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BODY-MAPPING BASED ON THERMOGRAPHIC MEASUREMENTS UNDER DIFFERENT INFLUENCING FACTORS

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SUMMARY: The presented research focuses on the use of thermography to observe influences of different influencing factors on the changes of lower body temperatures. Based on the outcomes of the research fit of garment plays an important role for the retention of heat between the textile material and skin, especially in the zone of both upper and lower shin. Also only tight model of trousers is capable to preserve the temperature in zones of thigh and knees of male volunteer. The given body-maps present differences in values of average temperatures (ΔT) considering the garment fit. In the indoor environment, tight model of female trousers has significant influence on the average temperature in the zone of upper shin. This observation is even more pronounced in the outdoor environment. For the male volunteer, higher differences, between temperatures are seen in the outdoor environment only.

Key words: *comfort, thermography, garment fit, temperature, volunteer*

INTRODUCTION

Human thermal comfort is depended on a number of factors that are related to the body, climate conditions, parameters of environment and textile/clothing. Having this in mind, it is clear that clothing has a role of a barrier that protects the body from external factors. Human comfort, both thermophysiological and thermal, largely depend on the structure of the material - that is, the number and characteristics of individual layers of clothing, as well as the thermal insulation properties of the material from which the clothing is made *(Puszkarz and Krucinska, 2017; Mijović et al., 2009; Potočić Matković et al., 2014; Salopek Čubrić and Skenderi, 2013; Salopek Čubrić and Skenderi, 2014; Salopek Čubrić et al., 2019)*. Depending on the climate, duration and intensity of the exercise, clothing can either minimize or maximize heat transfers with fixed properties or specific active technologies.

Infrared thermography is a non-destructive measuring method for the determination of temperature distribution on the surface of objects. It is very popular among the researchers in various fields. In the field of textile engineering, thermography may be used to observe the production process, textile material properties, clothing comfort, failure and product development. Recently, much attention has been paid to mapping of body temperatures in order to adapt the fabric and garment to better meet the body needs *(Havenith et al., 2008; Fournet et al., 2013a; Fournet et al., 2015; Roberts et al., 2007)*. The researchers confirmed that thermography is a great tool to assess the efficiency of the clothing intervention and has great potential for evaluation of regional or whole-body patterns for targeted clothing *(Fournet, 2013; Fournet et al., 2012; Fournet et al., 2013b)*. Up to now, it was used to observe differences in temperature of the body dressed in clothing

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produced of different materials and with different fitting properties *(Matusiak, 2010).* Thermography also serves to evaluate the performance of clothing for personal use *(Mijović et al., 2012)*, protective clothing (e.g. intelligent and thermal adaptive clothing), *(Čubrić et al., 2013)* and for recreational and professional athletes *(Merla et al., 2010)*.

Thermographic assessment of clothing functionality is crucial in cold environments where, due to reduced clothing insulation and inability to compensate heat loss with heat production, hypothermia can occur *(Ainslie and Reilly, 2003)*. Preliminary results of investigation using thermography with participation of 2 male volunteers showed that method is promising for improved thermal comfort and reduced skin temperature changes in cold thermal environment (temperature was 2 °C), but not in a hot thermal environment (temperature was 29 °C), *(Kinnicutt et al., 2010)*. Thermography has also been used to measure changes in upper body temperature of divers wearing thick neoprene diving suit *(Potočić Matković et al., 2019)*. According to the results, highest body skin temperature before immersion was recorded in central upper chest body zone, then in left and right upper chest. Highest temperature drop was recorded in the first 5 minutes of immersion in water, especially in a zone of neck. After 25 min of immersion, lowest skin temperature was recorded in the zone of neck and it was 17% lower than before immersion. Authors point out that outcomes of research will facilitate the process of designing wetsuits in order to increase/decrease thermal insulation in the zones that are identified and finally to maintain optimal thermal comfort. Authors of another study *(Havenith et al., 2008)* suggested that placing extra insulation in the design of clothing on the specific cold body regions would be beneficial for improvement of overall thermal comfort.

For a number of clothing applications, a good compromise must be found between heat and moisture/sweat transfer. This is especially important for the clothing worn in the cold thermal environments where sufficient insulation must ensure adequate thermal, but material needs to allow the transfer of sweat that is produced at moderate to high workloads. In such cases, vapour resistance of material should be small to avoid excessive moisture build-up. In the study (Wang et al., 2016) was shown that total clothing insulation is reduced by 20% when moisture content of the underwear is 100% of its dry weight. Authors conclude that adequate ventilation affects the garment microclimate and can contribute in reducing the build-up of condensated moisture. The differences in changes of body temperatures between female and male volunteers have been reported *(Fournet et al., 2013b)*. The study indicated that mean body temperature during the uphill running and resting stages was significantly lower for females compared to males (−0.7 °C).

It is a joint point of view of experts in the fields of ergonomy, human factors and textile engineering that further innovations beyond state-of-the-art should be focused towards efforts in the investigation of physiology and comfort of sportswear, body-mapping sportswear customized by function and development of personalized high-functional sportswear *(Fournet and Havenith, 2017)*.

The previous investigation conducted by authors of this paper was focused at the use of thermography to observe influences of different material characteristic in two thermal environments. The results indicated that the influence of material characteristics on the temperature of body zones is well seen in the moderate environment. Furthermore, it was shown that there is no uniformity of changes in the cold environmental conditions to confirm the influence of material characteristics *(Salopek Čubrić and Čubrić, 2018)*.

The research presented in this paper focuses at the use of thermography to observe influences of garment fit, activity level and gender to the changes of temperature on the clothing surface in moderate and cold thermal environments.

METHODOLOGY

The experimental part of the paper presented is focused towards the investigation of changes of skin temperature on lower part of the body. In the focus of scientific interest are changes of temperatures caused by the following four influencing factors (IFs):

- IF1: gender (female vs. male),
- IF2: trousers fit (loose vs. tight),
- IF3: air temperature (standard indoor vs. cold outdoor measured on volunteers wearing trousers) and
- IF4: human activity (stillness vs. running).

Definition of influencing factors

Detailed description of defined influencing factors (IFs) is given below.

a. IF1: Gender

For this investigation was important to compare results of temperature changes between male and female volunteer and at the same time to observe the influence of other influencing parameters, one at the time (fit, air temperature and human activity). Therefore, the investigation is focused at two volunteers of different gender. Both volunteers are in good health condition, with strong willingness to participate in the experiment and conduct all tasks completely in accordance with the instructions given.

The details regarding the volunteers are as follows:

- female volunteer: 40 years, height 162 cm, weight 53 kg, BMI 20;
- male volunteer: 44 years, height 185, weight 83, BMI 24.3.

b. IF2: Trousers fit

In order to observe the influence of trousers fit to the temperatures of the lower part of the body, different trousers are designed and prepared for experiment. In this case, this refers to two modifications of trousers regarding the fit, i.e. the loose and tight models. Trousers are additionally customized for male and female volunteers taking part in the experiment, considering their exact body measures.

c. IF3: Air temperature

In order to get more details on temperature distribution in different thermal environments, the investigation is carried out in two different environments, i.e.:

- indoor, where the air temperature was 22±0.1°C, relative humidity 60%, air velocity 0.5 m/s and
- cold outdoor, where the air temperature was 5±0.5°C, relative humidity 40%, air velocity 2.5 m/s.

d. IF4: Human activity

Regarding the influence of the activity to the changes of body temperature, the measurements are carried out before the activity, i.e. in the condition of stillness, as well as after moderate activity. The moderate activity within this experiment was running with average speed of 7.5 km/h, in duration of 30 minutes. The research is approved by Ethical Committee of the University of Zagreb Faculty of Textile Technology, on May 05, 2019. The Committee confirmed that proposed research is in accordance with research ethics, Code of Ethics of Croatian Science Foundation and the Code of Ethics of the Ethics Committee in Science and Higher Education.

Thermal measurement

The measurement of skin temperature is conducted using the thermal camera FLIR E6. The specifications of used camera are given in the Table 1.

Table 1. IR camera specifications (Flir)

Tablica 1. Specifikacije IR kamere (Flir)

IR Resolution	120 × 90
MSX Resolution	320 × 240
Thermal Sensitivity	<0.10°C
Field of View	45° × 34°
Detector	Uncooled Microbolometer
Screen	3.0 in. 320 × 240 colour LCD
Frame Rate	9 Hz
Image Modes	IR image, visual image, MSX, thumbnail gallery
Multi Spectral Dynamic Imaging	IR image with enhanced detail presentation
Temperature Range	0° to 150°C (Standard Range is –20°C to +250°C (–4°F to +482°F))
Accuracy	±5% or 5°C, whichever is greater, at 25°C (77°F) nominal (Standard Accuracy is ±2°C (±3.6°F) or ±2% of reading, for ambient temperature 10°C to 35°C (+50°F to 95°F) and object temperature above +0°C (+32°F))
Emissivity Correction	Variable from 0.1 to 1.0

The changes of skin temperature due to previously defined influencing factors are observed for the following zones of lower body: pelvis, upper thigh, lower thigh, knees, upper shin and lower shin, as shown in Figure 1.

The measurement with thermal camera is repeated 10 times for each participant and each observed combination of influencing factors, what makes in total 16 different combinations of influencing factors and 160 measurements in total, all listed in the Table 2.

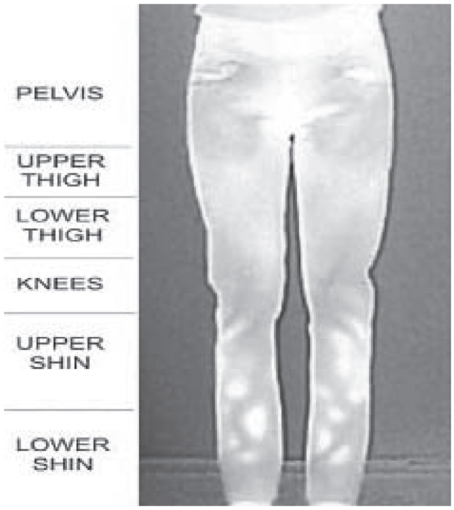


Figure 1. Observed zones

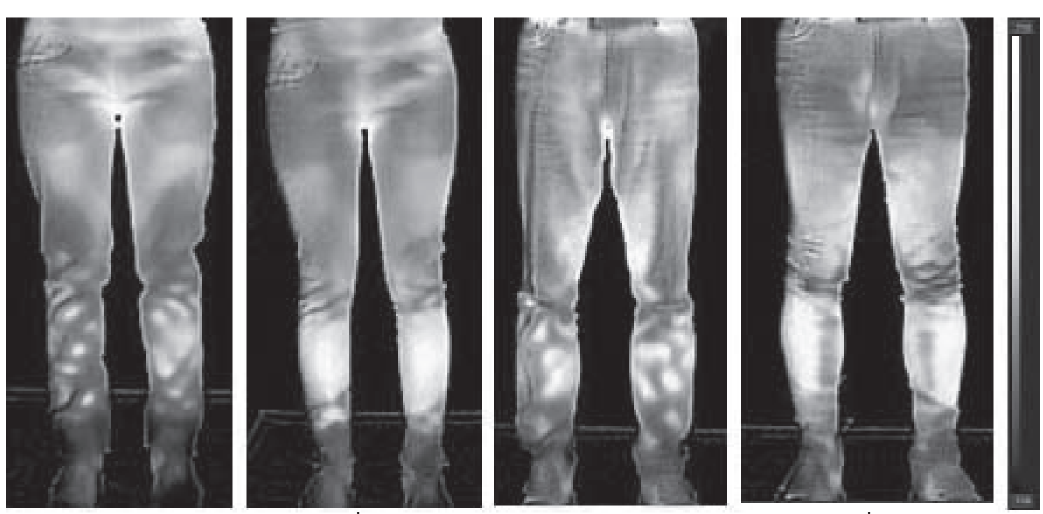
Slika 1. Promatrane zone

Table 2. Combinations of influencing factors

Tablica 2. Kombinacije utjecajnih čimbenika

Combi-nations	**Influencing factors**							
	IF1		**IF2**		**IF3**		**IF4**	
	female	male	loose	tight	indoor	outdoor	stillness	running
C1	x		x		x		x	
C2	x			x	x		x	
C3	x		x			x	x	
C4	x			x		x	x	
C5	x		x		x			x
C6	x			x				x
C7	x		x			x		x
C8	x			x		x		x
C9		x	x		x		x	
C10		x		x	x		x	
C11		x	x			x	x	
C12		x		x		x	x	
C13		x	x		x			x
C14		x		x				x
C15		x	x			x		x
C16		x		x		x		x

The analysis of thermograms taken under all of above defined combinations are analysed using the Flir Tools Software. The illustrative examples of thermograms presenting female and male participant wearing loose and tight trousers are shown in the Figure 2. The presented thermograms are taken indoor in the state of stillness.



a. b. c. d.

Figure 2. Examples of thermograms taken indoor for: a. female wearing loose model, b. female wearing tight model, c. male wearing loose model, d. male wearing tight model

Slika 2. Primjeri termograma dobivenih u zatvorenom za: a. žensku osobu odjevenu u prostrani model, b. žensku osobu odjevenu u tijesan model, c. mušku osobu u prostranom modelu odjeće, d. mušku osobu u tijesnom modelu odjeće

RESULTS AND DISCUSSION

Figures 3-6 give graphical presentation of average measured temperatures for observed body zones under different combination of influencing factors.

For all presented combinations of influencing factors, lowest temperatures are measured for the zone of lower shin, what is affected by higher circulation of air due to throusers oppenings.

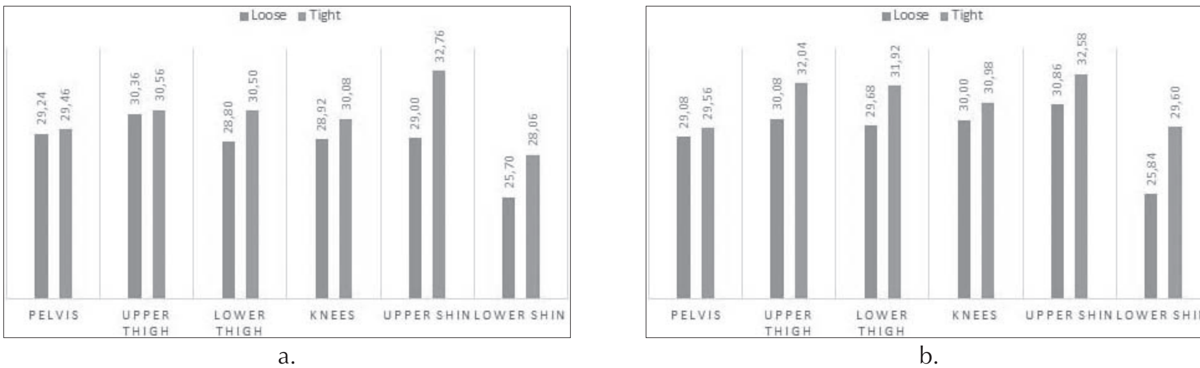


Figure 3. Temperatures (°C) of observed body zones taken indoor, without activity for: a. female, b. male

Slika 3. Temperature u stupnjevima Celzijusa promatranih zona tijela izmjerene u zatvorenom, bez aktivnosti za: a. žensku osobu, b. mušku osobu

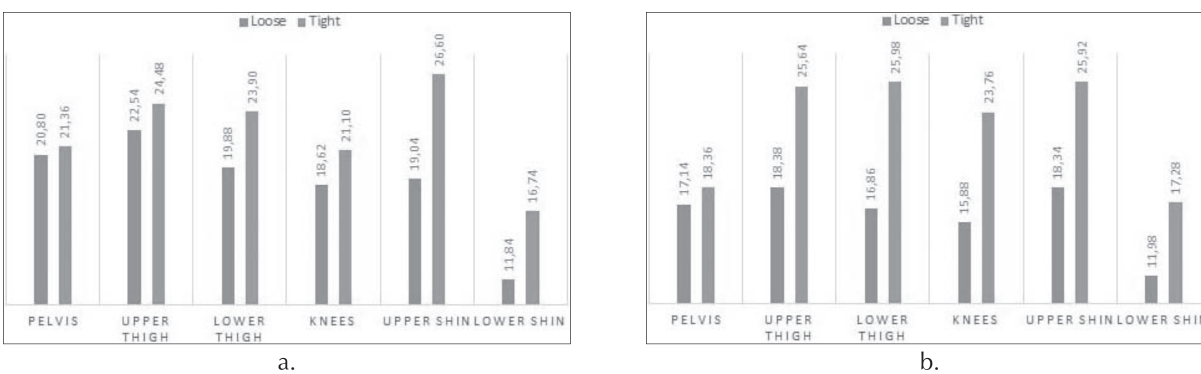
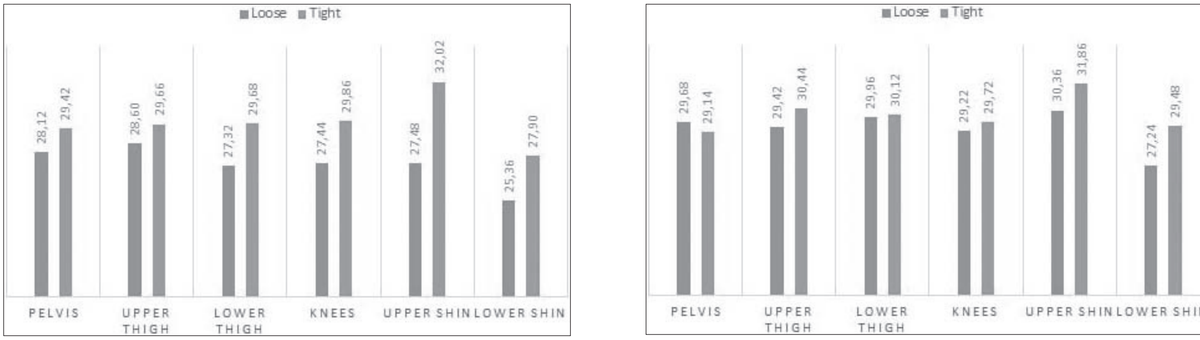


Figure 4. Temperatures (°C) of observed body zones taken outdoor, without activity for: a. female, b. male

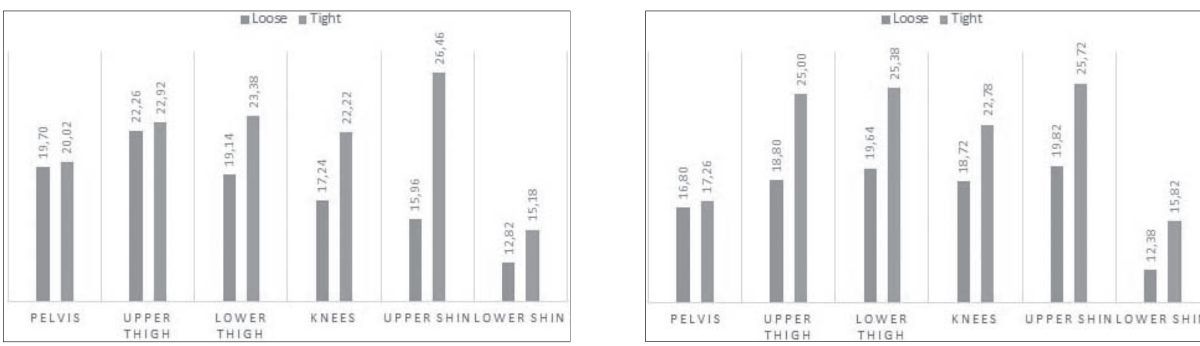
Slika 4. Temperature u stupnjevima Celzijusa promatranih zona tijela izmjerene u vanjskom prostoru, bez aktivnosti za: a. žensku osobu, b. mušku osobu



a. b.

Figure 5. Temperatures (°C) of observed body zones taken indoor, after activity for: a. female, b. male

Slika 5. Temperature u stupnjevima Celzijusa promatranih zona tijela u zatvorenom prostoru, nakon aktivnosti za: a. žensku osobu, b. mušku osobu



a. b.

Figure 6. Temperatures (°C) of observed body zones taken outdoor, after activity for: a. female, b. male

Slika 6. Temperature u stupnjevima Celzijusa promatranih zona tijela u vanjskom prostoru, nakon aktivnosti za: a. žensku osobu, b. mušku osobu

Regarding the remaining body zones, somewhat lower temperatures characterized zones of knees and pelvis. In the environmental conditions that may be associated with office work environments (indoor, temperature 22°C, without activity; Figure 3), slight differences between temperatures caused by trousers fit are observed for both female and male volunteer. Surprisingly, higher differences of average values are observed for the zone of upper shin (female volunteer only). In this case, the finding should be taken with caution because the standard deviation of the measured temperatures is a bit higher (i.e. equals to 0.45). The similar regularity is observed after activity, again for female volunteer only (Figure 5). The measurements taken without activity, but outdoor, in the cold environment revealed signifficant changes between the temperatures affected by throusers fit, both for female and male volunteer. The changes are especially prominent for the zones of upper and lower shin. Interestingly, higher changes for the zones of thight and knees are observed for male volunteer. The similar outcomes for male volunteer are demonstrated after the activity taken outdoor. Interestingly, under such conditions (i.e. activity in cold environment), highest differences are observed for female volunteer, preciselly, for the zone of upper shin.

The standard deviations of measured temperatures are given in the Table 3.

Table 3. Standard deviations of measured temperatures

Tablica 3. Standardne devijacije izmjerenih temperatura

Influencing factor				Body zone - standard deviation (°C)					
IF1	IF2	IF3	IF4	Pelvis	Upper thigh	Lower thigh	Knees	Upper shin	Lower shin
F	L	I	S	0,11	0,15	0,07	0,22	0,30	0,28
F	L	O	S	0,00	0,09	0,50	0,36	0,38	0,45
F	L	I	E	0,27	0,24	0,41	0,33	0,29	0,36
F	L	O	E	0,12	0,21	0,54	0,32	0,15	0,29
F	T	I	S	0,15	0,19	0,07	0,18	0,43	1,06
F	T	O	S	0,09	0,04	0,26	0,19	0,39	0,44
F	T	I	E	0,36	0,13	0,08	0,13	0,16	0,42
F	T	O	E	0,29	0,22	0,04	0,41	0,17	0,29
M	L	I	S	0,13	0,04	0,18	0,40	0,31	0,45
M	L	O	S	0,28	0,11	0,31	0,40	0,56	0,63
M	L	I	E	0,04	0,04	0,21	0,04	0,17	0,55
M	L	O	E	0,00	0,10	0,15	0,18	0,11	0,57
M	T	I	S	0,05	0,05	0,13	0,04	0,04	0,12
M	T	O	S	0,18	0,19	0,08	0,09	0,13	0,08
M	T	I	E	0,23	0,26	0,39	0,08	0,27	0,04
M	T	O	E	0,09	0,29	0,13	0,13	0,22	0,52

Table legend: F-female, M-male, L-loose, T-tight, I-indoor, O-outdoor, S-stillness, E-exercise

As can be seen from the Table 3, the standard deviation of measured temperatures are in the range 0,00-0,54°C for female volunteer and 0,00-0,63°C for the male volunteer. For the male volunteer, higher standard deviations are noted for the zones of lower thigh and lower shin. At the same time, lower values for the male volunteer are observed for the zone of lower shin only.

Lower body maps for both female and male volunteers are shown in the figures 7 and 8.

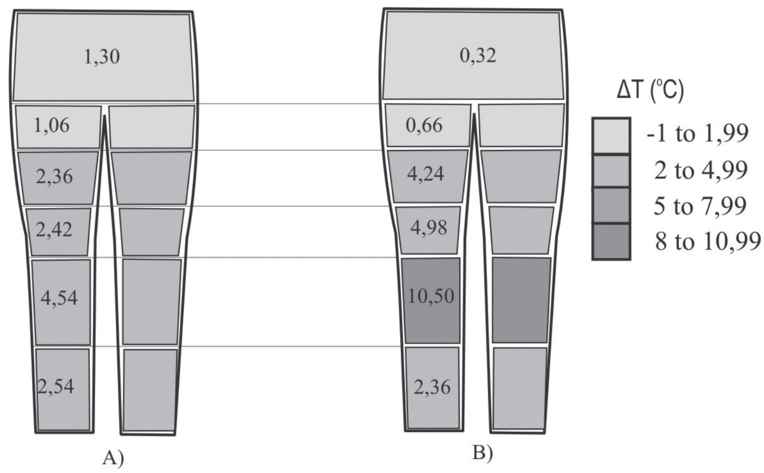


Figure 7. Body maps for female participant – differences in values of average temperatures considering IF2: a) indoor, running activity, b) outdoor, running activity

Figure 7. Tjelesne mape za ženu ispitanicu – razlike u vrijednostima prosječnih temperatura s obzirom na IF2: a) unutra, aktivnost trčanje, b) vani, aktivnost trčanje

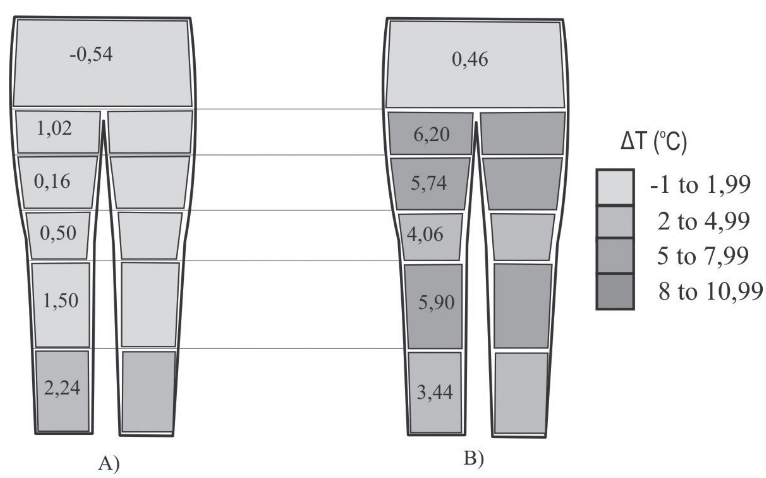


Figure 8. Body maps for male participant – differences in values of average temperatures considering IF2: a) indoor, running activity, b) outdoor, running activity

Slika 8. Tjelesne mape za muškog ispitanika – razlike u vrijednostima prosječnih temperatura s obzirom na IF2: a) unutra, aktivnost trčanje, b) vani, aktivnost trčanje

The maps present differences in values of average temperatures (ΔT; tight/loose) considering the IF2, i.e. the garment fit. Separate body maps are given for running activity conducted indoor (a.) and outdoor (b.). As can be seen from the figures, the temperature distribution patterns are quite different for male and female volunteers. Furthermore, the patterns for the same gender differ considering the IF3. In the indoor environment, tight model of female trousers has significant influence on the average temperature in the zone of upper shin (ΔT equals 4,54 °C). This observation is even more pronounced in the outdoor environment (ΔT in the upper shin zone is 10.50 °C). For the male volunteer, higher differences between temperatures are seen in the outdoor environment only.

CONCLUSION

The presented research focuses on the use of thermography to observe influences of different influencing factors (gender, trousers fit, air temperature and human activity) on the changes of lower body temperatures. Based on the outcomes of the research, the following conclusions can be drawn:

- fit of garment (in this case trousers) plays an important role for the retention of heat between the textile material and skin, especially in the zone of both upper and lower shin. This is especially pronounced in the cold environment for both female and male volunteer.
- the tight model of trousers shown preservation of the temperature in zones of thigh and knees of male volunteer both indoor and outdoor after running activity.
- in indoor conditions, lower difference in temperatures are observed. In this case, the zone of lower shin is more affected.

The body maps should find main implication in further physiological modelling (especially in the cold environment and for differences between genders) and clothing design (related to garment construction and optimal fit).

The current study was not specifically designed to include a large number of volunteers, so, given the number of participating volunteers, caution must be exercised. Results so far have been promising and will be used as basis for the follow-up research with inclusion a larger group of participants.

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TJELESNO MAPIRANJE POMOĆU TERMOGRAFSKIH MJERENJA PRI RAZLIČITIM UTJECAJNIM ČIMBENICIMA

SAŽETAK: Istraživanje se bavi korištenjem termografije za promatranje utjecaja različitih čimbenika na promjene temperature donjeg dijela tijela. Rezultati upućuju da pripijenost odjevnog predmeta ima važnu ulogu u zadržavanju topline između tekstilnog materijala i kože, posebno u zoni gornje i donje potkoljenice. Nadalje, samo pripijen model hlača može zadržati temperaturu u zonama natkoljenice i koljena kod muškog ispitanika. Predstavljene tjelesne mape prikazuju razlike vrijednosti prosječnih temperatura (ΔT) s obzirom na pripijenost odjevnog predmeta, tj. koliko tijesno ovaj pristaje uz tijelo. U zatvorenom prostoru tijesan model ženskih hlača znatno utječe na prosječnu temperaturu u zoni gornje potkoljenice. Ovaj je nalaz čak i više izražen u vanjskom prostoru. Kod muškog ispitanika veće razlike u temperaturi primjećuju se samo u vanjskom prostoru.

Ključne riječi: *udobnost, termografija, veličina (pripijenost) odjevnog predmeta, temperature, ispitanik volonter*

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