1) the average values of Esk and Ecl at three sites showed no significant difference in the initial stage until Esk abruptly increased;

2) following the sudden increase in Esk, Esk decreased exponentially but Ecl gradually increased over a period of 1 hr;

3) Esk returned to the inital levels, and Ecl remained in the range between 60 and 80 W/m^2 during the last one-third of entire exposure.

These results may be associated with the onset of sweat secretion (sudden increase in Esk), the progress of saturation with water vapor in clothing microenvironment (exponential decay of Esk) and moisture and water gain in fabric (gradual increase in Ecl). In addition, substantial reduction of Esk in the heat indicated lack of ventilation as the obvious nature of protective clothing.

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58 Helicopter pilot suits for offshore application: a survey of thermal comfort and ergonomic design

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The objective of this study was to determine the existing problems associated with helicopter pilot survival suits currently in use. A survey of helicopter pilots from both Canadian commercial and military disciplines was conducted. Pilots commented on eight different types of survival suits. Reduced thermal comfort as well as lack of ventilation were the two most common criticisms of the pilot suits. The "greenhouse" effect, common to helicopter cockpits, results in hot working ambients both in summer and winter. The air cooling mechanisms employed in summer may cause a "chilling" effect following an on-ground stand-by where cockpit temperatures may reach 40°C. Thermal stress may also be induced with high cockpit temperatures caused by the sun's radiation in winter and summer. Suit design was another area considered. 72% and 86% of military and commercial pilots respectively felt their freedom of movement was hindered by their survival suits. Certain designs were considered more hazardous than others with regards to clips and hooks catching switches on the control panel. Difficulty in donning suits appeared to be a universal problem irrespective of type of suit used. Lack of comfort and movement in addition to thermal stress may lead to reduced time to fatigue and, thus, occurrence of errors and accidents. The results of this survey reflect the inadequacies of the helicopter pilot survival suits presently in use. It is suggested that evaluation of these suits be made on the basis of their ventilation capabilities, ergonomic design and thermal properties in a variety of ambient environments.

Session IX
Thermoregulatory Modelling
Abstracts 59-61

59 Modelling human exposure to thermal stress

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Physical scientists and engineers, and to a lesser degree biological scientists, rely on mathematical models to describe natural systems with which they deal. Mathematics provides both a convenient language for describing quantitatively various components of a system and logical rules for converting a given description into a form more suitable for a particular purpose. Although some may argue that the human thermal system is too complex to be described mathematically, the author would argue that such a complex system can only be described adequately in mathematical terms. To be sure,

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