HEAT CONDUCTIVITY AND MOISTURE PERMEABILITY THROUGH THE POCKET SPRING MATTRESS

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Key words

Heat, Moisture, Mattress, Thermal comfort, Thermo-physiology

Abstract

A person with his thermo-physiological characteristics directly influence the mattress by changing his properties and a healthy bed climate. In this paper, the heat conductivity and moisture permeability through the mattress with the pocket spring core during the sleep were studied. Each of four subjects slept for seven nights on the same mattress in their own bedroom. Seven sensors measured the heat and moisture content released by the subject to the mattress and the environmental conditions. The results have shown that during first 180 minutes of lying, the temperature increases on all sensors and starts to decrease after that time. It has been observed that the moisture in most cases increases in the direction from the top layer of mattress towards the centre, and that the moisture above the coconut coir layer does not stay much longer than in the other mattress layers and can be relatively quick to dry out.

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1. INTRODUCTION

In this paper, the heat conductivity and moisture permeability through the mattress with the pocket spring core during the sleep were studied. Each of four subjects slept for seven nights on the same mattress in their own bedroom. Heat and moisture that subjects were released in the mattress and surroundings were measured by seven probes placed between mattress layers and in the bedroom.

The aim of the paper was research on distribution of heat and moisture through the mattress in real conditions, and how long it takes to mattress release accumulated moisture.

Sleep can help people overcome tiredness and is very important to one’s memory. It was commonly acknowledged that the quality of sleep was mainly affected by the mental-physical factors of a sleeping person and the environmental factors in a bedroom (Dongmei et al., 2013). It is well known that human body generates thermal energy all the time. The regulation of a normal physiological skin microclimate is necessary to maintain thermal equilibrium between the heat gained within the body from metabolic processes and heat losses from the skin to the environment (Nicholson et al., 1999; Hänel et al., 1997). In addition to the heat, the human body is constantly excreted moisture through the skin.

Sleep quality depends on materials touching the body, liquid absorption capacity and temperature (Grbac and Dalbelo Bašić, 1994; Grbac and Dalbelo Bašić, 1996). Difficulties in the test of comfort properties arise from the fact that comfort in a bed is a complex phenomenon, consisted of subjective feeling and physical properties of the interface between a mattress and the human body (Lee and Park, 2006).

The humidity at the skin/support interface should ideally be between 40 and 65% RH and the interface temperature should not change by more than a few degrees (Cochran and Palmieri,
1980), while e.g. […] the temperature under the ischial tuberosity varies between 30 °C and body temperature, and […] the heat flux away from the skin may vary during changes of (sitting) posture by anything from -9 to +106 W/m² (according to Nicholson et al., 1999). Hänel et al. (1997) quoted that in a warm climate it is essential for the experience of good comfort that beds and car seats have sufficient capacity of transporting moisture away from the contact area. This capacity is closely connected to the air permeability properties of the upholstery. Their experiment has shown that thermal behaviour of […] bed is mainly governed by the thermal properties of the upper layer, i.e. that which is in contact with the body. Varying the design of the supporting part has not shown any significant effect.

Bed climate plays a significant role in the thermal comfort during sleeping period. The temperature of mean bed climate is recommended as between 30.3 °C and 32.5 °C to satisfy the demand of human thermal comfort during sleep (Song et al., 2015). The dream is greatly influenced by the quality and comfort of the mattress, which can negatively affect the rest, if the user is unwell and feels uncomfortable during lying down (Grbac, 2006).

Okamoto-Mizuno and Mizuno (2012) infers that the most frequent reason healthy people without insomnia woke up from sleep or felt uncomfortable during their usual sleep was that they felt excessively high or low ambient temperature. Sleep thermal comfort is one of the critical factors affecting sleep quality. A comfortable thermal environment is essential for shorter sleep latency and sound sleep duration (Liu, Y., et al., 2014) (quoted in: Shen et al., 2015). The main characteristics of a high-quality mattress are the conductivity of heat and moisture on the surface and through mattress layers, durability and mechanical properties (such as firmness and optimum hardness), and the fulfilment of anthropometric and hygienic requirements (Grbac, 1988; Grbac, 2006).

We become more sensitive to the influences of sleeping environment and bed quality. Diverse types of beds are manufactured today, using vertical or horizontal coil springs, or other materials. It was essential to obtain the most natural sleep environment and reduce external disturbing factors. Therefore, Bader and Engdal (2000) investigated the subjects in their own bedroom and instead of using electrodes fixed on the body they used sensor pads. Following a control of the methodology, they have studied the sleep quality of subjects sleeping in their own beds.

2. METHODS AND MATERIALS

SAMPLE

Sample of mattress (190 × 90 × 18) cm was standard model of one Croatian mattress producer, and for experimental purposes it was labelled with "M1", while surfaces (sides) were labelled with "A" and "B".

Sample "M1" was a mattress with a pocket spring core, layer of rubberised coconut coir (650 g/m², d = 5 mm), layer of polyurethane (PUR) foam (PT 2541, 25 kg/m³, d = 25 mm, 3.4 kPa) and upper fabric layer quilted with polyester (PES 60%) and lyocell (LYC 40%) fibres (250 g/m²), PES wool (300 g/m²) and flizeline (30 g/m²).
SUBJECTS
Four (two female and two male) healthy subjects were participated in experiment. The subjects' details are given in the following table:

Table 4. Anthropometric characteristics of subjects

<table>
<thead>
<tr>
<th>Subjects' code</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>Average (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>26</td>
<td>24</td>
<td>26</td>
<td>19</td>
<td>23.8 (3.3)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170</td>
<td>178</td>
<td>164</td>
<td>184</td>
<td>174.0 (8.8)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>56</td>
<td>74</td>
<td>48</td>
<td>71</td>
<td>62.3 (12.3)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19.38</td>
<td>23.36</td>
<td>17.85</td>
<td>20.97</td>
<td>20.4 (2.4)</td>
</tr>
</tbody>
</table>

Female subjects were coded with P1 and P3, while male subjects with codes P2 and P4. Regarding to BMI it may be concluded that female subjects (P1, P3) were in groups of underweight and normal range, and male subjects (P2, P4) were in group of normal range (according to BMI classification, WHO).

METHODS
A study of heat conductivity and moisture permeability of the mattress with the pocket spring core was carried out for a total of 28 days, from May 23rd to June 22nd, 2016. Subjects was sleeping on a mattress for seven consecutively nights, incorporating probes measuring temperature and relative humidity. Subjects P1 and P2 were slept on "side A" in first two weeks in the same bedroom/house, while subjects P3 and P4 were slept on "side B" in second two weeks in the same bedroom of another house. Prior to the experiment it was determined that subjects should not drink alcohol at least six (6) hours before bedtime, should not rest or lie during the day on the mattress in which the experiment was being conducted, the duvet (or any kind of bedcover) should not be left on the mattress during the day for better ventilation. The subjects wore short-sleeved sleepwear (100% cotton) and slept on a bed covered with a bed sheet (100% cotton) and or without a duvet (cotton cover filled with silicon polyester fibres). The sleepwear covered the trunk, upper arms, and thighs.
Temperature and relative humidity measurements were carried out using seven measuring probes (S-THB-M008) with temperature and humidity sensors in the same housing, and data were collected using the HOBO® Weather Station H21-001 electronic device (Onset Computer Corporation, USA) (Figure 2). Data processing was implemented with MS Office Excel.

Seven measuring probes were set up as follows, assuming that subject is lying on its back:

- Probe 3: on the mattress top layer, below the decorative fabric, approximately underneath the scapula of the subject,
- Probes 2 and 4: approximately 20-25 cm left and right of probe 3,
- Probe 5: underneath probe 3, on a rubberised coconut coir layer, below the top mattress layer,
- Probe 6: underneath probe 5, at the centre of the height of the spring core,
- Probe 7: in the room (on a neutral wall or furniture without the influence of heat or direct sunlight) near the bed and at the level of probe 3. There was also a "Probe 1" located under the duvet but it was not considered in this paper.

**STUDY LIMITATIONS**

We acknowledge that this study has some limitations. First, the subjects slept in their own bedrooms and room conditions, at different temperature conditions, without heating or air conditioning. Outdoor air temperature and relative humidity had an impact on the bedroom climate. It should be taken into consideration that the weather conditions within a month during experiment were changed significantly and that there were colder and warmer days/night(s) with relatively great temperature differences. Second, some subjects were used duvet (previously defined) during the sleep, according to their needs or climatic conditions during night(s).
3. RESULTS AND DISCUSSION

Results are presented below, and due to limited space, only arithmetical means are shown. Complete data can be found in the original paper (Marić, 2016).

The following codes are used to represent data and results: T3/TH3 – temperature/moisture content between upper layer of mattress and decorative fabrics; T2/RH2 and T4/RH4 – temperature/moisture content left and right from T3/RH3; T5/RH5 – temperature/moisture content between rubberised coconut coir layer and upper layer; T6/RH6 – temperature/moisture content in the middle of pocket spring core; and T7/RH7 – temperature/relative humidity in the ambient.

Measuring took place in two bedrooms in two different buildings (houses), for two weeks in each. Mean values of ambient temperature (T7) and ambient relative humidity (RH7) during experiment are shown in Table 2.

Table 5. Mean values of ambient temperature and relative humidity during nights and days of experiment

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7 at night (°C)</td>
<td>23.3</td>
<td>24.3</td>
<td>26.8</td>
<td>27.0</td>
</tr>
<tr>
<td>T7 at day (°C)</td>
<td>23.6</td>
<td>24.0</td>
<td>26.9</td>
<td>26.9</td>
</tr>
<tr>
<td>RH7 at night (%)</td>
<td>66.4</td>
<td>66.4</td>
<td>61.5</td>
<td>56.4</td>
</tr>
<tr>
<td>RH7 at day (%)</td>
<td>63.3</td>
<td>62.5</td>
<td>60.1</td>
<td>53.7</td>
</tr>
</tbody>
</table>

To simplify data obtained from probes 2, 3 and 4, their values were unified. Thus, in the following views, the temperature tags T2-3-4 and the moisture content tags RH2-3-4 refer to the average values of those measured at a given time on probe 2, probe 3 and probe 4. Since probe 3 was in the centre of the mattress width, it was expected to be most exposed to the temperature and moisture of the subjects’ body. Probes 2 and 4 are partially affected if a person is sleeping supine, and when a person slept lateral, probes were completely exposed (but in this case, the middle and the probe on the edge were less affected).

One of the research aim was to explore distribution of temperature during first few hours in bed. Results have shown that the time in which temperature increase on all probes is around 3 hours from the moment of lying in bed, i.e. first notable temperature peak reach in that period. After approximately 180 minutes temperature start to behave unpredictably, but in most cases, decrease (Figure 4).

![Figure 4. Example of temperature in mattress layers during first 3 hours, for seven nights](image-url)
It was investigated how moisture in mattress behave during the usage of bed, and afterwards during the day.
In case of nights, moisture content increase from upper layer towards the middle of mattress (Figure 5), and it depends on relative humidity in bedroom as well.

![Figure 5. Average moisture content per subject during seven-night period](image)

For seven days, relations between probes (RH2-3-4 vs. RH5 vs. RH6) remain the same in comparison with night ones, but the values are expectedly lower. Those differences were greater in inner layer of mattress than the one near the surface, and were in range 6-12 % RH. Differences on RH2-3-4 between night and day were from 2 % to 7 % RH, while in the bedroom was only around 1 % RH (Figure 6).

![Figure 6. Average moisture content per subject during seven-day period](image)

If we observe moisture content/relative humidity during weeks, we can see that in the first three weeks (what correspond with subjects P1, P2 and P3 on Figure 6) those values were higher up to 10 % RH than in the week four.
Figure 7. Example of moisture motion during the night, morning and day

After the subject got out of bed, the mattress begins to cool and dry. Figure 7 shows the motion of moisture on probes 5 and 6 in the mattress and in the room (probe 7). The sudden fall of the RH5 and RH6 curves (around 100th record) occurred after the person left the bed, and later there was a slight increase, which follow oscillations of relative humidity in the bedroom. It can be noticed that RH5 is always lower than RH6, and RH5 reach RH7 faster (more or less equals them). Moisture RH6 follows the movement of RH5 and from the moment of rising one from the bed begins to decline, but always keeps 1% to 2.5% higher than RH5.

The space between layer of rubberised coconut coir and PU foam (place where moisture sensor RH5 installed) was chosen because that layer is not in direct human body influence, it is deep inside mattress and relatively closed. On the other hand, sensor RH6 was place in the space between cotton pocket springs and showed trends in that structure of mattress.

4. CONCLUSIONS

The aims of the research were to explore distribution of heat and moisture through the mattress layers in real conditions, and how long it takes to mattress release accumulated moisture. Based on the results of research, can be concluded:

- During first 180 minutes of lying, the temperature increases on all sensors and after that usually decrease, even though temperature behaviour can be very unpredictable.
- Moisture always increases in the direction from the top layer of mattress towards the spring pockets, regardless of day or night.
- Moisture content in mattress layers depends on relative humidity in the air, and it is always lower during the day comparing with the night period.
- Moisture accumulated in the inner structures of mattress (between coconut coir and upper layers of foam) does not stay much longer than in the other mattress layers and can be relatively quick to dry out.

References


Marić, K. (2016): Research of heat conductivity and moisture permeability through mattress with pocket spring core – graduate thesis (in Croatian), University of Zagreb, Faculty of Forestry, Zagreb.


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