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# FACTORS INFLUENCING THE EVALUATION OF BED THERMAL ENVIRONMENT

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## SUMMARY

Bed thermal environment is important for sleep quality. Quilts with different thermal insulation are used for its control. Thermal manikins are used to evaluate the bed thermal environment, in particular, the thermal insulation of quilts. In this paper the importance of several factors, including reproducibility of tests, design of mattress, tightness between manikin and quilt and placement of the quilts, on the accuracy of the evaluation is presented. The importance of these factors was studied experimentally. The results show that heat loss from the thermal manikin and the air temperature in the bed micro environment, i.e. the gaps between the manikin, the mattress and the quilt are strongly influenced by the factors. Large discrepancies may occur if the influence is not considered. Recommendations for proper design and performance of experiments leading to reliable evaluation of bed thermal environment are outlined. The results of this study are important for: 1) efficient control of bed thermal microenvironment; 2) optimal design of quilts and 3) design and control of room thermal environment for better comfort of occupants and minimal energy use.

**Keywords:** bed micro-environment, control, quilts, thermal insulation, evaluation, thermal manikin

## 1 INTRODUCTION

Bed thermal environment is important for sleep quality of people. Quilts with different thermal insulation are used for its control. Thermal manikins are used to evaluate the bed thermal environment, including the thermal insulation of quilts.

There are several standards and guidelines for testing thermal insulation of fabrics under steady state conditions. However, there is no specific standard for determination of thermal insulation of quilts. For this purpose, the standard that can be used is the ASTM F1720-14 “Standard Test Method for Measuring Thermal Insulation of Sleeping Bags Using a Heated Manikin” (2006).

According to the requirements in the standards the thermal manikin should have the shape and size of an adult male or female, which is capable of being heated to a constant average surface temperature of 35 °C. The manikin’s height should be between 1.5 and 1.9 m with a surface area between 1.5 and 2.1 m<sup>2</sup>. The manikin shall be placed in a climate chamber at least 1.5 m by 1.5 m by 2.5 m in dimension that can provide uniform conditions, both spatially and temporally (ASTM F1720 2006, ASTM F1291 2004).

Unlike sleeping bags quilts are placed looser around manikin’s body allowing layers/gaps of air to exist between the quilt and the body. The formation and size of the layers/gaps is difficult to control. This will increase the uncertainty in determination of the bed micro-environment and the thermal insulation of quilts. Several other factors, including reproducibility of tests, design of mattress, tightness between manikin and quilt and placement of the quilts, may influence the accuracy of the determination. The importance of these factors was studied experimentally. The most important findings are presented in this paper. Recommendations how to minimize the impact of the factors on the accuracy of determination of bed micro-environment and characteristics of quilts are outlined.

## 2 METHODS

### 2.1 Experimental set-up

Experiments were conducted in a climatic chamber (6.0 m × 4.7 m × 2.5 m, L × W × H). The chamber is ventilated by an upward piston airflow supplied from the entire floor area with an air velocity of less than 0.05 m/s. The upward piston flow of outdoor air ensures uniform air temperature and air velocity distribution in the chamber. The air is exhausted through openings on the ceiling. No recirculation of the air is used. The chamber is constructed to ensure a mean radiant temperature equal to the room air temperature and negligible radiant temperature asymmetry. The air velocity all over the chamber is lower than 0.1 m/s.

A non-sweating thermal manikin with a realistic female body shape (size 38, 1.68 m height) was used to simulate the dry heat loss from the body of an average person lying in bed (Figure 1). The body of the manikin has 23 segments, each with individually controlled heat output. Three control modes can be applied: a) the surface temperature of each body can be kept constant; b) the heat flux from each body (or the whole body) can be kept constant and 3) the surface temperature of the body can be kept as the skin temperature of an average person in state of comfort. During the present study, the surface temperature was kept constant at 35 °C for all body segments except feet and hands, which were kept at 32 °C. The heat loss from the body segments and the whole body was measured.



*Figure 1: The climate chamber with the manikin*

The thermal micro-environment established in the bed when the manikin was covered with a quilt was also measured. Air temperature and relative humidity were measured in the air gaps between the quilt and the body of the manikin. The locations of the measurements are shown in Figure 2. These were: the air gaps between left and right arms and the body of the manikin (referred as “left” and “right” in Figure 2) and two locations between the legs of the manikin (named as “thigh” and “ankles” in Figure 2). At each location air temperature sensors were placed on a small stand. The height of the right and left stands was 18.6 cm. The height of the stands between the thighs and the feet were 22.4 cm and 16.0 cm respectively. Three temperature sensors and one humidity sensor were attached on each stand. Temperatures was measured at the top, middle, and bottom of the stand identified in the following figures as “t”, “m” and “b”. Humidity sensor was attached in the middle of each stand. The top temperature sensors were aimed to be in contact with the inner surface of the quilt.

Platinum resistance temperature sensors (class A, accuracy 0.2 °C) were used. Agilent data logger 34972A was used for data acquisition. Temperature sensors and manikins were calibrated before the experiments. Humidity was measured by Sensirion digital humidity sensors SHT31 (accuracy ±2%; measuring interval 1 second).

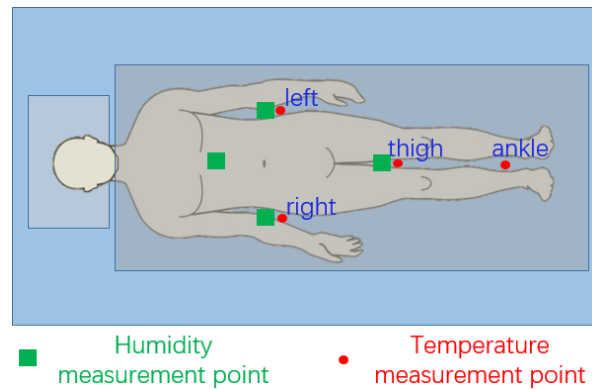


Figure 2: The location in the micro-environment around the manikin where air temperature and humidity were measured.

## 2.2 Factors affecting accuracy of obtained results

The accuracy of determination of bed thermal environment and thermal insulation provided by quilts depends on numerous factors. Some of the factors are personal and some environmental. In real life the posture of the person in bed, the part of the body covered by the quilt, material of the case the quilt is placed in, type of the bed mattress, etc. are some of the personal factors. It is difficult to account for such factors when defining the bed thermal environment and labelling the thermal insulation of a quilt. However, under laboratory conditions, when thermal manikin is used to resemble human body, the number of the influencing factors can be reduced and the importance of the following factors can be determined under well-defined conditions: repeatability of the experiment, effect of bed mattress, tightness between manikin's body and the quilt and the placement of the quilt.

Repeated measurements at the same conditions (at least 5 repetitions) were performed to define the test conditions that would ensure minimum uncertainty in determination of bed thermal environment and thermal insulation of quilts. A quilt with (600 g, 90% Muscovy down) was employed. The experiments were performed at 20 °C air temperature in the chamber.

## 2.2 Data analyses

The average value, the standard deviation and uncertainty of heat loss from the manikin and temperatures measured by the sensors attached to the stands were calculated based on the repeated measurements.

## 3 RESULTS AND DISCUSSION

Tests were conducted with manikin lying on a hard plate and on a mattress. The hard plate was a polyfoam plate 5 mm thick (Figure 1). In the case with mattress larger surface area of the manikin's body was in contact with the mattress compare to the case without mattress. As already stated the tests were repeated five times under the same condition. The quilt was removed from the manikin after each test. After 3 min it was put back over the manikin and the next test started.

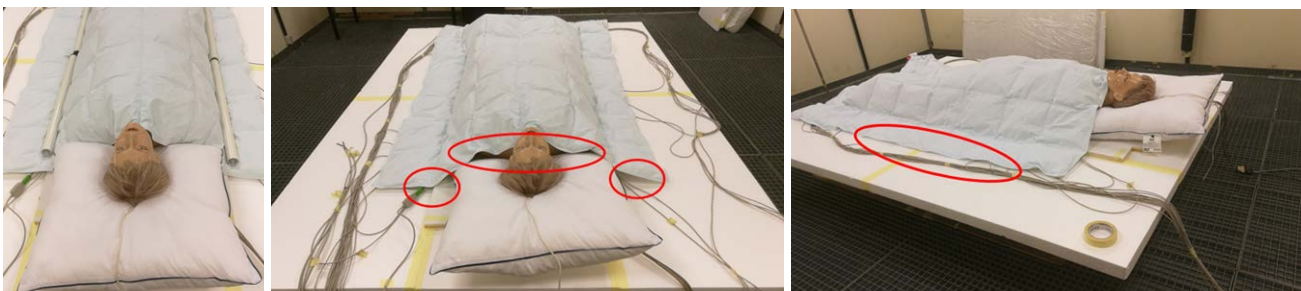
The temperature distribution in the bed micro-environment increased slightly when the mattress was employed. The average temperature of all the measuring points was 30.7 °C without the mattress and 30.9 °C with the mattress. On the contrary, the heat loss of the manikin decreased when the mattress was used (not the body segments exposed to the room environment). The heat loss of the manikin's

back decreased from  $22.8 \text{ W/m}^2$  to  $10.8 \text{ W/m}^2$ . The average heat loss of all segments decreased from  $28.1 \text{ W/m}^2$  to  $25.8 \text{ W/m}^2$ .

Based on the repeated measurements the standard deviation and the random uncertainty of the temperatures measured on the stands and the heat loss from the manikin's body segments was determined. The use of the mattress reduced the standard deviation and the random uncertainty. Without mattress the highest uncertainty in the measured temperature was  $0.41 \text{ }^\circ\text{C}$  and with mattress  $0.18 \text{ }^\circ\text{C}$ . The uncertainty of the heat loss from the individual segments was less than 5%. The average uncertainty for all segments" was 3% without the mattress and 1% with the mattress.

Quilts consist of several small sections (e.g.  $6 \times 8$  for the quilt used in this experiment). The quilt's characteristics will be different if the fillings of the sections with down are different. This effect was studied by placing the quilt in reverse position, i.e. one of the short sides first placed near the heat and then rotated to be near the feet. The difference in the measured temperature and heat loss caused by the placement of the quilt was rather small: the average temperatures in the two conditions was respectively  $30.9 \text{ }^\circ\text{C}$  and  $31.1 \text{ }^\circ\text{C}$  and the heat loss  $25.8 \text{ W/m}^2$  and  $26.0 \text{ W/m}^2$ . The conclusion is that the filling of the quilt was uniform.

The tightness between the manikin and the quilt affects the contact area, the air cavity (gap) volume between the quilt and the manikin and the infiltration between the bed micro-environment and the room environment. Three levels of tightness were considered in the test: (1) quilt tighten by heavy metal sticks (Figure 3 left), named as tighten-sticks; (2) quilt tighten by hands, i.e. press the edge of quilt by hands (Figure 3 middle), named as tighten-hands; (3) Loose shape quilt, i.e. do nothing (Figure 3 right), named as no-tightness.



*Figure 3. Quilt tightened around manikin by heavy metal sticks (left), hands (middle), left loose (right). The possible locations where infiltration between the bed micro-environment and the surrounding room environment are indicated.*

The temperature in the bed micro-environment and heat loss from the manikin depended on how tight the quilts was placed on the manikin. The temperature in the micro-environment was highest when the metal sticks were used (in average  $30.9 \text{ }^\circ\text{C}$ ), followed in the case when it was tightened by hands ( in average  $30.9 \text{ }^\circ\text{C}$ ) and the condition no-tightness (in average  $30.2 \text{ }^\circ\text{C}$ ). Comparison of the results is shown in Figure 4. Comparison of the heat loss from the manikin for the three conditions is shown in Figure 5. The average heat loss of all segments for the three conditions was  $25.8 \text{ W/m}^2$ ,  $26.3 \text{ W/m}^2$ , and  $30.4 \text{ W/m}^2$  respectively. Considering the uncertainty of the measurements it can be concluded that there was not difference in the measurements with metal sticks and tighten by hands. However, the temperature measured in the case of loos quilt was up to 15% different. The shape of the quilt under loose (no-tightness) condition allowed for infiltration of air, which was difficult to control. Because of this effect the difference in the heat loss between the left and right segments of manikin's body was  $0.2 \text{ W/m}^2$  and  $0.6 \text{ W/m}^2$  respectively.

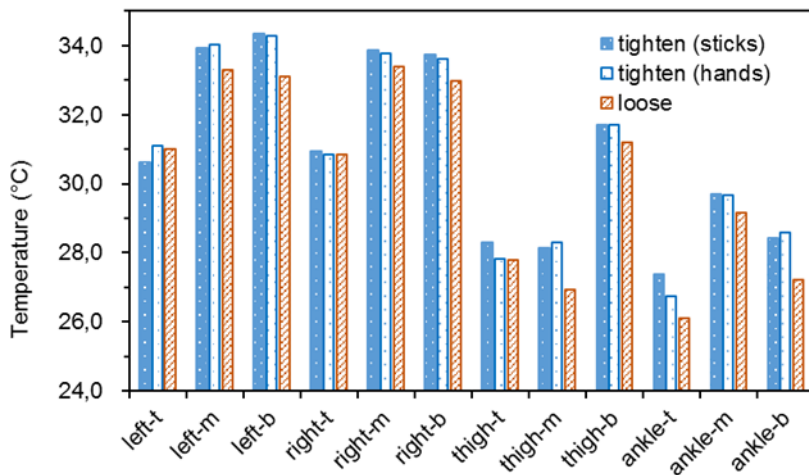


Figure 4. Air temperature measured in the bed micro-environment under different tightness between the quilt and the manikin. The abbreviations of the measured locations are defined in section 2.1.

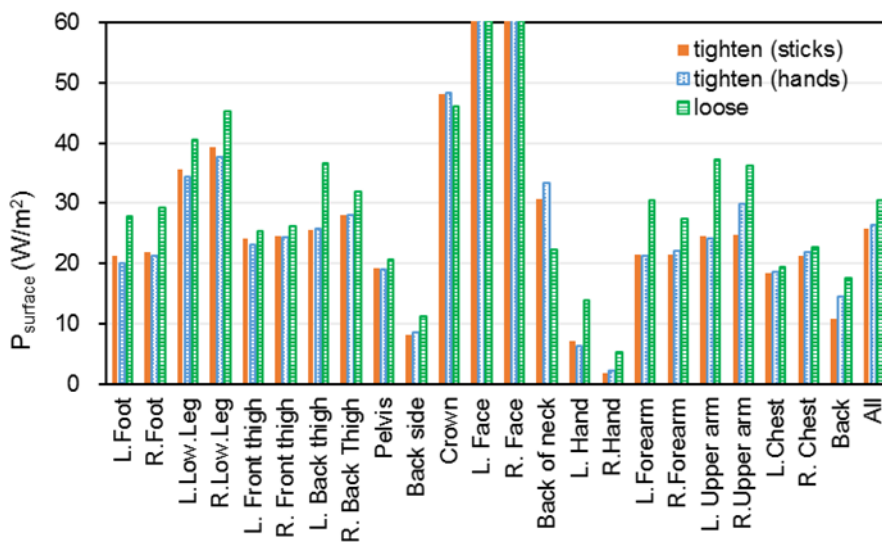


Figure 5. Heat loss ( $P_{surface}$ ) from the manikin under different tightness between the quilt and the manikin. The abbreviations of the measured locations are defined in section 2.1.

The contact area of the quilt with the manikin and with the mattress, the infiltration, the heat loss of manikin all affect the reproducibility of the experiment and thus the accuracy of determination characteristics of quilts. Several measures can be recommended in order to improve the accuracy. First, as mentioned above, adding a mattress is effective. It is recommended that the same mattress is used for tests of different quilts. It is recommended to insulated the mattress from bellow. In this study the mattress was placed on 5 mm thick polyfoam plate (see Figures 1 and 3). The plate should be larger than the mattress. This will help to position the quilt over the manikin without hanging from the sides of the mattress. The second important factor is the infiltration between the bed micro-environment and the surrounding room environment. Several possible locations of the infiltration are possible as shown in Figure 3. These are difficult to control. The infiltrated air affects the repeatability and accuracy of the measurements. The gap near the neck can be sealed as shown in Figure 6. Third

important consideration is the positioning of the feet. Depending on the design of the manikin, the position of the feet can be changed during the experiment when the quilt is placed or removed as shown Figure 6. This will affect the air temperature measurements in the bed micro-environment. Therefore the feet should be kept at the same position during repeated tests. Last but not the least, it is recommended to make some marks on the bed and the quilts in order to make sure that the same side and direction of the quilt are used in tests under different conditions. For the quilt used during the present experiments the filling of sections was the same but this may not be the case for other quilts.



Figure 6. Sealed neckline – left; Position of feet: straight – middle; tilted – right.

#### 4 CONCLUSIONS

Bed micro-environment and characteristics of quilts can be determined experimentally by thermal manikin. The repeatability of the experiments, the heat loss from the thermal manikin and the air temperature in the bed micro environment, i.e. the gaps between the manikin, the mattress and the quilt are strongly influenced by the design of mattress and tightness between the manikin and the quilt. Large discrepancies may occur if this influence is not considered. Recommendations for proper design and performance of experiments leading to reliable evaluation of bed thermal environment are outlined in this paper. The results of this study are important for: 1) efficient control of bed thermal microenvironment; 2) optimal design of quilts and 3) design and control of room thermal environment for better comfort of occupants and minimal energy use.

#### ACKNOWLEDGEMENTS

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