EFFECTS OF THE DISTRIBUTION OF SKIN TEMPERATURES ON THE THERMAL INSULATION OF CLOTHING

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INTRODUCTION

Comprehensive databases concerning thermal insulation of clothing have been published with thermal manikins by several authors. Since thermal manikins have several body segments, the skin temperature for each segment must be set separately. However, it is not known how the distribution of skin temperatures affects the thermal insulation of clothing. If the effect is significantly large, the comparison among the data from different researchers will make no sense.

EXPERIMENTAL METHOD

Experiments were carried out during April, 1994. Relative humidity was kept at 50% and air velocity was under 0.15m/s in the climatic chamber. Thermal manikin was exposed with a standing posture. This manikin is thermally divided into 19 parts. The skin temperature of each body part was controlled with electric heated wire. Skin temperature and surface area of each body part are shown in Table 1. In the setting of the skin temperature, the ambient temperature (operative temperature) was kept at 28°C. The differences between the set skin temperature and the measured for Cases A (like a distribution of human body temperature), B (lower extremities), C (non-heated head and extremities), and D (uniform) were within ±0.3°C for all body parts. Table 2 shows clothing ensembles.

EQUATIONS FOR CALCULATION

The thermal insulation was calculated with the following equations.

$Ia = (ts, n - to) / 0.155Qa$ ...(1)

$It = (ts, cl - to) / 0.155Qt$ ...(2)

$Icl = It - Ia / fcl$ ...(3)

$fcl = 1 + 0.3Icl$ (McCullough 1985) ...(4)

where,

Ia	The thermal insulation of nude skin surface	(clo)
Icl	The basic thermal insulation of clothing	(clo)

It		The total thermal insulation of clothing	(clo)
Qa		Heat loss from the nude thermal manikin	(W/m^2)
Qt	:	Heat loss from the dressed thermal manikin	(W/m^2)
fcl		Clothing area factor	(-)
to		Operative temperature	(°C)
ts, cl	:	Skin temperature of the dressed thermal manikin	(°C)
ts, n	:	Skin temperature of the nude thermal manikin	(°C)

Body parts	Surface area (m^2)	Skin temperatures (°C)			
		Case A	Case B	Case C	Case D
Whole Body	1.4454	32.7	32.7	32.7	32.7
Head	0.1255	34.7	33.1		32 7
Chest	0.1418	34.1	33.1	32.7	32.7
Back	0.1378	33.3	33.1	32.7	32.7
Abdomen	0.0742	33.8	33.1	32.7	32.7
Hip	0.1267	32.2	33.1	32.7	32.7
R. Upper arm	0.0621	32.7	33.1	32.7	32.7
L. Upper arm	0.0599	32.7	33.1	32.7	32.7
R. Forearm	0.0360	32.7	33.1	32.7	32.7
L. Forearm	0.0375	32.7	33.1	32.7	32.7
R. Hand	0.0308	33.0	30.1	-	32.7
L. Hand	0.0280	33.0	30.1	-	32.7
R. Thigh	0.1077	32.3	33.1	32.7	32.7
L. Thigh	0.1123	32.3	33.1	32.7	32.7
R. Knee	0.0225	31.5	33.1	32.7	32.7
~~L. Knee~~	~~0.0227~~	31.5	33.1	32.7	32.7
~~R. Leg~~	~~0.0954~~	32.0	33.1	32.7	32.7
~~L. Leg~~	~~0.0971~~	~~32.0~~	33.1	~~32.7~~	~~32.7~~
~~R. Foot~~	~~0.0629~~	~~30.7~~	~~30.1~~	-	~~32.7~~
~~L. Foot~~	~~0.0636~~	~~30.7~~	30.1	-	~~32.7~~

note:- shows non-heated. R = Right; L = Left.

Table *2*. Clothing ensembles

Nude	no insulation
Trousers ensemble	long-sleeve shirts, bra, shorts, socks
Skiwear ensemble	ski outfit, long-sleeve shirts, bra, shorts, socks, gloves
Winter ensemble	ski outfit, long-sleeve shirts, bra, shorts

RESULTS OF THE EXPERIMENT

The measurement of the insulation was carried out under the condition of the operative temperature between 14 and 30°C. The thermal insulation of whole body was almost the same in tlus temperature range. The thermal insulation of nude skin surface and the total thermal insulation of clothing are shown in Table 3. The effect of the skin temperature distribution on these values of thermal insulation for the whole body was relatively small.

		Mean Value of Thermal Insulation (clo)			
		Case A	Case B	Case C	Case D
Nude	Ia	0.67	0.66	0.64	0.67
Trousers ensemble		1.22	1.26	1.34	1.21
Ski ensemble	It	1.95	2.02	2.49	1.96
Winter ensemble				2.43	1.78

The head was not clothed, the hands were not clothed or only with gloves, and the feet were clothed only with socks. For that reason, the values of thermal insulation at these parts were smaller than those of others. The total thermal insulation of the whole body for Case C was highest among all distributions, because the values of thermal insulation at the head, the hands and the feet were not included in the total thermal insulation for the whole body. Basic thermal insulation of clothing is shown in Table 4. The differences of basic thermal insulation of clotlung for whole body among Cases A, B, and D were within 0.lclo.

Table 4. Basic thermal insulation.

	The Basic Thermal Insulation of Clothing (clo)			
	Case A	Case B	Case C	Case D
Trousers ensemble	0.66	0.72	0.85	0.63
Ski ensemble	1.48	1.57	2.07	1.49
Winter ensemble			2.06	1.30

CONCLUSIONS

1) The total thermal insulation of nude skin surface was not affected by skin temperature distributions in the temperature range of this report.
2) It was difficult to measure precisely the thermal insulation of clothing in Case C.

REFERENCE

McCullough, E. A., Jones, B. W., and Huck, J., A Comprehensive Data Base for Estimating Clothing Insulation, ASHRAE transactions, 91 (2), 29-47 (1985)