Use of 3D Body Scanning Technique to Investigate an Effect of Garment Design on Heat and Mass Transfer in Clothing

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Abstract

The heat and mass transfer in clothing do not only depend on the properties of fabric but also on the variation of the thickness of air layers and the magnitude of the contact area. The garment design and the body geometry have major influence on the above-mentioned parameters. Thus, this project addressed the effect of the fit of sport garments for female and male body shapes. Different garment designs were developed and confectioned considering anatomical and physiological gender differences. Each garment was subjected to 3D scanning and analysis of air gap thickness and contact area by imposing 3D scans of the nude and dressed manikin and advanced post-processing in dedicated software. It was found that the distribution of contact area and thickness of air layers is similar for both male and female upper body except for the breast and lumbar area. The knowledge gained from this study could be used to improve and individualize functional garments and to help in design process of body-mapped garments.

Keywords: air gap, clothing contact area, 3D body scanning, heat and mass transfer in clothing

1. Introduction

Manufacturers of clothing have developed a variety of fabrics and membranes that support natural physiological mechanisms to maintain the thermal balance of the human body, such as cooling by evaporation of sweat, and reducing or enhancing dry heat loss. Many new materials have been developed in the last years to make the “wear-experience” as positive as possible for the customer and to widen the range of climatic environments and the fields of application in which a garment can be worn. Particular attention is put on functional fabrics, whereas fit and pattern are rather elements of design than functionality. However, the fact that for an optimal effect of the fabric a certain fit is indispensable is often neglected. For example it is important to have a certain body contact to assure that the sweat will wick and cool the skin by evaporation instead of dripping off. Also the distance between body surface and garment and the stationary air that is trapped in between clothing layers plays an important role for heat resistance of clothing. On the other hand moving air can transfer significantly more heat in case of free or forced convection within a garment. Therefore, the air gap thickness and contact area between skin and garment are very important factors for heat and mass transfer in clothing.

A method to visualize air gaps and contact area with the help of a 3D Body scanner was recently developed at Empa [1, 2]. The development of this novel and accurate method opened a new horizon for clothing research.

The aim of this project was to experimentally determine trends in the distribution of the air gap thickness and contact area for male and female bodies and different garment types. For this reason, the distribution of the air gap thickness and contact area for the upper male and female bodies and for different garment types was experimentally determined. At first, information about the differences in female and male body features in terms of pattern making and physiological response were gathered to develop a theoretical guideline for a dedicated best functional garment. Furthermore, different garment designs were developed and confectioned accordingly to gain understanding of how differently fitted garments drape around the body and how air gap thickness and contact area are distributed.

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2. Methods

2.1 Manikins

In our study a motionless male and female manikins (Figure 1) were scanned nude or dressed in sample clothing in standing position. To ensure a stable and reproducible position of the manikin during the test, special locks preventing movement and twisting of the body parts and a supporting construction for arms and legs were used.

Figure 1. Male and female manikins used in this study in front and back view.

2.2 Garments

The design of the sample garments for the male and female manikin was made considering heat loss and gender-related sweating patterns at various activity and environmental scenarios (Table 1). A loose fit was chosen to support ventilation in warm environment, so that the body can cool down to keep the core temperature stable. A tight fit was chosen to support evaporative cooling in two ways, namely, by prevention of the sweat which is held and evaporated from the T-shirt and by lateral transport of sweat to other body areas that sweat less so that the cooling area increases.

Table 1. Proposed T-shirt designs.

	Loose Fit	Tight Fit
Male design	 ease allowances on girth: chest = 12.0cm hips = 12.0cm	 ease allowances on girth: chest = -19.0cm waist = 4.0cm hips = -16.0cm
Female design	 ease allowances on girth: chest = 17.0cm hips = 11.0cm	 ease allowances on girth: chest = -7.5cm waist = -12.0cm hips = -14.0cm

2.3 Scanning and post-processing procedure

Scanning and post-processing procedure consists of the following steps [1, 2]:

- Scanning nude & dressed manikin using Artec MHT (Artec Group, USA);
- Cleaning and reorientation of the scans in dedicated software (Geomagic Qualify 12, USA);
- Alignment of the scans;
- Geometrical determination of the distance between super-imposed surfaces recognized as air gap thickness and contact area.

3. Results

The photographs and post-processed exemplary single 3D scans of T-shirts are shown in Figure 2. The distinction between contact area and air gap is indicated on the colour scale (green for contact area and yellow-red for air gap). Figure 3 show the mean air gap thickness and the mean contact area of six 3D scans repetitions and its standard deviation for each body part and for each studied male and female T-shirt, respectively.

Figure 2. Photographs and corresponding post-processed exemplary 3D scans indicating the contact area and the air gap thickness of the loose- and tight-fitting garments in male and female manikins.

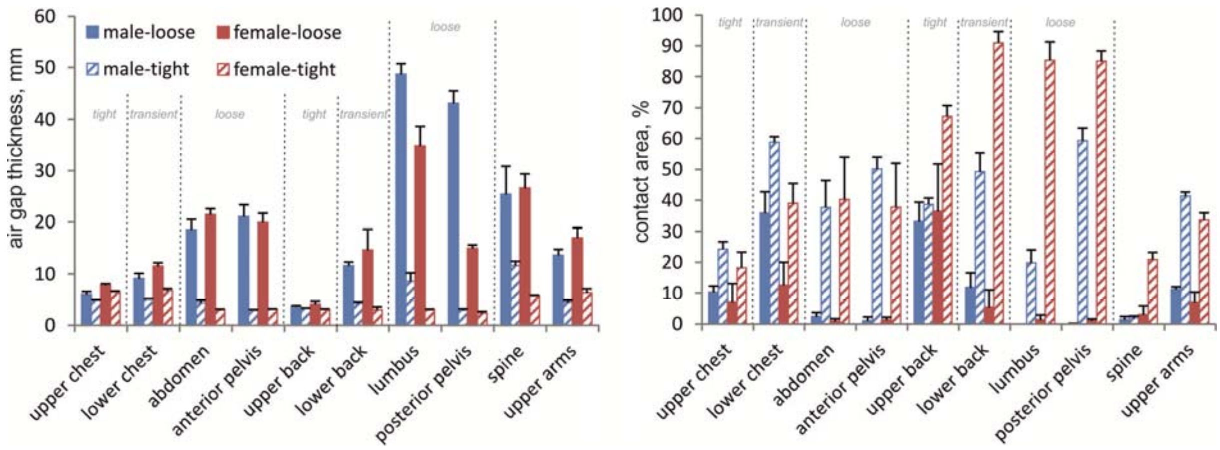

Figure 3. Comparison of the mean air gap thickness and contact area (and their standard deviation) for loose and tight T-shirts for male and female manikins.

4. Discussion

In general, with the decrease of ease allowance the air gap thickness decreased while the contact area increased for both gender designs. Additionally, three regions with distinct draping trends were distinguished, namely a ‘tight’ region, a ‘loose’ region and a ‘transient’ region. The shoulders, upper chest and upper back constitute the ‘tight’ region with usually larger contact area and small air gap thickness regardless of the garment fit. Since shoulders and inclined upper back and chest surface support the garment, it lies upon or close to the skin in this body region due to gravity force. The contact area at the upper chest is lower than expected as the garments were outspread between shoulders, breasts and collar bones so that the contact in the middle of upper chest was reduced (see figure 2).

Secondly, the abdomen, anterior pelvis, lumbus and posterior pelvis (‘loose’ region) provide the most of air gap volume, and the air gap thickness and contact area strongly depend on the garment fit. At the lower chest and lower back (‘transitory’ region) the draping behaviour of the garment is a mixture of trends in both adjacent regions. In these both regions the air gap thickness changed among the different fits and decreased with the decrease of ease allowances in the garment. This trend was more pronounced at the back than the chest. This observation suggests that increasing ease allowance induces draping towards the back, while the garment stays rather flat in the front.

The contact area was as expected almost 0 % at lower trunk for loose fit design and for both genders, because the garments supported by breasts and shoulder blades were hanging further away from the body. The only contact was created by inner parts of pleads and at the side seams, where the arms forced the garment closer towards the body. For the tight fit the contact area was noticeably greater in the ‘loose’ region for both genders.

The results shown in Figure 3 indicate that there is no great difference between the male and female loose fit designs for both air gap thickness and contact area at nearly all body parts. The only exceptions constitute greater air gap thickness at the lumbus and posterior pelvis and the greater contact area at the lower chest in male loose design as compared to female loose design.

The spine region showed a relatively high air gap thickness and almost no contact for loose fits. Since this area has a complex geometry (longitudinal depression accompanied by transverse convexity of shoulder blades), the small contact area was observed also in the tight fit designs with somewhat greater contact for female form due to the less pronounced shoulder shape.

The general expectation for the comparison between the same fit for male and female T-shirts was that due to the different breast anatomy the female manikin has less contact area on the upper and a greater air gap thickness on the lower chest than the male manikin. Also the female should have less air gap thickness on the back part, because of the less pronounced shoulder blades. His hypothesis was only partially supported by the results of this study. The contact area at lower chest in female manikin was lower than in male manikin and the air gap thickness slightly higher but there was no remarkable difference for both parameters at the upper chest and abdomen. Secondly, at the back of the body the air gap thickness was greater at the lumbus and posterior pelvis for male manikin due to more athletic shoulders and protruding shoulder blades.

5. Conclusions

It was found that the distribution of contact area and thickness of air layers is similar for both male and female upper body except for the breast and lumbar area. The results provided also information about the influence of pattern design on air gap thickness and contact area and how these parameters may potentially affect the thermal response of the human body in different environments. The knowledge gained from this study could be used to improve and individualize functional garments and to help in design process of body-mapped garments.

References

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