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Determining temperature ratings for children's sleeping bags

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A B S T R A C T

Manufacturers label their sleeping bags with a temperature rating to assist consumers in selecting a bag that will provide them with an acceptable level of thermal protection under the expected conditions of use. These temperature ratings are typically based on thermal manikin testing and whole-body heat loss models. Due to physical and physiological differences between children and adults, existing adult sleeping bag temperature rating models cannot be applied to children's bags. Therefore, a model for determining the temperature ratings of children's sleeping bags is proposed. Issues related to measuring the thermal insulation of children's sleeping bags are also discussed. The results of the model indicate that an older child has a higher temperature rating than a younger child for the same level of insulation. This is due to the higher sleeping metabolic rate of younger children.

1. Introduction

Manufacturers label their adult sleeping bags with a temperature rating to help consumers select a bag that will provide them with an acceptable level of thermal protection under the expected conditions of use. These temperature ratings are normally determined by first using a thermal manikin to measure the insulation provided by the sleeping bag when used with auxiliary products (e.g., pad, clothing). The measured insulation value is then used in a whole-body heat loss model to predict the environmental temperature for comfort. Several adult temperature rating models for sleeping bags have been developed and validated (Huang, 2008; McCullough et al., 2005) including the models used in EN 13537, Requirements for Sleeping Bags (2012). However, due to physical and physiological differences between children and adults the existing adult temperature rating models cannot be applied to children's bags.

1.1. Purpose

A body heat loss model based on the physiology of children has already been developed for clothing (McCullough et al., 2009). The purpose of this paper is to modify this model for children's sleeping bags. This is a difficult task because children grow rapidly – changing in physical size and physiology until they reach adulthood. The size of the child's sleeping bag stays the same, so the fit of the child in the bag will vary over time as well. This paper attempts to address some of these issues.

2. Sleeping bag overview

Sleeping bags are used to provide thermal protection for people sleeping outdoors or in a cabin or tent. In addition, children's sleeping bags are used for indoor "slumber parties" and for backyard camping in mild weather. Styles of sleeping bags include mummy, barrel, semi-rectangular, and rectangular. Mummy styles have a hood, but the other styles often do not. The children's market is dominated by lightly insulated rectangular sleeping bags which are often decorated (e.g., with licensed characters, bright colors, etc.) to make them attractive to children. Bags are produced for the adult market in sizes for both men and women. Children's bags are designed to fit the smaller stature of children, and are commonly designated with terms such as "kid", "youth", "junior", "girls", or "boys". The product description usually includes an appropriate age range or a maximum height of the child that will fit the bag. The maximum height for a child-size sleeping bag is typically between 54 inches (1.4 m) and 66 inches (1.7 m). Children's bags are also available in other sizes to target specific markets (e.g., preschool age), although these are less common.

3. Methodology for determining insulation

To determine a temperature rating, the insulation provided by

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the sleeping bag system is first measured using a thermal manikin. For adult sleeping bags, the thermal insulation is measured by testing the bag on an adult-size manikin according to ASTM F 1720 (2016) or EN 13537 (2012). EN 13537 (2012) includes temperature predictions based on adult physiology and explicitly states that it is not applicable to children. Thus, ASTM F 1720 (2016) is the only applicable standard. It specifies the use of a thermal manikin formed in the shape and size of an adult male or female, so modifications to the test method need to be made to test the smaller children's bags. These modifications and associated issues are discussed in section 3.1. Because the insulation value will be used to predict a temperature rating, the sleeping bag should also be tested with appropriate auxiliary products (see section 3.2).

3.1. Manikin size issues

There are two possible approaches to modify the ASTM F 1720 (2016) test method: 1) test the bag on a child-size manikin, or 2) scale the bag to fit an adult-size manikin. Although the thermal manikin testing of clothing and sleeping bags has become widespread over the past several decades, child-size manikins are extremely rare. Thermetrics, a major manufacturer of manikins in the United States, has produced a “size 10” child manikin for AITEX in Spain. They have also produced a smaller “size 8” child manikin for the Institute for Environmental Research at Kansas State University.

Under static manikin testing conditions where there is no body movement, loose garments generally provide more insulation than tight garments due to gaps of still air between the body and garment layers (Chen et al., 2004; Li et al., 2013; McCullough, 1993). Thus, if a bag is too loose or tight fitting on a thermal manikin (i.e., the “wrong size” on the manikin), the results may over- or underestimate the thermal insulation as compared to a bag that fits properly. To avoid these fit issues, if a child-size manikin was not available then a bag style would have to be scaled up to fit an adult-size manikin. Likewise, if a small child bag was to be tested on a large child manikin (or vice versa), the bag would have to be scaled to fit the manikin. This would not be an easy task. The design, materials, and proportions of the bag would have to stay the same as the actual product for sale. The thermal resistance of the external air layer may also be affected by changes in the outer surface area-to-volume ratio of the scaled up sleeping bag and changes to the length of the bag. In addition, the insulation of the sleeping bag itself may be affected by changes in the bag construction when scaling it to fit an adult-size manikin. Even if children's bags are tested on a child-size manikin the fit is going to vary across styles of bags. This is because the sizes are not consistent from manufacturer to manufacturer. This is not a problem with clothing which is produced in numerous sizes (i.e., the proper fit can be achieved).

There are no published studies on the heat transfer implications of scaling children's sleeping bags to fit adult-size manikins. Kuklane et al. (2004) examined the effect of manikin body size by comparing two baby manikins to an adult manikin. For undressed conditions, external air layer insulation measurements were similar for all manikins when contact with surrounding surfaces was minimized. They also placed the nude manikins on an insulating surface, but these results were affected by the fact that the baby manikins had rigid body parts that prevented the arms and legs from touching the surface, whereas the adult manikin had arms and legs in contact with the surface. Kuklane et al. (2004) concluded that there were no significant differences between manikins of different sizes for undressed conditions. A comparison of clothed manikins of different sizes was not included in the study. Fukazawa et al. (2009) compared the convective heat transfer coefficients for an adult female shaped thermal manikin and a 6 month-old size baby shaped thermal manikin that were in a standing posture and facing the air stream. Both manikins were unclothed, but the adult female manikin wore a wig whereas the baby was bald. The convective heat transfer coefficient of the whole body was found to be about 1.6 times greater for the baby as compared to the adult.

Measuring insulation of sleeping bag systems on a thermal manikin should yield accurate and repeatable results. Further research is needed to determine the effects of testing one size of bag on assorted sizes of manikins, as well as scaling bags to fit different sizes of manikins. Due to these sizing issues, children's bags should be tested on a child-size manikin, and the height of the manikin should be within the height range given by the manufacturer in the product literature.

3.2. Auxiliary products

According to ASTM F1720 (2016), thermal manikin tests may be conducted on a sleeping bag by itself (option #1) or in combination with auxiliary products (option #2). Because the insulation value is being used to determine a temperature rating, it is recommended that the sleeping bag be tested with auxiliary products such as clothing and a ground pad. This is more representative of actual use conditions. For example, EN 13537 (2012) specifies that thermal underwear, socks, and a ground pad are used with the sleeping bag during the manikin test. Environmental conditions vary widely from winter to summer and from outdoor to indoor use, and one set of garments may not be a logical solution for all conditions. For instance, if a children's bag is designed for “slumber party” use, lightweight sleepwear may be more appropriate than thermal underwear. The intended end use of the sleeping bag should be taken into consideration when selecting auxiliary products.

4. Heat transfer model for determining the temperature rating

After the thermal insulation of a sleeping bag system has been measured using a thermal manikin, the result can be used to calculate the temperature rating. The temperature rating is an estimate of the environmental temperature at which a person can remain thermally neutral in a sleeping bag or sleeping bag system. Thermal neutrality occurs when the total body heat loss is equivalent to the heat generated by the body (i.e., no heat debt). This can be expressed by a simple heat balance equation (ASHRAE, 2013):

$$Q_{met} = Q_{sk,d} + Q_{sk,e} + Q_{res,d} + Q_{res,e} \tag{1}$$

where

Q_{met} = the body metabolic energy generation per unit surface area (W/m^2)
$Q_{sk,d}$ = dry heat transfer from the body (W/m^2)
$Q_{sk,e}$ = evaporative heat transfer from the body (W/m^2)
$Q_{res,d}$ = the dry energy loss due to breathing (W/m^2)
$Q_{res,e}$ = the evaporative loss due to breathing (W/m^2)

Due to their physical and physiological nature, children differ from adults in their response to thermal stress. These responses include changes in body temperature, metabolic rate, circulation, hormones, sweat rate, sweat composition, and fluid regulation. These differences have already been examined and summarized in a chart by McCullough et al. (2009). Additionally, Falk (1998) has published a review of the effects of thermal stress in the pediatric population. The physical and physiological differences between children and adults that should be accounted for in heat loss

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