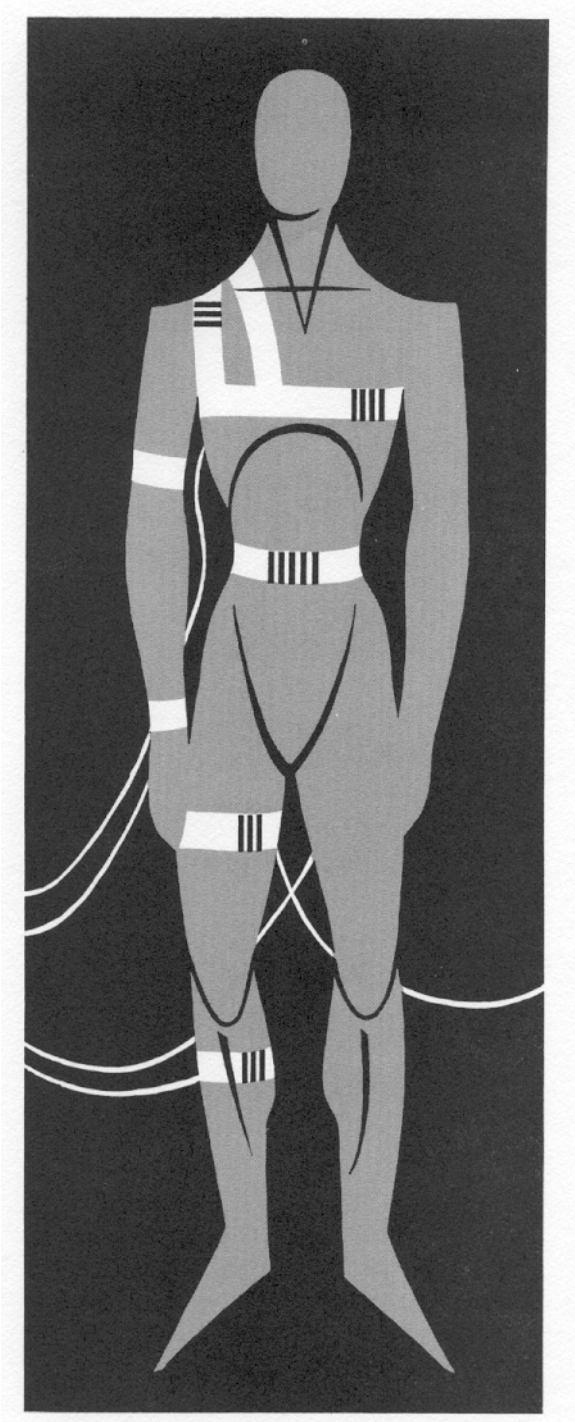

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A Report on

Evaluation of the Thermal Comfort Properties of a Comforter Used in Different Ways

submitted to

American Quality Assurance Corp.

by

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May 2005

Technical Report #05-57

The purpose of this project was to evaluate the thermal performance of a comforter designed to provide more insulation when one side is facing the body and less insulation when the other side is facing the body. The insulation values of the comforter were measured with a life-size heated manikin lying on a bed in an environmental chamber. Comfort ranges were predicted using the equations in EN 13537, Requirements for Sleeping Bags (CEN, 2002).

Methodology

Apparatus

The thermal insulation (clo) value of a bedding system is measured using an electrically-heated manikin in thermal equilibrium with its surroundings. The manikin at Kansas State University consists of a black anodized copper skin formed to simulate the physical shape and size of a typical man (i.e., 1.8 m^2 surface area, 176 cm height, and 41 kg weight). Heating wires are bonded to the inside surface of the copper skin to provide internal heating distributed so as to simulate the skin temperature distribution of a human. This type of manikin consists of two circuits – one for heating the hands and feet and one for heating the rest of the body. The skin temperature of the manikin is measured using 16 thermistors located on different parts of the body. The power cables and thermistor wires go from his body cavity through the left side of his neck to the control and measurement equipment. The entire system is computer operated.

Manikin Procedures

The thermal insulation value was measured according to the basic procedures given in EN 13537 (CEN, 2002). However, instead of using the set up for sleeping bags (i.e., a ground pad, thermal underwear and socks, etc.), a twin size mattress and box springs were placed in the chamber and covered with a cotton percale bottom sheet. A pillow with a cotton percale pillow case was put at the head of the bed. The nude manikin was placed on his side on top of the mattress and then covered with the comforter.

The environmental conditions in the chamber were controlled as follows:

- ambient air temperature, 10ºC (50ºF)
- air velocity, 0.2 m/s (50-60 ft./min.)
- relative humidity, no specified level but the dew point temperature was controlled to 1ºC
- manikin surface temperature, 33ºC (91ºF)

The air temperature was measured continuously with four thermistors placed at the same height as the horizontal manikin, 0.3 m (1 ft.) from the bag. The dew point temperature was measured continuously with a sensor in the same location in the chamber. The fan speed in the chamber was set at a specified level, and the air velocity was measured periodically using an anemometer.

To conduct a test, the comforter was fluffed and placed on the manikin and either drawn up to the ear (i.e., full coverage) or drawn up to the arm pit with one arm allowed to hang out (i.e., partial coverage). Both sides of the comforter were tested. (See Figures 1-4 at the end of the report.) Equilibrium was maintained for at least 2 hours prior to testing. Equilibrium was indicated by a steady-state power reading that had not changed more than 2%. Data were collected every 30 seconds for 30 minutes for the test.

The total thermal insulation value (I_t) of the bedding system – comforter, bed, pillow – plus the surrounding air layer was calculated using the following equation:

$$I_t = \frac{K(T_s - T_a)A_s}{H} \qquad (1)$$

where

I_t = total thermal insulation of the bedding system plus the air layer, clo

K = units constant = 6.45 clo·W/m²·ºC

T_s = mean skin temperature, ºC

T_a = ambient air temperature, ºC

A_s = manikin surface area, m²

H = power input, W

The insulation value of the bedding system in each use configuration was reported as the average of three replications of the test made on one comforter sample.

Clo Units

The standard requires reporting the results in SI units of m^2·ºC/W. However, the clo unit is often used to express the insulation of a textile system. Gagge et al. (1941) defined the value for 1 clo by first considering that the resting metabolic heat production of an average man is about 50 kcal/m²·h. Approximately 25% of this heat is lost via the respiratory system and by diffusion of moisture through the skin. Therefore, 38 kcal/m²·h remains to be lost through the

clothing via radiation, conduction, and convection (Hollies and Goldman, 1977). The temperature difference across the clothing is equal to the difference between the mean skin temperature (T_s) and the ambient air temperature (T_a), assuming the mean radiant temperature of the surroundings is equal to the air temperature. Consequently, a clothed person with a comfortable skin temperature of 33.3ºC (92ºF) in a comfortable environment at 21ºC (70ºF), has a 12ºC temperature gradient across which 38 kcal/m²·h is transferred. A heat transfer coefficient of 0.32ºC·m²·h/kcal is calculated by dividing the temperature difference by the heat flow (i.e., 12/38) (Hollies and Goldman, 1977). About 0.14 of the 0.32 total is contributed by the surrounding air layer, so 0.18 is contributed by the clothing alone. Thus, 1 clo of insulation is equal to 0.18 $m^{2.o}C{\cdot}h/kcal$. A thick business suit ensemble provides an average of approximately 1 clo of intrinsic insulation for the whole body (not including the air layer resistance which is included in the total insulation values measured for sleeping bags and bedding systems).

Temperature Predictions

In section 3, the standard defines four temperatures that designate the range of utility for a sleeping bag system (CEN, 2002). Only three temperatures are applicable for a comforter system used indoors.

Comfort temperature (T_{comf}): Lower limit the comfort range down to which a sleeping bag user with a relaxed posture such as lying on the back is globally in thermal equilibrium and not feeling cold (related to standard woman and in standard conditions of use).

Limit temperature (T_{lim}): lower limit at which a sleeping bag user with a rolled-up body posture is globally in thermal equilibrium and not feeling cold (related to standard man and in standard conditions of use).

Maximum temperature (T_{max}): Upper limit of comfort range; the temperature up to which a partially uncovered sleeping bag user (standard man) does not perspire too much.

Section A.7 and Annex C of EN 13537 (CEN, 2002) provide data tables and equations for predicting the temperatures defined above. The linear regression equations derived from the data in the standard are given for insulation values in clo units as follows:

$(T_{comf}) = 32.24 – (4.80 \times I_t)$

$(T_{lim}): = 31.81 – (5.60 \times I_t)$

$(T_{max}): = 38.38 – (5.66 \times I_t)$

Results

The thermal insulation values and temperature predictions for the comforter bedding systems are given in Table 1. The normal comfort range for this comforter is between 22°C and 27°C, depending upon how it is worn. The maximum temperature for use with the shoulders and one arm sticking out would be 33°C. Of course, more body parts could be exposed, and the upper limit would increase. All of these values will change slightly with changes in body position and movement during the night.

Table 1

Thermal Insulation Data and Temperature Ratings for Comforter Systems

Bedding System Configuration	Insulation Value ($m^2 \cdot °C/W$)	Insulation Value (clo)	EN 13537 Temperature Ratings		
			T comfort	T limit	T max
1. Winter configuration with comforter pulled up to the ear	0.279	1.8	24°C 75.2°F	22°C 71.6°F	28°C 82.4°F
2. Summer configuration with comforter pulled up to the ear	0.217	1.4	26°C 78.8°F	24°C 75.2°F	30°C 86.0°F
3. Summer configuration with comforter pulled up to the arm pit and arm hanging out	0.155	1.0	27°C 80.6°F	26°C 78.8°F	33°C 91.4°F

References

European Committee for Standardization. EN 13537, Requirements for Sleeping Bags. Brussels: CEN, July 2002.

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Gagge, A.P., Burton, A.C., Bazett, H.C. "A Practical System of Units for the Description of Heat Exchange of Man with his Environment," Science, Vol. 94, 1941, pp. 428-430.

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Figure 1. Nude manikin on mattress in environmental chamber.

Figure 2. Winter configuration with comforter pulled up to the ear.

Figure 3. Summer configuration with comforter pulled up to the ear.

Figure 4. Summer configuration with comforter pulled up to the arm pit and arm hanging out.