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Development of Design Detail for Clothing Thermal Comfort: Measurements with a Thermal Manikin

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PolyU – UoA 38

Contents

Development of Design Detail for Clothing Thermal Comfort: Measurements with a Thermal Manikin

Descriptor

Special treatments on fabric can reduce skin temperature. It can be achieved by special weaving/ knitting structures or high-wicking chemicals on fabric or yarns. In design aspects, such effect can be partly achieved by applying porous panels on the garment. However, limited research has been conducted to study other more effective design methods and their effectiveness with a scientific approach. To fill this research gap, this study developed a design detail, which was placed underneath the garment to enhance natural ventilation between the body and the layer of fabric. Basic T-shirt design was selected to test the feasibility of this design.

In order to evaluate the effectiveness of the new design with an objective measurement, a thermal manikin (Walter) was used. T-test was used to analyse the data collection. Thermal insulation (Rt) and water vapour resistance (Ret) were analysed in standing and walking postures. The tests were conducted in a climatic chamber at 20.0 °C and 65 percent RH with an air velocity of 0.3 m/s (no-wind condition) and 2 m/s (windy conditions). The results showed that the new design could reduce water vapour resistance of a conventional T-shirt in windy and walking conditions.

The new design detail proved to significantly reduce Ret of the thermal manikin in certain situations. Two academic articles were published which shared and discussed the results. Such findings had not been reported previously in any academic publications. This study justified and demonstrated how the new design method could improve the natural ventilation of a normal T-shirt, thus it began a new area of investigation within related fields. The results and methodology of the present study can allow the sports clothing industry to better target clients. Furthermore, this design can be applied to other types of garments for professional use, such as military and construction work.(300 words)

Researcher’s background

Dr. Ho’s research focus is on the investigation of functional clothing. He had experience to design functional uniform for Hong Kong sport team and adaptive clothing for health care centres. Apart from the practice-based research, he also investigates the relationship between design and comfort level of clothing with the support of scientific data. The examples included the development of design details to enhance garment’s thermal comfort; and the evaluation of garment construction to fit Chinese men with apple body shapes.

Research Context

To solve the problem of low air ventilation between the fabric layer and the skin surface, many different types of athletic garments have been designed with open apertures or vents (achieved by opening or the use of a mesh fabric) in certain areas to improve the release of body heat and moisture.

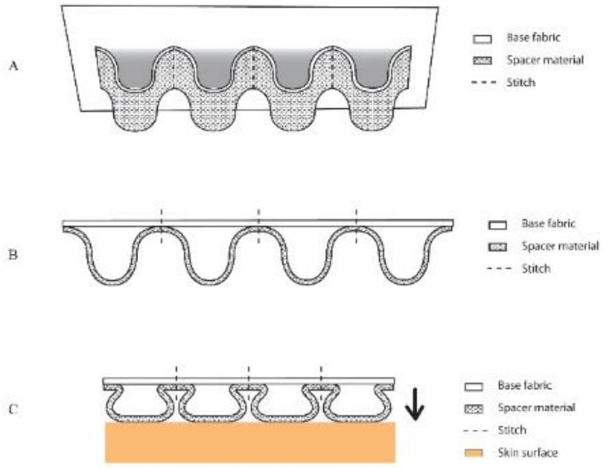
However, ventilation may be inhibited if the fabric clings to the wearer's skin. When properly worn, fabric of the garment should drape downwards, following the contours of the body (Ho et al, 2008). Thus, the fabric is in close contact with the shoulders, chest, and upper back. When the wearer starts to sweat, the fabric clings to these body areas, causing discomfort and loss of modesty. The clinging of the fabric to the skin eliminates the air gap and leads to sweat accumulation in the air gap, leading to decreased air flow. In addition, some sweat will be absorbed by the fabric, making it less porous and thus inhibiting heat and moisture exchange through the fabric.

To fill this research gap, a design that prevents the wet fabric from clinging to the upper body is designed for improving air ventilation. In order to testify this design method, a single-layer T-shirt was selected as the starting tool to start with. The design was tested by thermal manikin (Walter).

What constitutes the research output / body of work

Design detail

In this practice-led design research, a design principle and detail was developed: attaching spacer blocks to the garment for better circulation. This design was justified by the data analysed by a walkable thermal manikin.



Impact

Rather than producing a final product, this study reported the development of design details and the related evaluation data by the test of thermal manikin. This topic and findings were not published in any academic journals previously.

Academic publication (2015, 2016)

The related study areas were published and discussed in 2 international academic journals (please see next page for the list).

Research questions

The research sets out to

1. Design a new method to further improve natural ventilation of a garment.
2. Realize to what extend the new design method can reduce the clothing thermal insulation (R_t) and water vapour resistance (R_{et}) under the test on a walkable thermal manikin (Objective measurement) when compared to the conventional T-shirts

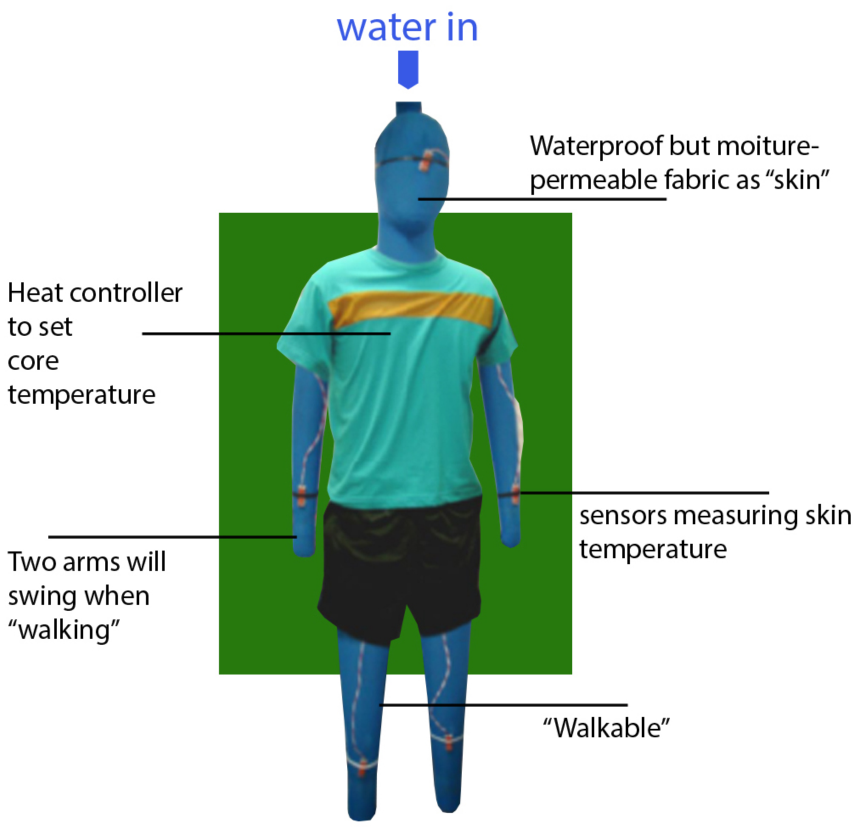
Research methodology

Sweating thermal manikin

All tests were conducted in a climatic chamber at 20.0±0.5°C and 65±02 percent RH with an air velocity of 0.3 m/s (no-wind condition) and 2±0.3 m/s (windy conditions). During the tests, the manikin remained in standing and walking postures (1.04km/hour).

The manikin was connected to a heat controller and sensors for measuring skin temperature. Because the manikin was covered with a waterproof but moisture-permeable fabric, it could simulate the sweating condition of a human body. It was filled with water to create a soft body similar to that of a human. Using a thermal manikin is an internationally standardized means of thermal evaluation in a controlled environment.

Data of clothing thermal insulation (*Rt*) and moisture vapour resistance (*Ret*) was collected for t-test and the coefficients of variation (to define the significance of the design) of repeated tests were <5.0 percent (Ho et al, 2015).



"Walter", a walkable thermal manikin installed in the Hong Kong Polytechnic University

Research methodology

Sweating thermal manikin

Clothing thermal insulation (*Rt*) and moisture vapour resistance (*Ret*) were the two major parameters for this study. Using a sweating fabric manikin enables determining these two parameters effectively (Fan and Chen, 2002). According to the specifications of the sweating thermal manikin, the total thermal insulation,

including the insulation of the clothing and surface air layer, is calculated as follows:

$$Rt = As\,(Ts - Ta)/Hs + Hp - He$$

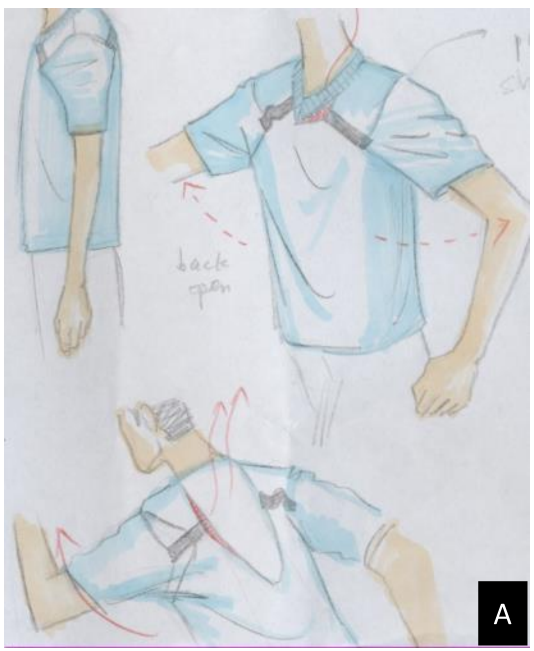
The total moisture vapour resistance, including that of the clothing and surface air layer, can be calculated using:

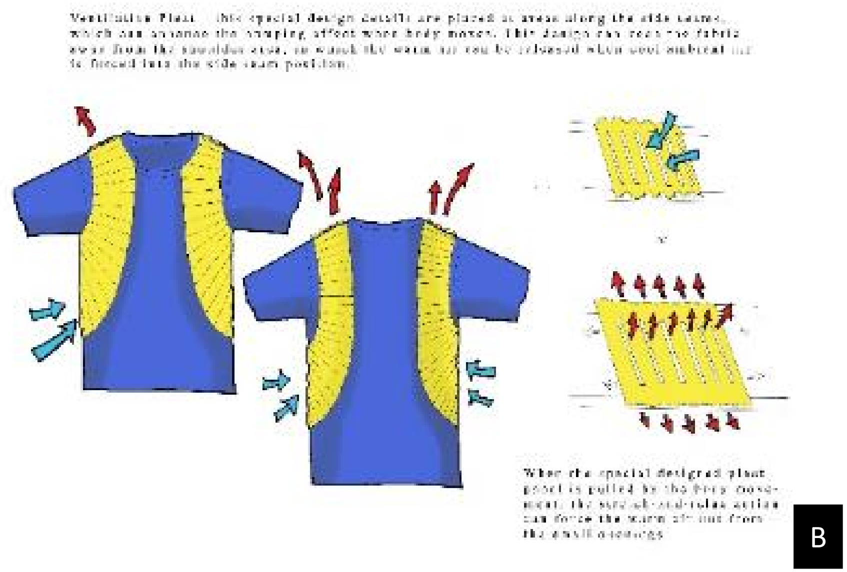
$$Ret = As\,[(P^*s - RHaP^*a)/He] - Res$$

where P^*s is the saturated water vapour pressure at the skin temperature, which is the water vapour pressure of the water film inside the skin.*RHa* is theRHof the surrounding environment as a fraction, P^*a *is* the saturated water vapour pressure in the surrounding environment and *Res* is the moisture vapour resistance of the skin.

Research material

The ventilative panels can be achieved by design details (such as cut holes on the garment) or open knit structure fabrics (such as mesh) which allow air to enter the microclimate between the skin and clothing to create more air circulation. Because of the open and porous knit structure of mesh fabric, air exchange is induced between the inside and outside of the garment. Because warm air rises, the mesh panels should be placed in the upper part of the garment, so that the warm air in the gap can circulate and be released through the open structure of the mesh fabric. When people move, the air within the microclimate of the garment can be forced to ambient temperature through the garment openings or fabric pores (Bouskill *et al.*, 2002; Havenith *et al.*, 1990; Nielsen *et al.*, 1985; Vokac *et al.*, 1973). The gap between the skin and inner fabric layer changes over time, depending on the level of activity and movement. During body movement, air enters and leaves as the fabric moves inwards and outwards towards the skin surface, thus causing the effects of ventilation (Ghaddar *et al.*, 2003). This ventilation of the clothing microclimate is known as the “pumping effect” (Olesen *et al.*, 1982; Vogt *et al.*,1983). However, this effect may be inhibited if the fabric layer clings to the skin surface, which blocks ventilation (Ho et al, 2015).





A & B. Rough sketches to explore the new idea.

Research material

DEVELOPMENT: Version 1

To enhance the pumping effect, piles of spacer material were cut to construct "shoulder pads" in the first trial, the similar concept was proposed in some patents (Bengtsson & Mullsjo, 1980; Lemonine, 1991; Moretti, 2002). However, the related report on its effectiveness and performance were not reported. Based on the idea, we developed the first version to have a better understanding.

The shoulder pads could be used for "propping up" the garment, but if excessive piles of spacer material were stacked together, it was considered to be possibly too heavy for the wearer. Furthermore, the thickness of the material could increase thermal insulation by reducing air flow, although the spacer material is fabricated with porous material. Therefore, this method had to be modified (please see next page for the development) (Ho et al, 2015).

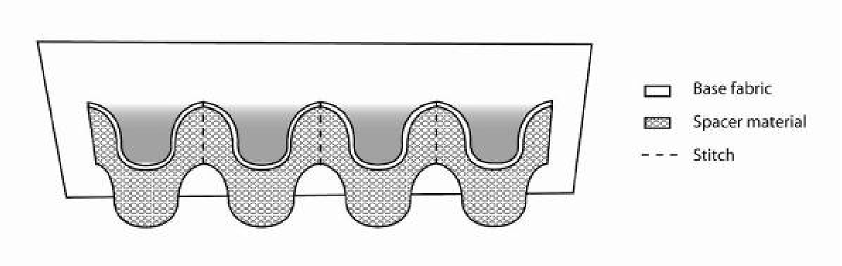
First attempt: Adding spacer block underneath the T-shirt

Research material

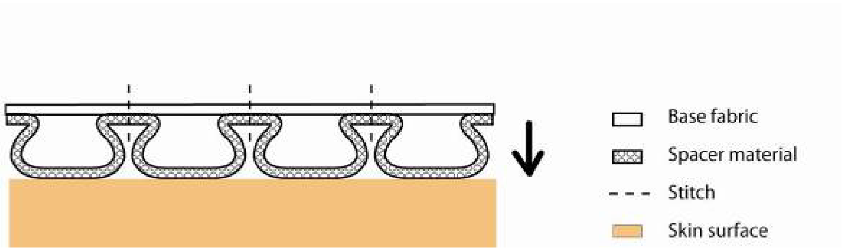
DEVELOPMENT: Version 2

To cope with the problem of the lack of air flow within the spacer object, a "U-shaped wave" shape was chosen to solve the problem. In this construction, wider space was created between the layers of the spacer materials so that theoretically it would not keep still air inside the spacer material, thus increasing the flow of air penetration in, which would contribute to the transfer of heat and moisture from the skin.

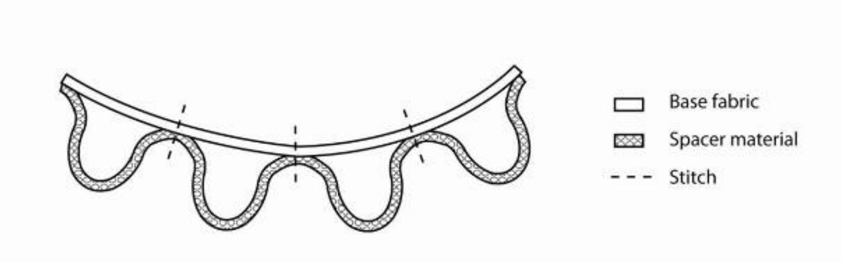
But there were two main problems that occurred once this design was made. The first problem was the collapse of the wave under weight. Although the spacer material used for the experiment was ideal in its stiffness, it could not hold the shape of the wave once the T-shirt was put on the body without distortion. This suggested that when the wave design material is put on the body, gravity and the
weight of the T-shirt press the wave downwards. This results in reduced distance between the garment and the skin surface i.e. reduced space and air circulation. Thus, the special construction had to be further developed to minimize the amount of
collapsing.



Development of wave construction of the spacer material



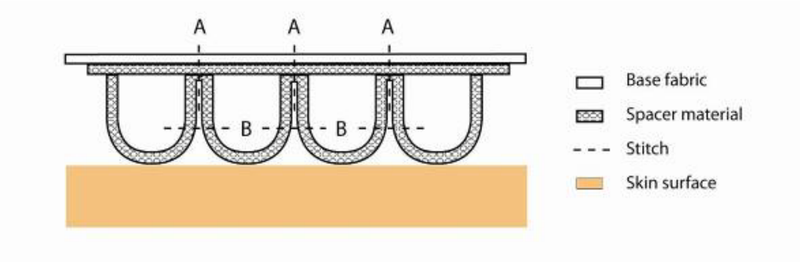
Collapse of the wave under the pressure of gravity and the T-shirt



Bending of the spacer material

Research material

In order to hold the shape of the wave without distortion or bending, loops were formed continuously so as to reduce the space between each individual "u-shaped wave". To solve the bending problem, a piece of flat spacer material was placed between the loops and T-shirt fabric to provide a stronger base. In addition, stitches "B" were placed so as to gather the loops together and stitch A was used to attach the loops and T-shirt fabric together. These two stitches eliminated the recovery ability of the spacer loops, so that the problem of bending was solved. Additionally, the stitch gathering the sides of each U-shaped wave together made them strong enough to support the weight of the garment, so that it was able to keep the desirable distance between the shell fabric and the body skin surface with minimum distortion.



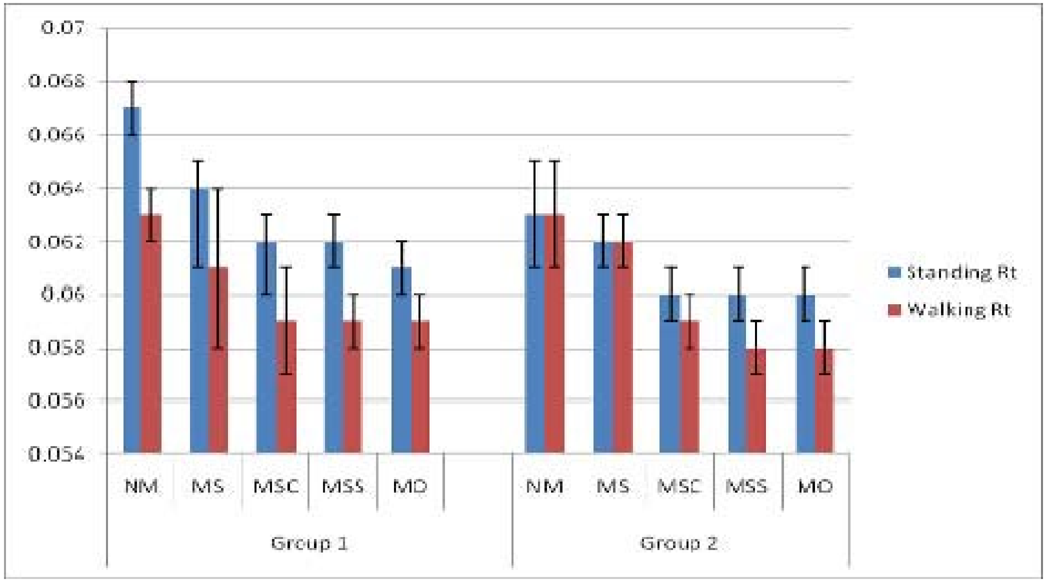
Design of the continuous loops of spacer material

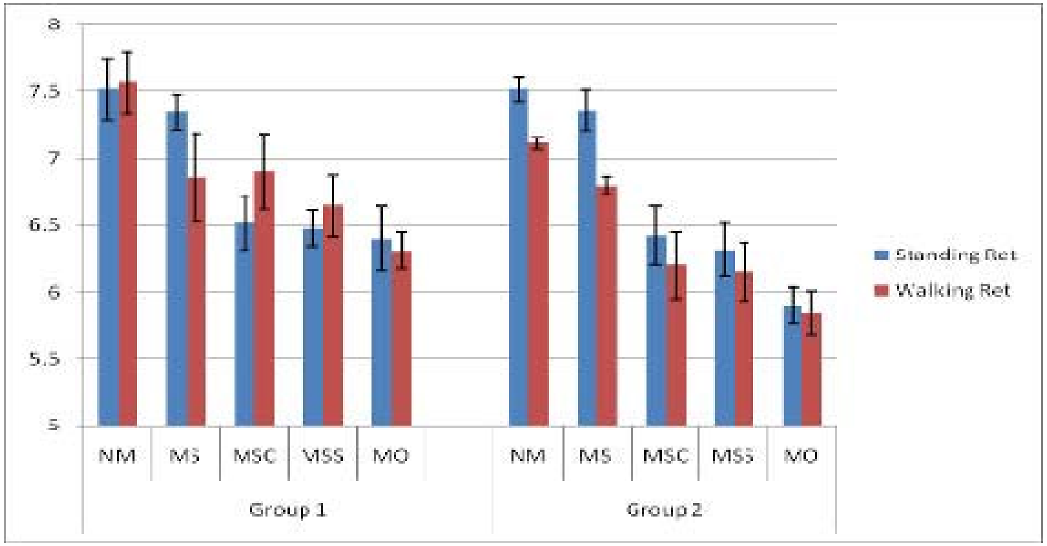
Spacer loops attached on the T-shirt

Research material

In order to further test the design concept using the new spacer loops, several T-shirts were made to evaluate the reduction in thermal insulation and moisture vapour resistance. Mesh panels were used in the new design as before, to act as a vented detail for achieving the chimney effect or ventilation. The designs were divided into two groups: with and without spacer loops located underneath the shoulders. Each group of design comprised five styles, with different placement of mesh panels. All T-shirts were constructed of the same size.

The figures at the right side shows the Rt and Ret data of two groups of T-shirts in windy condition.





Research material (testing result of phase 1 design)

Ho et al, 2015. T-shirt with propping effect for natural ventilation: Design development and evaluation of its functionality by thermal manikin in standing and walking motions, Journal of Textile Science and Engineering, *5* (5), 1000210

The data show that for a standing posture under windy conditions, open meshes on the shoulders are not as effective in releasing moisture vapor, irrespective of the presence of spacer loops. This suggests that the convection or chimney effect is not as effective for this design, unlike other designs with mesh panels placed across the chest, or two front vertical side panels near the side seams, even when both panels were kept open. It can be seen that when the meshes were placed only on the shoulders, approximately 2% lower Ret was recorded as opposed to the control piece ($t(4)=1.009$, $p=0.37$). Once the mesh panels of other body parts were opened, the percentage of reduction increased from approximately 2% to 13-14%, and the differences were significant (MSC: $t(4)=5.986$, $p=0.004$; MSS: $t(4)=6.818$, $p=0.002$; MO: $t(4)=5.836$, $p=0.004$). This indicates that vented designs placed solely on the shoulders cannot achieve a chimney effect, although moisture vapor would still be released from the porous fabric. However, if mesh panels were placed on other body parts at the same time, the ventilation effect would be more relevant. This result showed that dry air could enter the T-shirt through these mesh panels, and carry away the moisture vapor by natural convection.

The test results showed that the expansion of the air gap between the skin surface and garment layer could contribute to a certain degree of heat and moisture transfer. All these T-shirts were made of 100 percent cotton fabric without specification of the air and water vapour permeability. This study did not investigate how this design method (i.e. increasing the air gap between the garment and body, and incorporating ventilative panels to improve air circulation) can benefit garments made of fabric with higher air permeability.

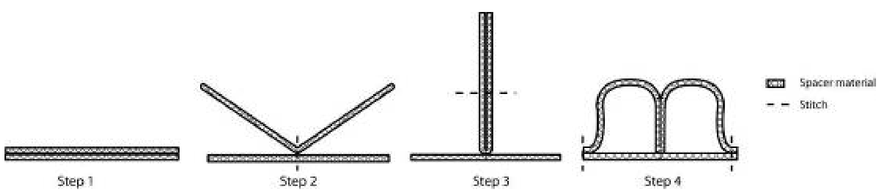
Thus, next development phase (in next few pages) aimed to further develop this concept by improving the construction of the spacer blocks to enable the chimney effect of the garment. Fabric with higher air and water vapour permeability was used to determine whether this design method is applicable to higher performance on heat and moisture transfer.

Research material

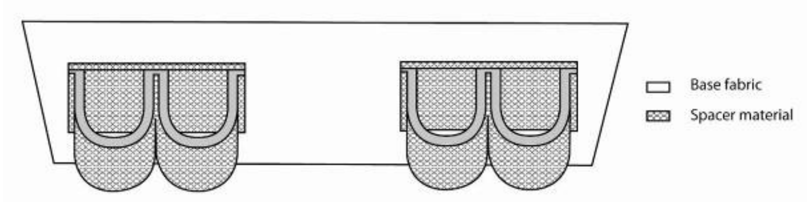
Ho et al, 2016. Effect of athletic T-shirt designs on natural ventilation, *Research Journal of Textile and Apparel*, *20*(2), 112 - 123

DEVELOPMENT: Version 3

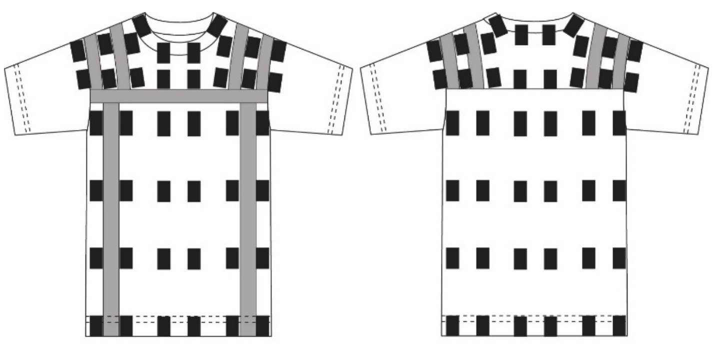
A chain of spacer loops could not be generated by a sewing machine, although the stitches were important as they could lock two spacer loops firmly to solve the problem of bending and collapsing. Hence, a new design was developed. The figures show a construction of the spacer blocks. By using this new design, all the sewing could be done with a sewing machine, and the loops were still locked by stitch B in order to secure it and avoid collapse due to the relatively heavy weight of the garment.



Construction process of the single spacer loops



Outlook of the spacer blocks formed by two loops



All T-shirts in this study were made of 100% polyester fabric with higher air (over 400 at 100 Pa) and water vapour permeability (over 72 in initial status).

This time, the placement of the spacer blocks is placed around the body instead of the shoulders only.

Research material

Ho et al, 2016. Effect of athletic T-shirt designs on natural ventilation, *Research Journal of Textile and Apparel*, *20*(2), 112 - 123

Testing Results

			NM	MS	MSC	MSS	MO
R_t	Standing	Group A (no spacer blocks)	0%	-3.2%	-3.2%	-4%	-5.6%
		Group B (with spacer blocks)	-2.4%	-5.6%	-4.8%	-4%	-6.4%
	Walking	Group A (no spacer blocks)	0%	-0.9%	-0.9%	-2%	-2.7%
		Group B (with spacer blocks)	-0.9%	-2%	-2.7%	-4%	-4.4%
R_{et}	Standing	Group A (no spacer blocks)	0%	-7.4%	-7.2%	-8.1%	-9.2%
		Group B (with spacer blocks)	-0.7%	-12.7%	-11.5%	-13%	-13.7%
	Walking	Group A (no spacer blocks)	0%	-1.2%	-4.8%	-6%	-6.3%
		Group B (with spacer blocks)	-1.4%	-4.5%	-5.1%	-9%	-11.5%

Percentage change of Rt and Ret of all T-shirts under no-wind condition

			NM	MS	MSC	MSS	MO
R_t	Standing	Group A (no spacer blocks)	0%	-1.6%	-1.6%	-5%	-4.8%
		Group B (with spacer blocks)	-3.2%	-3.2%	-7.9%	-4.8%	-7.9%
	Walking	Group A (no spacer blocks)	0%	-1.6%	-1.6%	-4.9%	-4.9%
		Group B (with spacer blocks)	-4.9%	-4.9%	-6.6%	-3.3%	-8.2%
R_{et}	Standing	Group A (no spacer blocks)	0%	-5.8%	-6.2%	-7%	-7.5%
		Group B (with spacer blocks)	-0.3%	-7.8%	-11.8%	-8.8%	-14.6%
	Walking	Group A (no spacer blocks)	0%	-5%	-10.7%	-7.5%	-11.3%
		Group B (with spacer blocks)	-5.1%	-8.2%	-16.8%	-12.4%	-17.4%

Percentage change of Rt and Ret of all T-shirts under windy condition

Research material

Ho et al, 2016. Effect of athletic T-shirt designs on natural ventilation, *Research Journal of Textile and Apparel*, *20*(2), 112 - 123

The fabric used for making the T-shirts was recorded as having high air permeability. In general, the fabric could contribute to reducing *Rt* and *Ret* significantly only under the windy condition. For the NM and MO styles without spacer blocks, for example, the MO styles reduced *Rt* and *Ret* by 5.6 and 9.2 per cent under a no-wind standing condition, by 2.7 and 6.3 per cent under a no-wind walking condition, by 4.8 and 7.5 per cent under a windy standing condition and by 4.9 and 11.3 per cent relative to the NM design (without spacer blocks), respectively, under a windy walking condition. When spacer blocks were added to the design, the reduction was 6.4 and 13.65 under a no-wind standing condition, 4.42 and 11.5 per cent under a no-wind walking condition, 7.9 and 14.6 per cent under a windy standing condition and 8.2 and17.4 per cent, compared with the NM (with spacer blocks) design under a windy walking condition.

Of all the designs, MO with spacer blocks achieved the lowest values for the reduction of *Rt* and *Ret* in both the standing and walking postures under windy conditions. When the thermal manikin was standing under a windy condition, MO with spacer blocks reduced *Rt* by 7.9 per cent and *Ret* by 14.6 per cent, compared with the NM design without spacer blocks. MO with spacer blocks even had lower *Rt* and *Ret* values than those of MO without spacer blocks, with the difference being 3.1 per cent for *Rt* and 7.1 per cent for *Ret*. This indicates that although the thermal manikin was standing still without moving arms, the wind was sufficiently effective for strengthening the ventilation. The combination of the spacer blocks and vented panels improved the effective release of moisture vapour.

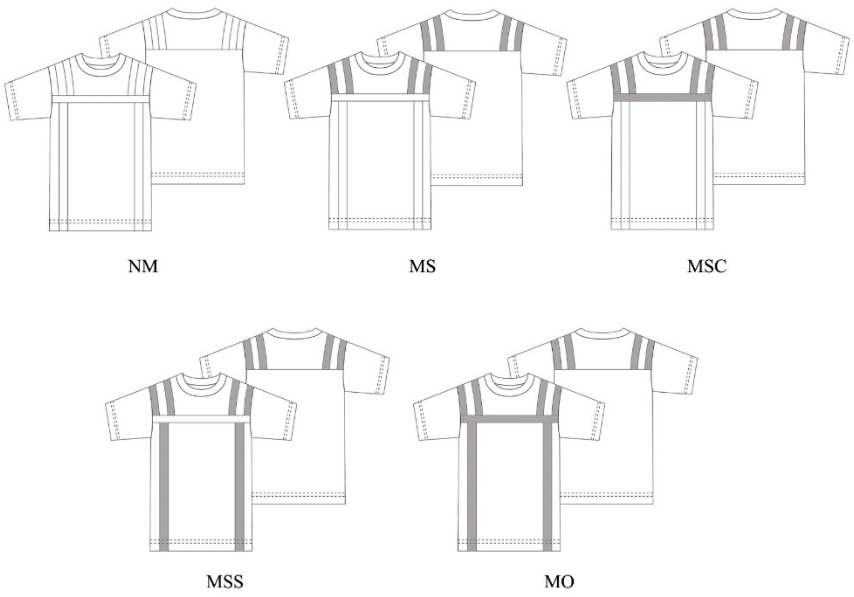
The ventilation was even stronger under the walking condition. The MO design with spacer blocks reduced *Rt* by 8.2 per cent and *Ret* by 17.4 per cent, compared with NM without spacer blocks. Comparing these results with the same style (MO) without spacer blocks shows that the T-shirt with spacer blocks lowered *Rt* by 3.3 per cent and *Ret* by 6.1 per cent (5.347); the difference was significant for reducing the moisture vapour resistance. The data suggest that this new design concept could allow a garment made of breathable fabric to further reduce the total thermal insulation and moisture vapour resistance when the vented chest, shoulder and two-side panels are applied.

Research material

Ho et al, 2016. Effect of athletic T-shirt designs on natural ventilation, *Research Journal of Textile and Apparel*, *20*(2), 112 - 123

Conclusion

Under the no-wind condition, the vented panels added on the T-shirts improved the total thermal insulation by 0.9-5.6 per cent and moisture vapour resistance by 1.2-9.2 per cent. When the spacer blocks were added, improvement was recorded from 0.9 to 6.4 per cent for total thermal insulation and from 0.7 to 13.7 per cent in moisture vapour resistance. The improvement of the percentage was markedly higher when more vented panels were added on the garment. Under the windy condition, T-shirts with vented panels improved the total thermal insulation from 1.6 to 5 per cent and moisture vapour resistance from 3.2 to 8.2 per cent. A T-shirt with vented panels and spacer blocks could improve the total thermal insulation from 3.2 to 7.9 per cent and moisture vapour resistance from 5.1 to 17.4 per cent, except for NM in Group B, which showed no improvement. This result indicates that this design concept was more effective at reducing the moisture vapour resistance under all conditions, when vented panels were incorporated into the T-shirt design.



Dissemination and distribution of outcomes

Refereed journal articles

Year	Title/journal
2016	Effect of athletic T-shirt designs on natural ventilation, *Research Journal of Textile and Apparel*, *20* (2), 112 - 123 (doi: 10.1108/RJTA-12-2015-0035)
2015	T-shirt with propping effect for natural ventilation: Design development and evaluation of its functionality by thermal manikin in standing and walking motions, Journal of Textile Science and Engineering, *5* (5), 1000210 (open access journal) (http://ira.lib.polyu.edu.hk/handle/10397/67309)

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Declaration