CONTROLLING SKIN HUMIDITY BY CLOTHING MOISTURE PERMEABILITY

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INTRODUCTION

A hypothesis that skin humidity could be a cause of discomfort in comfortable temperatures was tested in a series of human subject experiments. An important issue of the study was to control the level of skin humidity while other confounded factors, such as fabric against skin, thermal sensation and activity level, were kept constant. The level of skin humidity depends on the actual and saturated vapor pressures of the skin, determined by skin temperature, sweat gland activity, clothing moisture characteristics, air movement in the environment and the vapor pressure in the surrounding air (1). In the present study, we attempted to control skin humidity by controlling the clothing moisture permeability and the environmental conditions. The method used to control skin humidity for sedentary subjects is presented, and a comparison of estimated and measured skin humidity was made.

MATERIALS AND METHODS

Human subjects were exposed to 5 different levels of skin humidity. A two-layer experimental clothing ensemble was used in all experiments. The ensemble consisted of a woven cotton inner layer and outer layers that were used to regulate the moisture permeability of the ensemble. The outer layers were made of 3 different types of rainwear fabric, ranging from very permeable (GoreTex) to almost impermeable (polyurethane coated nylon). The outer layers were tailor-made and had tight-fitting openings at the ankles, wrists and neck. Socks and

Table 1. Water vapor resistance, weight and thickness of the fabrics used.

	Textile layer		Water vapor resistance [~mm air equivalent]	Sp. weight [g·m^{-2}]	Thickness [mm]
Inner	Cotton		2.0	150	0.70
Outer	A	(GoreTex™)	4.3	107	0.33
	B	(Microfibre)	7.8	95	0.21
	C	(Polyurethane coated nylon)	220.8	214	0.70

thin, moisture-permeable cotton shoes supplemented all clothing ensembles. The vapor permeability, specific weight and thickness of the various textiles used are shown in Table 1.

The study was intended to attain the desired levels of skin humidity by combining the estimated moisture permeability of the clothing and the thermal conditions in the climate chamber. Moisture permeability indices of the clothing ensembles were estimated fiom measured values of vapor resistance, taking into account that the head and hands were uncovered, and the feet were covered by highly moisture-permeable shoes. After the experiments, the actual average moisture permeability indices were calculated according to a method suggested by Holmér and Elnäs (2).

Based on measured values of clothing insulation and estimated values of clothing moisture permeability, a simplified version of the 2-node model of human thermoregulation was used to predict the air temperature and humidity that would provide the desired level of skin humidity and thermal sensation (3). To facilitate a certain, small sweat secretion, a thermal sensation between neutral and slightly warm was the aim in all experiments. Relative skin humidity (Rh_{sk}), defined as the ratio of water vapor at the skin surface to the saturated vapor pressure at skin temperature, was used as a measure for skin humidity. Recordings of relative humidity and air temperature between the skin and inner clothing layer, and of skin temperature, were made at the chest, inside right upper arm, at the upper back, inside right thigh and at the right calf. These were used for calculation of local relative skin humidities. Overall, relative skin humidity for the whole body was calculated fiom the area-weighed average of the local relative skin humidities.

The insulation values of the clothing ensembles were measured by means of a standing thermal manikin. In Table 2, the measured basic insulation and estimated moisture permeability indices are shown together with the environmental conditions in the experiments and the predicted mean vote (PMV).

Table 2. Desired levels of skin humidity established with different combinations of vapor permeabilities of clothing and environmental conditions as predicted by the modified 2-node model (3).

Relative skin humidity	Outer layer	Moisture permeability	Clothing insulation [clo]	Relative humidity of air [%]	Air temperature [°C]	Water vapor pressure [kPa]	PMV
0.32	A	0.40	0.63	50	25.5	1.62	0.3
0.53	B	0.32	0.90	80	25.0	2.51	0.5
0.56	C	0.12	0.89	50	25.0	1.57	0.3
0.69	C	0.12	0.89	80	25.0	2.51	0.5
0.75	C	0.12	0.89	80	25.5	2.59	0.6

RESULTS .

In Table 3, the mean and standard deviation of the relative skin humidity averaged over 15 min (105 to 120 min after commencement of the experiment)

Table 3. Mean and standard deviation of measured Rh_{sk} for females, males and both sexes combined. Mean values are from the observations made in the last **15 min** of each experiment.

Rh_{sk} Planned	Rh_{sk} measured								
	Females			Males			Females and males		
	N	*mean*	*SD*	*N*	*mean*	*SD*	*N*	*mean*	*SD*
0.32	8	0.36	0.01	8	0.41	0.02	16	0.39	0.03
053	7	053	0.04	7	057	0.11	14	055	0.08
056	8	057	0.07	8	0.63	0.13	16	0.60	0.10
0.69	7	0.63	*0.09*	8	0.74	0.07	15	*0.69*	*0.09*
0.75	8	0.64	0.07	8	0.76	0.11	16	0.70	0.11

are shown separately for females and males, and for both sexes combined. Rh_{sk} was significantly different in females than males; the males exhibited a slightly higher and the females a lower Rh_{sk} when compared with the planned values at

	Mean	SD	N	Mean	SD	N	Mean	SD	N
Estimated i_m	0.40			0.32			0.12		
Measured i_m	0.35	0.18	8	0.21	0.16	8	0.07	0.06	31

DISCUSSION

Estimated and observed skin humidity measurements agreed well, indicating that skin humidity can be controlled by the moisture permeability of the clothing. Also, the 2-node model predicted the level of skin humidity in correspondence with the observed values. Based on heat and mass transfer theory, the model expresses skin humidity as a function of environmental parameters, clothing characteristics and metabolic rate (3).

The measured moisture permeability indices corresponded rather well with the estimated values, although the standard deviations were large. The basis for calculating the permeability indices was the repeated observations of a subject's weight. In some experiments, the weight observations fluctuated because even minor body movements displaced the center of gravity of the subject relative to the balance. **As** the calculation of the permeability index was very sensitive to the measured weight loss, the large standard deviations may be explained by the weight loss fluctuations. In comparison, Holmér and Elnäs (2) found standard deviations of moisture permeability measurements with human subjects in the range 0.03 to 0.10.

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