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DETERMINATION OF CLOTHING COMFORT PROPERTIES WITH THE SWEATING THERMAL MANIKIN

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INTRODUCTION

For the determination of the thennophysiological properties of clothing systems basically two types of methods are used: physiological investigations using human test subjects and physical simulation tests. Until now the physical tests have been restricted to measurements of thermal resistance with dry thermal manikins. To evaluate the evaporative heat loss, a system with a wetted liner has been used (1), which however has the disadvantage of being a non-steady state measurement.

A sweating thermal manikin Coppelius was constructed within a Nordic development project, and test runs in climatic chambers have been performed since last autumn.

METHOD

The main features of the sweating manikin Coppelius are:

- a computer controlled heating system; 18 individual body sections,
- a computer controlled sweating system; continuous sweating over the whole body except head, hands, and feet; 187 sweat glands,
- anatomical body dimensions according to a Swedish man, size C50,
- prosthetic joints in shoulders, elbows, hips, and knees to permit movements and different body postures (a movement mechanism has not however yet been applied io the system).

A more detailed description of the manikin construction is given elsewhere (2).

The tests are performed in an exactly controlled climatic chamber (cold chamber +20...-50 °C; warm chamber +10...+70 °C / 15...95 % RH, with an accuracy of ± 1 °C and ± 3 % RH).

Water is supplied to the manikin from a reservoir, which is placed on a balance in the control room (m_s). The supplied water evaporates on the manikin surface, but partly recondensates in the clothing. The gross weight increase (m_t) is recorded by continuous weighing of the manikin + clothing during the test. Each garment is also weighed before. and immediately after the test, which gives the condensation in the individual layers (m_c). The condensation in the skin layer of the manikin (m_m) is the total weight change subtracted by the moisture in the clothing. The water vapour permeability M_e is calculated as the evaporated water in percents of the supplied water.

The heat supply (H) to the individual body sections is recorded continuously, and based on temperature measurements on the manikin surface and in the environment thermal insulation values (I_T) are calculated. The fact that the heat supply partly is used to evaporate water is considered by calculating the corrected thermal insulation I_{Tcorr}, which corresponds to the dry heat loss.

RESULTS

The measurements with Coppelius give different kinds of information about the tested clothing system:

- the heat supply and thermal insulation on the individual body sections and area weighed mean values,
- water vapour transmission and condensation under the specific conditions.

The manikin has been in use only for a short time, which mostly has been wed to establish its possibilities and limits. Table 1 shows some examples of test results, performed under different conditions. The measurements without clothing were done to establish the properties of the manikin itself under different sweating conditions. In the dry test, the weight of the manikin decreases slightly due to the heating under the surface.. With increasing sweating, there is also an increasing weight increase in the manikin skin material, and the percentual evaporation M_e decreases. The heat supply increases with the increasing water supply, as heat is needed for the evaporation.

The long underwear and underwear + thermodress clothings are taken from an investigation of the reference clothing of the Nordic standard (3), which is reported more completely in (2). The water vapour resistance and the thermal resistance increase with each additional layer of clothing, which is seen in the measured values of

TABLE 1. **Results of** some measurements with Coppelius

clothing	environm. (°C/%RH)	sweating (g/m²h)	m_s (g)	m_c (g)	m_m (g)	m_e (g)	M_e (%)	H (W/m²)	I_T (m²°C/W)	I_{Tcorr} (m²°C/W)
no clothing	+20 / 40	0	-	-	-4	-	-	145	0,103	(0,103)
		100	380	-	40	340	89.5	202	0,074	0,107
		200	760	-	149	611	81,5	261	0,057	0,093
long underwear	+20 / 40	0	-	-4,9	-	-	-	105	0,143	(0,143)
		100	426	6,8	52.2	367	86,1	171	0,088	0,143
		200	757	29,1	187,9	540	71,3	225	0,067	0,121
underwear + thermo-dress	+20 / 40	0	-	-7.0	-	-	-	56	0,268	(0.268)
		100	426	25.5	105,5	295	69,2	116	0,129	0.239
		200	759	89,0	284,0	386	50,9	149	0,101	0,194
asbestos removal overall	+25 / 40	100	425	2,6	111.4	311	73,2	112	0,063	0,082
	+35 / 30	100	426	4,7	135,3	286	67,1	55	-	-
jogging dress	+5 °C	200	844	113.1	223	508	60.2	261	0,115	0,167

weight changes and heat input. With an increasing sweating level the condensation both in the clothing and in the manikin skin layer increase rapidly, and the percentual water vapour permeability decreases. The heat input increases with the sweating level, and the values for the thermal insulation decrease. For the I_{Tcorr} this is due to the wetting of the clothing.

Three asbestos removal overalls, which had been tested in a physiological study in Sweden (4), were tested under similar conditions with Coppelius, with the aim to verify the differences between the overalls with physical measurements. The results for the polypropylene overall (PP) are given here. In the test at 35 °C, there is no temperature gradient between the manikin surface and the environment, and the total heat supply is used for evaporation of water.

Four breathable but still watertight jogging dresses were compared in a small study for a Finnish TV program, and the results for the best one is given here (a microfibre dress). The tests with Coppelius were performed in a cool environment, with the result that although the materials have a good water vapour permeability according to a standard test, there was a considerable condensation in the clothing in a true wear conditions.

DISCUSSION

Objective investigations of the thermal properties and moisture transmission in clothing systems under different sweating and environmental conditions can be made with the sweating thermal manikin Coppelius. The results are used to estimate the thermal comfort offered and stress caused by the clothing in different wear situations. A higher sweating level or a lower ambient temperature causes an increased undesired condensation, which decreases the thermal insulation of the clothing. Based on the results, conclusions can be drawn regarding the limits in use of the clothing. However, more research work on different types of clothing and for different types of wear situations is needed to establish a base for future possible standardisation of the measurements.

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