

47 Thermal resistance and water vapour transmission measurements with a sweating cylinder

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The thermal protection effect of clothing is traditionally expressed through its thermal resistance value, measured with hot plate methods for materials and thermal manikins for garments or clothing systems. The water vapour permeability, measured with skin model type of apparatus, expresses the possibility of evaporative cooling through perspiration when using a certain clothing system. In a real wearing situation there is an interaction between the dry and the evaporative heat loss through the clothing, and particularly in extreme thermal environments the results of the standard measurements can be very misleading.

As a part of the Scandinavian Coppelia project, which aims at a sweating thermal manikin, a sweating cylinder for measurements of combined heat and moisture transmission measurements through clothing materials was constructed. The cylinder produces a controlled amount of water vapour from the surface, and heat input values, temperatures at different points, and weight changes are recorded during the tests.

The cylinder is dressed with test materials and placed in the test environment. A microcomputer system regulates the surface temperature to a predetermined value (+35°C). The thermal resistance of the test materials is calculated from the temperature gradient and heat input values. In most cases only a part of the water input is transmitted in the form of vapour through the clothing and a part is condensed, due to the water vapour resistance of the textiles and to the lower saturated water vapour pressure in the colder environment than on the cylinder surface (skin). The ratio of evaporated water to water input is taken as a measure of the water vapour permeability.

Measurements of cold weather clothing in different environment temperatures and at different sweating rates show the quantitative changes in thermal insulation and water vapour permeability. An increase of the water input from 0 to 145 g/m².h might cause a decrease of nearly 50% in the thermal resistance value, and a decrease of the environment temperature from +20 to -20°C causes a drastic decrease in the water vapour permeability. At -40°C most textile combinations are virtually impermeable to water vapour.

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48 Clothing surface area as related to body volume and clothing microenvironment volume

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The evaluation of clothing surface area becomes important in analyses of heat exchange between the clothed body and its environment. The evidence accumulated in the studies of radiation area (Bedford, 1935; Guibert and Taylor, 1952; Nielsen and Pederson, 1952; Fanger, 1972) has led to the conclusion that the ratio of clothing surface area to body surface area (f_{cl}) may be defined as a function of clothing insulation. However, there has been disregard of the effects of clothing fit, despite of the observations of McCullough *et al.* (1984) that f_{cl} does not correlate strongly with clothing insulation alone.

Radiation area factors were derived with a photographic method (Horikoshi and Kobayashi, 1982) for five subjects wearing four different helicopter pilot suits. While sitting on a seat suspended in the center of a box shaped frame, photographs were taken of the subjects with a fish-eye lens at 90 equidistant points on the six sides of the frame. The derived factors of 0.7 ± 0.18 (mean \pm SD) for the unclothed case closely

agreed with that reported by Fanger (1972), while it scattered in a relatively wide range for a given suit.

The present study proposes a new approach for predicting f_{cl} as related to the body volume and the clothing microenvironment volume, and defines f_{cl} as:

$$1) f_{cl} = (1 - V_{\mu} \sum_{i=1}^N V_i)^{0.5}$$

where, V_{μ} = volume of clothing microenvironment (m^3)
 V_i = volume of i -th body component (m^3)
 m = exposed body components (e.g. head, feet and hands)

Assuming that volume of the head is 7% of the total body volume (V_b , m^3), equation 1 can be rewritten as:

$$2) f_{cl} = (1 + 0.93 \cdot V_{\mu} / V_b)^{0.5}$$

Since all the suits tested enclosed the entire body surface with the exception of the head, equation 2 can be compared with the observations. The body volume and the clothing microenvironment volume of each subject were determined using the water displacement method and the method suggested by Sullivan et al. (1985), respectively. The predictions showed a good correlation with the values derived from the photographic method. It is therefore suggested that improvement in the prediction of f_{cl} has been achieved by incorporating clothing fit.

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49 Biophysical devices for measuring heat transfer through clothing materials

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At our Institute the assessment of heat exchange and vapor transmission through clothing materials is currently achieved by a series of techniques and devices.

1. Wettable flat plate - Heat transfer properties of fibers and fabrics are carried out by use of a heated, wettable flat plate. The plate consists of three separate heated and controlled sections. All heat leaving these test sections passes through the fiber or fabric. The plate allows the user to determine the dry heat transfer (clo) and the evaporative heat transfer (i_m) of flat pieces of materials before they are made into part of a clothing ensemble.

2) Copper hand - A sectional copper hand is employed for prototype handwear items. The copper hand has twenty-three thermally isolated sections which allows the evaluation of total and individual regional insulation values of handwear items.

3) Copper feet - Two sectional copper feet are employed for footwear items. Each foot has twenty-eight thermally isolated sections. Total and individual regional insulation values of footwear items are processed on a microcomputer.

4) Copper manikins (static) - three types of manikin are currently used to measure the static heat transfer properties of clothing ensembles.

The first type consists of single circuit manikins which allow the measurement of the overall insulation and permeability of clothing without control of the surface