between the skin and ambient air (torr). When ¥ becomes small (<0.1) or ventilation is being kept high as observed in daily clothing assembly, the general equation 1 is reduced to:

$$Esk/(hea \cdot \Delta P_V) = ¥/(1 + hea/hecl) \qquad (2)$$

and hecl can be defined as:

$$hecl = Dw \cdot \lambda / (R_V \cdot Tcl \cdot lg) \qquad (3)$$

where, Dw = the diffusivity of water vapor (m^2/hr), λ =the latent heat of vaporization (Kcal/kg), R_V = the gas constant for water vapor (torr/m^3•kg^{o}K); Tcl = temperature at clothing layer (^{o}K) and lg = thickness of clothing layer (m). On the other hand, when ventilation is so limited that microenvironment becomes appreciable resistance to moisture permeation, equation 1 can be rewritten as:

$$Esk/(hea \cdot \Delta P_V) = ¥/(1 + 0.43 \cdot ¥ \cdot hea \cdot Icl) \qquad (4)$$

where, Icl = insulation of clothing layer (clo).

The values of the permeation factor {Esk/(hea • ΔP_V)} for helicopter suits were obtained from human experiments, and showed a close agreement with those predicted with equation 4.

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57 Dynamic moisture transfer through clothing worn

N. Kakitsuba, C.A. Gaul, H. Michna and *I.B. Mekjavic*, School of Kinesiology,Simon Fraser University, Burnaby, British Columbia, Canada

Complication of the evaporation process through clothing worn may be attributed to the effect of absorbency (Pratt et. al., 1956), the hygroscopic properties of clothing (Nelbace and Herrington, 1942) and ventilation in clothing microenvironment (Birnbaum and Crockford, 1978; Olesen et. al., 1982; Vogt et. al., 1984). The hygroscopic properties can be characterized by moisture gain and loss in varying relative humidity, which may cause imbalance between the rate of evaporation from the skin (Esk) and that from the clothing surface (Ecl). Similarly, considering that clothing insulation in warm environment and during exercise decreases due to increased ventilation, any change in ventilation may also lead to such disproportion in heat loss by evaporation. Thus, these implications appear to be of great importance in both sensible and insensible heat exchange through clothing, yet little work has investigated these significant effects on the evaporation process through clothing. In this study, using a newly developed device, changes in Esk and Ecl were observed while ambient temperature was elevated.

The device was first developed by Lamke et al., (1977), and more recently Kakitsuba (1982) improved the system to allow measurement at multiple sites simultaneously. However, the device used for this study has been further improved to minimize its size applicable for measurement underneath clothing. It consists of two relative humidity sensors coupled with thermistors so that absolute humidities at two points within boundary layer can be determined. The rate of evaporation can then be derived by applying Fick's law of diffusion.

Four male subjects wore four different types of helicopter suits (Nomex, Goretex, Cotton ventile, Nomex/Insulite) and sat in the middle part of a box shaped frame enclosed with thick black drapery. Ambient temperature was elevated from 20^{o}C to 40^{o}C within 90 minutes and kept constant at 40^{o}C for 2.5 hr. The rates of local evaporation from the skin at three sites (chest, arm and thigh) and those from the clothing surface at corresponding sites were monitored throughout exposure. The results are as follows:

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

C.A. Gaul and I.B. Mekjavic, School of Kinesiology, Simon Fraser University, Burnaby, British Columbia, Canada

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

E.H. Wissler, University of Texas at Austin, Austin, Texas USA

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,