the description will be incomplete and somewhat lacking in precision, and its faults will be made obvious by the very definiteness that characterizes a mathematical model. Nevertheless, quantitative comparison of computed and measured human responses to various combinations of thermal stress and exercise provides a powerful mechanism for improving a model, and, thereby, increasing our understanding of thermal physiology.

In this paper, the author traces briefly the development of human thermal models during the past forty years, and then describes a recently developed model. A comparison of representative computed results with corresponding measured values is presented, before typical applications are described. The paper concludes with a discussion of aspects of modelling that are in need of improvement, and a bit of speculation about the impact that new computers will have on human thermal modelling.

60 Three-dimensional simulation of cold and warm defence in man

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Taking into account the spatial dependence of parameters and variables, an adequate simulation of the thermoregulatory system of man comprises a set of partial differential equations, the parameters of which have to be based on the realistic geometry and anatomy of the human body. Therefore we have constructed a three-dimensional digital atlas with a grid of 0.5cm for head and extremities and 1 cm for the trunk, and have solved the system of equations by an implicit 'alternating direction' method on the vector-computer CYBER 205.

The simulation-system has delivered a realistic picture of the topography of temperatures under neutral conditions. Compatibility of reality and simulation was achieved solely on the basis of physical considerations and physiological data base. An adjustment of parameters of the passive system was not necessary. Therefore the simulation is suited to analyze functional controller equations by way of comparison of experimental and simulation results.

The physiological distribution of metabolic heat production and blood flow turned out to be an essential feature for a compatibility of the results. For cold defence a spatially distributed control of the skeletal muscles, with special regard to the proximal areas, must be required in order to get the decrease of temperature in the extremities, well-known from experiments. A uniform control of all skeletal muscles turned out to be an inadequate controller structure. The small local differences of temperatures in warm stress make it, however, very difficult to analyze distributed controller structures for warm defence.

Global and local consequences of the inhomogeneity of the human body and its geometry can be demonstrated by the simulation. The transversal temperature profiles of the extremities and the uniform temperatures in the brain are examples for the global influence, the decrease of spinal cord temperature with respect to the adjacent tissue, due to high blood flow, is an example of local effects.

The simulation of dynamic effects is possible, but fails at present on account of the small working storage of the CYBER 205 version at the Ruhr-University. First tests demonstrate that the time courses of temperatures will be computed correctly.

61 Prediction of the psychrometric range of a clothing system using the relation between subjective comfort votes and physiological variables

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An experiment was set up to determine the psychrometric range of a military clothing system. The clothing system consisted of 11 items, enabling the user to wear a variety of clothing assemblies according to the weather conditions. The clothing system was developed to cover the temperature range between -20 and +30 degrees Celsius at activity levels ranging from rest to heavy work.

Four clothing combinations (cold to hot weather gear) were involved in the test, each tested on four subjects at two metabolic levels [standing (65 W/m^2, duration of experiment 3 hours) and bicycle ergometer work (230 W/m^2 for 1 hour)] and in three climatic conditions. The climatic conditions were chosen in combination with the estimated clothing insulation and the metabolic rate, in order to result in mild cold stress or mild heat stress.

Data were collected on O_2 uptake, skin temperatures and humidities, oesophageal and rectal temperatures, suit surface temperatures and, in a 15 minute cycle, subjective comfort sensations regarding both temperature and humidity.

With these data, the clothing insulation values for each outfit and climatic conditions were determined, using the method of partitional calorimetry. Further, the relation between subjective comfort votes and physiological variables was investigated by multiple regression analysis, up to 78 percent of the variance in comfort votes being explained in terms of physiological parameters. In this way the physiological status could be determined, associated with any of the comfort votes. Subsequently, this status and the actual determined clothing insulation values were used to predict the ambient (climatic) and work rate conditions that would evoke such comfort votes, resulting in the prediction of the psychrometric range.

The results show that the width of the psychrometric range runs from 7°C for comfortable cold to comfortable warm, up to 22°C for uncomfortable cold to uncomfortable warm. The range is more or less symmetrically distributed around the neutral point, indicating that redistribution of heat loss in combination with clothing behaviour in the cold is as effective as is sweating in the heat. The width of the psychrometric range tends to increase with work rate, and shows only a slight dependence on insulative value.

Using the method described above, the complete psychrometric range of the system is predicted from measurements at only a limited number of climatic conditions.

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62 Standards for human exposure to heat

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Heat stress does not begin at any specific combination of temperature/humidity; it has occurred at temperatures near -5°C. It results from a mismatch between six factors:

1) the worker's heat production (usually a key factor)
2) a humidity (or more precisely, ambient vapor pressure) too high to allow sufficient sweat evaporation for the required cooling (E_{req})
3) radiant heat, in effect adding up to 7°C to the air temperature in direct sun, more in steel mills, etc.
4) clothing which limits the maximum obtainable sweat evaporative cooling (E_{max}), almost invariably the case for any type of protective clothing even if its moisture permeability is normal ($i_m \approx 0.5$) as its insulation (clo) increases the sweat evaporative path thus limiting a key E_{max} parameter (i_m/clo)