FOUL WEATHER CLOTHING STUDIED WITH A SWEATING AND A MOVING MANIKIN

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INTRODUCTION

Choosing protective clothing against foul weather is often difficult because protection and comfort requirements are in conflict. Depending on the situation where the protective clothing is used, it should give protection against chemical, mechanical, heat, cold or other environmental hazards, while it should also provide tliennal comfort. Foul weather clothing must be watertight but in pliysically stressing situations it should allow moisture to be transported in vapour form to the ambient **air.**

Both material properties and the design of tlie garment have mi impact on breatliability. The amount of heat and water vapour transmission can be adjusted by ventilation through the openings of the garment. Movements mid wind speed have an influence on the ventilation effect.

In this study sis different foul weather clothing ensembles were compared. The effect of ventilation on thermal insulation was determined in different conditions.

MATERIALS AND METHODS

In this study tlie sweating tliennal manikin Coppelius and tlie walking manikin Tore were used to measure tlie properties of the following foul weather clothing ensembles, both clothes open aid closed

1. Jacket without a hood, trousers, PVC, Finland
2. Jacket with a hood, trousers, PU, Finland
3. Jacket witli a hood, trousers, PVC, China
4. Jacket with a hood, trousers, Gore-Tex® fabrics, Sweden
5. Jacket with a hood, trousers with shoulder straps, PVC, Finland
6. Finnish Army chemical and foul weather protective combination, jacket witli a hood, trousers, Finland.

Ensembles 1 to 5 were evaluated in conjunction with long underwear as specified by standard prEN 342, whereas ensemble 6 was evaluated witli absorbent carbon underwear. Standard prEN 342 specifies requirements and test methods for performance of clotling for protection against cold.

Tlie sweating manikin Coppelius is based on tlie dry thermal manikin Tore, to which ai additional sweating mechanism has been added. The basic idea is that it produces heat aid moisture in a way similar to the human body. Tlie main features of Coppelius are:

1. 18 individually controlled body sections, electrically heated
2. Continuous sweating from body surface (except head, hands and feet)
3. Anatomic body dimensions, size C50
4. Prosthetic joints in shoulders, elbows, hips and knees.

Tlie cross section of a sweat gland is shown in figure 1 and the test set up with Coppelius in the climatic chamber in figure 2.

The test parameters can be chosen as follows:

1. Sweating level 0...300 $g/m^2 \cdot h$ (normally constant over tlie sweating surface)
2. Ambient temperature mid humidity (-50 ...+70°C, 15 ... 95 % RH)
3. Skin temperature (normally constant +33 °C over tlie surface)
4. Test time (norinally 3 h for sweating and 2 h for dry tests).

In this study, tlie simultaneous heat and water vapour transmission through clothing system 1 - 5 were determined under two different ambient conditions: 20°C / 40 % RH aid 20°C / 85 % RH with the sweating manikin Coppelius. Clothing system **6** was tested only wider ambient conditions 20°C / **85** % RH. Each clothing combination was tested under two different sweating levels: 0 and 200 $g/m^2 \cdot h$. In addition, clothing system **6** was evaluated at the sweating level of 100 $g/m^2 \cdot h$.

The measurements gave the following information under each test condition:

- heat supply H [W/m^2] required to keep tlie manikin's skin temperature constmit at +33 "C
- thermal insulation I_T (*dry* measurements) or I_{Tcorr} (sweating measurements [$m^2 \cdot °C/W$]
- water vapour permeability M, as % of supplied water
- the regulatory effects of sweating on heat loss: H, (evaporative part) aiid H_w (wetting part) [W/m^2].

Tlie test time for *dry* measurements was 1.5 hours, while sweating measurements were intended to be carried out in 3 hours. However, due to tlie substantial condensation during the sweating, tlie measurements were terminated when the condensed water started to drop onto the floor which in all cases, escept for clothing system ***6***, happened before tlie 3-hour test time was completed. Two parallel measurements were made for each clothing/test condition combination.

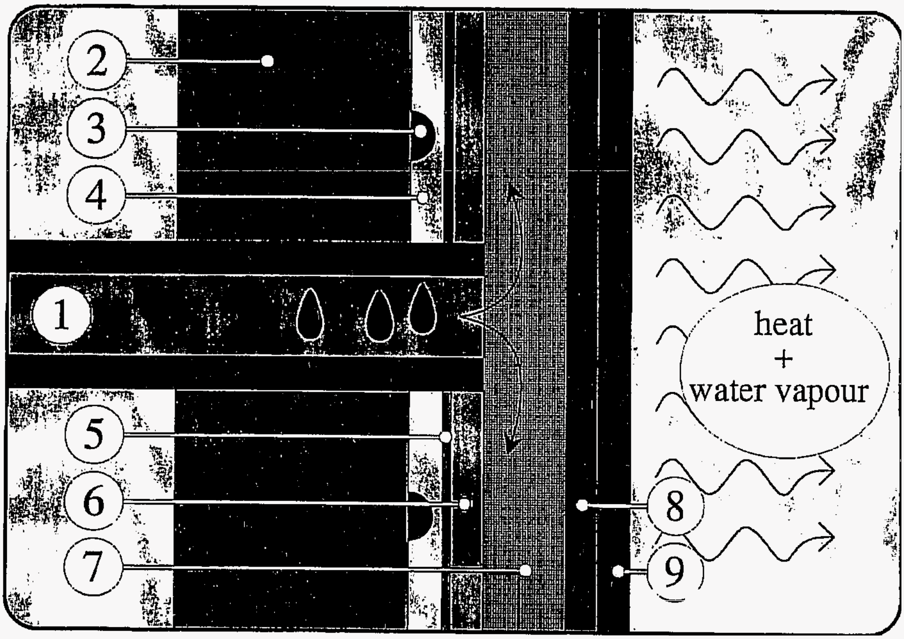

Figure 1. Cross section of a sweat gland (1=water supply, ?=plastic shell, 3 heating wire, 4=isolation, 5-metal layer, 6=mechanical protection, 7=non-woven material, 8=microporous membrane, 9=protective net)

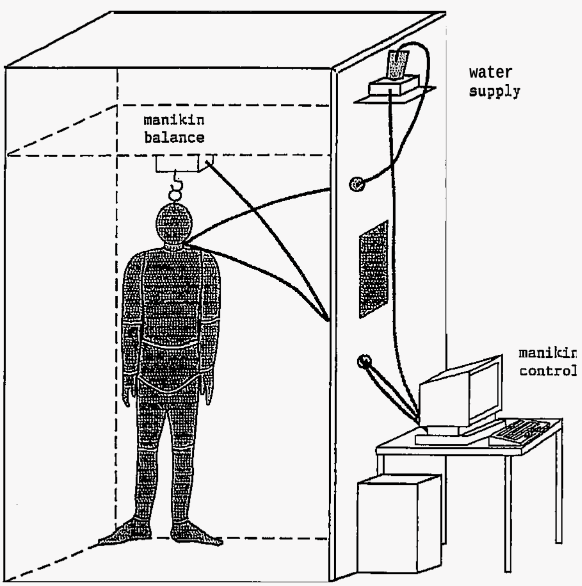

Figure 2. Test configuration with the manikin in the climatic chamber.

Witli the walking manikin Tore, tlie effect of wind speed and walking speed on heat supply and thermal insulation were determined wider ambient conditions 20°C / 40 % RH. Wind speeds were 0, 0.5 and 1.0 m/s and walking speeds 0, 0.37. 0.80 and 1.20 m/s, respectively. The following equations were used for calculating tlie test results:

total tliernial iiisulation (dry)	$I_T = \frac{t_s - t_a}{H}$	[m²•°C/W]	(1)
corrected tlierinal insulation (sweating)	$I_{Tcorr} = \frac{t_s - t_a}{H - H_e}$	[m²•°C/W]	(2)
heat of evaporation	$H_e = \varphi \cdot m_e$	[W/m²]	(3)
heat loss due to wetting	$H_w = H - H_{dry} - H_e$	[W/m²]	(4)
water vapom permeability	$M_e = \frac{m_e}{m_s} \cdot 100$	[%]	(5)

where t_s is the skin temperature, t_a is the ambient temperature, H is the measured heat supply, φ is tlie specific heat of evaporation (=0,684 W•h/g), m_e is tlie measured amount of evaporated water (g/m²•h), m_s is tlie supplied amount of water i.e. sweating level (g/m²•h), and H_{dry} is tlie measured heat supply in the equivalent dry test.

RESULTS

Tlie effect of sweating on heat supply is shown in figure 3. Under ambient conditions 20°C / 85 % RH, sweating increased heat supply H from 58 % to 128 % compared with the corresponding values in *dry* measurements.

Tlie influence of sweating on tlie heat supply depends on two different effects. The evaporating water binds heat, which is transmitted witli tlie water vapour to tlie ambient air. This can be regarded as the desired, positive effect of sweating. On tlie other hand, the condensation of water in the clothing layers causes an increase in tlie conductive heat transfer through tlie clothing. Tlus wetting causes discomfort and tlie so called "post esercise chill" as heat production,decreases. In figure 4, tlie influence of sweating on heat loss is divided into the evaporative (H_e) and the wetting (H_w) parts. In the case of tlie breathable Gore-Tes ensemble (sample 4) the evaporative part is dominant in all measurements, whereas in tlie case of tlie ensemble 3 the wetting part is dominant. In tlie case of ensembles 1, 2 and 5, tlie evaporative part is dominant under ambient conditions 20°C / 40 % RH, when measured with the clotlies open. When relative humidity is increased from 40 % to **85** % and/or clothes are closed, the wetting part becomes dominant. In tlie case of ensemble *6* (measured under ambient conditions 20°C / 85 'Yo), the evaporative part is dominant when measured clothes open, but clothes closed, tlie wetting part becomes dominant.

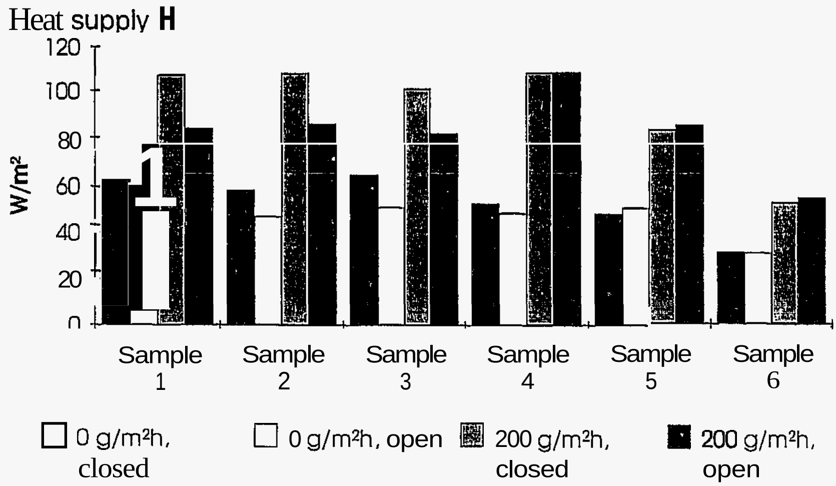

Figure 3. The effect ojsweating on heat supply (ambient conditions 20°C' / *85 % RH).*

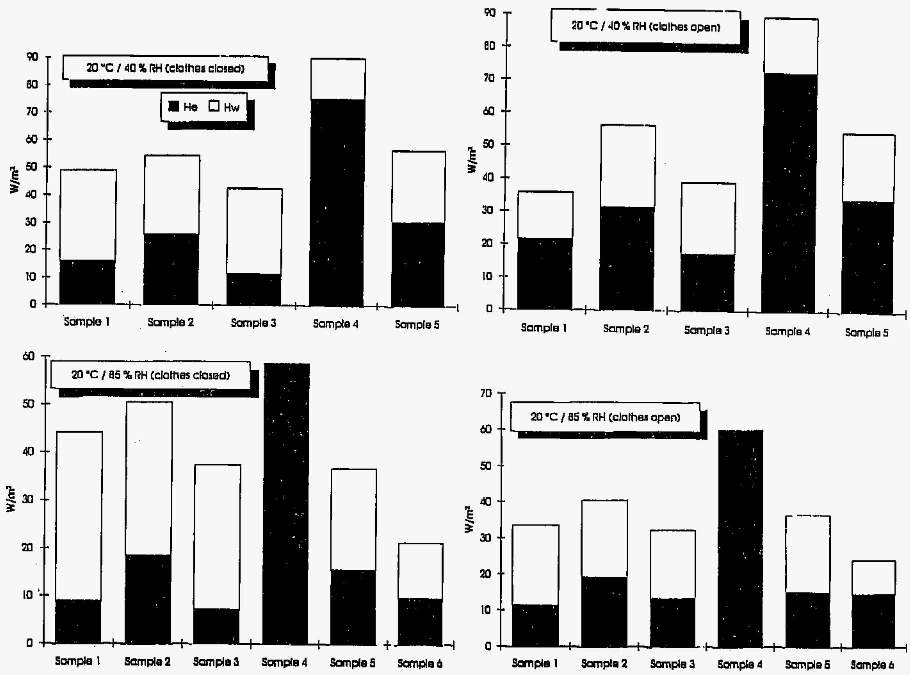

Figure 4. The regulatory effect of sweating on heat supply in different conditions.

When wiiid speed increased from 0 to 1.0 m/s, tlie decrease in tlierinal insulation was 22 to 32 %, but when wind speed increased from 0.5 to 1.0 m/s, the change was only marginal (Table 1). Thermal insulation was also decreased when walking speed increased from 0 to 1.20 m/s. The drop was between 26 and 46 %.

Table 1. The effect of wind **speed** *and* **walking** *speed on thermal insulation.*

Sample	Thermal insulation (manikin standing, no wind)	Wind speed (manikin standing) [m/s]		Walking speed (no wind) [m/s]		
	[m²•K/W]	0.5	1.0	0.37	0.80	1.20
		Decrease in thermal insulation (%)				
1. closed	0,282	27	*32*	27	34	40
open	0,278	27	30	29	35	39
2. closed	0,282		28			38
open	0,285		30			38
3. closed	0,272		29			36
open	0,270		30			40
4. closed	0,248		29			35
open	0,282		31			37
5. closed	0,287	*22*	28	*26*	34	39
open	0,278	23	29	27	35	38
6. closed	0,324	28	27	31	37	*46*
open	0,317	29	32	30	38	*46*

CONCLUSIONS

There was no significant difference in heat supply between tlie measurements with open aid closed garments. The amount of lieat and water vapour transmission can be adjusted effectively by ventilation through the openings of the garment only to **a** certain point. When the sweating level aid relative humidity of the ambient air is increased, thermal comfort is soon lost due to heavy condensation. The effect of wind was relatively small, between 22 and 32 %. Increased walking speed, however, substantially increased heat loss.

In sweating measurements with Coppelius, tlie heat transmitted with tlie water vapour to tlie ambient air (breatliability) was significantly higher in tlie case of tlie Gore-Tes ensemble (sample 4) compared witli corresponding values for other samples. Thus, ensemble 4 was tlie **most** functional foul weather clotling solution in the measured conditions.

On the other hand, *dry* manikin measurements with Tore showed that tliere is no significant difference in thermal insulation between different ensembles except for the army clothing system (sample 6) which provided slightly better insulation than the others. The difference, however, diminishes when the walking speed is increased from 0 to 1.20 m/s. In other words, ventilation by movement is most effective in the case of ensemble *6*.

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