Testing sleeping bags using a supine sweating fabric manikin

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INTRODUCTION

Apart from thermal insulation, moisture permeability or evaporative resistance is the most important factor in determining the thermal comfort of clothing. This is the case not only for outdoor clothing, but also for quilts, beddings and sleeping bags. This is because, although people normally don't produce sensible perspiration during sleeping, the insensible perspiration may be accumulated in the sleeping bag over a long period of time, resulting severe discomfort associated with the dampness and the significant reduction in the thermal insulation of the wet sleeping bags (Lotens and Havenith 1995, Lotens et al 1995).

Although efforts (Camenzind et al, 2001; Havenith 2004) have been made to evaluate the moisture permeability or evaporative resistance of the sleeping bags, accurate and reproducible methods for the direct measurement are still not available. Therefore, in the international standard (EN 13537) the evaporative resistance is only estimated from the moisture permeability index of the materials used for constructing the sleeping bags. The accuracy of such estimation is questionable. In this paper, we report on a supine sweating fabric manikin system for directly measuring the evaporative resistance of sleeping bags.

METHODS

Figure 1 shows the novel supine sweating fabric manikin under testing. The manikin had a statue of 1.70 meter, a total surface area of 1.79m^2, and a body weight of about 70kg, similar to those of a medium size male adult. Unlike those copper or plastic thermal manikins, the softness of our manikin body and its similar weight to a male adult creates a highly realistic compression to the sleeping bag under tests.

To simulate perspiration, the manikin was covered with a breathable fabric skin made of a three layer laminated fabric consisting of an outer nylon fabric, an inner polyester lining fabric and an intermediate PTFE membrane, similar to the breathable fabric used for the standing fabric manikin-Walter (Fan et al, 2002). The perspiration rate of the manikin was measured in real time by a siphon system (Wu and Fan 2006).

Figure 1 Supine sweating fabric manikin

The total thermal insulation of sleeping bag is determined by (Fan and Chen 2002):

$$R_c = \frac{A_s \cdot (T_s - T_a)}{H_d} \quad (\text{°C m}^2/\text{W}) \tag{1}$$

Where, R_c is the total thermal insulation of sleeping bag in ºC m^2/W; A_s is the total area of manikin in m^2; T_a is the environment temperature in ºC; T_s is the mean skin temperature of manikin in ºC; H_d is the dry heat loss of the manikin in watts.

The total evaporative resistance of sleeping bag is determined by (Fan and Chen 2002):

$$R_e = \frac{A_s \cdot (p_{ss} - p_{as} RH_a)}{H_e} - R_{es} \quad (\text{Pa m}^2/\text{W}) \tag{2}$$

Where, R_e is total moisture vapor resistance of the clothing ensemble in square meter Pa m^2/W; p_{ss} is the saturated moisture vapor pressure at skin temperature in Pascal (Pa); p_{as} is the saturated moisture vapor pressure at environment temperature in Pascal (Pa); RH_a is the relative humidity of the environment in Percentage (%); R_{es} is the moisture vapor resistance of the skin in Pa m^2/W. The moisture permeability index is calculated by:

$$i_m = \frac{R_c}{0.0165 \times R_t} = 60.6 \times \frac{R_c}{R_t} \tag{3}$$

Where , i_m is the moisture permeability index of sleeping bag.

Measurement of total thermal insulation of sleeping bags in non-isothermal condition

To measure the thermal insulation of the sleeping bags, tests were conducted in a climate chamber with the air temperature of 12 ºC ±0.3, the wind of 0.3±0.1 meter per second and the relative humidity of 50% ± 3%. The difference between the air and radiant temperature was less than 0.1 ºC. The wind was uniform and parallel, generated by nine axial fans.

Figure 2 shows the position of the manikin in the chamber. A fabric skin of little vapor permeability was used when measuring the total thermal insulation of the sleeping bags. The perspiration rate of the supine manikin in nude under the above described testing condition was about 16 grams per hour, which simulates the insensible perspiration of a man while sleeping.

The mean skin temperature of the supine manikin was maintained at 35 ºC and the resulting heat loss was measured. Twenty two temperature sensors were attached on the fabric skin for measuring the local skin temperatures from which an area weighted mean skin temperature can be calculated.

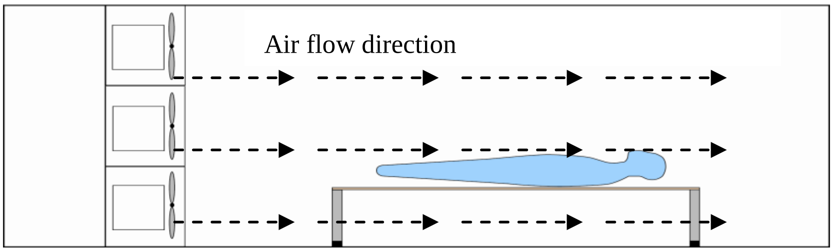

Figure 2 Manikin position

Measurement of total evaporative resistance of sleeping bags in isothermal condition

The total evaporative resistance of the sleeping bags or the nude manikin, tests were measured under the isothermal condition (viz. both the air temperature of the climatic chamber and the mean skin temperature of manikin were set at 35 ºC) so as to prevent condensation taking place within the sleeping bag under testing. During the testing, the wind velocity and relative humidity in the chamber were controlled at 0.3±0.1 m/s and of 50% ± 3%, respectively. The wall radiant temperature was measured to be less than 0.1 ºC from the air temperature.

When testing the evaporative resistance, a highly breathable fabric skin was used to simulate gaseous perspiration. The perspiration rate of the manikin in nude under the described isothermal condition was 136 grams per hour. All tests were repeated for four times. Each test lasted over 24 hours.

SAMPLES

The specifications of eleven samples tested are listed as Table 1. All samples were hung in the climate chamber for over 24 hours before testing. The samples were shaken for 1 minute for expansion just before testing.

RESULTS AND DISCUSSION

The test results of total thermal insulation, evaporative resistances and permeability indices are also listed in Table 1. For total thermal insulation test, the coefficient of variance of each sample are lower than 3%. For evaporative resistance tests, the coefficients of variance of the tested samples are less than 5%. The reproducibility is high in comparison with those reported in the literature (Meinander 2003) and the acceptable levels in ASTM F1720-06 and EN 13537 2002

Table 1 Specifications and test results of sleeping bags

Sample	Filling	Size (cmxcm)	Weight (g)	Mean R_c (ºC m^2/W)	CV of R_c (%)	Mean R_e (Pa m^2/W)	CV of R_e (%)	i_m
Nude (supine)				0.13	0.68	46.5	3.29	0.169
1	Goose Down	210 x 75	599.4	0.37	2.60	137.9	2.46	0.164
2	Goose Down	210 x 75	824.0	0.45	0.77	167.1	2.00	0.162
3	Goose Down	210 x 75	1034.2	0.51	2.27	169.7	5.06	0.181
4	Goose Down	198 x 77	1073.2	0.49	1.38	208.7	5.57	0.142
5	Goose Down	215 x 75	764.8	0.39	1.46	176.7	2.79	0.134
6	Goose Down	215 x 75	825.8	0.42	0.92	203.8	3.63	0.125
7	Polyester	210 x 80	843.2	0.37	1.58	158.7	3.63	0.142
8	Polyester	212 x 80	1462.3	0.49	1.13	191.9	1.18	0.154
9	Polyester	230 x 80	1388.2	0.46	0.95	169.4	4.81	0.166
10	Polyester	215 x 80	1382.6	0.47	1.64	179.6	2.23	0.160
11	Polyester	215 x 75	906.4	0.38	1.53	120.6	1.76	0.192

McCllough (1989) reported that the average i_m value for indoor clothing is around 0.4 based the tests of 22 clothing ensembles. Havenith (1999) and ISO 9920 reported that the average i_m value of outdoor 1 to 2 layer clothing was around 0.38. However, our results indicate that the i_m of sleeping bags tested by the supine sweating thermal manikin are between 0.125 and 0.192. In supine posture, a large area of manikin skin is directly compressed by the supporting impermeable wooden ground, so the evaporative resistances of sleeping bags are substantially higher than those expected from the test results at the standing posture.

Evaporative resistance verses total thermal insulation of sleeping bags

Figure 3 plots the total evaporative resistance against the total thermal insulation. As can been seen, the relationship between them is relatively weak (r^2=0.3688, $P<0.05$). Sleeping bags with similar total thermal insulation can have substantial differences in evaporative resistances. The evaporative resistance of sleeping bags cannot simply be predicted from the thermal insulation values, it is essential to directly measure the evaporative resistance by using supine perspiring manikins.

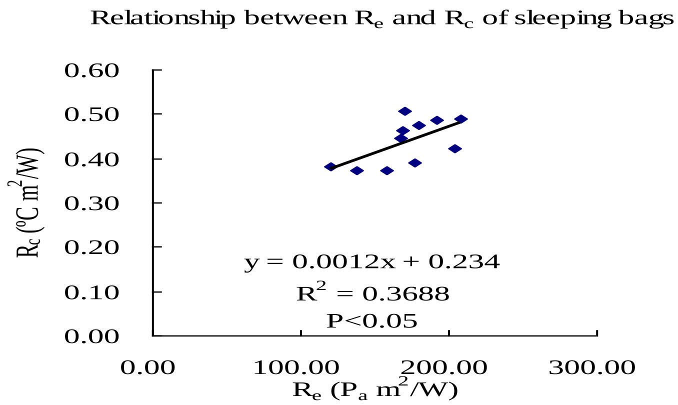

Figure 3 Evaporative resistance (R_e) vs total thermal insulation (R_c)

CONCLUSIONS

From the testing of eleven sleeping bags, it can be concluded that the measurement of thermal insulation and evaporative resistances of sleeping bags using our novel supine sweating manikin is reproducible. The study further showed that the moisture permeability index of sleeping bags are between 0.125 and 0.192, much smaller than those of clothing worn at the upright position, because the impermeable supporting ground creates additional evaporative resistance.

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