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Kuklane, Kalev

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Evaporative resistance of sleeping bags - measurements on a thermal manikin Tore

Kalev Kuklane

Thermal Environment Laboratory, Division of Ergonomics and Aerosol Technology,
Dept. of Design Sciences, Lund University, Sweden
correspondence to: kalev.kuklane@design.lth.se

Introduction

Thermal insulation of the sleeping bags can be measured by a European standard EN 13537 (EN-13537 2002). There is also available an American standard ASTM F 1720 – 06 (ASTM-F1720-06 2006) covering this area. The testing and recommendations for sleeping bag use are related to comfort or cooling in dry conditions. However, moisture accumulation in bags may occur during use (Havenith et al. 2004). In the latest years a lot of attention has been paid to effect of moisture in protective clothing and testing methods have been developed and improved (Havenith et al. 2008; Wang et al. 2011; Wang et al. 2010). Although the standard methods are available (ASTM-F_2370-05 2005) there is lack of data on highly insulating products, such as sleeping bags. Some recent efforts in this area have been, however, carried out (Wu and Fan 2009). The aim of this study was to evaluate evaporative resistance of the selected new reference bags for EN 13537, and compare mass and heat loss methods in isothermal and non-isothermal conditions with wet underwear instead of textile skin.

Materials and methods

Sleeping bags and underwear

Three sleeping bags out of the standard calibration set for EN 13537 were selected for testing: F (Eclipse 100, Bertoni: dawn, mummy shape, low insulation, 678 g), B (Kiowa Comfort 220, VAUDE: synthetic, rectangular, medium insulation, 1590 g) and E (Denali 5 Seasons, Mammut, Ajungilak: synthetic, mummy shape, high insulation, 3856 g). These bags were described and dry insulation measured in a previous study (Kuklane and Dejke 2010). Instead of textile skin the standard underwear (sweater and trousers of a three layer knitted fabric consisting of cotton (42 %) and polyester (58 %), thermal resistance of the material 0.046 m^2K/W) was wetted. The underwear was tested by itself, too. A standard mat according to EN 13537 was used in all tests as well as knee-long socks.

Instrumentation

The manikin was equipped with extra humidity and temperature sensors (EK-H3 equipped with SHT75 sensors, Sensirion AG, Switzerland) on to its surface, and dressed in wet underwear (water content 810±15 g). The whole system was placed on a weighing scale (Mettler K240 connected to GWB Mettler ID2 MultiRange, Albstadt, Germany, resolution ±2 g) for continuous mass loss recording. Air temperature (PT 100 connected to PT-104, Pico Technology Ltd., UK, accuracy ± 0.03 °C) and relative humidity (EK-H3 equipped with SHT75 sensors, Sensirion AG, Switzerland) were also recorded.

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Procedures and calculations

The test procedures combined the ones of EN 13537 and ASTM-F2370-05 and modified them according to the specific needs. Manikin surface (T_s) was always kept at 34 °C. The tests were carried out in non-isothermal (T_a=12.0±0.1 °C) and isothermal conditions (T_a=34.1±0.1 °C). The air velocity stayed at 0.29±0.08 m/s. The ambient humidity stayed at 77±4 and 26±3 in non-isothermal and isothermal conditions, respectively. The corresponding water vapour pressure in the air was 1083±47 and 1400±157 Pa, respectively. The dry and wet (apparent) insulation values that were utilized in the analysis were calculated according to the parallel calculation method of ISO 15831 (ISO-15831 2004), and were not adjusted to match the values of the reference manikin.

The saturation at evaporation point was not assumed to be 100 percent. Instead, water vapour pressure gradient between manikin surface under wet underwear and air was used to calculate evaporative resistance from mass loss (weighing scale) based heat loss, and also from recorded manikin heat loss.

The calculations followed ASTM-F2370-05. The heat loss from the manikin was always corrected for the dry heat gain (isothermal) or loss (non-isothermal). The skin temperature correction equations by Wang et al. (Wang et al. 2010) and Ueno and Sawada (Ueno and Sawada 2011) were tested.

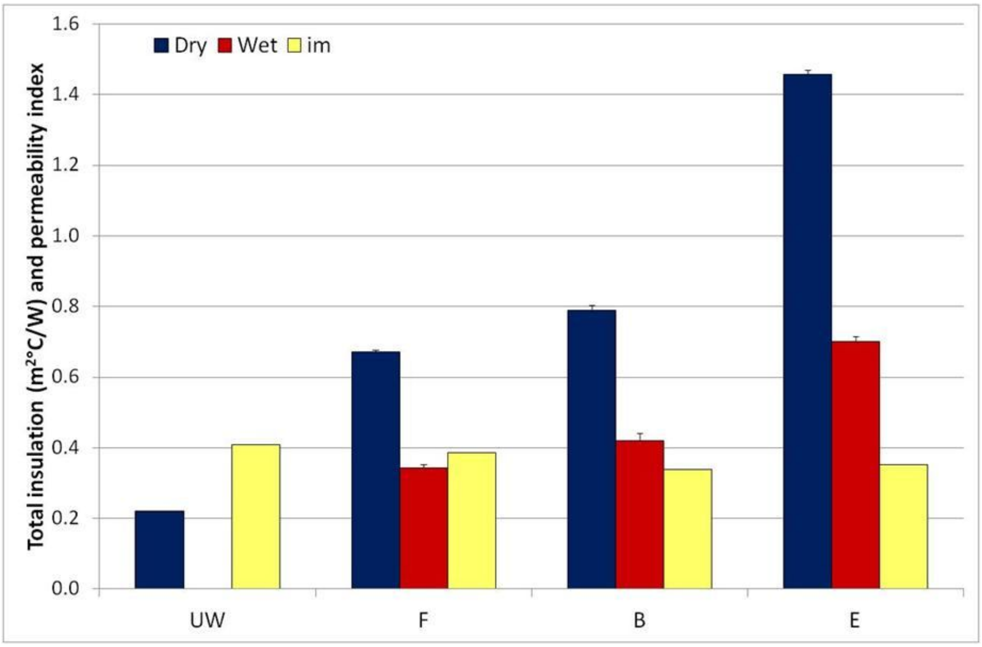

Figure 1. The total thermal insulation (Dry), apparent thermal insulation (Wet) and permeability index (im) of the tested sleeping bags and the underwear (UW) when measured at 12 °C.

Results and discussion

Basic assumptions and corrections

Water vapour pressure gradient between manikin surface under wet underwear and air was used to calculate evaporative resistance from mass loss (weighing scale) based heat loss, and also from recorded manikin heat loss. The relative humidity between manikin surface and wet underwear was in all sleeping bag conditions in average 93±2 % being somewhat higher for thicker and lower for thinner bags, in underwear test (only at isothermal conditions at 34 °C) 89±0 %.

The heat loss from the manikin was always corrected for the dry heat gain (isothermal)) or loss (non-isothermal). However, it was minimal at isothermal conditions (0±2 W/m^2). It can be directly related to the high insulation of the sleeping bags and relatively high interface temperature between manikin surface and the wet underwear reducing the influence of the environment. Still, it can't be said as that the factor is negligible – in warm bags the heat losses were low and the corrections would be within the magnitude of 5-10 %.

The skin temperature correction equations by Wang et al. (Wang et al. 2010) and Ueno and Sawada (Ueno and Sawada 2011) were compared with measured interface temperatures. While the corrections in between the correction algorithms varied in average only 0.5±0.5 % then the difference with the measured interface temperature was 3±3 %. It was assumed that the corrections are not valid for very insulating products with relatively low heat loss, and the measured, commonly lower temperatures, were utilized for water vapour pressure calculation at the manikin surface, instead (in average 4933±117 and 5261±200 Pa for non-isothermal and isothermal conditions, respectively). If considering the underwear working as "skin" then a different correction equation could be suggested for highly insulating products or if the heat loss is low (below 50 W/m^2):

$T_{skin}=34-0.0395\times HL$

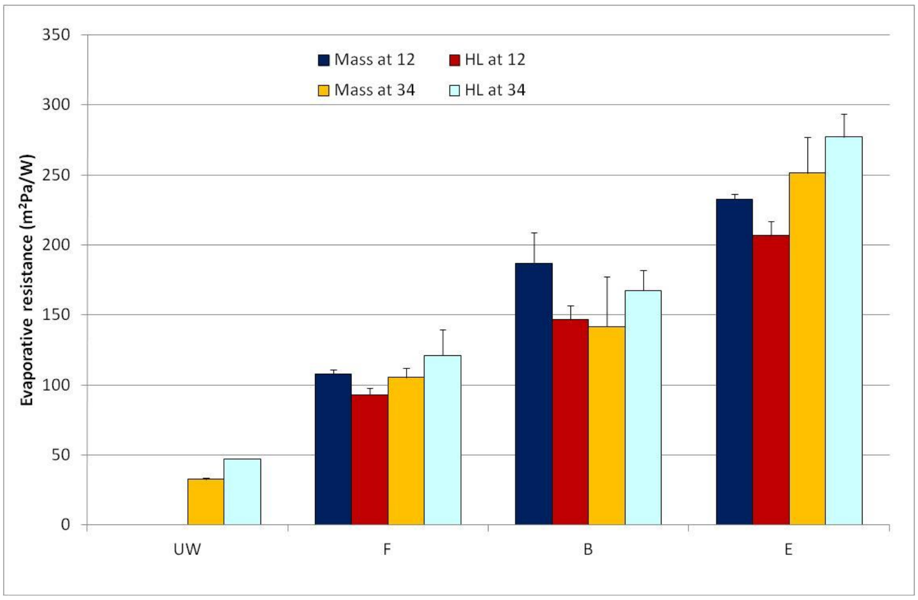

Figure 2. The total evaporative resistance of the sleeping bags and the underwear (UW) measured at 12 °C and calculated from mass loss (Mass at 12) and from manikin heat loss (HL at 12), and measured at 34 °C and calculated from mass loss (Mass at 34) and from manikin heat loss (HL at 34).

Evaporative resistance

The all tested bags were high quality products. Their permeability index (i_m) stayed below 0.4 (Figure 1). Evaporative resistance (Figure 2) of the bags varied from about 90 to over 200 m^2Pa/W under non-isothermal and from 120 to over 270 m^2Pa/W under isothermal conditions according to the heat loss based calculations. The evaporative resistance of the bags varied from about 110 to 233 m^2Pa/W under non-isothermal and from 105 to over 250 m^2Pa/W under isothermal conditions if it was calculated based on mass loss. Evaporative resistance of underwear under isothermal conditions was 33 and 47 m^2Pa/W based on mass and heat loss, respectively. The difference between heat and mass loss methods varied depending on thermal conditions and showed higher evaporative resistance for mass loss than for heat loss method at non-isothermal, while the differences in isothermal conditions were vice versa, i.e. the higher value was acquired for the heat loss.

Conclusions

In the case of tight fitting underwear that is a part of the system it can be utilized as a wet layer next to manikin surface. It will be possible to subtract it for clothing intrinsic evaporative resistance (R_{ecl}) estimation (ASTM-F_2370-05 2005). In this way the whole system and the sleeping bag evaporative resistance may be tested in one step. An extra "skin" under tight underwear may not give a "true" value due to a strong wicking effect. If the underwear is loose fitting then this suggestion does not need to be valid.

The suggested skin temperature corrections (Ueno and Sawada 2011; Wang et al. 2010) seem not to be valid at the low range of the heat loss. This may affect not only sleeping bag testing but also testing of clothing for extreme cold. A separate empirical equation for lower range of heat loss was suggested in this paper. However, it does need to be validated.

Depending on the application of data the test methods and procedures should be standardised: product testing for evaporative resistance measurements should be carried out at isothermal conditions by mass loss method, while potential exposure evaluation is better addressed by the heat loss method utilized in the recommended user temperatures.

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