

Effect of clothing ventilation on thermal insulation and vapor resistance

Xiaoqun Dai¹ and George Havenith²

*1 Soochow University, College of Textile and Clothing Engineering,
Suzhou, 215006, P. R. China*

*2 Loughborough University, Human Thermal Environments Laboratory, Department of Human
Sciences, Loughborough, LE11 3TU, UK*

Contact person: daixqsz@suda.edu.cn

Abstract: In this study, ventilation of clothing microenvironment, thermal insulation and vapor resistance of two jackets made of different materials were measured locally at front, back, side and arm by using an articulated thermal manikin in a controlled climate chamber ($29\pm 1^\circ\text{C}$, $40\pm 10\%$ RH). The various conditions of microenvironment ventilation were created by making the manikin stand and walk, combined with three wind speeds of <0.15 , 0.4 and 2.0m/s respectively. The analysis of the measurement results showed that clothing ventilation affected vapor resistance more than it did thermal insulation. The effects of ventilation also varied because of different ways of ventilation arising: penetration through the fabric was proven to be the most effective way in vapor diffusion although it does not seem helpful for heat diffusion.

Keywords: clothing ventilation, heat transfer coefficient, vapor diffusion

INTRODUCTION

Clothing ventilation has been considered as a major pathway for heat and vapor transfer. Clothing materials, body posture, movement and wind are all influential on the ventilation of the microenvironment. Some study was carried to investigate the effect of material air permeability on ventilation (Ueda and Havenith 2002). Many efforts were made to predicting convective heat transfer coefficient from change of posture, movement and wind, based on the data in a reference condition like standing with no wind. The evaporative heat transfer coefficient or permeability index was then obtained through Lewis relation. However, the Lewis relation was proven not to be correct for many windy conditions. Since heat diffusion is the combination of convection and radiation, Havenith et al. tried to separate the convective and radiative heat resistance, and proposed a new vapor permeability index based on the convective heat resistance (Havenith, Heus et al. 1990), which was said to remain constant as the ventilation changed with movement and wind. However, as reported, the predicted values of i_m were lower than actual values. Some recent study showed that Lewis relation may not hold in low wind situation (Qian and Fan 2006). Here, the difference of the effect of penetration through fabric on heat and vapor transfer may need to be taken into consideration.

To investigate the effect of clothing ventilation (arising in different ways) on heat and vapor transfer, in this study, the local ventilation of the clothing microenvironment, thermal insulation and vapor resistance were measured by using an articulated thermal manikin. The various conditions of microenvironment ventilation were created by choosing garments of different materials, making the manikin stand and walk, combined with change of ambient air movement respectively.

METHODS

Clothing ensembles

Tops: To investigate the effect of materials on ventilation, two jackets of same style but made of different materials were used for the study. Jacket A was made of a waterproof and air impermeable material and jacket B was made of a normal textile material and thus air permeable. A long sleeve T-shirt and a jean were used as underwear and bottom for the two jackets.

Measurement of clothing microenvironment ventilation

Trace gas diffusion method was used to measure the ventilation on the body surface and argon was used as the trace gas (Lotens and Havenith 1988). A distribution tubing system was placed underneath the T-shirt to obtain as even as possible distribution of argon over the upper body surface, the sampling tubing system was placed similarly to the distribution one. To measure the local ventilation, additional single sampling tubes were also placed on the torso front, back, side and arm respectively.

Measurement of clothing thermal insulation and vapor resistance

The whole thermal insulation I_t and vapor resistance R_e , and the local ones at torso, front, back and arm for the two jackets were obtained by using an articulated thermal manikin, Newton (Measurement Technology Northwest) according to ISO 9920:2007. The manikin skin temperature was set as 35°C. The ambient temperature and relative humidity were set as 29±1°C and 40±10%.

Body movement and wind

To investigate the influence of movement of the body and the surrounding air, the manikin was set into two states: standing still and walking at a speed of 45±1steps/min. A wind channel was used to create the forward wind and the wind speed was set as 0.4, and 2.0m/s respectively. Together with the no wind (<0.2m/s), there were three conditions of air movement.

RESULTS

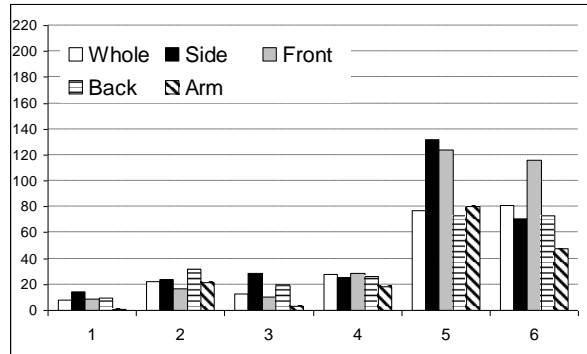
In Fig. 2, where 1 through 6 denote the conditions of standing and walking without wind, in wind of 0.4 and 2.0m/s respectively, the ventilation (V_A and V_B), heat transfer coefficients (h_{tA} , and h_{tB}), and the evaporative heat transfer coefficients (h_{eA} and h_{eB}) for jackets A and B are shown. The increases of V , h_t , and h_e due to walking, wind and material difference are listed in Table 1.

Microenvironment ventilation V

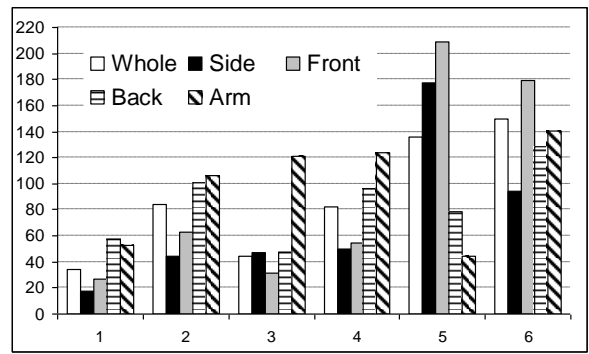
The clothing ventilation usually arises in three ways: by permeation through fabric, by natural convection through openings, or by the pumping or bellow effects resulting from body movements forcing air around clothing in or out through openings such as collars, cuffs, bottoms and other vents. Fig. 2(a) and (b) show the whole ventilation and the local ventilation at the side, front torso, back and arm. Obviously, the ventilation at each local place is different, maybe

because of the different local air pressure fluctuations due to differences in thickness of the gap between the manikin surface and the clothing.

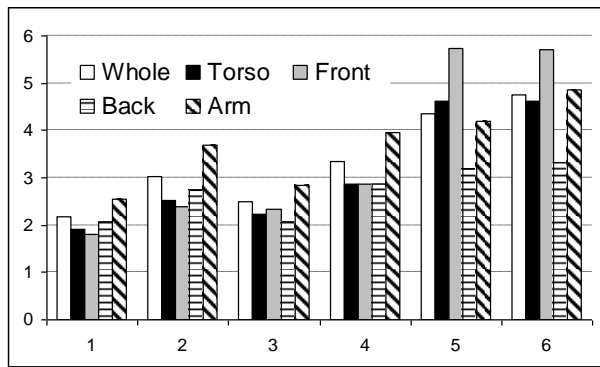
When there is no wind, the manikin stands still, the ventilation is the lowest among all the tests for the two jackets because only permeation through the fabric and natural convection take place. Since the two jackets are of same style, there should be little difference in natural convection through openings. Therefore, the big difference of ventilation (up to 76%) between the two jackets must result from the different air permeability of the two materials. However, as ventilation increases with walking and wind, this difference decreases.



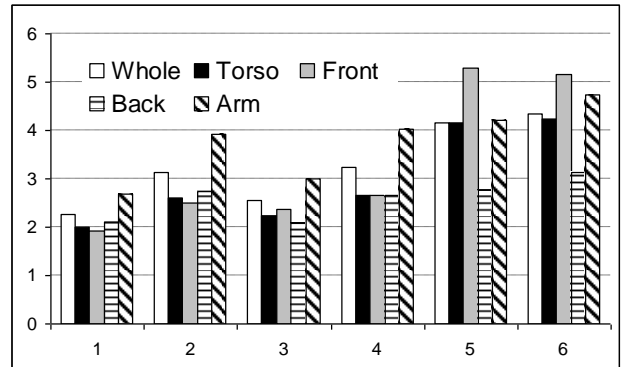
(a) V_A (l/min)



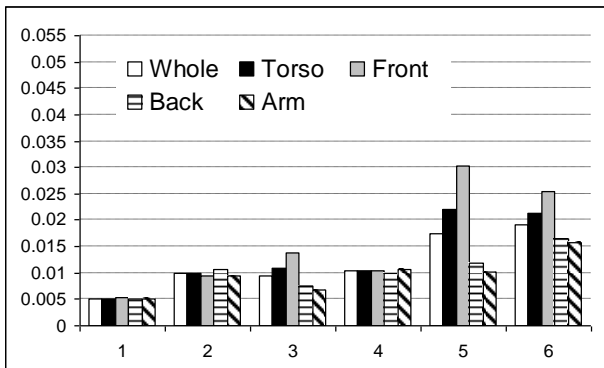
(b) V_B (l/min)



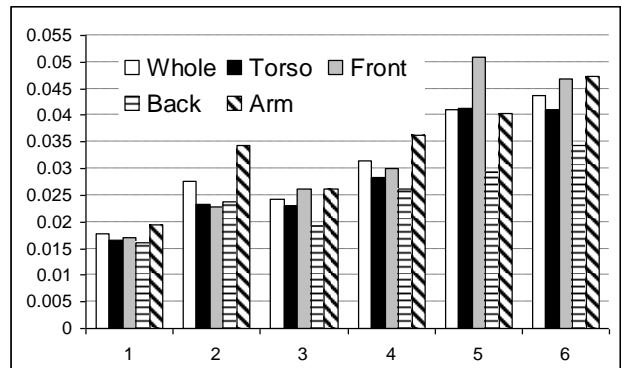
(c) h_{tA} (W/m^2K)



(d) h_{tB} (W/m^2K)



(e) h_{eA} (W/m^2K)



(f) h_{eB} (W/m^2K)

Figure 2 Ventilation, heat and evaporative heat transfer coefficients of two jackets

Table 1 Increase of V , h_t , and h_e due to walking, wind and material difference(%)

	1:Stand/no wind	2:Walk/no wind	3:Stand /0.4m/s	4:Walk /0.4m/s	5:Stand /2.0m/s	6:Walk /2.0m/s
ΔV_A	0	172.7	53.2	232.4	827.8	878.3
Δh_{tA}	0	39.3	15	53.3	100	119
Δh_{eA}	0	90.1	80.9	102.2	236.1	270.8
ΔV_B	0	147.7	29.2	140.8	297.2	338.8
Δh_{tB}	0	37.5	12.8	41.9	83.3	91.3
Δh_{eB}	0	56.5	37.4	78.2	131.5	146.7
$(V_B - V_A)/V_A$	75.7	73.3	71.2	66.5	43.4	45.9
$(h_{tB} - h_{tA})/h_{tA}$	4.3	3	2.5	-3.3	-4.3	-9.5
$(h_{eB} - h_{eA})/h_{eA}$	70.8	64.5	61.6	66.9	57.6	56.1

For the manikin walking without wind, the ventilation increased by 173% for A and 148% for B, confirming the strong effect of pumping. For the lower wind of 0.4m/s, ventilation for the standing manikin increased by 53%(A) (29%, B) from the no wind condition, which was not comparable with the increase resulting from walking at all. However, when the wind speed was as high as 2.0m/s, the ventilation increased up to 828% for jacket A (132%, B) from the no wind condition, and the ventilation increase due to walking was small. This indicated that the forced convection by the high wind was the major way of ventilation while the pumping effect of movement seemed no longer to have significant effect on ventilation. So, an interaction of these two effects was present.

Moreover, for both jackets, the side and front ventilation of standing were obviously higher than the respective ones of walking although the whole ventilation of standing was lower than that of walking as expected. This could be considered that as the forward wind blowing air to the back, the arms' swing may break the blowing and reduce the forced ventilation.

Heat transfer coefficient h_t

As shown in Fig. 2(c) and (d), the heat transfer coefficient h_t (the inverse of the total thermal insulation I_t) increased as the wind speed increasing and body walking. However, compared with the high speed wind of 2.0m/s, the effect of natural convection and pumping was less. Moreover, values of h_t shown in Fig. 2(c) were close to the respective ones in Fig. 2(d), indicating that the different air permeability of the jacket materials had no significant effect on heat loss.

Usually, there are three ways for manikin's heat loss: radiation, convection and conduction. When the manikin stands still without wind, the major way of heat loss is radiation, heat loss of natural convection and conduction through fabric is very little. The increases of h_t due to wind 15% for A and 13% for B were lower than those resulting from pumping effect. However, when the wind speed is very high, heat diffusion due to the forced convection comes to be as much as that of radiation because the increase was up to 132%. In addition, for two jackets, the value of the heat transfer coefficient at front of manikin standing in the wind of 2.0m/s was higher than that when walking in the same wind. This was consistent with the ventilation results, confirming further that the ventilation resulting from forced convection is another major way for heat loss.

Evaporative heat transfer coefficient h_e

Fig. 2(e) and (f) show the evaporative heat transfer coefficient h_e (the inverse of the vapor resistance). For jacket A, which was made of waterproof material and was supposed to be poor of vapor permeability, h_e of the manikin standing without wind was very low because vapor diffusion occurred only through the natural convection through openings. On the contrary, h_e for jacket B under the same situation was more than three times higher, showing that vapor penetration through fabrics in this condition played a far greater role in vapor transfer than natural convection (Havenith, Heus et al. 1990).

For both jackets, both walking and low wind enhanced vapor diffusion to similar extent, the increases agreed with the respective ventilation increases, proving the effect of pumping and enhanced surrounding convection in vapor diffusion. As the wind speed increasing, the pumping effect on vapor diffusion reduced. As shown in Table 1, the increase of h_e was up to 270%, far higher than that of h_t which was up to 119% although the increase of h_e was not proportional to the increase of V either.

In general, difference of h_e between two jackets, which was up to 71% (stand without wind), was much greater than that of h_t , which was lower than 10%. It confirmed that ventilation from penetration through fabrics plays a main role in vapor diffusion than it does in heat loss. Moreover, as show in Table 1, the difference of V between the two jackets under same condition was consistent with that of h_e indicating that no matter how the movement and wind change the ventilation and vapor resistance, the penetration through fabric and its effect on vapor transfer seems to keep constant.

CONCLUSIONS

In this study, to investigate the effect of clothing ventilation on heat and vapor diffusion, ventilation of clothing microenvironment, thermal insulation and vapor resistance were measured on two jackets made of different materials worn on an articulated thermal manikin respectively. It was confirmed that clothing ventilation affects more on vapor resistance than it does on thermal insulation. Moreover, the effects of ventilation on heat and vapor diffusion varied because of different ways of ventilation arising, penetration through fabric was proved to be the most effective way in vapor diffusion although it seemed not helpful for heat diffusion.

REFERENCES

- Havenith, G., R. Heus, et al. (1990). Clothing ventilation, vapour resistance and permeability index: changes due to posture, movement and wind. *Ergonomics* 33(8): 989-1005.
- Havenith, G., R. Heus, et al. (1990). Resultant clothing insulation: a function of body movement, posture, wind, clothing fit and ensemble thickness. *Ergonomics* 33(1): 67-84.
- Lotens, W. A. and G. Havenith (1988). Ventilation of rainwear determined by a trace gas method. *Environmental Ergonomics*. I. B. Mekjavic, E. W. Banister and J. B. Morison. New York, Taylor & Francis: 162-176.
- Qian, X. M. and J. T. Fan (2006). Interactions of the surface heat and moisture transfer from the human body under varying climatic condisitons and walking speeds. *Applied Ergonomics* 37: 685-693.
- Ueda, H. and G. Havenith (2002). The effect of fabric air permeability on clothing ventilation. *Environmental Ergonomics* X, Fukuoka, Japan.