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CLOTHING INFLUENCE AND THE INFLUENCE OF AIR HUMIDITY

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Introduction

An important function of clothing is to maintain a thermal balance between the wearer and the environment. Clothing is a significant and interesting subject for physiologists, engineers and those concerned with human heat tolerance and thermal comfort during rest and exercise.

A review of the literature about clothing insulation reveals that almost all the studies are limited to the subject of average clothing insulation. (See Zhu (1985), Mc Cullough (1985) and Olesen (1986)).

In the thermoregulation model, which considers the human body as one segment (as by Fanger (1970)), this approach is adequate. Recently, however, the physiological models of thermoregulation have been greatly developed. In addition to the one node model, there is now, for example, the two node model (see Gagge (1986)), and the six node model (as by Stolwijk (1971)). Consequently, clothing insulation should also be divided into relevant segments in order to study the effect of every body segment.

It is not possible for an individual part of the body to be in discomfort. The concept of discomfort is a concept of "feeling" - one which affects the whole of the human being. Certain strong environmental conditions will create a feeling of discomfort. An example of this is an asymmetrical situation.

Usually, heat resistance from the skin to the outer surface of the clothed body (intrinsic clo value, I_{cl}) is calculated as

$$I_{cl} = I_T - \frac{I_a}{f_{cl}} \qquad (1)$$

where I_T = total thermal insulation of clothing plus the air layer and

$$I_T = K \frac{\bar{\Theta}_s - \Theta_a}{P} \cdot A_s \qquad (2)$$

where $\bar{\Theta}_s$ is the mean skin temperature

Θ_a is the air temperature

P is the power input

I_a is thermal insulation of air layer around a nude manikin and

f_{cl} is the clothing area factor

This makes the assumption that the thermal insulation of the air layer around the nude manikin is equal to that around the clothed manikin. However, this is not the case. The free convective coefficient α_c is equal to $A \cdot \Delta\Theta_{s-a}^{m}$ (see Wang (1989), which means that

$$I_a = f(\Delta\Theta_{s-a}) \qquad (3)$$

The purposes of this study were to measure clothing insulation for every segment, using the skin and clothed surface temperature and to determine whether the air relative humidity affected the clothing insulation.

METHODOLOGY

Environment, thermal manikin and clothing

Measurements were performed in a climatic chamber of dimensions 4400 x 3700 x 2820 mm. The air temperature was controlled around 20°C and the air relative humidity was between 50% and 90%. The room temperature and air relative humidity were almost uniform and the air velocity less than 0.05 m/s.

A full-scale heated manikin was used separated into seven segments or pairs of segments: head, trunk, arms, hands, thighs, legs and feet. However, in this experiment, thighs and legs were considered as one segment, namely legs. The skin temperature for every segment could be regulated, see Fig. 1.

Fig. 1 A clothed manikin

A winter dress assembly was chosen to measure clothing insulation and the garment characteristics are given below.

Measurement of clothing insulation value

For every test condition the steady state was measured. For every segment, average skin temperature, average clothing surface temperature and electrical power were measured. Then the heat transfer resistance from skin to outer surface of the clothed body I_{cl} was calculated as

Table 1 Characteristics of Garment

Garment	Fabric Construction	Fibre Content	Fabric Thickness (mm)	Area
shirt	plain weave	cotton	0.35	1.05
pullover	knit	acrylic	1.30	0.90
socks	plain weave	acrylic	1.60	0.16
cap	plain weave	acrylic	1.80	0.10
scarf	plain weave	wool	1.00	0.31
underwear	plain weave	cotton	0.60	1.08
overcoat	twill weave	wool	1.50	1.42
jeans	plain weave	cotton	1.00	1.03

$$I_{cl_i} = K \frac{\Theta_{si} - \Theta_{cl_i}}{P_i} \cdot A_{s_i}$$

where I_{cl} = intrinsic thermal insulation of clothing, clo

Θ_s = mean skin temperature

Θ_{cl} = mean clothing surface temperature

P = power input

A_s = manikin surface area

K = units constant = 6.45 clo $W/m^2 \cdot {}^oC$

subscript i = segment i.

RESULTS

Thermal insulation (clo) values for all segments are given in Table 2 and Fig. 2 to 8.

Table 2. Clo value for different segments

		Air relative humidity (%)					
Segment	i	54	56	64	70	83	86
Head	1	1.53	1.45	1.42	1.29	1.42	1.43
Trunk	2	2.73	2.47	2.42	2.41	2.43	2.65
Arms	3	2.21	2.02	2.21	2.21	2.19	2.11
Hands	4	0.00	0.00	0.00	0.00	0.00	0.00
Legs	5	1.82	1.65	1.62	1.63	1.68	1.55
Feet	6	1.67	1.57	1.53	1.53	1.60	1.54

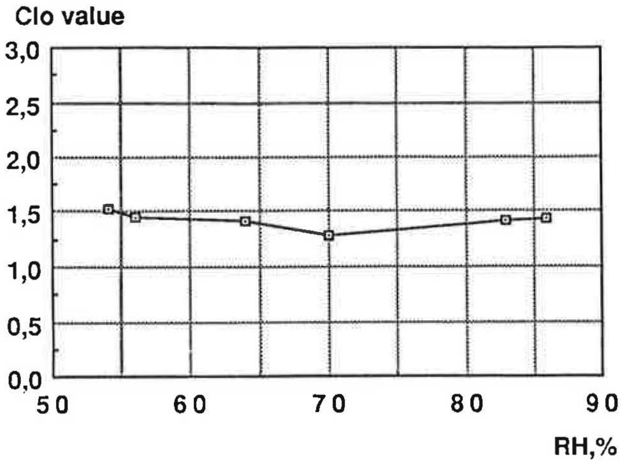

Fig. 2 Clo value for head

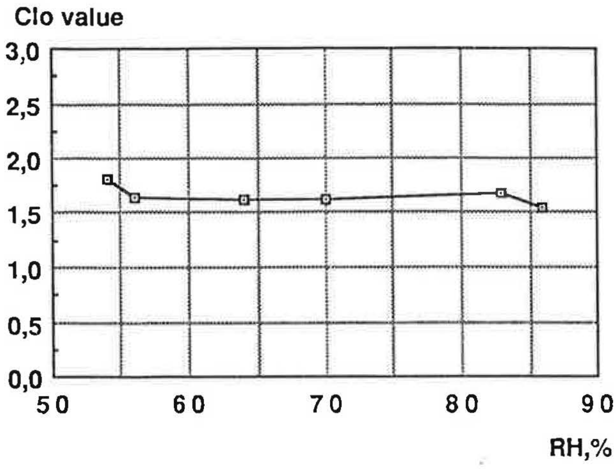

Fig. 5 Clo value for legs

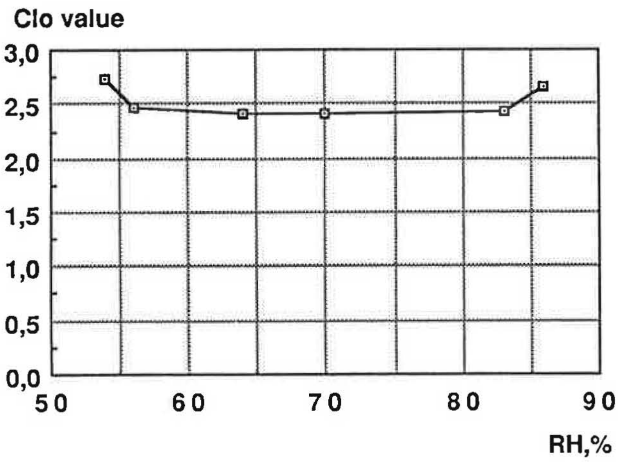

Fig. 3 Clo value for trunk

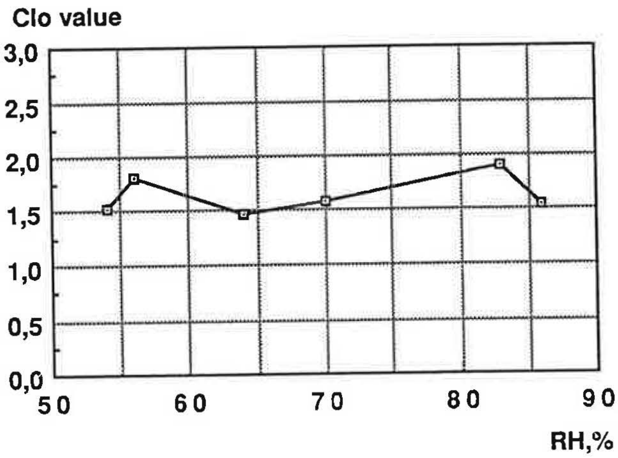

Fig. 6 Clo value for feet

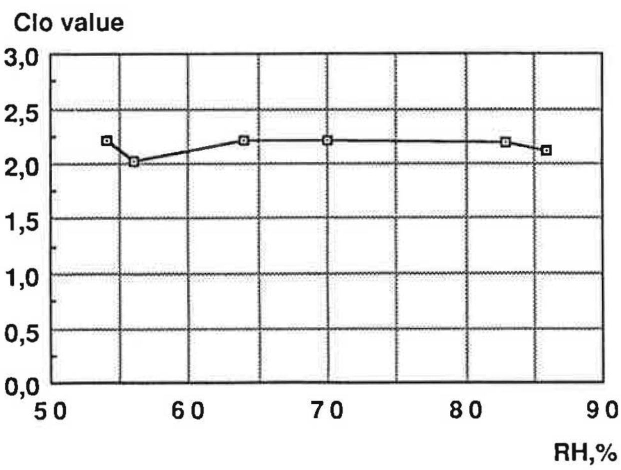

Fig. 4 Clo value for arms

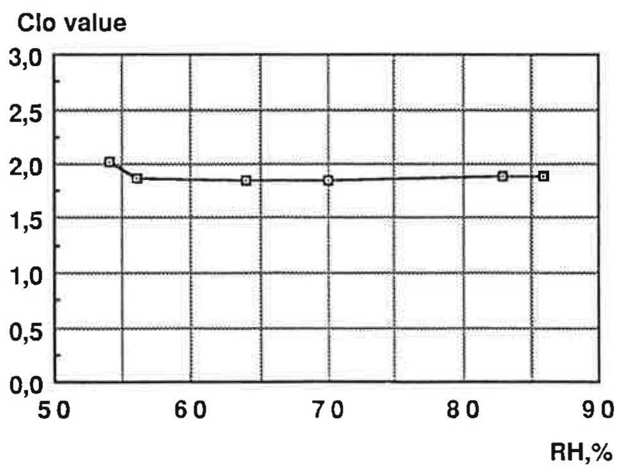

Fig. 7 Mean clo value

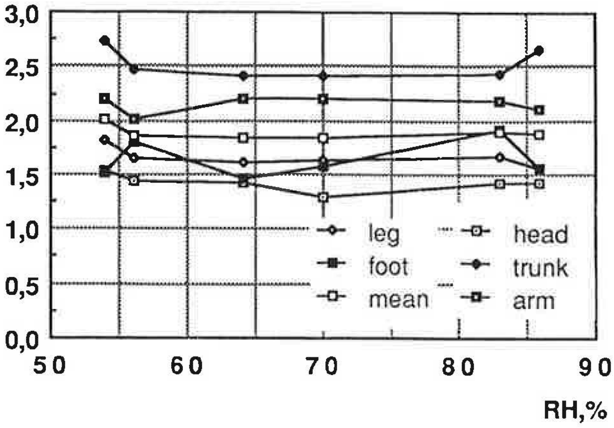

Fig. 8 Clo value

The mean walues are calculated from

$$\overline{I_{cl}} = 1/\{\sum_{i=1}^{6} (A_{si}/I_{cl,i})/\sum_{i=1}^{6} A_{s,i}\} \quad (4)$$

The clo value of a given textile system is dependent upon the insulating properties and the layering of the component fabrics, the amount of body surface area covered by clothing and the looseness or tightness of fit (See Mc Callough (1984)).

Different segments have different clothing or different clothing area factors. Consequently the clo values are different. Changes in the humidity content of the textile caused by variations in the air humidity have only a small influence on the conductive resistance (Ree, 1941) and changes in the air relative humidity have only a small or negligible effect on the clo value, as shown by this study.

Conclusions

Thermal insulation (clo) values differ between segments. These differences can be considerable.

Relative air humidity has only a small, and in some cases, negligible influence on the clo values.

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