Quantitative validation of 3D garment simulation software for determination of air gap thickness in lower body garments

E Mert[1,2], A Psikuta[1], M Arevalo[3], C Charbonnier[4], C Luible-Bär[3], M A Bueno[2] and R M Rossi[1]

[1]Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Biomimetic Membranes and Textiles, St Gallen, Switzerland
[2]Université de Haute Alsace, Laboratoire de Physique et Mécanique Textiles, Ecole Nationale Supérieure d'Ingénieurs Sud Alsace, Mulhouse, France
[3]Haute Ecole d'Art et de Design Genève, University of Geneva, Geneva, Switzerland
[4]Artanim Foundation, Geneva, Switzerland
agnes.psikuta@empa.ch

Abstract. The heat and mass transfer through the garment to maintain the heat balance between the human body and the environment is dependent on the air gap thickness underneath the garment, which in turn is affected to a great extent by the body movement. Therefore, in this study, 3D garment simulation software was quantitatively validated by comparing the air gap thickness results obtained for stationary postures simulated by 3D simulation software and measured with 3D scanning method. The aim was to assess the capability of 3D garment simulation software to accurately determine air gap thickness distribution. Moreover, the effect of differences between air gap thickness of real and virtual garments on the thermal resistance of the garments was evaluated for individual body regions. It was found that the agreement between the two methods was within the range of 10 mm for air gap thickness. This difference resulted in small differences in thermal resistance for tight (up to $0.025 m^2K/W$) and loose fit (up to $0.013 m^2K/W$).

Key words: Air gap thickness, 3D garment simulation software, heat and mass transfer in clothing

1. Introduction

The clothing has a basic function to protect human body from external hazards and to keep it in a state of well-being [1]. The protective performance and comfort characteristics of clothing are not only affected by the isolative properties of the fabric used in the garment but also by the trapped air layer underneath the garment as well as the adjacent air layer above the garment [2, 3]. To date, the determination of air gap thickness was done on manikins which were in stationary postures using advanced 3D scanning methods [4-7]. Newly developed 3D scanners enable to evaluate the distribution of the air gap thickness on garments during movement by capturing up to 15 frames per second. However, the derivation of the air gap thickness between the skin and the garment would be impossible due to the poor posture and movement control (nude and dressed bodies need to be of exactly same shape for imposition and calculation of the parameters). On the other hand, 3D garment simulation software allows the simulation of the nude body as well as the garment on the body in desired static posture or during movement [8]. Based on these data, the air gap thickness for moving body can be calculated using 3D simulation tool. However, there is no quantitative validation of such tools in the literature. Therefore, the aim of this study was to quantitatively validate the 3D garment simulation software Fashionizer (MIRALab, Switzerland) by comparing the air gap thickness results obtained from this simulation software with the ones obtained from 3D scanning method to assess the capability of this tool to determine the air gap thickness distribution. Moreover, the effect of differences between the air gap thickness of real and virtual garments on the thermal resistance of the garments was evaluated for individual body regions to evaluate the significance of the 3D garment simulation software.

2. Methods

In this study, sweatpants in three different fits (tight, regular and loose) made out of knitted single jersey fabric (98% cotton (CO) and 2% Elastane (EL)) were used to confection the actual garments and to simulate the virtual garments. The physical properties of the fabric, such as weight, thickness, friction coefficient, bending and tensile strength, were characterized for the garment simulation. The properties of the knitted fabric are presented in Table 1.

The measurement of weight was done using a precision scale (according to ISO 9073-1:1989 [9]) and the measurement of thickness was carried out using Franc thickness tester (according to ISO 5084:1996 [10]). The “tilted plane” method was used to measure the friction coefficient of fabric. The angle when the fabric started to slide down was analyzed and the tangent of this angle was recorded as the static friction coefficient [8]. The bending property of the fabric was measured using the hanging (pear) loop length test in weft and warp directions [11]. The tensile strength of the fabric was characterized using TIRAtest 2703 (TIRA GmbH, Germany) in warp, weft and shear directions, separately.

Table 1. The properties of the fabric and the ease allowances of the garments used in the presented study.

Measured parameters of the sampled fabric	Single jersey (98% CO and 2% EL)
Weight (g/m^2)	225
Thickness (mm)	0.7
Friction coefficient to skin	0.53
Bending weft (N.m10^{-6})	0.6
Bending warp (N.m10^{-6})	1.2
Tensile strength weft (N/m)	200
Tensile strength warp (N/m)	120
Tensile strength shear (N/m)	100

To demonstrate the reliability of the 3D garment simulation software for the determination of the air gap thickness, a quantitative validation was done by comparing air gap thicknesses determined from the simulated avatar wearing virtual clothing with air gap thicknesses determined with actual garments on a motionless male manikin using 3D scanning and post-processing methods, described in previous studies [4]. Artec MHT 3D body scanner (Artec Group, USA), Fashionizer software and Geomagic Control 2015 (3D systems, USA) as further post-processing software were used in this study [4, 8].

To simulate the garments in 3D simulation software, the digitalization of the 2D patterns was necessary. The 2D paper patterns of the garments were fixed on a digitalization board (Lectra, France) and traced to obtain the virtual pattern in CAD software. For the 3D simulation of garments, the scanned body of manikin, virtual garment patterns and the characterized fabric properties were imported to the 3D simulation software. The virtual pattern pieces were placed around the avatar in so called T posture and virtually tailored. The garment was allowed to drape on the avatar and exported as obj file to Geomagic Control 2015 (3D systems, USA) for further post-processing [4]. The ease allowances of the sweatpants are presented in Table 2.

Table 2. Ease allowances of the garments used in the presented study.

Garment	**Ease allowances (cm)**		
	Hip	**Thigh**	**Lower legs**
Sweatpants in tight fit	6	3	-3
Sweatpants in regular fit	6	6	5
Sweatpants in loose fit	9	10	12.5

Moreover, the air gap thicknesses determined from actual and virtual garments were used in a steady state heat transfer model reported by Mert et al. [3] to assess the differences in the thermal resistance of the garments for individual body regions of real and virtual garments, such as anterior and posterior pelvis and thigh, shin and calf. The simulation was done under the air temperature of 20°C, skin temperature of 35°C, relative humidity of 50% and air velocity of 0.15 m/s for a single fabric layer with thermal resistance (Rct) of 0.022m^{2}K/W.

3. Results

Figure 1 presents the Tukey mean-difference plot (the difference of the air gap thickness of both methods on y-axis against the average of the air gap thickness of both methods on x-axis) for the air gap thickness observed in actual and virtual sweatpants for three different fits (tight, regular and loose). Additionally, the differences in the thermal resistance of real and virtual garments for tight and loose fits are presented in Figure 2.

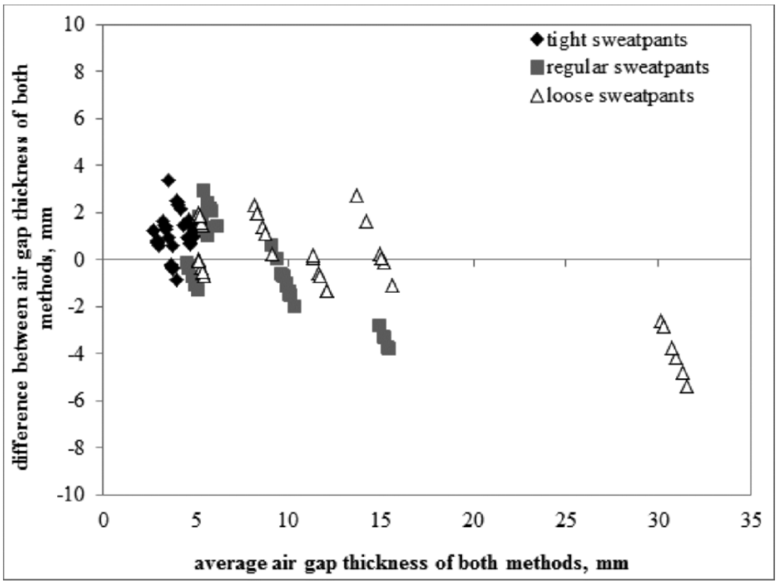

Figure 1 Tukey mean-difference plot for air gap thickness of actual and virtual sweatpants.

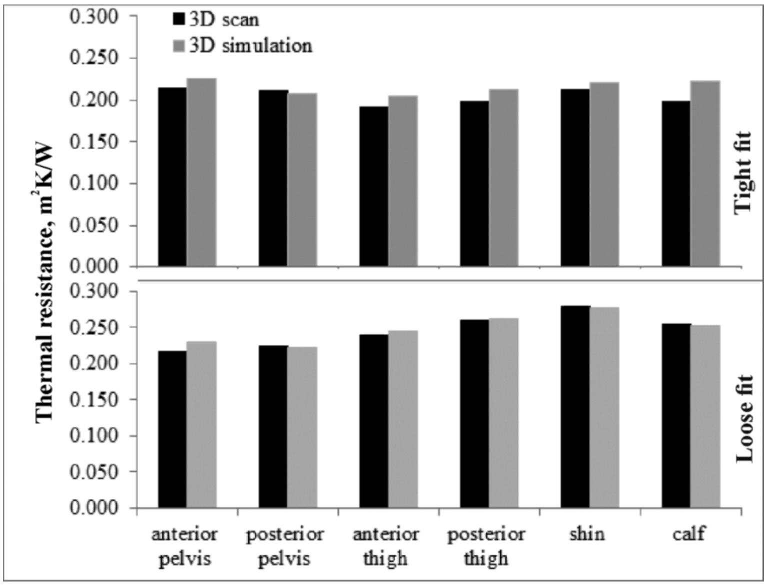

Figure 2 The thermal resistance of the real and virtual sweatpants for individual body regions.

4. Discussion

The presented study showed that the 3D simulation software was sensible enough to observe the differences in air gap thickness obtained from the virtual garment over body regions. The change in the air gap thickness of virtual garments over body regions followed the same trend as the real garments. For both air gap thickness results from real and virtual garments, the air gap thickness was smaller for convex body regions such as pelvis, anterior thigh and calf, whereas it was larger for concave body regions such as posterior thigh and shin.

The validation results showed that the agreement between the two methods was within a range of 10 mm for air gap thickness (Figure 1). It was observed that larger air gap thicknesses at the loose sweatpants let to more inaccurate results, as shown by the greater difference between the methods for larger air gap thickness. The reason for this difference between the air gap thickness of real and virtual garments is that the real garments were placed on the waist as it would be in reality, whereas it was not possible to place the waist line of the sweatpants (pin the garment on the manikin) at the desired place on the manikin using 3D simulation software. As a result, the distance between the elastic belt of the real garment and the belly button of the manikin was 5cm, whilst it was 2.5 cm between the belt of virtual garment and simulated manikin. However, as shown on figure 2, the differences in air gap thickness of actual and virtual garments (tight and loose fit) had only marginal effect on the thermal resistance for tight (up to 0.025m^{2}K/W) and loose fitted garments (up to 0.013m^{2}K/W), which proved the reliability and significance of 3D garment simulation software for lower body garments.

5. Conclusion

This study addressed for the first time the quantitative validation of 3D garment simulation software. Moreover, in this study, the analysis of error was related comprehensively to the thermal resistance of the garment. The differences between the two methods were within the range of 10 mm for the air gap thickness, which had only small effect on the thermal resistance of the tight (up to 0.025m^{2}K/W) and loose fitted garments (up to 0.013m^{2}K/W). These results prove the reliability and significance of 3D garment simulation software for lower body garments.

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