THE EFFECT OF HUMAN-MATTRESS INTERFACE'S TEMPERATURE ON PERCEIVED THERMAL COMFORT

Califano R., Naddeo A.*, Vink P.***

**Dept. Of Industrial Engineering, University of Salerno (ITALY), Via Ponte don Melillo,1 – 84084 Fisciano (SA), Italy*
****Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15 2628 CE Delft, The Netherlands*

Corresponding Author: Prof. Alessandro Naddeo, e.mail: anaddeo@unisa.it,
Phone: +39 089 964311, Fax: +39 089964037, Mobile: +39 320 7406170

ABSTRACT

In recent years, methods that allow for an objective evaluation of perceived comfort, in terms of postural, physiological, cognitive and environmental comfort, have received a great deal of attention from researchers. This paper focuses on one of the factors that influences physiological comfort perception: the temperature difference between users and the objects with which they interact. The first aim is to create a measuring system that does not affect the perceived comfort during the temperatures' acquisition. The main aim is to evaluate how the temperature at the human-mattress interface can affect the level of perceived comfort. A foam mattress has been used for testing in order to take into account the entire back part of the human body. The temperature at the interface was registered by fourteen 100 Ohm Platinum RTDs (Resistance Temperature Detectors) placed on the mattress under the trunk, the shoulders, the buttocks, the legs, the thighs, the arms and the forearms of the test subject. 29 subjects participated in a comfort test in a humidity controlled environment. The test protocol involved: dress-code, anthropometric-based positioning on mattress, environment temperature measuring and an acclimatization time before the test. At the end of each test, each of the test subject's thermal sensations and the level of comfort perception were evaluated using the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) scale. The data analyses concerned, in the first instance, correlations between the temperature at the interface and comfort levels of the different parts of the body. Then the same analyses were performed independently of the body parts being considered. The results demonstrated that there was no strong correlation among the studied variables and that the total increase of temperature at interface is associated with a reduction in comfort.

Keyword: Comfort evaluation, Objectifying Comfort, Temperature, Thermal Comfort, Mattress, Bedding systems

1. INTRODUCTION AND THE STATE OF THE ART

Currently, the term comfort is often seen related to the marketing of products like chairs, cars, clothing, hand tools and even airplane tickets (Vink & Hallbeck, 2012). In the scientific literature, the term discomfort shows up often, since it is used in research. Vink & Hallbeck (2012) studied 104,794 papers in which the term discomfort is used. Most of these studies refer to temperature as the source of the discomfort or patient comfort. There are also many application studies that measure discomfort as a subjective phenomenon to be related to musculoskeletal injuries. The assumption is that there is a relationship between self-reported discomfort and musculoskeletal injuries. This relationship was made clearer by Hamberg-van Reenen et al. (2008), where local experienced musculoskeletal discomfort was measured in different body regions on a 10-point scale six times during a working day. They longitudinally tracked over 1,700 participants and showed that those reporting higher discomfort had an increased chance of back, neck and shoulder complaints three years later (the RR varied from 1.8 to 2.6). However, the theories relating comfort to products and product design characteristics are rather underdeveloped according to Vink & Hallbeck, (2012), to Naddeo et al., (2014) and a new model (Fig. 1) was proposed (Vink, 2014). The Artefact (A) and Human (H) are in an environment. Usage (U) causes an Interaction (I) between the human and the artefact, which causes human body effects (B). Then it will be Perceived (P) in the human brain, which is influenced by Expectations (E) and could give a certain Comfort (C) and Discomfort (D).

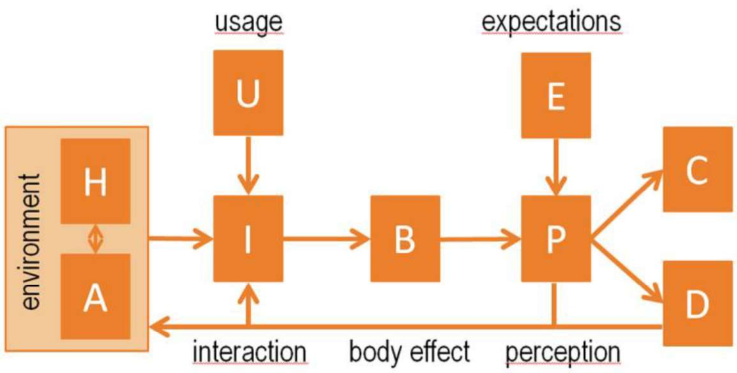

Fig. 1. A comfort model. The Artefact (A) and Human (H) are in an environment. Usage (U) causes an Interaction (I) between the person and product, which causes human Body effects (B). Then it will be Perceived (P) in the human brain, which is influenced by Expectations (E) and could give a certain Comfort (C) and Discomfort (D).

As described by Vink (2005) the interaction in this model can be recorded by many sensors. There is locally visual input, smell and sound and all over the body input from temperature, proprioscepsis and pressure and touch. These all influence comfort and discomfort. Interestingly, Chen et al. (2014) described the same sensory input related to sleep quality. They state that sensory input plays an important role in neuronal activities during sleep. The temperature, light, sound and smell around the environment influences the individual's sleep pattern and related functions. The pressure distribution on the human body during sleep is another aspect of sensory input that plays a role. Some aspects about influence of posture (Verhaert et al., 2012; Park et al., 2009; Naddeo et al., 2015-1) and biomechanics of the spine (De Vocht et al., 2006; Jacobson et al., 2002; Verhaert et al., 2011) on perceived comfort/discomfort have been already studied but have been never deepened through a statistical approach. Expectation also plays a fundamental role in the comfort perception as described in Naddeo et al. (2015-2). "Over-concentrated" or "over-even" pressure distribution may influence the sensory input and disturb sleep-related brain networks or may change the physiological posture for better sleep. In fact, sleep is a complex phenomenon: sleep quality is affected by a combined action of physiological, psychological and external environments (Chen et al., 2013). Lee and Park (2006) studied the influence of mattress types on sleep quality and skin temperature. They found that when subjects slept on a self-reported "comfortable" mattress, the sleep efficiency and the skin's temperature were higher than when subjects slept on an "uncomfortable" mattress. This relationship between temperature and comfort during sleeping is interesting for studies on comfort in general as temperature is most often mentioned in the scientific literature and might be relevant. The research questions are: how and how much the perceived temperature can affect the perceived comfort? What are, if any, the most sensible human body parts to the temperature changes? Are these changes detectable and can be measured in a controlled environment. To answer to this question some hypotheses have been formulated:

1) The mattress is comfortable under the postural point of view (as detected in a previous work not published for "non disclosure agreement" reason);
2) A temperature growth will be found in all tests, because the body temperature is higher than the mattress' one;
3) The increase of temperature might cause a decrease of perceived comfort but not a discomfort state for the subjects;
4) Different body parts could detect the temperature increase in a different way.

5) Thermal comfort is defined by ASHRAE Standard 55 (American Society of Heating, Refrigerating and Air-Conditioning Engineers) (ASHRAE, 2003) as a mental condition expressing the satisfaction of the individual for the thermal environment in which he or she operates.

2. MATERIAL AND METHODS

2.1 PURPOSE

One of the factors that could contribute to comfort/discomfort perception is the thermal equilibrium caused by the interaction between a person and the object with which he interacts (Naddeo et al., 2014;Vink, 2014). This assumption is easy to demonstrate, especially in the cases when nearly the whole body is in contact with an object, even for a long period of time, such as the interaction between a person and a seat or a mattress. Yao et al. (2007) studied the relationship between skin temperature and thermal comfort, checking the best method to analyse the phenomenon and the correlation between comfort perception and skin temperature.

The purpose of the study was to evaluate how the temperature at the human-mattress interface can affect the level of perceived comfort and how the data acquisition can be made without affecting the subjects' perceived comfort. To do that, several tests involving the entire back part of a human body were performed with the subject lying, in supine position, on a mattress.

2.2 PARTICIPANTS

Participants were recruited from young professors and students in their last year of Master's degree courses in Mechanical and Management Engineering at the University of Salerno.
The sample can be considered homogenous: 29 subjects (12 women and 17 men) whose age was between 23 and 40 years. Most of participants came from the same geographical area and were accustomed to similar weather conditions, so their sensibilities to cold/warm were likely to be similar as well. The sample was clustered in terms of age, gender, anthropometric characteristics (height, weight and anthropometric percentile). Subjects were asked to use standardized clothes (no shoes, long sleeves' shirt and shorts or thin cotton trousers). All subjects who participated gave their informed written consent. No subjects reported any musculoskeletal or neurological conditions that precluded their participation in the study.

2.3 TESTING DEVICES

A mattress, a temperature data acquisition system, and a questionnaire were used in this study.
The mattress used was the "SHIRLEY" model of the Valflex® line. This is an anatomical multi-foam mattress in which three different layers are combined one on top of the other: the top layer is made of Multi Foam Fresh Gel, the middle layer is made of Mind Foam Memory Effect with massaging effect and the lower layer is made of Technocell AquPur high-density with open cell, which ensures very good weight support. The total mattress' height was 22 cm, 80 cm wide by 188 cm in length. The mattress was covered with an elastic cover made of cotton and polyamide that hid the internal characteristics of the mattress and helped to distribute the weight of subjects in a proper manner.
The temperature measurement system consisted of fourteen 100 Ohm Platinum RTDs (resistance temperature detectors), four RTD analog inputs, each with four channels (Type 9217, National Instruments Italy S.r.l). The accuracy of measurement of the RTDs used was ±0.05°C.
The RTDs were placed on the mattress and covered by a thin elastic cover made of cotton that did not compromise the validity of the tests and, by limiting direct interaction between the subject and the sensors, prevented the subjects from being annoyed by the RTDs when they were lying down. The RTDs were placed on the left and right sides of the mattress under the trunk (2), the shoulders (2), the buttocks (2), the legs (2), the thighs (2), the arms (2) and the forearms (2), as shown in Fig. 2.

Fig. 2. Location of RTDs on the mattress pad material (on the left, under the thin cover) and their corresponding position on the subject's skin (red points).

Because the anthropometrics measurements of the subject were not identical, the subjects were clustered in four groups by height and, for each group, the RDTs were relocated.
Based on the "Thermal comfort" definition by ASHRAE *Standard 55*, subjects were asked directly about thermal sensations and their "votes" were expressed by a numerical value on the ASHRAE scale. The questionnaire used is shown in Fig. 3.

	Evaluation Index						
	Very hot with excessive discomfort	Hot with strongly localized discomfort	Slightly hot with slight discomfort	Neither hot nor cold. Comfort	Slightly cool with slight discomfort	Fresh with strongly localized discomfort	Cold with excessive discomfort
Shoulder (Right Side)							
Shoulder (Left Side)							
Right Arm							
Left Arm							
Right Forearm							
Left Forearm							
Trunk (Right Side)							
Trunk (Left Side)							
Buttock (Right Side)							
Buttock (Left Side)							
Right Thigh							
Left Thigh							
Right Leg							
Left Leg							

Fig. 3. Comfort questionnaire (Body parts in the rows, evaluation value in the columns)

2.4 PROCEDURES

Testing was conducted in a humidity-controlled room (50% ± 2%). Three testing sessions were conducted on different days. The ambient temperature was registered but not controlled. Different ambient temperatures

were desirable because one of the aims of this study was to compare the comfort index and the ambient temperature. A rest period of 30 min (participants were seated during this period) was provided before the test sessions to acclimatize the subjects to the environmental conditions (Hedge et al., 2005; Bartels, 2003). After this period, the participants were asked to lie down on the mattress, making sure that each part of the body was on the correct RDT. The duration of the test was 15 minutes for all participants. This time duration was chosen on the basis of the experience of Karimi et al. (2003). They reported a threshold time of 10 min for a participant to achieve thermal neutrality at all contact points on a seat pan, without any external heating or cooling. Additionally, the experience of mattress producers and sellers suggested that, both in the case of testing a new mattress before buying and in the case of using a mattress before going to sleep, the time of lying on the mattress is often less than 15 minutes and this was taken into consideration when determining the duration of the test. In fact, a normal subject generally needs less than 15 minutes, in a steady posture, to begin to sleep. During sleep, perceptions of thermal comfort cannot be evaluated.
Temperature data at the interfaces was recorded every 6 seconds for the duration of the session starting from the time just before the participants lay down on the mattress.
After 13/14 minutes, while the subject was still lying on the mattress, questions about perceived comfort were asked. At the end of the test, the subjects were asked if they had detected something under their skin, in order to understand the "detectability" of the acquisition system.

2.5 COLLECTED DATA

For each test, three kinds of data were collected: anthropometric, temperature and thermal sensations.
A summary of the anthropometric data is provided in Table 1.

Table 1
Descriptive statistics of selected variables for the participant population.

	Age (years)	Stature (cm)	Mass (Kg)	Body surface Area (m^2)	Body Fat (%)	Body Mass Index
Mean	26.10	173.93	68.83	1.82	19.95	22.64
Std. Deviation	3.57	7.82	10.67	0.17	4.21	2.25
Minimum	23	159	51	1.51	14.24	18.87
Maximum	40	190	90	2.12	29.88	28.41

During the 15 minutes of the test, 150 temperatures were registered for each part of the body (left and right). Data acquired are shown below:

(1) Ti (°C): the first registered temperature at the interface
(2) Tf (°C): the last registered temperature at the interface
(3) Tm (°C): the average temperature at the interface during the 15-minutes test period
(4) Ta (°C): the average ambient temperature during the 15-minutes test period
(5) ΔT1 (°C): the difference between the average temperature and the average ambient temperature
(6) ΔT2 (°C): the difference between the initial temperature and the final temperature at the interface
(7) ΔT3 (°C): the difference between the final temperature at the interface and the average ambient temperature
(8) Hr (°C/min): the heating rate, obtained by dividing ΔT2 by 15 (minutes)

The choice of these parameters has been based on the thermal behavior of a complex system (human body – mattress) in a closed environment: all the parameters that can affect the thermal behavior, and consequently the perceived thermal comfort, have been monitored and recorded.
At the end of the test, the tester asked each subject to rate the perceived thermal comfort for each part of her/his body.

Because of the symmetry of the human body, averages of data (Index of Comfort = I.C.) for left (I.C. SX) and right (I.C. DX) for each body part were made in order to get total data for each body part. The values used by the questionnaire to record thermal sensations (and the related I.C.) are shown in Table 2.

Table 2
Index of Comfort (I.C.) associated with each item of the questionnaire.

Very hot with excessive discomfort	0
Hot with strongly localized discomfort	1
Slightly hot with slight discomfort	2
Neither hot nor cold. Comfort	3
Slightly cool with slight discomfort	2
Fresh with strongly localized discomfort	1
Cold with excessive discomfort	0

An example of the collected data are shown in Table 3.

Table 3
Summary of data collected during the test for the shoulders (numbered subjects in the rows).

	SHOULDER									
№	I.C. DX	I.C. SX	I.C.	Ti	Tf	Hr	ΔT1	ΔT2	Ta	ΔT3
1	1	1	1	32,64	32,88	1,61	7,06	0,24	25,69	7,19
2	2	2	2	36,98	37,17	1,21	10,81	0,18	26,27	10,90
3	2	2	2	35,42	35,62	1,30	9,28	0,20	26,24	9,38
4	3	3	3	34,41	34,54	0,92	8,64	0,14	25,83	8,71
5	2	2	2	36,47	36,60	0,86	10,21	0,13	26,33	10,27
6	2	2	2	35,86	36,04	1,25	9,62	0,19	26,34	9,70
7	2	1	1,5	33,82	33,87	0,36	7,41	0,05	26,44	7,43
8	2	2	2	35,75	35,87	0,78	10,48	0,12	25,49	10,38
9	3	3	3	37,02	37,15	0,91	11,01	0,14	26,08	11,07
10	3	3	3	36,01	36,15	0,92	10,04	0,14	26,04	10,11
11	3	2	2,5	35,32	35,52	1,36	9,42	0,20	26,00	9,52
12	3	3	3	33,94	34,02	0,53	7,68	0,08	26,30	7,72
13	2	2	2	36,41	36,56	0,98	11,54	0,15	24,95	11,61
14	3	3	3	36,81	36,91	0,71	12,54	0,11	24,32	12,59
15	2	2	2	36,22	36,40	1,22	12,19	0,18	24,13	12,27
16	3	3	3	35,95	36,12	1,15	11,90	0,17	24,14	11,98
17	1	2	1,5	35,61	35,82	1,39	12,08	0,21	23,64	12,18
18	3	2	2,5	35,75	35,91	1,05	11,81	0,16	24,03	11,89
19	2	2	2	36,24	36,36	0,81	11,95	0,12	24,36	12,00
20	3	3	3	35,94	36,06	0,84	6,78	0,13	29,22	6,84
21	3	3	3	35,80	36,00	1,35	7,22	0,20	28,68	7,32
22	1	1	1	35,17	35,41	1,63	7,03	0,24	28,27	7,15
23	3	3	3	34,98	35,23	1,70	8,83	0,25	26,27	8,96
24	3	3	3	35,87	36,04	1,17	9,24	0,17	26,71	9,33
25	3	3	3	36,32	36,52	1,33	9,11	0,20	27,31	9,21
26	2	2	2	36,66	36,78	0,80	7,56	0,12	29,16	7,62
27	2	2	2	36,72	36,83	0,73	7,41	0,11	29,36	7,47
28	2	2	2	36,51	36,63	0,80	6,94	0,12	29,63	7,00
29	2	2	2	37,16	37,27	0,73	9,28	0,11	27,94	9,33

A summary of the variables recorded for each part of the body are provided in the Tables 4, 5, 6, 7, 8, 9, 10.

Table 4
Descriptive statistics for the shoulders.

SHOULDER	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	1,00	3,00	2,34	0,67
I.C. SX	1,00	3,00	2,28	0,65
I.C.	1,00	3,00	2,31	0,63
Ti	32,64	37,16	35,78	1,04
Tf	32,88	37,27	35,94	1,03
Hr	0,36	1,70	1,05	0,33
ΔT1	6,78	12,54	9,49	1,88
ΔT2	0,05	0,25	0,16	0,05
Ta	23,64	29,63	26,39	1,72
ΔT3	6,84	12,59	9,56	1,87

Table 5
Descriptive statistics for the arms.

ARM	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	1,00	3,00	2,28	0,70
I.C. SX	1,00	3,00	2,21	0,68
I.C.	1,00	3,00	2,24	0,64
Ti	32,64	37,02	35,49	1,02
Tf	32,88	37,17	35,66	1,02
Hr	0,81	2,30	1,31	0,36
ΔT1	3,57	10,66	7,24	1,71
ΔT2	0,12	0,34	0,20	0,05
Ta	23,64	29,63	26,39	1,72
ΔT3	3,64	10,79	7,33	1,71

Table 6
Descriptive statistics for the forearms.

FOREARM	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	1,00	3,00	2,17	0,76
I.C. SX	0,00	3,00	2,14	0,79
I.C.	0,50	3,00	2,16	0,75
Ti	29,39	35,95	33,14	1,58
Tf	29,51	36,08	33,22	1,63
Hr	0,10	2,87	0,81	0,54
ΔT1	3,89	9,75	6,80	1,69
ΔT2	0,02	0,43	0,12	0,08
Ta	23,64	29,22	26,15	1,40
ΔT3	3,88	9,81	7,24	1,49

Table 7
Descriptive statistics for the trunk.

TRUNK	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	1,00	3,00	1,79	0,73
I.C. SX	1,00	3,00	1,79	0,73
I.C.	1,00	3,00	1,79	0,69
Ti	32,34	36,60	34,83	0,99
Tf	32,49	36,72	35,02	0,98
Hr	0,75	2,03	1,24	0,35
ΔT1	4,56	12,34	8,55	1,96
ΔT2	0,11	0,31	0,19	0,05
Ta	23,64	29,22	26,15	1,40
ΔT3	5,24	12,39	9,04	1,59

Table 8
Descriptive statistics for the buttocks.

BUTTOCK	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	0,00	3,00	1,62	0,78
I.C. SX	0,00	3,00	1,55	0,78
I.C.	0,00	3,00	1,59	0,77
Ti	30,62	36,07	34,15	1,28
Tf	30,86	36,22	34,39	1,25
Hr	1,03	2,75	1,58	0,42
ΔT1	5,47	11,83	8,01	1,71
ΔT2	0,15	0,41	0,24	0,06
Ta	23,64	29,22	26,27	1,54
ΔT3	5,57	11,90	8,12	1,70

Table 9
Descriptive statistics for the thighs.

THIGH	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	0,00	3,00	1,72	0,75
I.C. SX	0,00	3,00	1,69	0,76
I.C.	0,00	3,00	1,71	0,74
Ti	31,03	35,82	34,38	1,20
Tf	31,28	35,97	34,58	1,18
Hr	0,62	2,60	1,36	0,51
ΔT1	5,46	11,42	8,10	1,61
ΔT2	0,09	0,39	0,20	0,08
Ta	23,64	29,22	26,15	1,40
ΔT3	5,59	11,49	8,60	1,46

Table 10
Descriptive statistics for the legs.

LEG	Minimum	Maximum	Mean	Std. Deviation
I.C. DX	1,00	3,00	1,59	0,63
I.C. SX	1,00	3,00	1,62	0,62
I.C.	1,00	3,00	1,60	0,59
Ti	31,00	36,40	34,54	1,35
Tf	31,09	36,55	34,72	1,37
Hr	0,23	2,33	1,22	0,47
ΔT1	4,71	11,45	8,25	1,94
ΔT2	0,03	0,35	0,18	0,07
Ta	23,64	29,22	26,15	1,40
ΔT3	4,75	11,56	8,74	1,72

Data was gathered to evaluate the impact of individual characteristics of the subjects (i.e. age, gender, Body Mass Index, body fat and body surface area) and the impact of thermal parameters (Ti, Tf, Tm, Ta, ΔT1, ΔT2, ΔT3, Hr) on thermal sensations, as well as on comfort perception. There are previous studies that correlate individual characteristics with thermal sensation (Tuomaala et al., 2013), but no works have been found in the literature that discuss the correlation between temperature at the human-mattress interface and thermal sensation. For each part of the body, a multivariate analysis was performed to determine possible correlations among the variables. The statistical analysis software SPSS rel.13 was used to perform these analyses. Pearson correlation coefficients were calculated to determine the strength of the relationships between all the variables, as shown in Table 11.

Table 11
Statistical correlations among the variables

Correlations			Percentile	Tm	Ti	Tf	Hr	ΔT1	ΔT2	ΔT3
SHOULDER	IC	Pearson Correlation	0,304	0,212	0,217	0,212	-0,139	0,133	-0,139	0,133
		Sig. (2-tailed)	0,109	0,269	0,258	0,269	0,471	0,492	0,473	0,493
ARM	IC	Pearson Correlation	.387(*)	-0,113	-0,114	-0,109	0,141	0,084	0,141	0,087
		Sig. (2-tailed)	0,038	0,561	0,555	0,572	0,466	0,665	0,464	0,655
FOREARM	IC	Pearson Correlation	-0,02	-.411(*)	-.409(*)	-.410(*)	-0,189	-0,115	-0,189	-0,273
		Sig. (2-tailed)	0,92	0,027	0,028	0,027	0,327	0,552	0,327	0,152
TRUNK	IC	Pearson Correlation	0,248	-0,124	-0,129	-0,119	0,211	0,154	0,21	0,185
		Sig. (2-tailed)	0,195	0,523	0,504	0,538	0,273	0,424	0,274	0,335
BUTTOCK	IC	Pearson Correlation	-0,028	0,043	0,038	0,031	-0,147	0,232	-0,147	0,23
		Sig. (2-tailed)	0,886	0,824	0,844	0,873	0,447	0,225	0,448	0,23
THIGH	IC	Pearson Correlation	0,18	-0,258	-0,196	-0,181	0,283	0,259	0,284	0,183
		Sig. (2-tailed)	0,351	0,177	0,308	0,348	0,137	0,175	0,135	0,341
LEG	IC	Pearson Correlation	-0,169	-0,098	-0,102	-0,091	0,197	0,12	0,198	0,135
		Sig. (2-tailed)	0,382	0,612	0,599	0,64	0,305	0,535	0,304	0,484

**Correlation is significant at the 0.01 level (2-Tailed).
* Correlation is significant at the 0.05 level (2-tailed).

All the subjects, at the end of the test, have answered “No” to the question about detectability of acquisition system.

3. RESULT AND DISCUSSION

For each part of the body, statistical analyses were made to verify if there were correlations between the comfort index and the other variables (gender, stature, age, weight, anthropometric percentile, body surface area, body fat, Body Mass Index, Ti, Tf, Tm, Ta, ΔT1, ΔT2, ΔT3, Hr). The Pearson index did not reveal high correlations among the variables. In particular, the Pearson index revealed a correlation between percentile and IC index (the positive correlation is significant at the 0.05 level) in the case of the arms, and negative correlations between IC index and Tm, Ti and Tf in the case of the forearms (the negative correlations are significant at the 0.05 level).
While in the first part of the study, the analysis was related to the different parts of the body, the later analysis was aimed at determining the possible correlations between the registered temperature data on the skin at the interface and perceived comfort, independent of the body parts for which data was gathered. In particular, the correlations between IC index and ΔT2, ΔT3 and Tf were evaluated. For each pair of variables analyzed, 203 data (7 body parts * 29 subjects) were considered. An example is shown in Appendix 1.

For each variable (ΔT2, ΔT3 and Tf) considered, total data were divided into 4 equal sub-ranges and the related comfort data were clustered according to these sub-ranges. For each sub-range, the average and the variance of the comfort indices were calculated. Tables 12, 13 and 14 show the processed data related to ΔT2, ΔT3 and Tf.

Table 12
Processed data related to ΔT2 (in the first column: the ΔT2 intervals)

ΔT2 (°C)	IC_mean	VAR
0.015-0.12	1,952	0,477
0.121-0.220	1,926	0,559
0.221-0.330	1,924	0,547
0.331-0.430	1,857	0,714

Table 13
Processed data related to ΔT3 (in the first column: the ΔT3 intervals)

ΔT3 (°C)	IC_mean	VAR
3.640-5.880	2,079	0,674
5.881-8.120	1,819	0,608
8.121-10.350	1,907	0,501
10.351-12.590	2,286	0,370

Table14
Processed data related to Tf (in the first column: the ΔT2 intervals)

Tf (°C)	IC_mean	VAR
29.475-31.420	2,368	0,496
31.421-33.370	1,842	0,724
33.371-35.320	1,861	0,516
35.321-37.265	1,915	0,504

The study demonstrated that there was a trend, although not one that is very evident, between the Mean Comfort Index and increases of temperature (Fig. 4). With increases of ΔT2, the level of perceived discomfort decreases. However, the analysis of the values of variances did not confirm this trend (Table 13), but confirmed, instead, the results of the statistical analysis reported previously (Appendix 1).

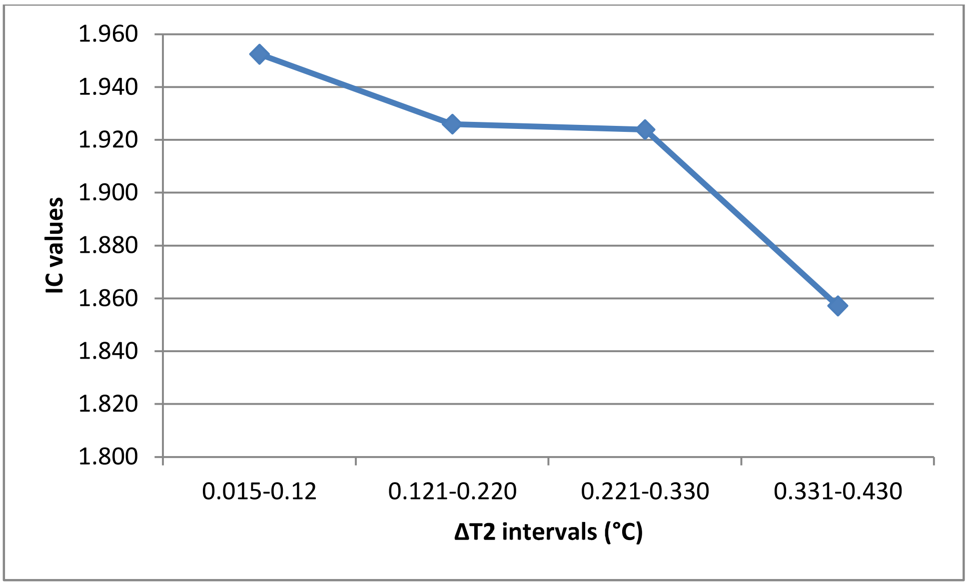

Fig. 4. Graph of the trend of the IC related to the ΔT2.

An analysis similar to that presented for the ΔT2 and final temperature was also made for the ΔT3. The graphs presented in Fig. 5 and Fig. 6 demonstrate that there were no further correlations among the variables.

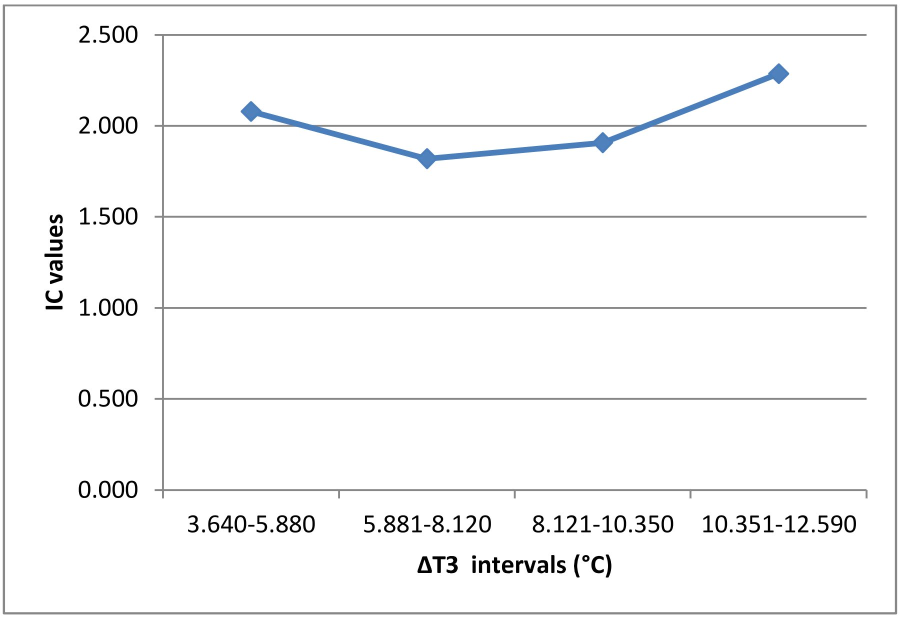

Fig. 5. Graph of the trend of the IC related to the ΔT3.

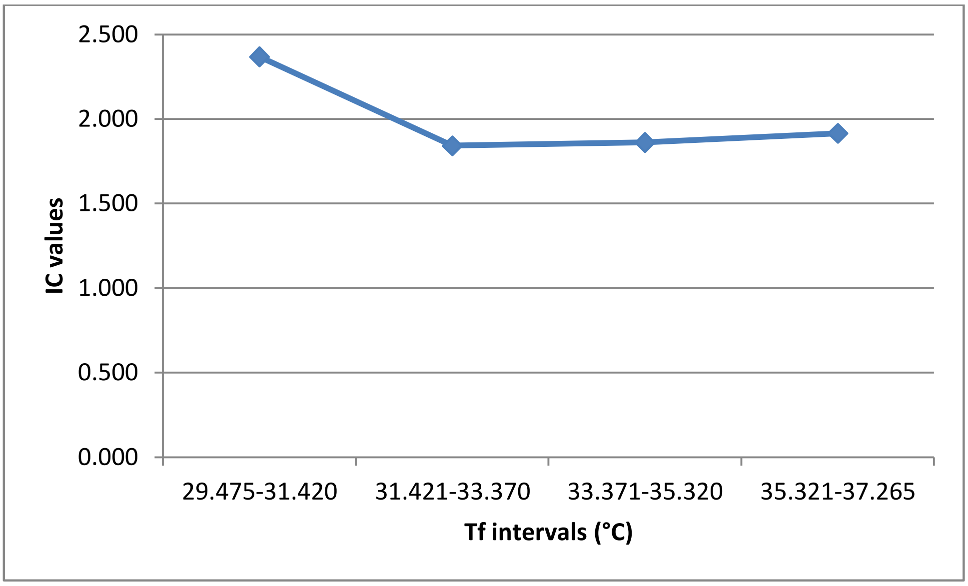

Fig. 6. Graph of the trend of the IC related to the T_f.

4. CONCLUSION

A psychophysical approach has been used to evaluate if there is a relationship between the temperature of the skin at the interface between the human body and the level of perceived comfort. To assess the level of comfort perceived by the user in relation to the temperature at the interface, it was decided to perform the test on a mattress to be able to consider the interactions of whole body with the mattress.

The way to do that was the creation of a measuring system that did not affect the perceived comfort during the temperatures' acquisition. The use of flat and thin RTDs under a soft elastic cover has permitted to obtain a "not-detectable by users" acquisition system.

During the tests, two types of data were recorded: the temperature at the interface and the subjective comfort perceptions of the participants.

In the first part of the study, the correlations between the temperature at the interface and comfort perception were evaluated in relation to each part of the body (arms, forearms, trunk, buttocks, legs and thighs). The Pearson index did not reveal high correlations among the considered variables. In particular, the Pearson index revealed negative correlations between IC index and Tm, Ti and Tf in the case of the forearms.

In the second part of the study, the aim was to verify the correlations between the Comfort Index and the skin temperature at the interface independently of the body parts considered. In particular, the correlations between IC index and ΔT2, ΔT3 and Tf were evaluated.

The analyses of the data confirmed the lack of strong correlations. The only interesting result regarded the correlation between increases of temperature, ΔT2, and the Comfort Index. The study demonstrated that a correlation exists between these two variables. Increases of the ΔT2 (total increase of temperature at interface) were associated with a reduction in comfort. This result is reflected in the fact that humans register for a certain amount of heat centrally in the brain, while the cold is mainly recorded from peripheral sensors.

This study suggest to designers that, when designing a new product for "bed" companies, the problem of interface temperature might have a minor priority towards other issues that are related, for example, with the acquired posture and the map of pressures; this is true since the temperature is always lower than the "normal" skin temperature (about 37°C). For higher temperature, the effect may drastically change. Limitations of this study can be found in the experimental setup, in which the ambient temperature cannot be controlled (even if no correlation between perceived comfort and ambient temperature has been found), and in the lack of information about perspiration/sweat of subjects' skin during the test; both these aspect can affect the perceived comfort and might be controlled/acquired in future experiments. Future developments can be thought about understanding the correlation between temperature and pressure at interface, not only in supine position but also in prone and lateral position. Another limitation of the study is about the limited range (about 23-30°C) of temperatures recorded in the climate chamber. In extreme situations, the results of the same experiment could be different.

Acknowledgement

Mattresses and other furniture have been furnished by Rinaldi Group s.r.l., a top-quality mattresses' manufacturer of south part of Italy (Giffoni Valle Piana – Salerno), for research purposes. Experimental tests were performed in the virtual reality laboratory (VRLab) of the Department of Industrial Engineering at the University of Salerno, Italy. Many thanks to the students of last year's mechanical and management engineering class (2015), who gave us their time and patience in carrying out many hours of testing.

References

1. ASHRAE. Thermal environmental conditions for human occupancy. BSR/ASHRAE Standard 55P. Fourth Public Review. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2003.
2. Bartels, V.T., 2003. Thermal comfort of airplane seats: influence of different seat materials and the use of laboratory test methods. Appl. Ergon. 34, 393-399.
3. Chen, Z., Li, Y., Liu, R., Gao, D., Chen, Q., Hu, Z., Guo, J., 2014. Effects of Interface Pressure Distribution on Human Sleep Quality. DOI: 10.1371/journal.pone.0099969.
4. Chen, Y., Guo, Y., Shem, L., Lium, S., 2013. The quantitative effects of mattress and sleep postures on sleep quality. International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings, 107-115.
5. DeVocht, J. W., Wilder, D. G., Bandstra, E. R., Spratt, K. F., 2006. Biomechanical Evaluation of Four Different Mattresses. Applied Ergonomics 37 (3): 297-304. doi:10.1016/j.apergo.2005.07.002.
6. Hamberg-van Reenen, H.H., van der Beek, A.J., Blatter, B.M., van der Grinten, M.P.,Mechelen, W., Bongers, P.M., 2008. Does musculoskeletal discomfort at work predict future musculoskeletal pain?. Ergonomics 51(5), 637-648.
7. Hedge, A., Saito, M., Jagdeo, J., 2005. Does ergonomic chair design affect thermal comfort?. In: Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, Florida, September 26e30, 2005. Human Factors and Ergonomics Society, Santa Monica, California, USA, pp. 793-797.
8. Jacobson, B. H., Gemmell, H. A., Hayes, B. M., Altena, T. S., 2002. Effectiveness of a Selected Bedding System on Quality of Sleep, Low Back Pain, Shoulder Pain, and Spine Stiffness. Journal of Manipulative and Physiological Therapeutics 25 (2): 88-92. doi:10.1067/mmt.2002.121410.
9. Karimi, G., Chan, E.C., Culham, J.R., 2003. Experimental study of thermal modeling of an automobile driver with heated and ventilated seat. In: 2003 SAE Digital Human Modeling Conference, Number 2003-01-2215 (Montreal, Quebec, Canada).
10. Lee, H., Park, S., 2006. Quantitative effects of mattress types (comfortable vs. uncomfortable) on sleep quality through polysomnography and skin temperature. International Journal of Industrial Ergonomics 36(11), 943-949.
11. Naddeo, A., Cappetti N., D'Oria, C., 2015. Proposal of a New Quantitative Method for Postural Comfort Evaluation. International Journal of Industrial Ergonomics 48: 25-35. doi:10.1016/j.ergon.2015.03.008.
12. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2015. The Role of Expectation in Comfort Perception: The Mattresses' Evaluation Experience. Procedia Manufacturing, Volume 3, 2015, 4784-4791, ISSN 2351-9789, doi:10.1016/j.promfg.2015.07.582.
13. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE, edited by T. Ahram, W. Karwowski and T. Marek.
14. Park, S. J., Kim, J. S., Kim, C. B., 2009. Comfort Evaluation and Bed Adjustment According to Sleeping Positions. Human Factors and Ergonomics in Manufacturing 19 (2): 145-157. doi:10.1002/hfm.20142.
15. Tuomaala, P., Holopainen, R., Piira, K., Airaksinen, M., 2013. Impact of individual characteristics – such as age, gender, BMI, and fitness – on human thermal sensation. Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28.
16. Verhaert, V., Druyts, H., Van Deun, D., Exadaktylos, V., Verbraecken, J., Vandekerckhove, M., Haex, B., Vander Sloten, J.. 2012. Estimating Spine Shape in Lateral Sleep Positions using

Silhouette-Derived Body Shape Models., International Journal of Industrial Ergonomics 42 (5): 489-498. doi:10.1016/j.ergon.2012.08.002.

17. Verhaert, V., Haex, B., de Wilde, T., Berckmans, D., Verbraecken, J., de Valck, E., van der Sloten, J., 2011. Ergonomics in Bed Design: The Effect of Spinal Alignment on Sleep Parameters. Ergonomics 54 (2): 169-178. doi:10.1080/00140139.2010.538725.
18. Vink, P., 2005. Comfort and design: principles and good practice. Boca Raton: CRC Press 2005, ISBN 0-8493-2830-6.
19. Vink, P., 2014. The sweetness of discomfort: Designing the journey. Inaugural Lecture, Delft University of Technolog, June 4, 2014.
20. Vink, P., Hallbeck, S., 2012. Editorial: comfort and discomfort studies demonstrate the need for a new model. Appl. Ergon. 43, 271–276.
21. Yao, Y., Lian, Z., Liu, W., Shen, Q.. 2007. Experimental Study on Skin Temperature and Thermal Comfort of the Human Body in a Recumbent Posture Under Uniform Thermal Environments. Indoor and Built Environment 16 (6): 505-518. doi:10.1177/1420326X07084291.

APPENDIX 1

Table of data used to evaluate the correlation between ΔT2 and IC index; for each pair of variables analyzed, 203 data (7 body parts * 29 subjects) were considered.

ΔT2	IC	ΔT2	IC	ΔT2	IC	ΔT2	IC	ΔT2	IC	ΔT2	IC
0,241	1	0,265	3	0,238	3	0,208	2	0,154	2	0,118	1
0,182	2	0,180	3	0,262	1	0,280	2	0,260	2	0,146	1,5
0,195	2	0,225	2	0,135	2,5	0,094	1,5	0,200	3	0,120	2
0,138	3	0,175	2	0,186	3	0,247	1	0,320	3	0,140	2
0,129	2	0,155	1	0,151	2	0,390	2	0,344	1,5	0,211	1
0,187	2	0,130	3	0,204	2	0,203	2	0,229	2,5	0,191	2
0,053	1,5	0,190	1,5	0,192	1	0,269	2	0,174	3	0,189	2
0,117	2	0,135	2	0,280	2	0,220	3	0,186	3	0,184	1
0,136	3	0,131	2	0,265	3	0,348	1,5	0,228	2	0,112	3
0,138	3	0,043	3	0,210	2	0,299	3	0,170	1	0,216	1,5
0,203	2,5	0,059	3	0,305	2	0,136	2	0,200	2	0,206	1
0,080	3	0,096	2	0,150	1	0,165	1	0,255	1	0,350	3
0,148	2	0,080	3	0,145	2	0,225	1	0,096	1	0,180	2
0,106	3	0,078	1,5	0,135	1	0,188	0	0,200	1	0,225	2
0,183	2	0,079	2	0,243	1	0,295	2	0,180	3	0,215	1
0,172	3	0,109	1,5	0,225	1	0,195	2	0,093	1	0,160	2
0,208	1,5	0,048	3	0,257	1	0,300	3	0,157	1	0,165	1
0,158	2,5	0,040	0,5	0,282	2	0,190	1	0,123	1,5	0,155	1
0,121	2	0,105	2	0,189	1	0,145	2	0,148	2	0,150	2
0,125	3	0,173	1	0,212	2	0,180	2	0,219	1	0,125	1
0,203	3	0,148	3	0,184	1,5	0,145	2	0,139	2	0,145	2
0,245	1	0,116	3	0,154	3	0,146	2	0,152	2	0,125	1
0,255	3	0,123	3	0,176	3	0,034	2	0,145	2	0,015	2
0,175	3	0,038	2	0,242	1	0,135	1	0,157	2	0,060	1,5
0,200	3	0,186	3	0,239	1,5	0,182	1	0,121	2	0,151	2
0,120	2	0,123	2	0,177	1	0,088	2	0,173	1,5	0,154	1
0,110	2	0,098	2	0,413	1	0,094	1,5	0,246	3	0,256	2
0,120	2	0,176	2,5	0,155	2	0,196	1,5	0,202	2	0,186	2
0,110	2	0,271	3	0,334	1	0,071	1	0,214	3	0,140	2
0,216	2	0,430	3	0,258	2	0,219	1,5	0,250	2	0,157	1
0,375	1	0,240	2	0,207	0	0,115	2	0,170	1	0,233	2
0,239	3	0,095	1	0,305	1	0,168	2	0,242	2	0,231	2
0,189	3	0,258	1	0,275	2	0,236	1,5	0,138	3	0,243	2
0,207	1	0,317	1	0,290	3	0,214	3	0,109	2		

Aggregate data for all body parts.