# Issues Concerning the EN 13537 Sleeping Bag Standard

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The EN 13537 Standard requires a manikin test to measure the insulation value of a sleeping bag as part of a system which includes clothing and a pad (CEN, 2002). The insulation value is used in a heat loss model to determine a comfort temperature, a limit temperature, and an extreme temperature. A second manikin test can be conducted to determine the maximum temperature for comfort, but this is optional. A labeling requirement is also given.

The overall approached used in the standard is theoretically sound. The major factors that affect a person's thermal comfort in a sleeping bag are taken into account in the method – the environmental conditions, the thermal and evaporative resistance provided by the sleeping bag system, and the metabolic heat production of the person. In addition, the temperature ratings generated by the steady-state models in the standard have been validated by human subject research (McCullough, Huang, & Jones, 2005). Since the standard's adoption in 2002, numerous sleeping bags have been tested at several labs. Manufacturers and laboratory personnel have expressed some concerns about procedures in the standard that affect inter-laboratory variability. In addition, there appears to be some confusion regarding the differences between EN 13537 (CEN, 2002) and ASTM F 1720 (ASTM, 2009). This paper will describe the basic differences between the two sleeping bag standards and offer suggestions for possible changes in EN 13537.

## ASTM Standard for Measuring the Insulation of Sleeping Bags

ASTM F 1720 provides a method for measuring the total thermal insulation of a sleeping bag (Option #1) or a sleeping bag system (Option #2) – including the air layer resistance on the surface. For Option #1, the nude manikin is placed in the sleeping bag on a thin cot, and the bag's insulation is measured. This is the best method to use for product development because differences in filling materials or designs and differences between competitor's bags will show up better than when auxiliary products are used with the bag.  Option #2 is a more realistic test because the clothing and pad that a consumer would typically use with the bag can be added to create a sleeping bag system. Other auxiliary products such as camp pillows, bag liners, and bivy sacks can also be used. The system insulation value will be much higher than that measured for the bag alone.  The users of the standard may select any auxiliary products they wish to test with their bag.

The insulation of the bag *system* can vary greatly depending upon which auxiliary products are used. To illustrate this point, a recent study was conducted where levels of clothing insulation, mummy bag insulation, and pad thickness/insulation were systematically varied to determine the effect on system insulation (McCullough, Zuo, & Huang, 2009). Data for synthetic bags are shown in Table 1 and data for down bags in Table 2. The data show that the insulation of the system components is not additive. In other words, a person cannot add clothing insulation and pad insulation to the insulation value of a bag measured according to Option #1 to determine the total insulation value of the system. Although linear and quadratic equations can be used to estimate the impact that clothing and pads can make on a bag system (McCullough, Zuo, & Huang, 2009), the individual insulation values cannot be added up with accuracy. Therefore, the insulation values for a sleeping bag system are more difficult to use in product development than data measured for the bag alone. However, the insulation value for a sleeping bag system should be used as the basis for predictions of the air temperature for comfort. The EN 13537 manikin test is comparable to Option #2 of the ASTM standard with one exception: It requires that a wooden board be placed under the manikin and elevated off the floor instead of using a thin cot. Compression of the bottom of the bag under the manikin is not an issue since a pad is specified as part of the system in the EN test.

Note: A cot is used in the ASTM test for two reasons: 1) it elevates the manikin off the insulated floor so that the environmental temperature is the same all around the bag, and 2) it makes the manikin's body compress the bag along the bottom better than having his rigid body touch the surface in a few places (e.g., his shoulders and buttocks). This is important for Option #1 where the bag is tested alone, without a pad.

## **No Temperature Ratings in ASTM F 1720**

The primary lab in the United States that routinely runs ASTM F 1720 for manufacturers is the Institute for Environmental Research at Kansas State University. The standard is also followed by the U.S. military labs in Natick, MA, and it is required in military sleeping bag specifications. Both labs use the insulation value measured in the standard manikin test in whole-body heat loss models to predict the temperature for comfort. In steady-state models, there is a balance between the rate of body heat production and the rate of body heat loss to the environment. These models are conservative and result in higher temperature ratings. However, the body can tolerate some heat debt during sleep without discomfort or waking. Heat debt refers to the situation where a person is losing more heat than he/she is producing, and the skin temperature and internal body temperature are decreasing. Heat debt models predict the lowest acceptable temperature for comfort during a limited exposure time where a little body cooling is allowed; typically predictions are made for 8, 6, or 4 hours of sleep (Huang & McCullough, 2003). This modeling is **not** part of the ASTM standard. The labs provide it as an additional service because the manufacturers want a temperature rating to use in product descriptions.

## EN Standard for Sleeping Bags

The total insulation value for a sleeping bag system (i.e., clothing, pad, bag) and the boundary air layer around the system is measured with a manikin on an elevated wooden board. The developers of the standard tried to write the document so that a variety of manikins and chambers could be used. As a result, the variability among labs can be large. To address this issue, they developed a calibration procedure that involves having each lab test eight bags and develop a correlation factor to apply to their measured data to make it match data collected at one particular lab. The standard then uses the total insulation value of the sleeping bag system in steady-state models to predict a temperature range for comfort. Some specific aspects of the method are discussed below, with recommendations for change.

**EN Manikin Test Set-up**

**Section 4.3.3** states that the thermal properties of a sleeping bag and the comfort, limit, and extreme temperatures should be determined according to Annexes A, B, and C.

**Recommendations for Annexes A and B.** It is recommended that the information in Annexes A and B be combined and rewritten to make the manikin calibration and test procedures more clear. Details are given below.

**Section A.4.1** states that the manikin should be dressed in a track suit (i.e., knit warm-up suit or thermal underwear) where the fabric insulation is 0.049 $m^2 \cdot K/W$ ±10%. Knee socks with a fabric insulation of 0.054 $m^2 \cdot K/W$ ±10% should also be used. The method for measuring the fabric insulation of these garments is not specified. Since sock material stretches when it is on the body, and it comes in small pieces, it will be difficult for a lab to test the sock material and select the correct pair of socks. In addition, the length of the sock (i.e., how much of the calf it covers) is not specified. Annex B describes the procedures used at Hohenstein Institute to measure the calibration values or standard insulation values that all labs should match. This procedure states that a face mask was used with mummy bags during the testing, but this is not stated in the procedures given in Annex A and the face mask is not described. (The face mask used by most labs is rather strange and would not be used by most consumers.)

**Section A.4.2** states that the manikin should be placed on an elevated board about 12 mm thick. Research by Kuklane (2009) has shown that using a thicker board does not affect the results. Therefore, the board specification is acceptable. The board is supposed to be covered by a pad (mat) that consumers might typically use. No specification of the ground pad is given, although Annex B states that a mattress with a thermal resistance of 0.85 $m^2 \cdot K/W$ ±7% should be used when the calibration bags are tested. Research has shown that the pad can make a huge difference in the insulation of a sleeping bag system (McCullough, Zuo, & Huang, 2009).

**Recommendations for A.4.1 and A.4.2.** Clothing items and pad should be specified in the standard and a source for purchase given. All labs should be using the exact pad and clothing. Ideally, these auxiliary products should be available for purchase from the lab that houses the calibration bags. We use a self-inflating foam pad and blow it up to make it more rigid under the manikin's weight. We have examined different pad pressures and found that they did not make a difference in the overall insulation value when the pad was placed on the board. However, a solid foam pad might be more durable than a self-inflating foam pad overtime. The pad should not be removed from the test because the manikin sinks into the cushioning pad and simulates the compression of the bottom of the bag during use. Without a pad, the manikin would rest on two or three pressure points on the hard board. In addition, most consumers use a pad.

Manufacturers are concerned that well-insulated bags designed for use in very cold environments would be used with a thicker pad and clothing in the field. Therefore, a method for dealing with this issue could be developed. For example, if a bag surpassed a particular insulation value when tested according to the standard, perhaps an additional amount of insulation could be added to reflect the consumer changing to a thicker pad and clothing. Of course this would be an arbitrary addition, but it would not involve any more testing and would reflect common practice.

It is recommended that a face mask not be used in the testing. However, if a face mask is included in the clothing used on the manikin, it should be a knit mask that covers the face and head. Whether the face mask is included or not, a diagram or photograph needs to be added to the standard that shows how the hood should be drawn over the face. This can make a difference in the measured insulation value. Some manikins have an unheated dead zone in the face where the cables connect to his eyes. Others have the cables coming out in the neck area, so clothes pins or some type of fasteners are needed to secure the proper fit around the face. For EN testing, we always make sure the hood is drawn from the forehead, around his face, under his chin. If the bag slips and covers the eyes or chin, the insulation value is increased. Note: The ASTM standard states that the hood should be drawn up to a 5 cm opening over the face. The U.S. military uses full coverage over the face in their testing. It is imperative that the treatment around the face be specified clearly in the standard.

The **scope** indicates that the standard covers all sleeping bags except military ones. The scope should be limited to mummy bags with a hood or additional dressing procedures should be added to the standard for bags without a hood. Procedures for testing bags with internal pads already in them should be added.

## Environmental Conditions in the Chamber and Conditioning

**Section A.4.3** gives ranges for environmental conditions that are acceptable. However, the wide range for air velocity – from still air conditions to 0.5 m/s – will contribute to inter-lab variability since air velocity affects the external air layer around the manikin. In addition, the direction of the air flow may affect the results. (Is it horizontal or vertical flow in the chamber? Does it flow across him or along his length?). The relative humidity range is wide (40-80%), but acceptable since at steady-state, relative humidity does not affect insulation (i.e., there is no absorption or desorption of moisture by fibers under steady-state conditions). In addition, the actual moisture content of the air is very low in cold temperatures.

**Section A.5** states that the bag should be conditioned in the cold chamber for 12 hours prior to testing. This is not really necessary since the bag needs to come to equilibrium on the manikin's hot body in the cold environment prior to taking any data. Conditioning the bag in the chamber may speed up this process, but it is not necessary for accuracy. It is more important for the bag to be shaken and allowed to rest in an uncompressed state (i.e., out of the storage sack) prior to putting it on the manikin.

**Recommendations for A.4.3 and A5.** The air flow range should be reduced to 0 – 0.3 m/s and specified as horizontal air flow from the manikin's head to his feet. Labs that have the air circulating from the ceiling should build an air flow tunnel within the chamber so that the flow is consistent and flows horizontally over the manikin. This is inexpensive and easy to do. The conditioning requirement in the chamber should be dropped, and a requirement to let the bag rest flat on the floor in an uncompressed state for 24 hours prior to testing should be added.

## Manikin Test and Calibration

**Section A.4.1** specifies the height range and surface area range of the manikin, but the weight range is not given. Most manikins weigh less than the average adult male because it takes more time to heat and cool a larger thermal mass. Kuklane (2009) determined that insulation values measured on a 70 lb. manikin and on the same manikin weighted to 108 lb. were within 3% of each other.

**Section A.6** describes the manikin test, but it never says that the manikin should be lying down with his arms at his sides. In **Annex B** where the calibration tests were described, the Hohenstein lab had the left arm folded over the chest. A.6 states that the test should be replicated three times. It is generally understood to mean that only one bag style needs to be tested, and that it is tested three times. It is not clear whether three measurements can be made in a row on one bag, or whether the bag needs to be taken off and put back on the manikin for three independent tests, or whether three samples of the same bag style need to be tested.

**Section A.8** is titled, "Calibration of Thermal Manikin" and describes a procedure for comparing a lab's measured insulation values on eight bags to "standard" values and using linear regression analysis to develop an adjustment or correlation factor to apply to the measured values if they are more than 5% from the standard ones. Little information is given on how to do this in A.8, but more information is given in **Annex B**. A description of the calibration bags and their "ideal" insulation values are not given in the standard anywhere. Annex B simply states that the standard values were measured at the Hohenstein Institute. Both A.8 and Annex B are poorly written and unclear, yet this is the most important part of the standard since so many variables (manikin skin temperature, air velocity, relative humidity, etc.) are allowed to vary in the method to accommodate different laboratories. In addition, the original set of reference bags have worn out and are no longer available (Kuklane, 2009).

**Recommendations for A.4.1, A.6, and A.8.** A weight range should be given for the manikin. At a minimum, Annex B should be referred to in section A.8 or Annex A and B should be combined. New bags should be obtained for a new interlaboratory study, and all labs currently using the standard should be invited to participate.

## Serial vs. Parallel Calculation of Insulation

**Section A.3** specifies a serial calculation of the insulation for a sleeping bag system where the individual resistances for each body segment are calculated and then summed. The model predictions of the temperature ratings were developed and validated using this calculation. However, numerous laboratories use the parallel calculation where all heat losses, temperatures (area-weighted), and areas are summed before the total resistance is calculated. Studies have shown that serial calculations of clothing and sleeping bag insulation result in higher insulation values and more variability between labs than parallel calculations do (Kuklane, 2009; Nilsson, 1997; McCullough et al., 2002). In addition, the EN models were also validated by a study using 60 subjects, five temperature levels, and three sleeping bag system insulation levels measured using the parallel calculation (McCullough, Huang, & Jones, 2005).

**Recommendation for A.3.** The standard should specify the parallel calculation of insulation in addition to the serial calculation and explain that serial values may result in higher insulation values. This approach was taken in a manikin standard for clothing – EN ISO 15831 (CEN, 2003).

## EN 13537 Temperature Predictions

The EN predictive models described in section **A.7 and Annex C** are steady-state models based on the classic heat balance equation. Dry heat losses from the body are calculated based on the manikin test and evaporative heat losses and respiratory heat losses are estimated. The models in the standard do not allow any heat debt like some other models do. Instead, the limit temperature is based on assumptions related to a physically fit male which result in a higher metabolic rate and lower predicted temperature. The comfort temperature is based on assumptions for a smaller woman with a lower metabolic rate (and higher temperature for comfort). Extreme temperatures and maximum temperatures are also given.

**Recommendations for A.7 and Annex C.** The maximum temperature rating should be removed from the standard. It is already optional in the method. If consumers get too hot in a bag, they can simply open the bag and stick different body parts out to provide cooling. The extreme temperature is really not necessary, and it adds complexity to the label. These temperature ratings are not really needed by consumers at the point of sale. The range of utility given by the comfort temperature and limit temperature is the most important information generated by the standard.

## Variability in Manikin Data and Resulting Temperature Predictions

**Section A.9** states that the reproducibility between the three original labs that tested the eight bags was 5%. It is unclear if this means that the insulation values measured for the eight bags were all within 5% of the mean or within ±5% (i.e., a range of 10%). Either way, this amount of variability is relatively low. The original labs tested the same exact bags, however, so product variability was not taken into account.

Some manufacturers feel that the variability among labs that are currently performing this test is higher than ±5% and unacceptable. The issue of variability is a complex one, and the standard cannot be blamed for all of it. Variability in the measured insulation value can be due to:

- **Product variability**. Manufacturers generally send only one sample for testing. Due to variations in materials and bag construction, each bag style has a normal range of insulation values associated with it.

- **Manikin test variability – internal repeatability.** Most labs have set up internal procedures to ensure consistency in their manikin measurements. The environmental chamber, the manikin, and the operator who dresses the manikin and runs the test all contribute to this variability.

- **Manikin variability – inter-laboratory reproducibility.** The calibration procedure in the EN standard was designed to minimize inter-lab variability, but this variability may be higher than expected. Revising the standard would help lower this variability.

The EN standard generates a specific range of comfort and limit temperatures from the insulation value measured in the manikin test. This range of utility is supposed to be a guideline for consumers to use at the point of sale. However, the precise prediction of the comfort and limit temperatures is causing problems for manufacturers when the insulation values on which they are based vary from lab to lab. The standard indicates that the variability associated with the manikin test results should be within ± 5% if labs that are outside that range apply an adjustment factor to their data. An example of ± 5% variability in clo values on the predicted comfort and limit temperatures is shown below. A ± 5% variability in insulation can yield almost a 10°F (or 5°C) difference in the limit temperature predictions for a 7.0 clo bag system. Since many manufacturers are focusing on the temperature ratings that are put on the bag labels, they may be thinking that the inter-lab variability is higher than it actually is – particularly in degrees Fahrenheit.

- 5% Lower insulation of 6.65 clo: Range of utility = 0°C to -5°C or 32°F to 23°F
- Average insulation of 7.0 clo: Range of utility = -1°C to -7°C or 30°F to 19°F
- 5% Higher insulation of 7.35 clo: Range of utility = -3°C to -10°C or 27°F to 14°F

This example indicates that even if the inter-lab variability in manikin results is within the ideal ±5% range, the affect on the resulting temperature predictions is unacceptable to manufacturers. It has become difficult for companies to manage the changes in temperature ratings on product labels and in technical literature from year to year that are due to sample variance and laboratory test variance – and not necessarily due to a minor change in bag design or materials. The constant changes in labeling and re-testing increase costs for manufacturers.

**Recommendations for A.9.** We would recommend using an approach similar to the one given in ASTM E 691 (ASTM, 2009) for conducting a new inter-laboratory study. If at least six labs test the same types of bags, the tolerances associated with the test method can be determined. Specifically, the following steps should be followed:

1. Procedures that are more detailed than the ones given in the standard should be developed prior to running an inter-laboratory study. (See suggestions in this paper.)
2. A specific set of clothing and a pad should be selected and made available to all labs.
3. All labs wanting to conduct EN 13537 should be given the opportunity to participate in the inter-laboratory study. A set of 3-5 bags should be selected to test. The range of possible insulation values should be represented by the bags and both synthetic and down mummy bags should be included. Each lab should receive their own set of bags. Note: Manufacturers would probably donate the bags in exchange for the data.
4. The average insulation values from each lab and the overall average from all labs should be reported (without identifying labs by name). The internal repeatability statistic and the inter-laboratory reproducibility statistic should be calculated for each bag's set of data.

5. The data should be shared with the labs and with the committee in charge of revising the standard.
6. A new precision and bias statement should be developed for the standard, and other changes made as needed.

Once the true variability of the standard is known (without using adjustment factors), the CEN committee could consider whether the establishment of broad temperature ranges that bags would be classified into based on their manikin test result would be a better approach to take. In other words, instead of predicting a precise temperature range for each bag based on its insulation test, they could set up five standard temperature ranges that bags could be classified into based on their insulation value. Procedures for handling "borderline cases" could be developed as well, considering the tolerance associated with the method.

## Summary

The European outdoor industry should be commended for developing a standard for determining temperature ratings of sleeping bags from manikin generated insulation values and heat loss models. Although there are some problems with the EN standard, it is a comprehensive document that is based on sound science, and the prediction results have been validated on human subjects. The standard could be greatly improved if the auxiliary products used in the manikin test were specified and easily available to test labs and if test procedures were more clearly specified. In addition, the variability associated with sleeping bags, the manikin test, and different labs is not clearly documented the standard. Therefore, a new inter-laboratory study should be conducted so that the tolerances associated with the manikin test and resulting temperature ratings can be determined.

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Table 1

*Synthetic mummy sleeping bags: the effect of pads and clothing on the insulation of sleeping bag systems*

| | Total insulation of bag systems worn without clothing (clo) | | | | |
|---|---|---|---|---|---|
| | 3 clo bag | 4 clo bag | 5 clo bag | 6 clo bag | 7 clo bag |
| No pad | 3.1 | 4.1 | 5.0 | 5.9 | 6.9 |
| 0.5 in. pad | 4.2 | 5.2 | 6.2 | 6.9 | 7.4 |
| 1.0 in. pad | 4.7 | 5.8 | 7.0 | 7.3 | 8.5 |
| 1.5 in. pad | 5.1 | 6.2 | 7.3 | 7.8 | 8.8 |
| 2.0 in. pad | 5.2 | 6.6 | 7.6 | 7.9 | 9.0 |
| 2.5 in. pad | 5.2 | 6.7 | 7.7 | 8.3 | 9.2 |
| | Total insulation of bag systems worn with long underwear and socks (clo)[a] | | | | |
| | 3 clo bag | 4 clo bag | 5 clo bag | 6 clo bag | 7 clo bag |
| No pad | 3.4 | 4.4 | 5.2 | 6.0 | 7.2 |
| 0.5 in. pad | 4.5 | 5.6 | 6.5 | 6.8 | 7.8 |
| 1.0 in. pad | 5.0 | 6.2 | 6.9 | 7.5 | 8.6 |
| 1.5 in. pad | 5.2 | 6.5 | 7.4 | 7.8 | 8.9 |
| 2.0 in. pad | 5.3 | 6.9 | 7.8 | 8.0 | 9.2 |
| 2.5 in. pad | 5.3 | 7.0 | 7.9 | 8.2 | 9.4 |
| | Total insulation of bag systems worn with fleece clothing and socks (clo)[b] | | | | |
| | 3 clo bag | 4 clo bag | 5 clo bag | 6 clo bag | 7 clo bag |
| No pad | 4.3 | 5.2 | 6.0 | 6.9 | 8.1 |
| 0.5 in. pad | 5.3 | 6.3 | 7.3 | 7.9 | 8.7 |
| 1.0 in. pad | 5.9 | 6.9 | 7.8 | 8.3 | 9.3 |
| 1.5 in. pad | 6.2 | 7.4 | 8.5 | 8.8 | 9.6 |
| 2.0 in. pad | 6.4 | 7.6 | 8.8 | 9.1 | 9.9 |
| 2.5 in. pad | 6.5 | 7.8 | 8.9 | 9.4 | 10.2 |

[a] Intrinsic insulation for the thermal underwear shirt, pants, and socks was 0.43 clo.
[b] Intrinsic insulation for the thermal fleece shirt, pants, and socks was 1.13 clo.

Source: McCullough, Zuo, & Huang, 2009.

Table 2

*Down mummy sleeping bags: the effect of pads and clothing on the insulation of sleeping bag systems*

| | Total insulation of bag systems worn without clothing (clo) | | |
|---|---|---|---|
| | Low clo bag[a] | Medium clo bag[a] | High clo bag[a] |
| No pad | 3.6 | 5.0 | 6.3 |
| 0.5 in. pad | 5.2 | 6.6 | 7.9 |
| 1.0 in. pad | 6.3 | 8.2 | 9.1 |
| 1.5 in. pad | 6.8 | 9.0 | 9.9 |
| 2.0 in. pad | 7.0 | 9.5 | 10.6 |
| 2.5 in. pad | 7.2 | 10.1 | 11.2 |
| | Total insulation of bag systems worn with long underwear and socks (clo)[b] | | |
| | Low clo bag | Medium clo bag | High clo bag |
| No pad | 3.9 | 5.1 | 6.6 |
| 0.5 in. pad | 5.6 | 6.8 | 8.1 |
| 1.0 in. pad | 6.6 | 8.1 | 9.3 |
| 1.5 in. pad | 7.3 | 9.1 | 10.4 |
| 2.0 in. pad | 7.5 | 9.7 | 10.8 |
| 2.5 in. pad | 7.8 | 10.1 | 11.2 |
| | Total insulation of bag systems worn with fleece clothing and socks (clo)[c] | | |
| | Low clo bag | Medium clo bag | High clo bag |
| No pad | 5.1 | 6.5 | 7.8 |
| 0.5 in. pad | 6.5 | 8.4 | 9.3 |
| 1.0 in. pad | 7.2 | 9.4 | 10.0 |
| 1.5 in. pad | 7.5 | 10.1 | 10.7 |
| 2.0 in. pad | 8.1 | 11.0 | 11.6 |
| 2.5 in. pad | 8.4 | 11.1 | 12.4 |

[a] Insulation values for the bags alone are given in the first row of data beside “no pad” and under “without clothing”.

[b] Intrinsic insulation for the thermal underwear shirt, pants, and socks was 0.43 clo.

[c] Intrinsic insulation for the thermal fleece shirt, pants, and socks was 1.13 clo.

Source: McCullough, Zuo, & Huang, 2009.