of vaporous water can be seen in the applicability of simple thermodynamical algorithms. In contrast to devices working with liquid water, the difficult determination of the evaporated amount by weighting is not necessary; it must be guaranteed, however, that condensation inside the dummy and the boundary layer to the clothing is avoided.

Thermodynamic Modeling

Figure 1 shows the thermodynamic balancing concept of heat and mass transports for the CYBOR-dummies with the corresponding sensor devices for measurement of air volume, temperature and relative humidity on the input and output sides of the system.

Based on the theory that the conditioned air is a mixture of two idealized gases (i.e., dry air and water vapor), enthalpies and mass streams can be calculated as proportions of the gas amounts. Of particular interest are: (1) total stream enthalpy h [W], which corresponds to the total heat amount, (2) dry stream enthalpy hd [W], which corresponds to the dry heat amount, and (3) wet mass flow $\dot{m}$ h [mgs-1], which corresponds to the perspiration ratio.

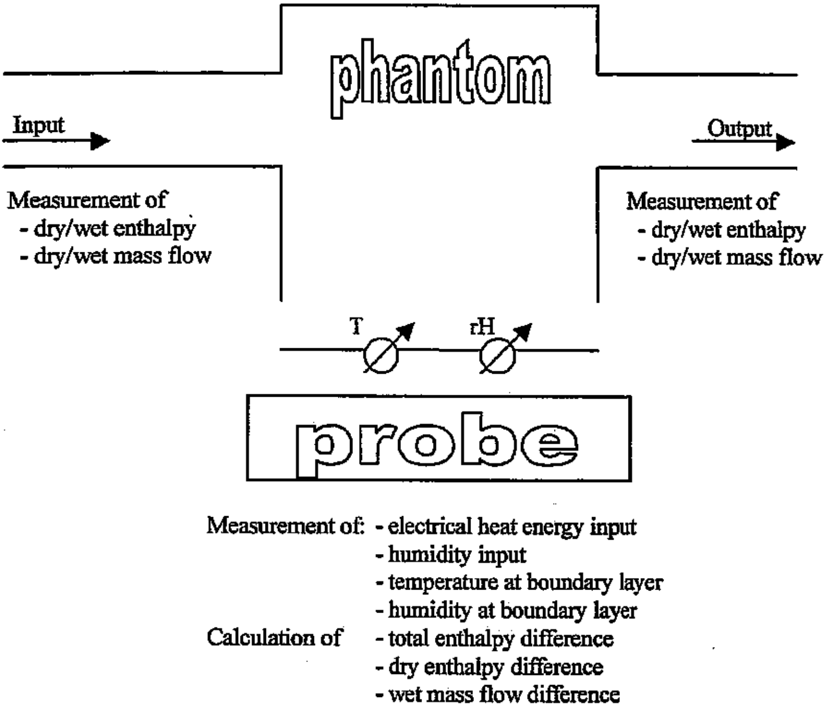

Figure 1. CYBOR heat and mass transport thermodynamics.

To determine interactions of the gas stream with the clothing system, it is important to know the differences between input stream and output stream values, specifically: (1) total heat gained or lost, h; (2) dry heat gained or lost, hd; and (3) humidity gained or lost, $\dot{m}$ h.

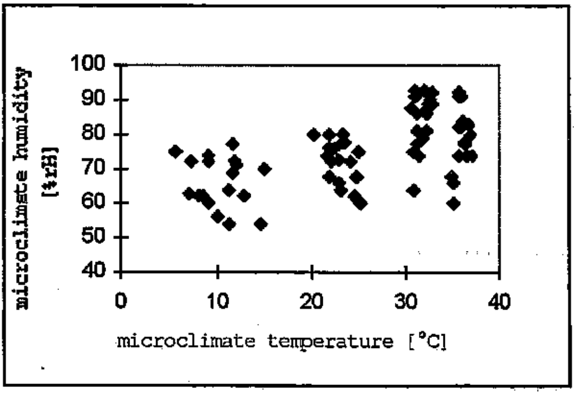

Figure 2. Microclimate conditions in shoes during wearing tests.

TESTS AND RESULTS

To evaluate the correlation of results from wearing tests and CYBOR-simulation tests, the following test procedure was designed:

During hundreds of wearing tests, under several test conditions, temperature and humidity levels measured in standardized shoe systems (reference shoe) have been recorded and are summarized in Figure 2.

In the study described above, the microclimate variables inside the reference shoe are the steady state variables to be controlled by the CYBOR-device, according to the specified test conditions. The dry energy and wet mass flow necessary to obtain the desired microclimatic conditions in the shoe are measured during the test (see Table 1).

Table 1. Set point and measured values of wearing and simulation test.

	Evironmental temperature (°C)			
Measurements	-16	0	16	32
RH (%)	60 ± 19	60 ± 23	75 ± 16	84 ± 14
T (°C)	10 ±5	22 ± 2.5	30 ± 2	36 ± 2
$\Delta \dot{m}_h$ ($mg \cdot s^{-1}$)	1.0 ± 0.7	3.5 ± 2	4.0 ± 2	7.0 ± 1
Δh_d (W)	3 ± 1.0	4 ±1.5	7 ±2.0	10 ± 1.0

For example, at an environmental temperature of 16°C the maximum values in the shoe are found to be: temperature = 30 + 2 = 32°C, and relative humidity = 75 + 16 = 91%.

To obtain this microclimate condition, the values for hd und $\dot{m}$ h are determined to be 7 + 2 = 9 W and 4 + 2 = 6 mg·s, respectively. The total heat amount is calculated to be 23 W.

To validate the determined dry and wet energies, a revised test procedure has been chosen wherein the values of hd and $\dot{m}$ h were used as set points for the CYBOR-system. It was expected that the same temperature and humidity steady states observed previously should appear when the same shoe system (reference shoe) is tested. The results show high correlations and reliabilities.

DISCUSSION

Based on simple thermodynamic relations, the CYBOR-system is able to import defined heat and sweat rates (hd and $\dot{m}$ h) to clothing systems. Thus, physiologically relevant microclimates for comfort prediction can be simulated.

The goal of an add-on-development concerning the control strategy was to realize a singular set point for the simulation procedures (i.e., total heat amount h) that has to be discharged in the corresponding body segment. The resulting amounts of dry and wet heat flows are detemined by an adaptive fuzzy controller. The controller algorithm is based on thermophysiological facts like the dependence of sweat gland activity on the skin temperature or the influence of the skin temperature on the possible amount of heat discharge. In addition to these thermoregulatory influences, the body-segment heat production and loss depend on global exogenous parameters like the temperature of the environment, physical work load, and clothing isolation. In order to determine the set point for the CYBOR-simulation, either the mathematical relations among all the interacting parameters must be known, or the empirical interdependencies have to be established in a neural network (see Figure.3).

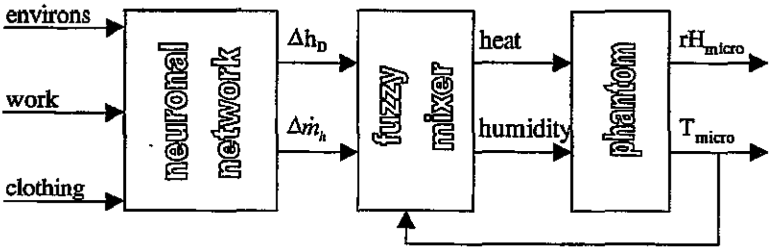

Figure 3. Neuro-fuzzy-concept of CYBOR-process-control

REFERENCES

1. Kurz, B. and Heidinger, F. 1995, Simulation model of thermoregulation for microclimatical investigations (Thermoregulatorisches Simulationsmodell für mikroklimatische Untersuchungen), ATZ *Automobiltechnische Zeitschrift*, 95, 74-78.
2. Seif, N. 1996, Design and realization of a fuzzy controller (Entwurf und Realisierung eies Fuzzy-Controllers), Unpublished diploma work at the electrical engineering department of University Of Applied Sciences, Munich, Germany.