

FOUL WEATHER CLOTHING STUDIED WITH A SWEATING AND A MOVING MANIKIN

H. Laamanen⁽¹⁾, H. Meinander⁽¹⁾ and Ingvar Holmér⁽²⁾

(1) VTT Chemical Technology, Tampere, Finland

(2) The National Institute for Working Life, Solna, Sweden

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 thermal comfort. Foul weather clothing must be watertight but in physically stressing situations it should allow moisture to be transported in vapour form to the ambient air.

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

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

1. Jacket without a hood, trousers, PVC, Finland
2. Jacket with a hood, trousers, PU, Finland
3. Jacket with 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 with 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 with absorbent carbon underwear. Standard prEN 342 specifies requirements and test methods for performance of clothing for protection against cold.

The sweating manikin Coppelius is based on the dry thermal manikin Tore, to which an additional sweating mechanism has been added. The basic idea is that it produces heat and moisture in a way similar to the human body. The 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.

The 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/m²•h (normally constant over the sweating surface)
2. Ambient temperature and humidity (-50 ... +70°C, 15 ... 95 % RH)
3. Skin temperature (normally constant +33°C over the surface)
4. Test time (normally 3 h for sweating and 2 h for dry tests).

In this study, the simultaneous heat and water vapour transmission through clothing systems 1 - 5 were determined under two different ambient conditions: 20°C / 40 % RH and 20°C / 85 % RH with the sweating manikin Coppelius. Clothing system 6 was tested only under ambient conditions 20°C / 85 % RH. Each clothing combination was tested under two different sweating levels: 0 and 200 g/m²•h. In addition, clothing system 6 was evaluated at the sweating level of 100 g/m²•h.

The measurements gave the following information under each test condition:

- heat supply H [W/m²] required to keep the manikin's skin temperature constant at +33 °C
- thermal insulation I_T (dry measurements) or I_{Tcorr} (sweating measurements) [m²•°C/W]
- water vapour permeability M_e as % of supplied water
- the regulatory effects of sweating on heat loss: H_e (evaporative part) and H_w (wetting part) [W/m²].

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

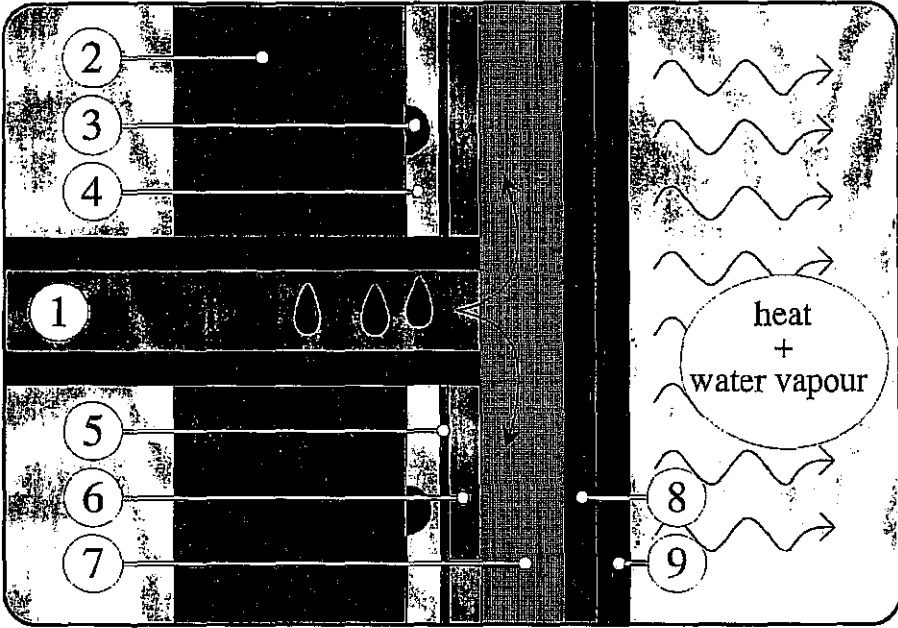


Figure 1. Cross section of a sweat gland (1=water supply, 2=plastic shell, 3= heating wire, 4=isolation, 5=metal layer, 6=mechanical protection, 7=non-woven material, 8=microporous membrane, 9=protective net)

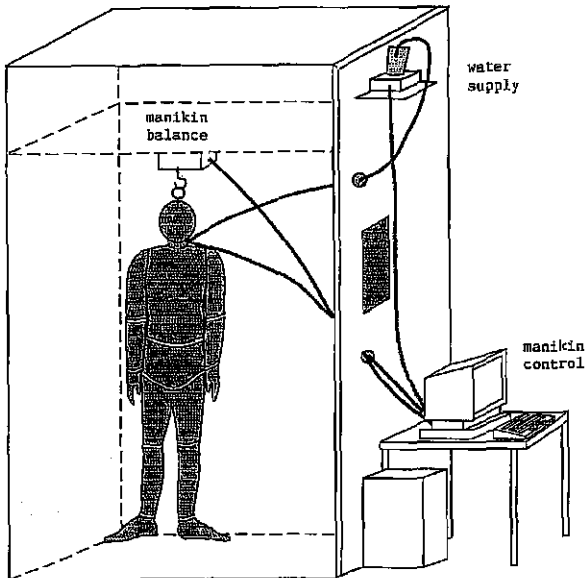


Figure 2. Test configuration with the manikin in the climatic chamber.

With the walking manikin Tore, the effect of wind speed and walking speed on heat supply and thermal insulation were determined under 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 the test results:

$$\text{total thermal insulation (dry)} \quad I_T = \frac{t_s - t_a}{H} \quad [\text{m}^2 \cdot ^\circ\text{C}/\text{W}] \quad (1)$$

$$\text{corrected thermal insulation (sweating)} \quad I_{T_{\text{corr}}} = \frac{t_s - t_a}{H - H_e} \quad [\text{m}^2 \cdot ^\circ\text{C}/\text{W}] \quad (2)$$

$$\text{heat of evaporation} \quad H_e = \phi \cdot m_e \quad [\text{W}/\text{m}^2] \quad (3)$$

$$\text{heat loss due to wetting} \quad H_w = H - H_{\text{dry}} - H_e \quad [\text{W}/\text{m}^2] \quad (4)$$

$$\text{water vapour permeability} \quad M_e = \frac{m_e}{m_s} \cdot 100 \quad [\%] \quad (5)$$

where t_s is the skin temperature, t_a is the ambient temperature, H is the measured heat supply, ϕ is the specific heat of evaporation ($=0,684 \text{ W}\cdot\text{h}/\text{g}$), m_e is the measured amount of evaporated water ($\text{g}/\text{m}^2\cdot\text{h}$), m_s is the supplied amount of water i.e. sweating level ($\text{g}/\text{m}^2\cdot\text{h}$), and H_{dry} is the measured heat supply in the equivalent dry test.

RESULTS

The 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.

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

Heat supply H

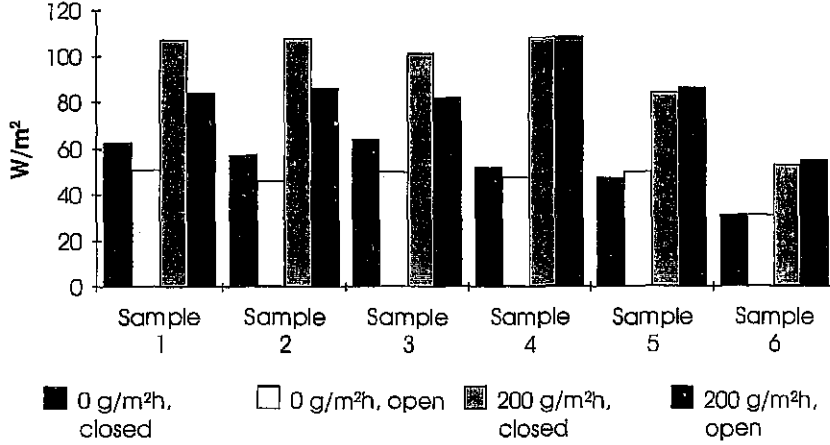


Figure 3. The effect of sweating on heat supply (ambient conditions 20°C / 85 % RH).

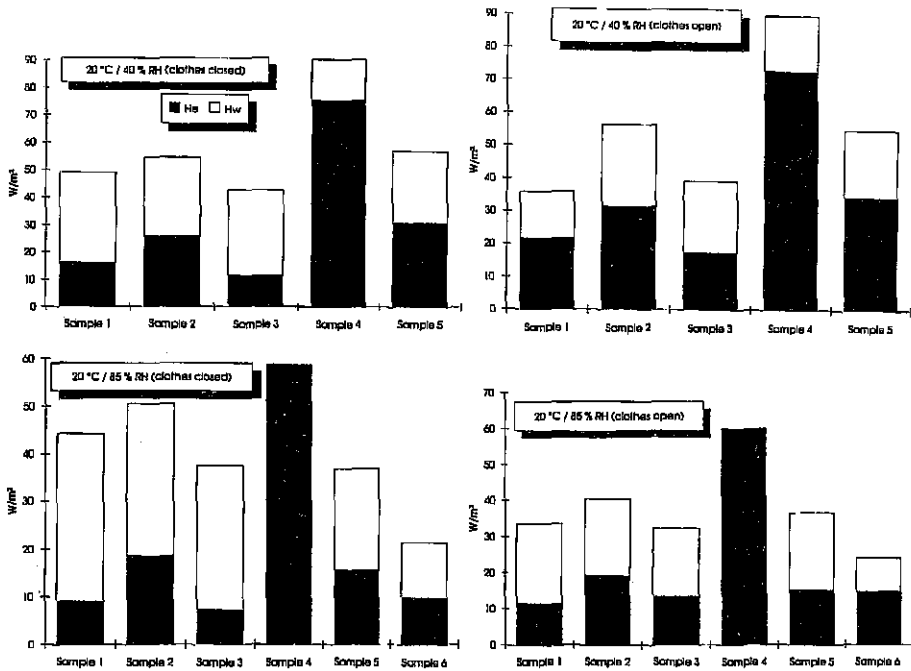


Figure 4. The regulatory effect of sweating on heat supply in different conditions.

When wind speed increased from 0 to 1.0 m/s, the decrease in thermal 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) [m ² -K/W]	Wind speed (manikin standing) [m/s]		Walking speed (no wind) [m/s]		
		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 the measurements with open and closed garments. The amount of heat 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 and 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, the heat transmitted with the water vapour to the ambient air (breathability) was significantly higher in the case of the Gore-Tex ensemble (sample 4) compared with corresponding values for other samples. Thus, ensemble 4 was the most functional foul weather clothing solution in the measured conditions.

On the other hand, dry manikin measurements with Tore showed that there 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.

REFERENCES

- /1/ Holmér, I. and Nilsson, H., "Heated manikins as a tool for evaluating clothing", *Annals of Industrial Hygiene*, (in press), 1994.
- /2/ Meinander, H., "Determination of clothing comfort properties with the sweating thermal manikin", *Proceedings of The Fifth International Conference on Environmental Ergonomics*, Maastricht, TNO Institute for Perception, Soesterberg, The Netherlands, 1992, pp. 40 - 41.
- /3/ prEN 342. Protective clothing against cold. CEN European Committee for Standardization, November 1993, 12 p.