International Journal of Occupational Safety and Ergonomics (*JOSE*) 2010, Vol. 16, No. 2, 199–216

Testing Sleeping Bags According to EN 13537:2002: Details That Make the Difference

Kalev Kuklane

Division of Ergonomics and Aerosol Technology, Lund University, Lund, Sweden

Valter Dejke

Department of Textiles and Plastics, Swerea IVF AB, Mölndal, Sweden

The European Standard on sleeping bag requirements (EN 13537:2002) describes a procedure to determine environmental temperature limits for safe usage of sleeping bags regarding their thermal insulation. However, there are several possible sources of error related to this procedure. The main aim of this work was to determine the influence of the various measuring parameters on the acuity of the respective parameters in order to judge the requirements. The results indicated that air velocity, mattress insulation and time between unpacking the bag and measurement had a significant impact on the result, with a difference of up to 5–15% in thermal insulation between minimum and maximum allowable parameter levels. On the other hand, manikin weight, thickness of the artificial ground and presence of a face mask were found to have a negligible influence. The article also discusses more general aspects of the standard including the calculation methods used.

sleeping bag mattress thermal manikin insulation European Standard calculation method

1. BACKGROUND

European Standard No. EN 13537:2002[1] on sleeping bag requirements allows an evaluation of the thermal properties of sleeping bags [1]. This evaluation results in comfort, limit, extreme and upper limit levels of temperature, which are the levels of temperature of the ambient air that correspond to different thermophysiological states, and thereby risk levels, of a user lying in a sleeping bag. Hereafter, these temperature levels are denoted temperature limits. The measurements have to be carried out on a thermal manikin. Several studies have shown that recommended temperature limits corresponded to subjective and objective recordings from human subjects during wear trials [2, 3]. The calibration procedure in which reference sleeping bags are used is an important part of the method of determining valid temperature limits for sleeping bags in the standard. The benefits of defining and using references have been demonstrated also for other standards, e.g., within the Subzero project [4] aimed at improving Standard No. EN 342:2004 [5], where reference clothing was selected to calibrate manikins. However, the original reference bags wore out and are not available any more.

Disclaimer. The views and ideas described in this paper belong to the authors and do not necessarily reflect the standpoints of the organisations they represent or CEN/TC 136/WG 11.

The authors appreciate the offer from CEN/TC 136/WG 11 to participate in the Round Robin testing.

Correspondence and requests for offprints should be sent to Kalev Kuklane, Dept. of Design Sciences, EAT, Lund University, Box 118, SE-221 00 Lund, Sweden. E-mail: <kalev.kuklane@design.lth.se>.

[1] Hereafter, Standard No. EN 13537:2002 will be referred to as "the standard".

The main aim of the present Round Robin study on sleeping bags organized by CEN/TC 136/WG 11[2] was to define new reference bags. However, there are uncertainties related to the influence of different measuring parameter settings on the thermal insulation results. Factors that may create uncertainties are specific setup conditions in different labs and specific manikin parameters. Too large intervals of acceptable values for measuring parameters with a strong influence on the result may have a negative influence on the repeatability, reproducibility and reliability of the results. Correspondingly, too narrow intervals for parameters with a small influence on the result make it unnecessarily difficult to meet the requirements on acuity. Furthermore, it is not obvious which calculation method is preferable for these kinds of measurements. Recent research points to considerable differences between the methods for specific products, test setups and test conditions. An erroneously selected calculation method may thereby have a large impact on the determination of temperature limits. Hence, it is important to explain the influence of different measuring parameters and calculation methods on the total thermal insulation of sleeping bags. Therefore, additional tests, outside the scope of the Round Robin test, were made at Lund University and Swerea IVF (both in Sweden) to clarify these relationships.

2. OBJECTIVES

An overall aim of the work presented here was to contribute to the process of making the standard more reliable and easy to use for persons operating the test, and possibly also (in the long run) to make the evaluation more generic and flexible for the end user. More specifically, the aim was to quantify the influence of various measuring parameter settings on the total thermal insulation results. Thereby it should be possible to identify the test parameters that need to be fixed more strictly in the standard and to point out those that have a lesser influence on the results allowing their respective intervals to be broadened.

The intention of this paper was to present the findings to people who were not directly involved in Round Robin tests or standardisation working groups on sleeping bags, but who still might have an interest in this area, e.g., those using thermal manikins for purposes other than testing sleeping bags. Even the distributors, resellers and end users could get an understanding on how various factors might affect thermal comfort in sleeping bags.

An additional objective of the paper was to initiate a discussion on issues related to the use of the serial and parallel calculation models for determining thermal insulation and on ways of dealing with those issues.

3. METHODS

The tests in this study were based on Standard No. EN 13537:2002 although some settings were modified for some measurements. The conclusions drawn in this paper are based on sleeping bag measurement results obtained at Lund University and Swerea IVF.

3.1. Thermal Manikins

A thermal manikin is a human-shaped dummy that is heated to a set surface (skin) temperature, e.g., 34 °C, and where power to keep this temperature is regulated. The required power is equal to heat losses from the manikin surface (with a correction for possible power losses in the regulation system and cables). Different regulation modes may allow keeping the heat loss constant and letting the surface temperature float, or allow flexible temperature and heat loss regulation that follows a certain physiological model. The manikins can be used to evaluate insulation of pieces of clothing and complete ensembles, but also to evaluate more or less complex environments, e.g., heating, cooling and ventilation solutions for indoor climate or in vehicles. More information on thermal manikins

[2] European Committee for Standardization (CEN)/Technical Committee 136/Working Group 11.

can be found in specific review papers [6, 7] or on the Internet [8].

Both thermal manikins used in this study were manufactured in the same Nordic development project, and belong to the so-called Tore series [9]. They are made of plastic foam fixed to a metal frame and have flexible joints to allow motion simulation. Kuklane, Heidmets and Johansson described a Tore-type manikin in greater detail [10]. The manikins used different regulation systems that were custom-developed independently for both test locations. During testing both manikins were run in constant surface temperature mode of 34 °C.

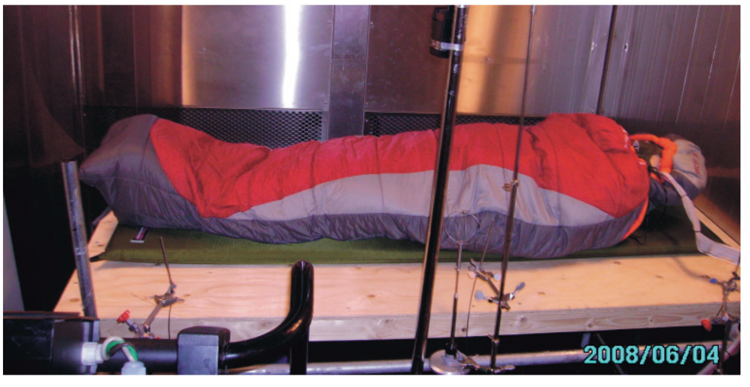
3.2. Sleeping Bags and Postures

The tests according to the standard were carried out on six sleeping bags (Table 1). The bags were chosen to cover a wide range of thermal insulation. Four sleeping bags had synthetic filling (A, B, C, E), whereas two had down filling (D, F). One bag (B) was rectangular, the rest were mummy-shaped. B and C, and D and E were meant to be used in about the same temperature ranges. Two postures were tested (Figure 1). In posture 1 the manikin was completely inside the bag, the zip was closed and any hood was closed tightly leaving only a small opening in the nose/face area. In posture 2 both

TABLE 1. Sleeping Bags (A–E were acquired in spring 2008, F in spring 2009)

Code	Manufacturer	Model	Colour	Filling	Shape	Weight (g)
A	Gold-Eck; Austria	Carinthia LITE 850	marine/light blue	synthetic	mummy	1 116
B	VAUDE; Germany	Kiowa Comfort 220	yellow/green	synthetic	rectangular	1 590
C	VAUDE; Germany	Arctic Basic 220	grey/red	synthetic	mummy	1 436
D	Halti; Finland	Air light 2000	black	down	mummy	1 876
E	Mammut, Ajungilak; Switzerland	Denali 5 Seasons	yellow/black	synthetic	mummy	3 856
F	Bertoni; Italy	Eclipse 100	blue/orange	down	mummy	678

posture 1



posture 2

Figure 1. Sleeping bag C in postures 1 and 2.

Figure 2. Rectangular sleeping bag B in posture 1.

hands were outside the sleeping bag and the zip was left open. A face mask was used for bags A, C, D, E and F for posture 1. Bag B (rectangular) was tested without the mask in posture 1 (Figure 2) according to the requirements in the standard. For posture 2 the face mask was not used for any of the bags.

3.3. Underwear

At both test locations the manikin was provided with long underwear (a sweater and trousers) made from a three-layer, cotton (42%) and polyester (58%), knitted fabric. At Swerea IVF the underwear had a thermal resistance of 0.051 and at Lund University 0.046 m^2K/W. The latter could be explained by a longer use of that set of the underwear. Knee-length socks were also used at both locations. A few tests were carried out on the thermal manikin dressed only in standard underwear, without a sleeping bag.

3.4. Climate Conditions

The tests at Lund University were carried out at –5, +5, +11 and +20 °C depending on the expected insulation and the need to keep the heat losses within proper ranges. If high-insulation bags are tested at high ambient temperature, the power requirement for several manikin body sections may be very low, reaching the level of regulation "noise" too closely. At too low temperatures some manikin zones may be at risk of reaching their maximum power capacity, and not being able to maintain the set temperature. Both situations may lead to substantial increase in measuring error. The standard deviation from the set temperature in a stable state for all temperature settings was always within ±0.2 °C. The tests at Swerea IVF were carried out at 3 ± 0.5 °C.

3.5. Calculation Methods

According to the standard, insulation for posture 1 is recommended to be calculated by a serial and for posture 2 by a parallel model [11], although it is possible to use an alternative calculation model if this gives a better correlation between measured and reference values for the reference sleeping bags. In the parallel calculation model the total thermal resistance is defined as the ratio between the temperature difference between the manikin and the ambient air, and the electrical power needed for the manikin temperature to remain constant, e.g., at 34 °C. In the serial calculation model the corresponding calculation is made for each manikin segment individually and the total thermal insulation value is defined as the weighted (with respect to the area of the respective segment) mean value of each segment. This model always gives equal or higher values of thermal resistance compared to the parallel model for measurements carried out in a constant surface temperature mode, and may exaggerate the total thermal resistance if the electrical power needed for one or a few segments is very low. However, this calculation model has sometimes proved to give better correlation between thermal insulation values of sleeping bags and wear trials.

This paper presents both calculation methods for all test conditions.

3.6. Test Parameters Studied

3.6.1. Mattress and artificial ground

Several measurements related to the mattress and the artificial ground (a wooden board) were conducted at Lund University; two board thicknesses and three mattress types were used in different combinations. The board thickness levels used were 12 mm (required by the standard) and 28 mm (a 16-mm board on top of a 12-mm board). The mattresses used were a 10-mm thick foam-rubber mattress with a thermal resistance of 0.230 m^2K/W, a 38-mm thick Therm-a-Rest® (Cascade Designs, USA) ProLite 4 with a thermal resistance of 0.516 m^2K/W (labelled with R 3.2 = 0.496 m^2K/W) and a 40-mm thick older model of Therm-a-Rest® with a thermal resistance of 0.868 m^2K/W. The standard requires the thermal resistance of the mattress to be within the interval 0.79–0.91 m^2K/W for calibration and “mat representative of the habits of sleeping bag users” for testing. At Swerea IVF a 40-mm thick McKinley Dalton 180 Air mattress (Intersport, Germany) with a thermal resistance of 0.845 m^2K/W was used. The thermal resistance of the mattresses was measured on a tog meter [12] at Swerea IVF.

3.6.2. Manikin weight

The weight of the manikin is not defined in the standard. The manikin body weight was modified to cover two levels: 32 and 49 kg. The original manikin weight was 32 kg and the 17-kg weight increase was obtained with lead bars fixed in the torso area. The tests were carried out with bags A and D.

3.6.3. Face mask

According to the standard, a face mask is required in measurements used to define comfort, limit and extreme temperatures of hooded bags (posture 1, cf. Figure 1). Bags A and E were also tested without a mask.

3.6.4. Air velocity

The standard requires air velocity during testing to stay below 0.5 m/s (0.3 m/s is recommended), and 0.3 ± 0.1 m/s in calibration procedures. At Lund University the tests were carried out with a mainly horizontal air flow of 0.32 ± 0.12 m/s, and in additional tests with bags A and E at 0.15 ± 0.07 m/s. At Swerea IVF the tests were carried out at an air velocity of 0.22 m/s.

3.6.5. Position of arms

To determine the upper temperature limit the manikin has to be tested with the arms outside the sleeping bag (posture 2, cf. Figure 1). If the shoulder joint of a manikin allows relatively free arm movement then, depending on the thickness of the sleeping bag, the arms may be spread up to a ~30° angle from the torso. The bags were tested under two conditions: with the arms freely at the sides and with the arms fixed parallel to the manikin sides with a cord going under the back from wrist to wrist.

3.6.6. Time between unpacking and measurement

According to the standard, the test samples should be taken out from the package and conditioned for at least 12 h prior to testing. Shaking the bag is generally recommended as a common praxis although this is not mentioned in the standard. Sleeping bag D (down) was tested after different conditioning times covering the range up to 196 h.

4. RESULTS

After adjusting all described measuring parameters to be as close as possible, the differences between the results of the standard tests from the two laboratories stayed on average at 1.9 and 3.5% for postures 1 and 2, respectively. The biggest difference was observed for bags D in posture 1 and E in posture 2 where the differences were above 12% in both cases. That could be partly related to possible different time between unpacking and measurement in the two cases, and in posture 2 partly to the possible variation in the position of the arms. As the present paper focuses on differences caused by the measuring setup, and to avoid the effects of interlaboratory variation, the results from Lund University were taken as a basis for discussion and were used in figures.

4.1. Thermal Insulation at Standard Parameter Settings

Figures 3–4 show insulation values for postures 1–2, respectively. The results show that for a case with even insulation (posture 1), the relative differences between the total insulation calculated using the parallel and serial models stayed essentially the same (with the serial model

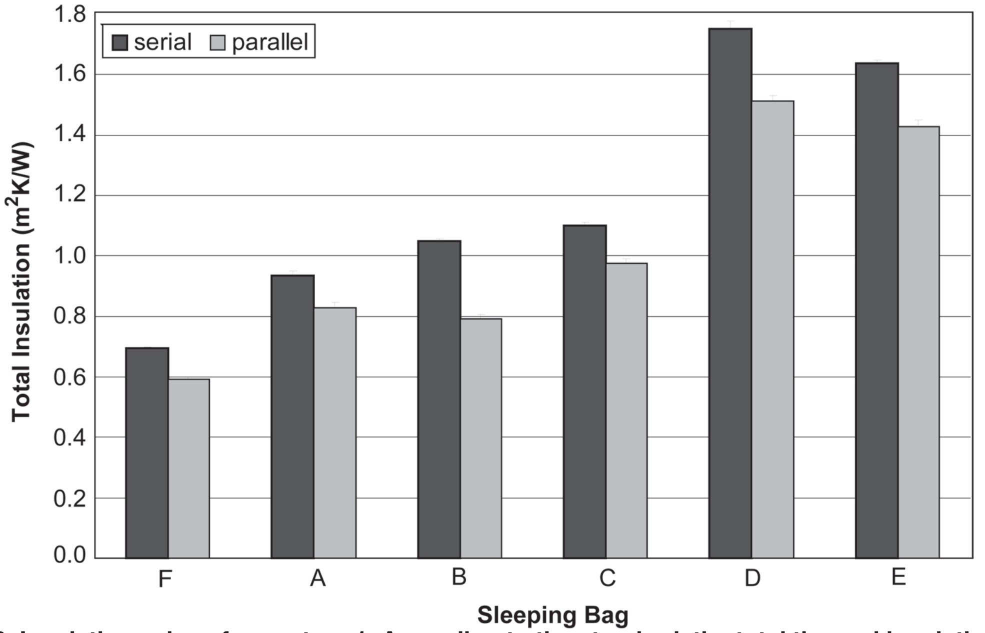


Figure 3. Insulation values for posture 1. According to the standard, the total thermal insulation used to determine the comfort, limit and extreme temperatures is recommended to be calculated by the serial model.

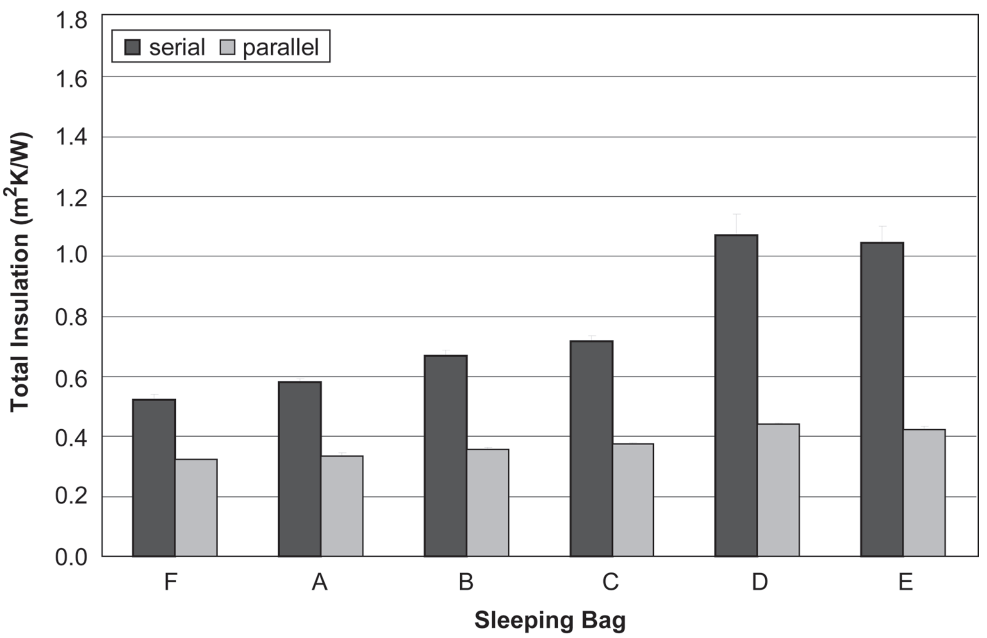


Figure 4. Insulation values for posture 2. According to the standard, the total thermal insulation used to determine the upper temperature limit is recommended to be calculated by the parallel model.

giving a ~15% higher insulation level. For uneven insulation, on the other hand, when the head, arms and upper chest were not covered with the sleeping bag whereas the rest of the body was highly insulated (posture 2), the corresponding difference grew with the total insulation value.

4.2. Influence of Test Parameters Studied

4.2.1. Mattress and artificial ground

As can be seen from the results (Figure 5, the first two and the last two conditions) adding an extra 16-mm board (12 + 16 = 28 mm) under the standard mattress did not affect the results. Thus, a board thickness within the interval of 12–28 mm could be allowed by the standard. However, whether a mattress was used or not, the insulation properties of the mattress affected the results considerably (Figure 5, middle four conditions).

4.2.2. Manikin weight

Figure 6 shows the effect of manikin weight on sleeping bag insulation. Although a clear reduction in insulation was observed locally (back), the total effect stayed slightly above 2% and was thus considered insignificant. Also, a few unpublished tests support this conclusion (Nilsson H, personal communication, 2000; Umbach KH, personal communication, 2009).

4.2.3. Face mask

The differences in conditions with and without a face mask were insignificant (Figure 7). During these test series the face opening could be pulled tightly so that only the nose and the mouth area of the manikin stayed exposed to the environment. However, in some cases where the manikin does not allow tight closing, (e.g., due to thicker cables or cables coming out in different

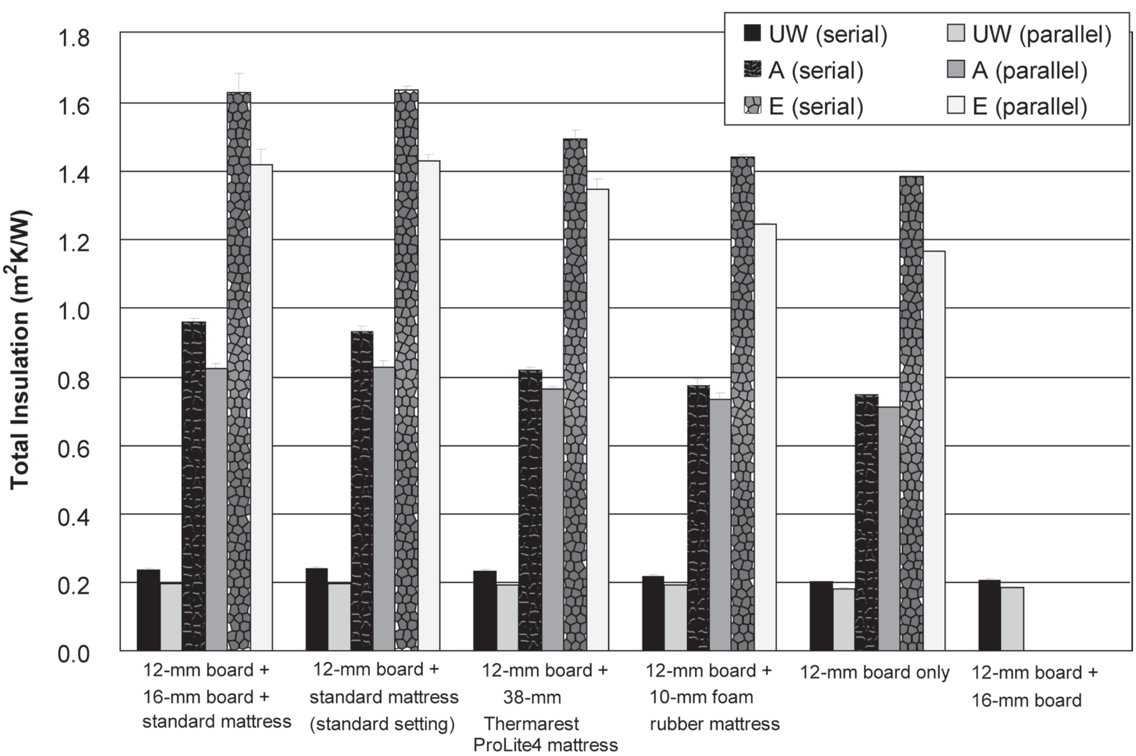


Figure 5. The effect of artificial ground (board) thickness (2 first and 2 last conditions) and mattress (middle 4 conditions) on measurements with underwear only (UW), and sleeping bags A and E (posture 1).

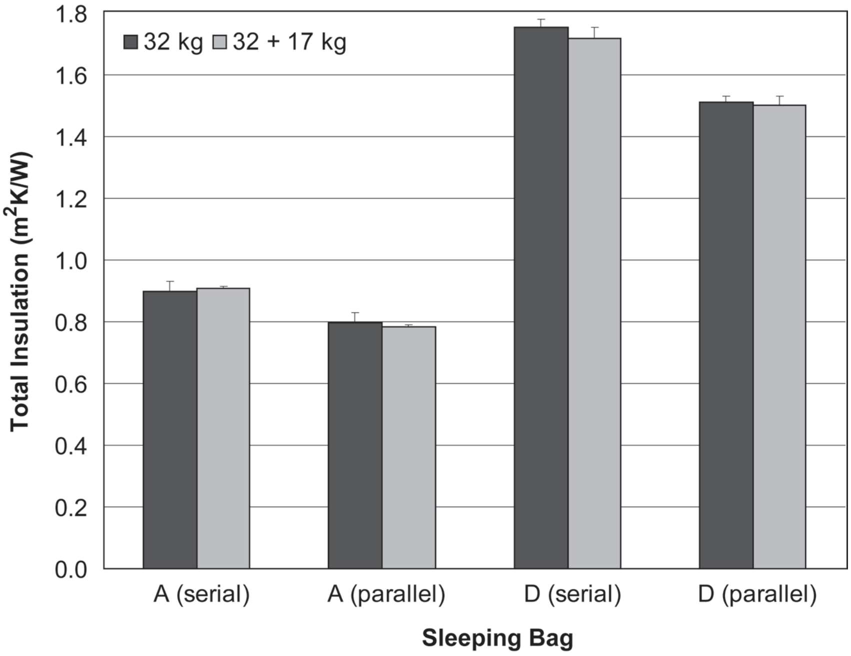


Figure 6. The effect of manikin weight on insulation of sleeping bags A and D (posture 1).

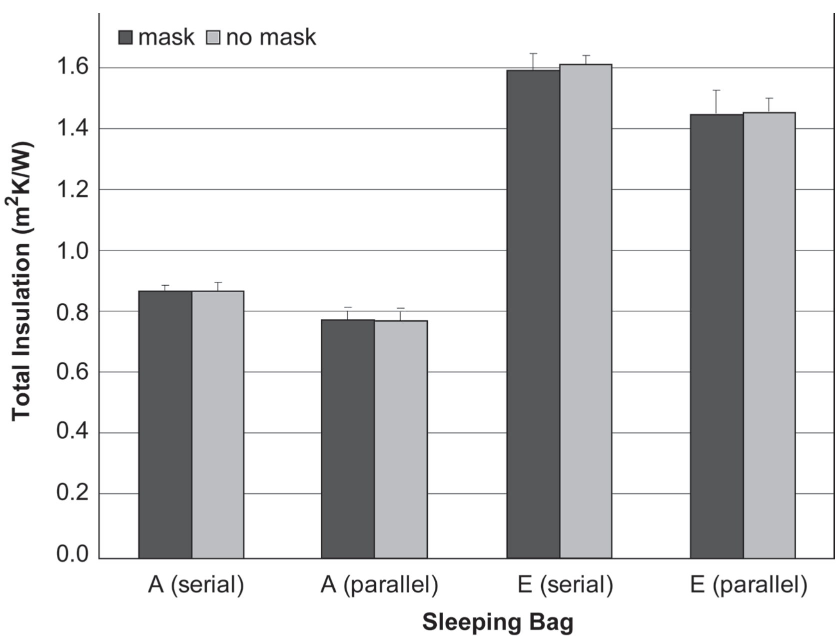


Figure 7. The effect of a mask on sleeping bags A and E (posture 1).

face areas) the influence of the presence of a face mask may be larger.

4.2.4. Air velocity

The difference in air velocity may cause a difference in the results of ~5% even at quite low air flows (Figure 8). In this case the sensitivity might increase also due to a shift from natural to forced convection at 0.15–0.20 m/s. On the other hand, the air flow in the test chamber was generally forced horizontally perpendicular to the length of the manikin, thus disturbing the air flow due to natural convection.

4.2.5. Position of arms

The position of the arms in posture 2 for finding the value of the upper temperature limit may affect the results by 10% (Figure 9). The effect

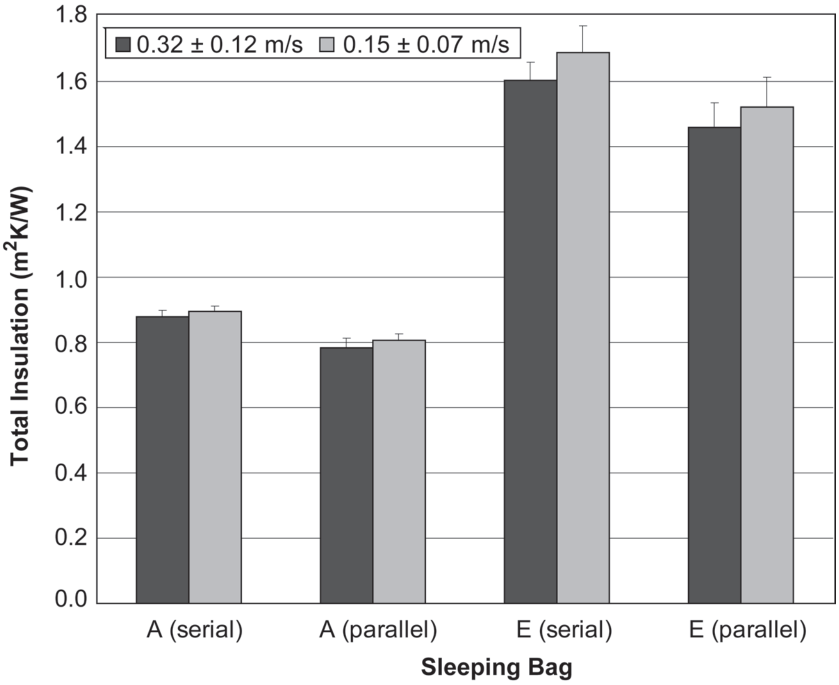


Figure 8. The effect of air velocity on sleeping bags A and E (posture 1).

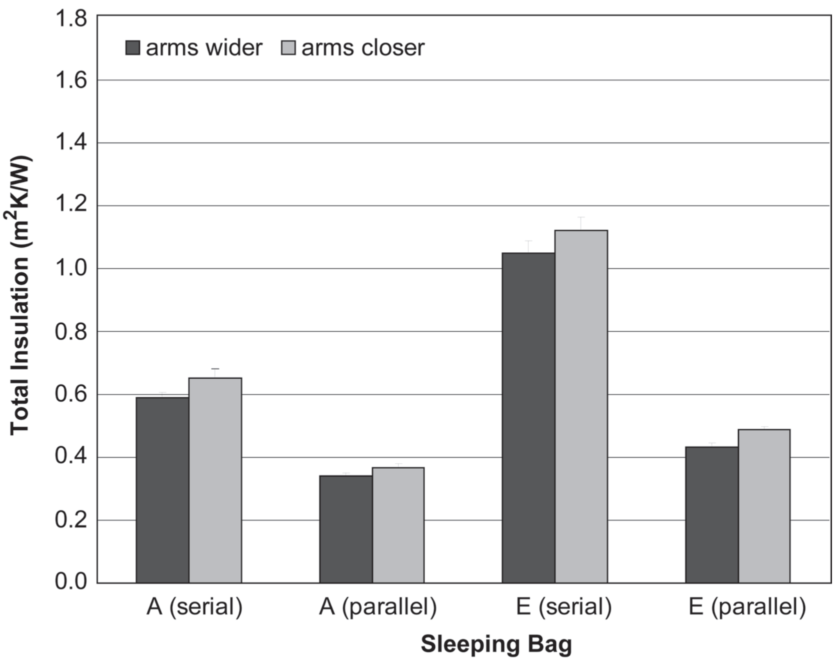


Figure 9. The effect of arms position on insulation of sleeping bags A and E for defining upper temperature limit value (posture 2).

depends on the flexibility of the manikin allowing lateral flexion at the shoulder joint. Leaving the arms outside the bag without any possibility of placing them close to the torso contributes to higher heat losses and lower insulation both at the arms and the torso compared to the case when the arms are fixed closer to the body.

4.2.6. Time between unpacking and measurement

The length of the time from taking the bags out of the casings before testing (conditioning time) to doing the measurements affected the results (Figure 10). The total insulation measured after 106 h from taking the bags out of the casing was

10 and over 15% higher for parallel and serial values, respectively, compared to the case when the corresponding conditioning time was 16 h.

4.3. Summary of Results

Table 2 shows a compilation of the test parameters studied, their chosen levels and the possible impact on the total thermal insulation and corresponding temperature limit values.

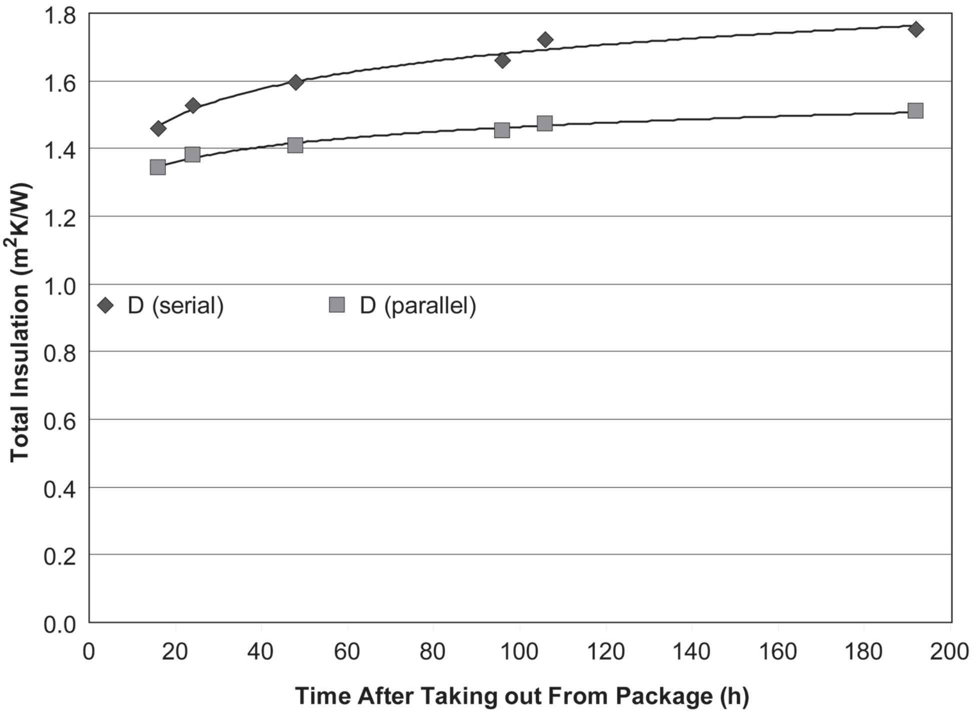


Figure 10. The effect of time between unpacking the bag from casing and measurement on the insulation of the down sleeping bag D (posture 1). Curves have been introduced to roughly indicate the trend.

TABLE 2. Compilation of the Test Results

Test Parameter	Levels Tested	Impact on Total Thermal Insulation (% Change From Standard Level)	Possible Influence on Results in Terms of Change in Temperature Limits	Comments
Artificial ground	12–28 mm board	0	negligible	board thickness of 12–28 mm can be accepted in standard
Mattress	0.1–0.85 m^2K/W	10	5–6 °C	a large influence that should be taken into consideration
Manikin weight	32–49 kg	~2	negligible	a wide range of manikin weight can be considered acceptable in the standard
Face mask	with/without	~1	negligible	the result may be strongly influenced by the size of the bag face opening and manikin cabling exiting the bag
Wind speed	0.15–0.32 m/s	5	2–3 °C	a noticeable influence that should be addressed in the standard
Position of arms	freely/pulled together	10	~1 °C	applies to posture 2 and upper temperature limit
Time between unpacking and measurement	16 h–2 weeks	15	8 °C	a large influence (especially in down bags) that should be addressed in the standard

5. DISCUSSION

5.1. Test Parameters Studied

5.1.1. Mattress and artificial ground

The standard allows using a "mat representative of the habits of sleeping bag users" for the measurements. A market survey might be necessary to define which mattress insulation most customers use. When considering various mattresses for the study it turned out that ordinary sport stores seldom had mattresses with thermal resistance above 0.79 m^2K/W available. They had mostly those of ~0.55 m^2K/W. In general, the most common assortment ranged from 0.20 to 0.80 m^2K/W with an expected average of ~0.50 m^2K/W. At the same time, special outdoor shops offered a wide range of products. Accordingly, the mattress used for calibration measurements had a thermal resistance higher than most commonly offered and used mattresses; however, products with an even higher thermal resistance, e.g., down mattresses, are available. Using a thinner mattress for standard testing could be suggested. Using a very thin mattress in reality would, in that case, not affect the thermal comfort drastically, since the temperature limits labelled on the bag would then have been determined using a relatively thin mattress. Correspondingly, a thicker mattress in real-life use would influence the outcome towards safer/warmer side. However, any change in mattresses would eventually require the manufacturers to retest their products to match new temperature limits. On the other hand, if earlier any mattress "representing user habits" was allowed for testing, and it is not known from the label which one was used; then approving insulation of the standard mattress for testing may require retests anyway. In any case, user information should point out the value of thermal insulation of the standard mattress to make the user aware of the importance of considering the mattress type, and that user temperatures are only valid if a mattress with a thermal resistance similar to the standard mattress (0.85 m^2K/W) is used. Furthermore, a note should be added informing that a mattress with low thermal resistance (<0.23 m^2K/W, e.g., 10-mm foam rubber) may increase temperature limit values by 5–6 °C compared to temperature limits on the label.

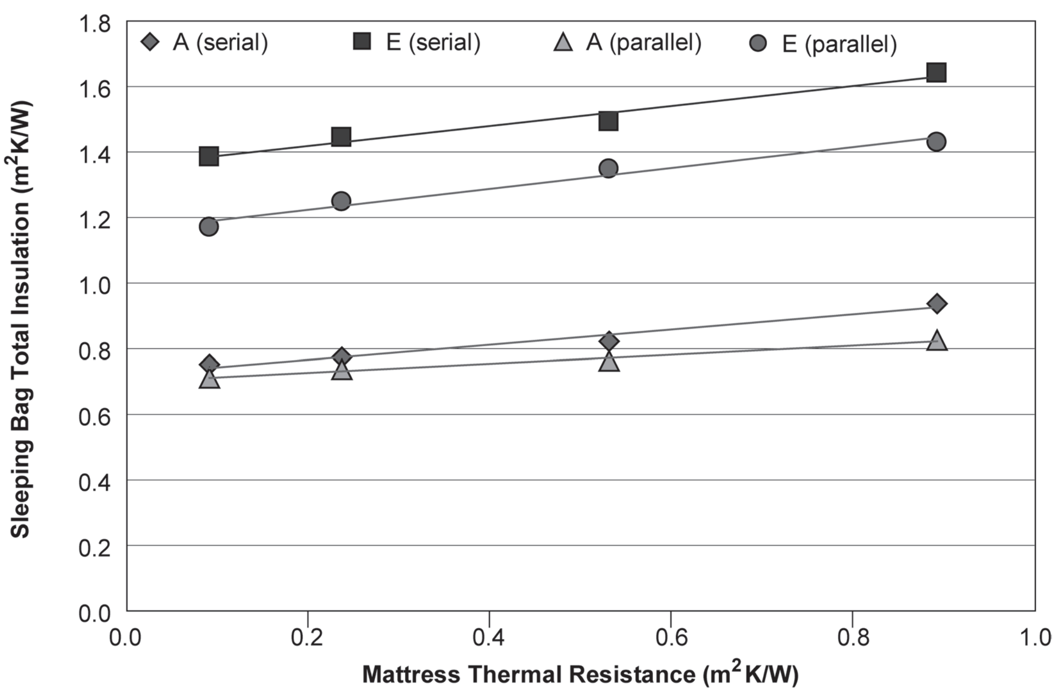


Figure 11. Relationship between mattress thermal resistance and measured sleeping bag thermal insulation. The thermal resistance of the board only is negligible in the case of the mattress. Lines were fitted to the data points to indicate the apparent approximate linear relationships. For the point without the mattress the thermal resistance of the artificial ground (board) was taken equal to air layer insulation that was measured with a nude manikin.

Another option would be to develop a model on the effect of the thermal resistance of the mattress on the thermal insulation of the sleeping bag (Figure 11) and on its impact on temperature limits. For example, comfort temperature of sleeping bags A and E according to our standard tests was +3.2 and –18.1 °C, respectively, while with the foam-rubber mattress it would be +8.3 and –13.8 °C, respectively. A proper prediction model would allow measuring the sleeping bags even without a mattress (comfort temperature would be about +9.1 for A and –10.6 °C for E) and using these values for estimating temperature limits with warmer mattresses. Also, an effect of the underwear might be useful in the model as a recent study on sleeping bags looking on auxiliary products reported considerable differences depending on the combination of mattresses and underwear [13, 14].

5.1.2. Manikin weight

The minimal effect of manikin weight (Figure 6) may be related to its rigidity. Specific contact points at the back, hips and legs take the most weight. The mattress may already be strongly compressed at these points; the effect is present only in a limited area. The outcome might be different (i.e., lower thermal resistance with higher weight) if manikins with flexible and soft body tissue [15] are used.

5.1.3. Face mask

The effect of a mask in this study was negligible (Figure 7), although, there are differences for some manikins (Umbach KH, personal communication, 2009). In general, a face mask is not necessary to measure sleeping bag insulation. The mask makes a relatively unfair condition for an unhooded sleeping bag (the mask is not allowed) compared to a hooded one. The values of sleeping bag insulation for bags F, A, B and C suggest that most probably they will not be used with a mask. In real life it could be expected that a user would use a face mask (or a hat) more probably with unhooded bags than with hooded ones (bag B versus A and C in Figures 1 [posture 1], 2 and 3). For D and E (extremely high insulation) the use of a mask could be expected. Still, even these bags could be tested without a mask. Otherwise, we may ask why sleeping bags with higher thermal insulation values should not be used with thicker underwear as well. Mask use is related to local cold protection, not to hypothermia to which the physiological model behind the standard refers. Manikin testing of sleeping bags without a mask is safer for users if a mask is used in real life.

There are some technical points that support the use of a mask on a manikin, namely, when very warm sleeping bags or sleeping bag systems need to be tested. To keep mean heat losses from the manikin above 20 W/m^2 as required by the standard, there might be a need to use quite low temperatures. If the hood opening cannot be fully tightened, especially if the manikin's face is a separate zone, the heating power may not be sufficient and the zone temperature may drop below the set value and there might be another type of error.

5.1.4. Air velocity

Air velocity is a factor that has to be considered as it may cause a difference in results even if it is within the range that the standard allows (Figure 8). From a practical viewpoint higher air velocity could be preferred as in nature there is seldom a situation with very low air motion, except if the sleeping bag is used in a tent or an igloo. For tent conditions the sleeping bag's comfort, limit and extreme temperatures are, however, not related to the outdoor temperature any more, but to the temperature in the shelter. It should be noted that at higher air velocity, e.g., 0.5 m/s as allowed by the standard, the insulation reduction could be stronger than that observed in this study [16].

From a modelling point of view insulation measured in still air would be the highest possible for a specific setup, and thus predictions towards any higher air velocities would always involve a reduction in insulation. This may simplify acquiring information on any different wind condition. Presently available wind (and motion) corrections on clothing do use this approach [5, 17, 18, 19]. However, there does not seem to be much information available on wind effects on sleeping bags. Also, Huang's recent review on sleeping bags does not address this issue [20]. To some extent the wind corrections for clothing in a standing position could also be adapted to sleeping bags, while no clothing system covers the higher insulation range of the sleeping bags. Thus, a new database on sleeping bags tested at various air velocities needs to be created to develop and/or validate wind corrections. On the other hand, usually a shelter, e.g., a tent, hut, igloo, or at least natural wind shelter (between the bushes, behind stones, etc.) is used, and it may be therefore why the need for wind correction for sleeping bags has not been focused on.

In contrast to the influence of wind, the moisture aspects in sleeping bags have been addressed [15, 21] and methodological bases are available [15, 22, 23]. Still, a special standard method for moisture in sleeping bags has not been proposed. Considerable interlaboratory variability in test results when moisture is involved [24] could be the reason, although recently a lot of research has been carried out in this area [25, 26, 27], and the test methods are being improved.

5.1.5. Position of arms

Spreading the arms from the body in posture 2 affects the results leading to a lower insulation value (Figure 9). This posture is also more affected than posture 1 by the changes in air velocity. The combination of both these factors may either increase or decrease the observed differences. The secondary question is how useful is the upper temperature limit at all: if it is too hot, the sleeping bag may be totally removed and comfort will be defined by underwear insulation if used. The 10% difference in measuring values affects the upper temperature limit only by ~1 °C (Table 2). The big difference between the bags in posture 1 (Figure 3, serial values) almost disappears (Figure 4, parallel values) giving upper temperature limit value differences of under 4 °C (23–26.7 °C).

5.1.6. Time between unpacking and measurement

The results shown in Figure 10 indicate a strong time influence even after the required 12 h of conditioning. The differences are probably more pronounced for bags with large insulation values with a lot of insulating padding (as the tested down bag D). It is difficult to recommend a proper procedure as sleeping bags may arrive at the testing laboratory in different shape. For example, they may be sent in casings or not, having been in casing for a few days or for over a month, etc. The most reproducible method would be to shake the bags and leave them hanging free for a week before testing. However, in real conditions sleeping bags are commonly kept packed for 12–16 h. People cannot be expected to leave them expanding for several hours before use. The following procedure could possibly be recommended for testing:

- take the bag out of the package at least 12 h before testing and leave it for conditioning;
- pack it again 1–2 h before testing;
- take it out of the package and fluff it for a minute;
- put it on the manikin and test;
- pack and fluff before each independent measurement.

A simpler suggestion for a standard procedure would be to tumble dry for a short time at room temperature, just after taking the bag out of the package, and before conditioning to reach relatively stable high insulation values within a very short time. However, the exact procedure and the effectiveness and reliability of that method have to be thoroughly investigated before it can be considered a suitable solution.

5.2. Consideration on the Influence of Chamber and Manikin Regulation Cycles

Low-manikin heat flux may cause an error that is not related to the mask, bag or posture but rather to the temperature regulation of the climatic chamber and manikin. Fluctuations of the temperature (which, according to the standard, should not vary by more than ±0.5 °C) and the electrical power of the chamber and manikin are to some extent inevitable. Due to the thermal inertia of the sleeping bag system (warmer bags may be more affected) the chamber temperature change affects manikin heat losses later than ambient temperature recordings, creating discrepancy that is reflected in calculated insulation. The lower the heat loss, the greater the error. From this point of view the minimal heat flux requirement in the standard (20 W/m^2) should not be lower. Using lower chamber set temperature and thus increasing heat losses would reduce the error. A way to diminish such errors even more is to use data from the full regulation cycle (a period that stays between two similar sinusoidal phases and includes both minimum and maximum temperature readings) to calculate insulation.

5.3. Use of Calibration Procedure

The establishment of limit temperatures in the standard is based on a calibration process, in which any differences between laboratories regarding the way measurements are done and measuring equipment are taken into account and compensated for. However, this approach requires that the settings used at the calibrating measurements are also used at a regular sleeping bag measurement. Hence, it is not enough to just choose measuring settings according to the standard for the calibration measurements and regular measurements independently.

5.4. Use of Physiological Model

It is very important that the correct thermal resistance from manikin tests is used together with the standard's physiological model to give proper temperature limits for a sleeping bag. The present standard method has been worked out and validated at the Hohenstein Institute, Germany [2]. Thus, to obtain reliable results it is required to calibrate the manikin with reference bags, and the results may be expected to be corrected against the reference values (however, these are not given in the present standard).

Other test procedures and prediction models can be found in the literature [28, 29]. Even in those it is important that the test and calculation method for thermal insulation fit the physiological evaluation method. An earlier study that tested over 40 people in an igloo at –1 °C [30, 31] gave a comparable fit with the standard method while using the parallel calculation method and principles from the IREQ standard [32]. The sleeping bag in that study had an insulation of 0.851 m^2K/W calculated with the parallel model. That corresponds to a bag similar to B or C where the insulation calculated with the serial method was on average 1.075 m^2K/W. The standard thermal insulation table in the standard gives a comfort temperature of somewhat below –1 °C. The subjects commonly used long underwear and estimated their thermal sensation over the night between neutral and slightly warm. From this it can be concluded that the methods used in the standard fit well and provide correct temperature limits for specific test conditions.

5.5. Choice of Calculation Method

Following the discussion in section 5.4., Wallerström and Holmér's study can be used as an example [33]. In that investigation the insulation of 6 sleeping bags with hoods was measured on human subjects. The measured insulation values stayed at 0.96–1.15 m^2K/W. The calculated comfort temperature stayed between +1 and –4 °C. Tests were carried out at ~0 °C and toe temperatures at the end of 90-min tests were on average between 19 and 25 °C. The tested sleeping bags were relatively similar and could be compared in total insulation with bag C of this study (0.975 and 1.101 m^2K/W for parallel and serial calculation, respectively) which gives comfort temperature of –1.9 °C according to standard. This additionally supports the temperature limits defined in the standard.

A recent well-defined study by Huang and McCullough on sleeping bags included human tests [29]. The paper compared various prediction models. The standard method compared well for both limit and comfort temperatures [3, 20].

However, the recent studies that relate to the differences in serial and parallel calculation methods give rise to some concerns [34, 35, 36, 37]. The most extreme case of differences between the methods was reported recently on the effects of auxiliary heating systems used in the cold. A serial method could produce there apparent insulation of more than 80 clo (1 clo = 0.155 m^2K/W) when using a vest [38]. Such an extreme case may be an exception, but the development of new technology and smart textiles that use auxiliary heating elements, e.g., PCM (phase change material), may still produce unrealistic results when the serial calculation method is used.

The serial model raises an additional issue if one would like to predict total dry heat losses at specific ambient conditions based on the insulation value, e.g., for human heat balance analysis. In manikin tests, these can be acquired by adding up heat losses (in watts) from all zones. However, the calculation backwards based on the serial insulation gives a lower value, while the parallel insulation would lead to original quantities. In posture 1 the differences would not be so big due to relatively even insulation distribution, while in posture 2 the differences would be more than twice as big for warmer sleeping bags (Figures 3–4). Also, if with even insulation the results from parallel and serial models have a good relationship (Figures 3 and 7; [16]), then for uneven insulation the relationship changes (Figure 4; [34]). Even after calibration this will affect the measuring results towards higher insulation, especially, in the case of a faulty sleeping bag where padding has been placed incorrectly or is loose and can shift and collect in certain areas leaving other areas with a poor insulation layer.

For research purposes high quality products are commonly used. During testing, however, faulty bags may come up. Thus, receiving a "good" relationship with a product manufactured as expected does not mean that the relationship works as expected with a bag made from smart textiles or used with a defective sleeping bag. To avoid promoting faulty products or obtaining unrealistic values for the ones that use smart technologies the serial insulation calculation method should be avoided.

6. CONCLUSIONS

The following conclusions could be drawn from this study:

- The results indicated that for determining comfort, limit, and extreme temperatures, air velocity, mattress insulation and conditioning time had a significant impact on the total thermal insulation. A difference in the range of 5–15% in total thermal insulation was obtained between minimum and maximum values (allowed by the standard) of the respective parameters.
- For measuring the upper temperature limit, the position of the arms was found to have the largest influence with up to a 10% difference in thermal insulation depending on the angle between the arms and the upper body of the manikin.
- The thickness of the artificial ground, the manikin weight and the presence of a face mask were found to have a negligible influence on the results. The latter two parameters may affect the results differently if other types of manikins are used.
- Regarding methods of calculating total thermal insulation, a number of issues were pointed out. The insulation values obtained from the serial equation may lead to unrealistic results for bags using auxiliary heating systems or PCM materials, while the parallel equation is considered more robust.
- When determining the total thermal resistance according to the standard, it is very important to use the same measurement settings in regular and in calibration measurements, for the obtained temperature limits to be valid.

REFERENCES

1. European Committee for Standardization (CEN). Requirements for sleeping bags (Standard No. EN 13537:2002). Brussells, Belgium: CEN; 2002.
2. Umbach KH. Ermittlung des Verwendungsbereiches von Schlafsäcken [Information on user interval for sleeping bags] (Hohensteiner Forschungsbericht

Bekleidungsphysiologie No. 1990:3). Bönnigheim, Germany: Hohensteiner Institute.

3. McCullough EA, Huang J, Jones BW. Evaluation of EN 13537 and other models for predicting temperature ratings of sleeping bags. In: Holmér I, Kuklane K, Gao C, editors. The 11th International Conference on Environmental Ergonomics. Lund, Sweden: Lund University; 2005. p. 425–8.
4. Meinander H, Anttonen H, Bartels V, Holmér I, Reinertsen R, Sołtyński K, et al. Thermal insulation of cold protective clothing using thermal manikins. Subzero project. Final Report. Tampere, Finland: Fiber Materials Sciences, Tampere University of Technology; 2003.
5. European Committee for Standardization (CEN). Protective clothing—ensembles for protection against cold (Standard No. EN 342:2004). Brussels, Belgium: CEN; 2004.
6. Wyon DP. Use of thermal manikins in enviromental ergonomics. Scand J Work Environ Health. 1989;15 Suppl 1:84–94.
7. Holmér I. Thermal manikin history and applications. Europ J Appl Physiol. 2004;92(6):614–8.
8. The Thermal Manikin Network. Retrieved January 25, 2010, from: http://hem.passagen.se/nilssons/mer_manikin_network.htm
9. Hänel SE. A joint Nordic project to develop an improved thermal manikin for modelling and measuring human heat exchange. In: Aspect médicaux et biphysiques des vêtements de protection [Medical and biophysical aspects on protective clothing] [conference proceedings]. Lyon, France: Centre de Recherche du Service de Santé des Armées; 1983. p. 280–2.
10. Kuklane K, Heidmets S, Johansson T. Improving thermal comfort in an orthopaedic aid: better boston brace for scoliosis patients. In: Fan J, editor. The 6th International Meeting on Manikins and Modelling (6I3M). Hong Kong: The Hong Kong Polytechnic University; 2006. p. 343–51.
11. International Organization for Standardization (ISO). Thermal manikin for measuring the resultant basic thermal insulation (Standard No. EN ISO 15831:2004). Geneva, Switzerland: ISO; 2004.
12. International Organization for Standardization (ISO). Textiles—determination of thermal resistance—part 1: low thermal resistance. (Standard No. ISO 5085-1:2004). Geneva, Switzerland: ISO; 2004.
13. McCullough EA, Zuo J, Huang J. The effect of auxiliary products on the insulation provided by sleeping bag systems. In: International Textile and Apparel Association's (ITAA) 2009 Annual Conference. Retrieved March 26, 2010, from: http://www.itaaonline.org/downloads/TAS-McCullough-The_Effect_of_Auxiliary.pdf
14. McCullough EA. Issues concerning the EN 13537 sleeping bag standard. Boulder, CO, USA: Outdoor Industry Association; 2009. Retrieved March 26, 2010, from: http://www.outdoorindustry.org/pdf/EN13537Mccullough062209.pdf
15. Wu YS, Fan J. Testing sleeping bags using a supine sweating fabric manikin. In: 13th International Conference on Environmental Ergonomics [CD-ROM]. Boston, MA, USA: USARIEM; 2009.
16. Anttonen H, Niskanen J, Meinander H, Bartels V, Kuklane K, Reinertsen RE, et al. Thermal manikin measurements—exact or not? International Journal of Occupational Safety and Ergonomics (JOSE). 2004;10(3):291–300.
17. Havenith G, Nilsson H. Correction of clothing insulation for movement and wind effects—a metanalysis. Europ J Appl Physiol 2004;92(6):636–40.
18. International Organization for Standardization (ISO). Ergonomics of the thermal environment—estimation of the thermal insulation and evaporative resistance of a clothing ensemble (Standard No. ISO 9920:2007). Geneva, Switzerland: ISO; 2007.
19. Nilsson HO, Anttonen H, Holmér I. New algorithms for prediction of wind effects on cold protective clothing. In: Kuklane K, Holmér I, editors. NOKOBETEF 6 and 1st European Conference on Protective Clothing. Solna, Sweden: Arbetsmiljö-institutet; 2000. p. 17–20.

20. Huang J. Prediction of air temperature for thermal comfort of people using sleeping bags: a review. Int J Biometeorol. 2008; 52(8):717–23.
21. Havenith G, den Hartog E, Heus R. Moisture accumulation in sleeping bags at –7 °C and –20 °C in relation to cover material and method of use. Ergonomics. 2004;47(13):1424–31.
22. American Society for Testing and Materials (ASTM). Standard method for measuring the evaporative resistance of clothing using a sweating thermal manikin (Standard No. ASTM F2370-05). Philadelphia, PA, USA: ASTM International; 2005.
23. Meinander H, Hellsten M. The influence of sweating on the heat transmission properties of cold protective clothing studied with a sweating thermal manikin. International Journal of Occupational Safety and Ergonomics (JOSE). 2004; 10(3):263–9.
24. Richards MGM, McCullough EA. Revised interlaboratory study of sweating thermal manikins including results from the sweating agile thermal manikin. J ASTM Int. 2005;2(4):13.
25. Havenith G, Richards M, Wang X, Bröde P, Candas V, den Hartog E, et al. Apparent latent heat of evaporation from clothing: attenuation and "heat pipe" effects. J Appl Physiol. 2008;104(1):142–9.
26. Kuklane K. Heat loss from a thermal manikin during wet tests with walking simulation. In: The 7th International Meeting on Manikins and Modelling (7I3M) [CD-ROM]. Coimbra, Portugal: Faculty of Science and Technology, University of Coimbra, Portugal; 2008.
27. Bröde P, Havenith G, Wang X, Candas V, den Hartog EA, Griefahn B, et al. Non-evaporative effects of a wet mid layer on heat transfer through protective clothing. Eur J Appl Physiol. 2008;104(2):341–9.
28. Holand B. Comfort temperatures for sleeping bags. In: Nilsson H, Holmér I, editors. In: The Third International Meeting on Thermal Manikin Testing; 3IMM. Solna, Sweden: Arbetslivsinstitutet; 1999. p. 25–8.
29. Huang J, McCullough EA. Evaluation of heat loss models for predicting temperature ratings of sleeping bags (Institute for Environmental Research Technical Report 03-80). Manhattan, KS, USA: Kansas State University; 2003.
30. Holmér I. Övernattning i igloo [Overnight sleeping in igloo]. In: Holmér I, editor. Arbete i kyla [Work in cold]. Solna, Sweden: Arbetsmiljöinstitutet; 1993. p. 36–38.
31. Holmér I. Protection against cold. In: Shishoo R, editor. Textiles in sport. Boca Raton, FL, USA: CRC Press; 2005. p. 262–86.
32. International Organization for Standardization (ISO). Ergonomics of the thermal environment—determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects (Standard No. ISO 11079:2007). Geneva, Switzerland: ISO; 2007.
33. Wallerström B, Holmér I. Bestämning av värmeisolationsförmågan hos olika sovsäckar [Determination of thermal insulation of different sleeping bags] (Report D, No. 5124). Solna, Sweden: Arbetarskyddsstyrelsen; 1981.
34. Kuklane K, Gao C, Holmér I, Giedraityte L, Bröde P, Candas V, et al. Calculation of clothing insulation by serial and parallel methods: effects on clothing choice by IREQ and thermal responses in the cold. International Journal of Occupational Safety and Ergonomics (JOSE). 2007;13(2):103–16.
35. Lee JY, Ko ES, Le HH, Kim JY, Choi JW. Serial and parallel method in calculation of single garments with a thermal manikin. In: Mekjavic IB, Stelios N. Kounalakis, Taylor NAS, editors. The 12th International Conference on Environmental Ergonomics. Ljubljana, Slovenia: Biomed; 2007. p. 430–3.
36. Oliveira AVM, Branco VJ, Gaspar AR, Quintela DA. Measuring thermal insulation of clothing with different manikin control methods. Comparative analysisof the calculation methods. In: The 7th International Meeting on Manikins and Modelling (7I3M) [CD-ROM]. Coimbra, Portugal: Faculty of Science and Technology, University of Coimbra, Portugal; 2008.

37. Nilsson H. Analysis of two methods of calculating the total insulation. In: Nilsson H, Holmér I editors. Proceedings of a European seminar on Thermal Manikin Testing. Solna, Sweden: Arbetslivsinstitutet; 1997. p. 17–22.

38. Holmér I, Gao C, Wang F. Can a vest provide 83 clo? Serial calculation method revisited [abstract]. In: Dezaire J, den Hartog E, Luiken A, editors. European Conference on Protective Clothing. Arnhem, The Netherlands: TNO; 2009. p. 12.