Textile Research Journal Article

Effect of Moisture Management on Functional Performance of Cold Protective Clothing

Abstract This paper reports a study on the effect of moisture management in the design of cold protective clothing. In this research, two kinds of clothing systems were tested, a traditional clothing system (clothing A), and a specially designed moisture management clothing system (clothing B). Both clothing systems have the same four-layer structure (underwear, vest, coat, and outer jacket), but with use of different functional fabrics. The experiments were conducted in a climate chamber where the temperature was controlled at –15 °C. Eleven young male subjects took part in wear trial experiments, in which they were dressed in clothing A or B and walked on a treadmill. The humidities and temperatures at the skin surface and at different layers of the clothing system were measured together with measurements of thermal and moisture sensations. The experimental results showed that the moisture management property of fabrics significantly affected the moisture diffusion and temperature distributions in the cold protective clothing systems, and influenced the thermal and moisture sensations.

Key words waterproof breathable fabric, wool, cotton, moisture management, moisture diffusion, temperature distribution, thermal sensation, moisture sensation

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In a cold environment, protective clothing is needed to protect the human body from severe cold. In order to get a comfortable thermal equivalence and physical sensation, appropriate clothing should be worn. On the one hand, the protective clothing should provide enough thermal insulation, and balance the heat loss and heat production in the body. On the other hand, the protective clothing should have good water vapor permeability to ensure that the water vapor produced by the human body can be easily disseminated through the clothing system. The human body regulates temperature effectively through the evaporation of perspiration [1]. At a given activity level, if the protective clothing has high water resistance, water vapor is accumulated in layers of the clothing system; when the water vapor concentration exceeds the saturation concentration level, condensation occurs, and water vapor becomes liquid water. The layers of the clothing system become wet, and the thermal conductivity of the wet layer increases. A wearer feels uncomfortable when the skin comes into contact with wet clothing. Further, as body heat cannot be disseminated though evaporation, the wearer will feel hot, humid and uncomfortable. When physical activity stops

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and the body cools down slowly, the thermal insulation of the wet inside layer of the clothing system will decrease dramatically and result in more heat loss through thermal conduction. The condensed liquid water will evaporate, take away heat, and cause serious “after-chill” discomfort [2].

Waterproof and breathable fabric is permeable for water vapor, but not permeable for wind and liquid water [3]. This property means that it is possible to keep the skin dry when cold protective clothing made from waterproof breathable fabric is worn [4].

Extensive research has been conducted to characterize the thermal insulation and water vapor permeability of clothing [5–8]. A series of indexes have been defined, including thermal resistance (Clo/Tog) and water vapor permeability (WVPI), together with development of test methods, instruments, thermal manikins, and testing standards. Meinander et al. (2004) reported that a correction on thermal insulation values determined with thermal manikins is needed at –25 °C [8]. These research works have laid the scientific foundation for the design and engineering of clothing and have been widely used to provide technical specifications for protective clothing, uniforms for defense forces, and high-performance sportswear. However, the test methods and test standards for thermal resistance and water vapor permeability have been mainly developed for the evaluation of clothing in the static/steady state without the presence of liquid water/sweat.

People who wear cold protective clothing are normally engaged in transient/dynamic activities, in which they may change their physical activities and/or go through different external environments such as different indoor/outdoor conditions. Under such dynamic/transient conditions, liquid water is likely to appear in the clothing systems due to sweating and/or condensations, which can cause significant changes in the thermal properties of clothing materials and temperature/moisture distributions in the clothing system. Hence, the management of water vapor transfer and liquid water transfer can become critically important in the design of clothing systems. The is a lack of studies into how the dynamic thermal functional and comfort performances are influenced by the moisture management properties of fabrics in the clothing systems, particularly for cold protective clothing. In this paper, we report a wear trial study with two clothing systems that have the same structure and with the use of different functional fabrics in the different layers for the purpose of revealing the effect of moisture management on the thermal functional and comfort performances of cold protective clothing.

Methods

Subjects

Eleven healthy male students volunteered as subjects and gave their consent to participate in the experiment. Their mean (with standard deviation) age, height, and weight were 21.4 (0.8) years, 1.73 (0.04) m, and 61.9 (6.7) kg respectively. Each subject was informed about the general purpose, procedure, and possible risk involved with the experiments. The basic requirements of the subjects are listed below:

1. Participants were self-reported good sleepers. They maintained a constant sleep–wake schedule one week prior to participation in this study.
2. Participants were free of medication.
3. Participants were required to refrain from heavy physical activity during the day prior to the experiment.
4. Participants were asked not to smoke, drink alcohol, tea, or coffee from the evening before the day of the experiment, until the measurements were performed.
5. The nature and purpose of the study was explained before participants gave written consent.

The protocol was approved by the Hong Kong Polytechnic University Human Subjects Ethics Sub-committee.

Clothing

Two kinds of multi-layer cold protective clothing systems were tested in the experiments. They were traditional clothing (clothing A) and MMF clothing (clothing B). All subjects were dressed in the same pants, cold protective trousers, socks, a pair of gloves, cold protective shoes, and a hat.

The clothing A consisted of four layers. The first layer was underwear that was a single layer made of a wool–cotton blend fabric. The second layer was a vest that contained three sub-layers: the first sub-layer was woven nylon fabric, the second sub-layer was non-woven polyester fabric, and the third sub-layer was waterproof fabric. The third layer was a coat that also comprised three sub-layers: the first sub-layer was woven nylon fabric, the second sub-layer was non-woven polyester fabric, and the third sub-layer was waterproof breathable fabric. The fourth layer was an outer jacket that consisted of two sub-layers: the inner one was mesh polyester fabric, and the other layer was waterproof breathable fabric. The detailed technical information of the fabrics is shown in Table 1. This use of fabrics is typical in cold protective clothing systems that are sold in the market, called here a traditional clothing system.

The clothing system B also consisted of four layers. The first layer was underwear that was a single layer made of wool–cotton blend fabric with a moisture management function. The second layer was a vest that consisted of three sub-layers: the first sub-layer was wool–cotton blend fabric with a moisture management function, the second sub-layer was non-woven polyester fabric, and the third sub-layer was waterproof breathable fabric. The third layer

Table 1 The structure of the clothing system A and physical properties of fabrics.

	1 Underwear	2 Vest			3 Coat			4 Outer Jacket	
Layer	1	1	2	3	1	2	3	1	2
Material	Wool–cotton blend	Woven nylon	Non-woven polyester	Woven nylon	Woven nylon	Non-woven polyester	Woven nylon	Mesh polyester	Woven nylon
Thickness (mm) at 0.6 kPa	0.99±0.01	0.25±0.01	4.79±0.21	0.30±0.01	0.25±0.01	4.79±0.21	0.37±0.01	0.55±0.01	0.37±0.01
Weight (g/m^2)	223.1±1.4	72.6±0.1	166.3±15.2	86.2±1.2	72.6±0.1	166.3±15.2	126.2±0.1	157.2±5.2	126.2±0.1
Thermal conductivity (W m^{-1} k^{-1})	0.075±0.005	0.093±0.002	0.051±0.008	0.073±0.002	0.093±0.002	0.051±0.008	0.085±0.003	0.063±0.002	0.085±0.003
Air permeability (ml/s/cm^2) at 100 Pa	>78.70	<0.02	>78.70	<0.02	<0.02	>78.70	<0.02	>78.70	<0.02
Water vapor permeability (gm^{-2} day^{-1})	884±45.3	329±13.4	1125±33.7	347±12.3	329±13.4	1125±33.7	1107±33.8	1275±39.3	1107±33.8
OMMC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74±0.046	0.00

OMMC: overall moisture management capability.

was a coat that also comprised three sub-layers: the first sub-layer was wool–cotton blend fabric with moisture management function, the second sub-layer was non-woven polyester fabric, and the third sub-layer was waterproof breathable fabric. The fourth layer was an outer jacket which consisted of two sub-layers: the inner one was wool–cotton blend fabric with a moisture management function, and the other one was waterproof breathable fabric. The technical details of the fabrics are shown in Table 2.

This clothing system was designed to allow efficient moisture vapor transfer and liquid water transfer from the inner layer to the outer layers/environment with use of moisture management fabrics and breathable fabrics in all the layers, a so-called moisture management clothing system.

Climate

All the experiments were performed in a bioclimatic chamber at an ambient temperature of –15.0 ± 0.5 °C. The air velocity was less than 0.1 m/s. Before entering the climate chamber, subjects changed clothing in a room in which the temperature was about 23.0 ± 1.0 °C. The relative humidity was about 65 ± 5%.

Measurements

In order to avoid circadian effects, all the tests were performed in the morning from 8:30 am to 11:30 am. Heart rate was continuously measured by a chest electrode belt with a heart rate meter (S810i, Polar Electro Oy, Finland) every 5 seconds. Blood pressure was measured every 10 minutes in the right arm (DynaPulse® 5000AUTO).

Ear canal temperature was measured with a thermocouple probe (LT8A, Gram Co, Japan) every 2 seconds. Skin temperature was measured with a thermocouple probe (LT8A, Gram Co, Japan) every 2 seconds on the left chest, left forearm, left thigh, and left calf.

Thermistors (HEL-700-T-1-A, Honeywell, U.S.A.) were used for temperature measurement of each layer of the clothing system. Humidity sensors (HIH-3610-001, Honeywell, U.S.A.) were used to measure the relative humidity of the clothing system.

Experimental Protocol

The experimental protocol is shown in Figure 1. It shows that there were nine stages in the experiment. Each stage lasted 10 minutes. The subjects were allowed to take breakfast provided by the researcher. They were only allowed to drink distilled water. First, every subject was requested to go to the toilet and completely empty their bladder. Total urine volume was measured using a scaled cylinder and its value was recorded. Then, the urine was poured into two 1.5 ml tubes, which were immediately stored in a deep freezer at –40 °C for later analysis of catecholamine. The subject's heart rate and blood pressure

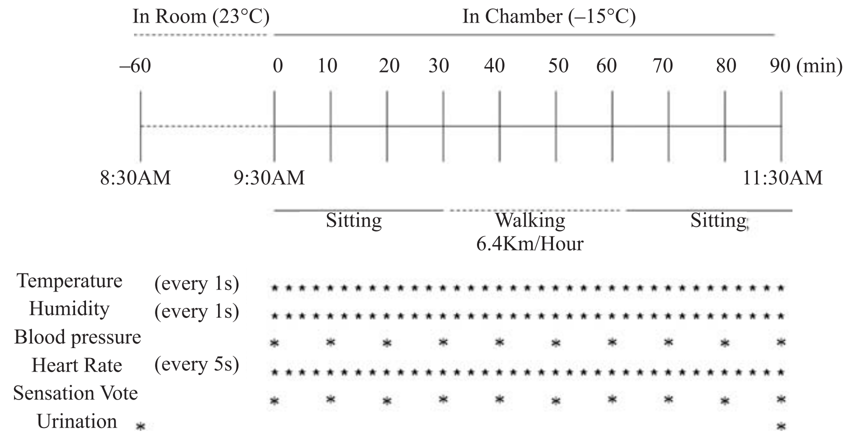


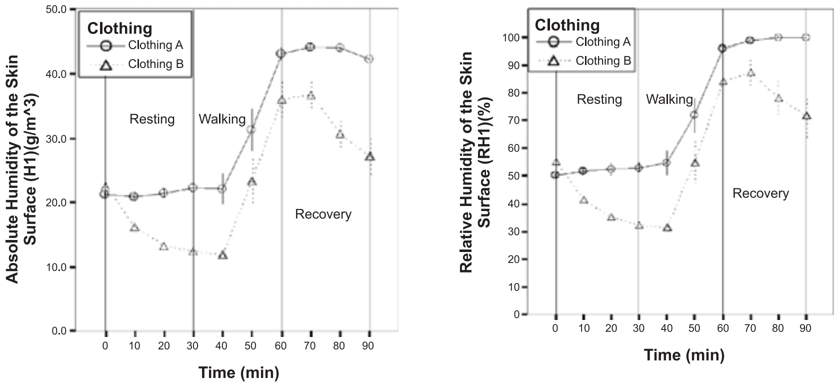
Figure 1 Experimental protocol.

Table 2 The structure of the clothing system B and physical properties of fabrics.

	1 Underwear	2 Vest			3 Coat			4 Outer Jacket	
Layer	1	1	2	3	1	2	3	1	2
Fiber content	Wool–cotton blend	Wool–cotton blend	Non-woven polyester	Woven nylon	Wool–cotton blend	Non-woven polyester	Woven nylon	Wool–cotton blend	Woven nylon
Construction	Knitted	Knitted	Non-woven	Woven	Knitted	Non-woven	Woven	Knitted	Woven
Thickness (mm) at 0.6 kPa	0.99±0.01	0.99±0.01	4.79±0.21	0.37±0.01	0.99±0.01	4.79±0.21	0.37±0.01	0.99±0.01	0.37±0.01
Weight (g/m^2)	221.7±1.7	221.7±1.7	166.3±15.2	126.2±0.1	221.7±1.7	166.3±15.2	126.2±0.1	221.7±1.7	126.2±0.1
Thermal conductivity (W m^{-1} k^{-1})	0.075±0.005	0.075±0.005	0.051±0.008	0.085±0.003	0.075±0.005	0.051±0.008	0.085±0.003	0.075±0.005	0.085±0.003
Air Permeability (ml/s/cm^2) at 100 Pa	>78.70	>78.70	>78.70	<0.02	>78.70	>78.70	<0.02	>78.70	<0.02
Water vapor permeability (gm^{-2} day^{-1})	1085±47	1085±47	1125±34	1107±34	1085±47	1125±34	1107±34	1085±47	1107±34
OMMC	0.86±0.01	0.86±0.01	0.00	0.00	0.86±0.01	0.00	0.00	0.86±0.01	0.00

OMMC: overall moisture management capability.

were also measured. Before entering the chamber, the sensors for the measurements of ear canal temperature, skin temperatures, and clothing microclimate (temperatures, humidities) at different layers were attached with adhesive surgical tape in the thermal neutral room. Subjects wore the experimental garment, filled out a questionnaire, and entered the chamber. Subjects took a rest for 30 minutes on a stool. Then each subject was requested to walk on a treadmill at a speed of 6.4 km/h for 30 minutes. Subjects were requested to rest on the stool for 30 minutes. Within the whole process, blood pressure was measured and a questionnaire was filled in every ten minutes. Finally, the subject was asked to go out of the chamber. All sensors were taken off. The subjects went to the toilet again, where each was required to empty the bladder. Urine volume was measured according to the same procedure described previously. Before and after the experiments, each layer of garment in the two clothing systems was weighed with an electrical balance (Sartorius, EA150FEG-1, Germany).



(a) (b)

Figure 2 The error bar charts of the humidity at the skin surface: (a) absolute humidity; and (b) relative humidity.

Table 3 Effects of clothing and stage of exercise on the absolute humidity of the skin surface.

Dependent Variable: Absolute Humidity at skin surface (H1) (g/m^3)

Source	Type III sum of squares	*df*	Mean square	*F*	Sig.
Corrected model	97,357.684[a]	19	5124.089	46.334	0.000
Intercept	653,799.459	1	653,799.459	5911.944	0.000
Clothing	26,925.335	1	26,925.335	243.471	0.000
Stage	64,386.030	9	7154.003	64.690	0.000
Clothing x stage	5003.472	9	555.941	5.027	0.000
Error	86,702.245	784	110.590		
Total	834,853.680	804			
Corrected total	184,059.930	803			

[a] *R* squared = 0.529 (adjusted *R* squared = 0.518).

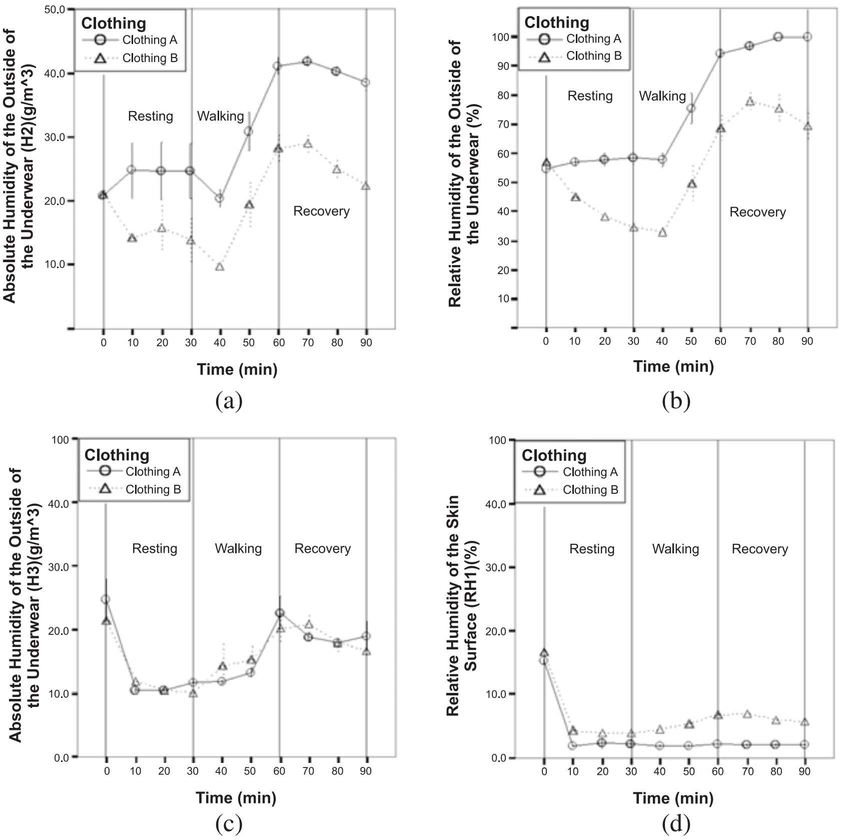
Results

Humidity changes and distributions

Statistical analyses were applied to the experimental data to reveal the effects of clothing construction design on the temperature and moisture distributions at different layers by using SPSS 12.0. The results of the analysis of variances are shown in Table 3. The absolute humidity at the skin surface is significantly influenced by the clothing systems, stage of exercise, and their interactions with $p < 0.001$.

Figure 2 compares the absolute humidity and relative humidity at the skin surface between clothing A and clothing B. Both absolute humidity and relative humidity were much higher at the skin surface when clothing A was worn than when clothing B was worn. The humidity increased quickly during the walking period due to sweating with both clothing systems. However, the relative humidity at the skin surface in clothing A reached 100% at the end of the exercise or in the early recovery period as shown in Figure 2(b), indicating that the moisture reached saturation with the appearance of liquid water on the skin surface. The skin surface relative humidity in clothing B only reached 87% at the end of the exercise or in the early recovery period as shown in Figure 2(b), showing that the moisture did not reach saturation and no liquid water appeared on the skin surface.

This procedure was applied to analyze the humidity at different layers of the clothing systems. In order to save space, the results are summarized in Table 4 in terms of statistical significances (i.e. p values). As Table 4 shows, the clothing system has significant influences on the absolute humidity and relative humidity at different layers with $p < 0.005$ for all values except the absolute humidity outside the vest. The exercise stage and the interaction between clothing and stage have significant influences on the humidity at different layers with $p < 0.001$.



(a) (b)

(c) (d)

Figure 3 Error bar charts of absolute humidities and relative humidity at different clothing layers: (a) absolute humidity outside the underwear; (b) relative humidity outside the underwear; (c) absolute humidity outside the vest; and (d) absolute humidity outside the coat.

Table 4 Effects of clothing, stage of exercise, and their interaction on humidities.

The absolute humidity	Clothing	Stage	Clothing x Stage
The absolute humidity of the outside of the underwear	0.000	0.000	0.000
The relative humidity of the outside of the underwear	0.000	0.000	0.000
The absolute humidity of the outside of the vest	------	0.000	0.003
The absolute humidity of the outside of the coat	0.000	0.000	0.000

Note: All the *p*-values greater than 0.05 are not listed in the table.

Figure 3 shows the error bar charts of the humidities listed in Table 4. Similar to the skin surface, both absolute humidity and relative humidity were much higher outside the underwear when clothing A was worn than when clothing B was worn, as shown in Figures 3(a) and 3(b). The humidity increased quickly during the walking period due to sweating with both clothing. However, the relative humidity outside the underwear in clothing A reached 100% at the end of the exercise or in the recovery period as shown in Figure 3(b), indicating that the moisture reached saturation with the appearance of liquid water on the underwear outer surface. The relative humidity outside the underwear in clothing B only reached 78% at the end of the exercise or in the early recovery period as shown in Figure 2(b), showing that the moisture did not reach saturation and no liquid water appeared on the underwear outer surface.

Figure 3(c) shows that there is no significant difference in the absolute humidity outside the vest between clothing A and clothing B. However, as shown in Figure 3(d), the absolute humidity outside the coat (but inside the outer jacket) was higher with clothing B than with clothing A,

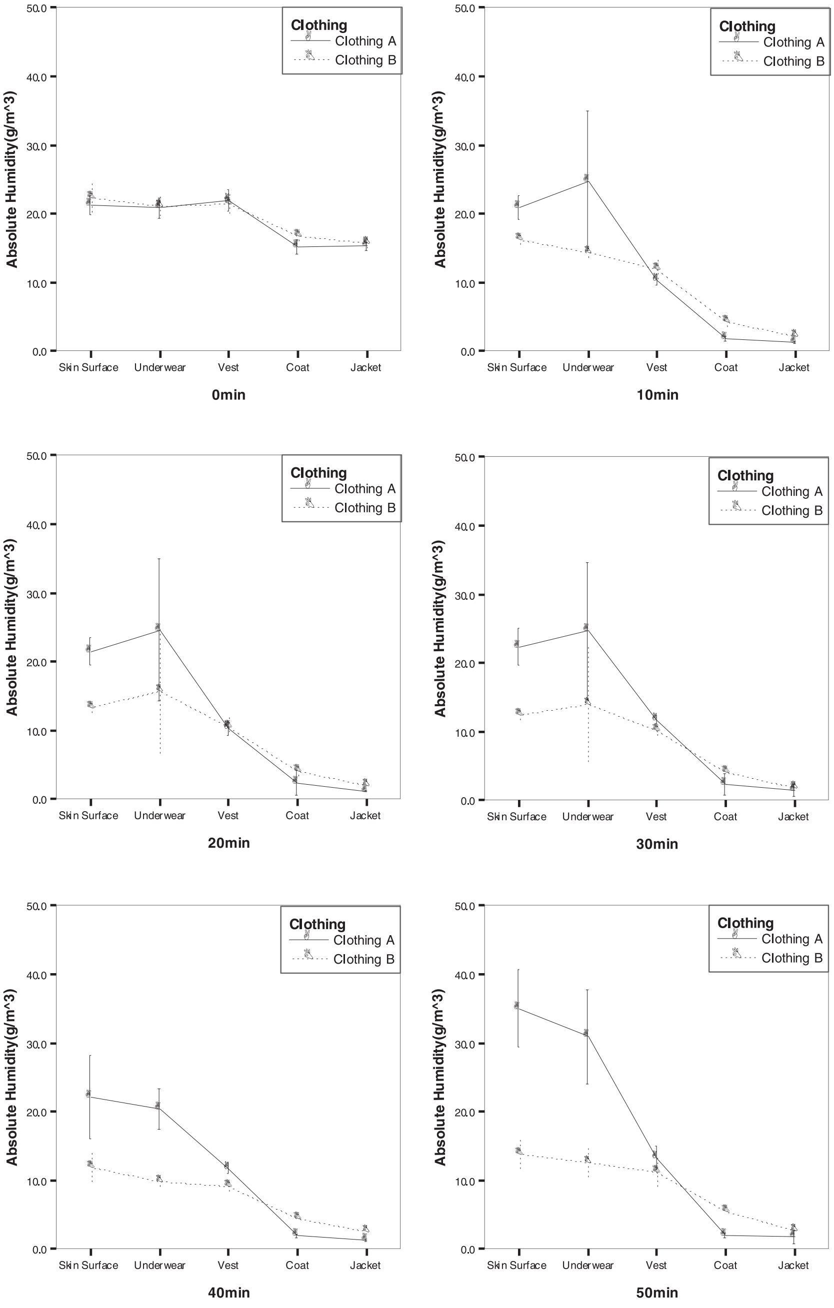


Figure 4 Absolute humidity distribution in the clothing systems at different time points.

indicating that more moisture was transferred from the skin surface to the outer layers in clothing B than in clothing A.

To confirm this observation, the humidity distributions at different layers were plotted at different time points in the experiment, as shown in Figure 4. At the beginning of the experiment (0 min), there is no significant difference in humidity at different layers between clothing A and clothing B. As moisture accumulates, particularly after sweating (10 min to 90 min), the absolute humidity at the skin surface and outside the underwear increases much more quickly and to a significantly higher value in clothing A than in clothing B. There is no significant difference in absolute humidity outside the vest between clothing A and clothing B. The absolute humidity outside the coat, however, was significantly lower in clothing A than in clothing B.

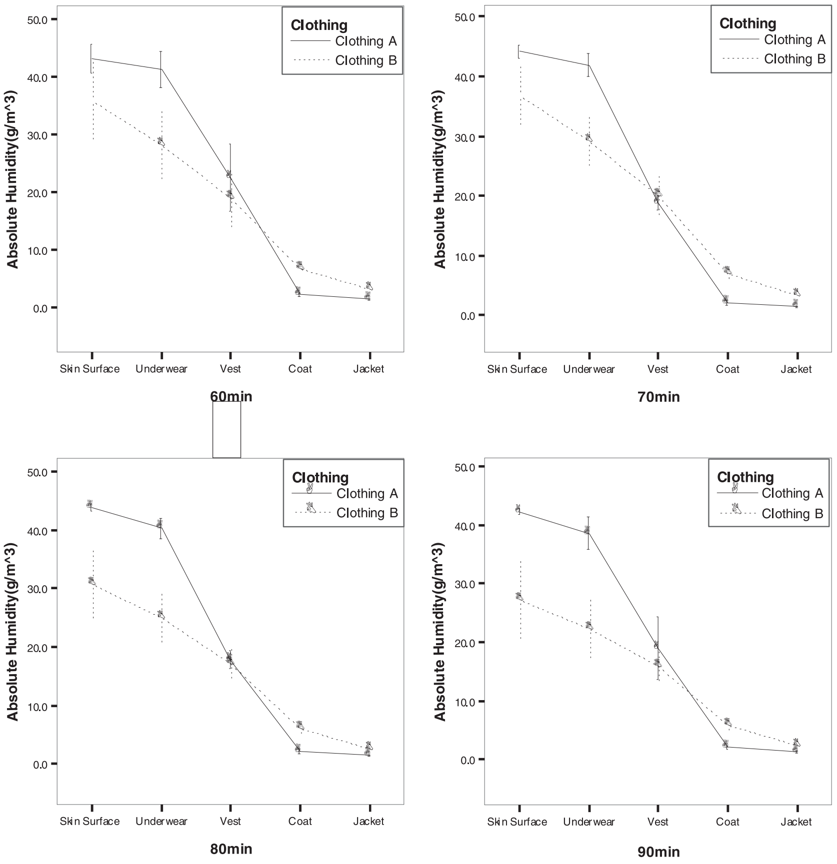


Figure 4 (continued) Absolute humidity distribution in the clothing systems at different time points.

Garment weight change

To further validate the measurement results on humidity, garment weight changes were measured and the results are shown in Figure 5. The increased weight of the underwear, vest, coat, and jacket were 21.5, 4.2, 6.1, and 2.6 g respectively for clothing A. The increased weight for clothing A decreased from the inside to the outside layers. The increased weight of the underwear, vest, coat, and jacket were –1.6, –0.1, 4, and 6.6 g respectively for clothing B. The increased weight for clothing B tends to increase from the inside to the outside layers. Analysis of variances shows that the clothing system has a significant influence on the increased weight of the clothing layers at $p < 0.05$. The interaction of clothing and layer is also significant ($p < 0.001$) on the increased weight. These results confirm that clothing A kept the moisture inside while clothing B transferred more moisture from the inside to the outside.

The moisture sensations error bar chart of clothing A and clothing B is shown in Figure 6. Clothing and time produce significant influences on body moisture sensation at $p < 0.001$. Clothing and stage also interact with each other; the impact of clothing on body moisture sensation differs between the nine stages in the experiments ($p < 0.001$).

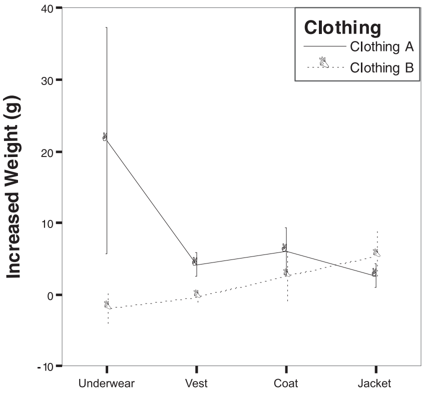


Figure 5 The error bar chart of the increased weight of layers of the clothing systems.

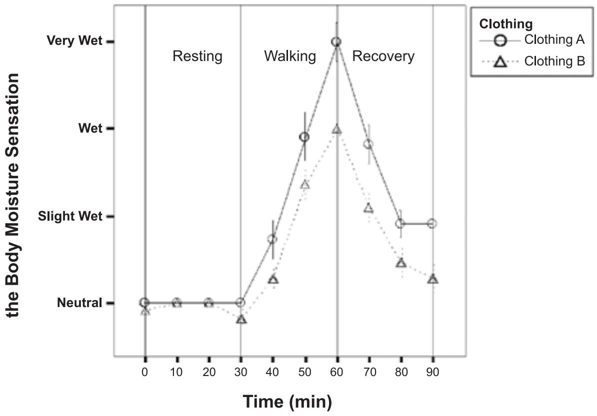


Figure 6 The moisture sensation error bar chart.

Table 5 Effects of clothing, stage of exercise, and their interaction on temperature.

Temperature	Clothing	Stage	Clothing x Stage
The temperature of the back skin	0.000	0.000	0.000
The temperature of the outside of the underwear	0.000	0.000	0.000
The temperature of the outside of the vest	0.000	0.000	0.000
The temperature of the outside of the coat	0.000	0.000	0.000

Figure 6 illustrates that in the first 20 minutes after participants entered the climate chamber the body moisture sensations of participants wearing clothing A and clothing B were similar. The value of the body moisture sensations was neutral. During the walking period and recovery period, participants felt much wetter when wearing clothing A than when wearing clothing B. The moisture sensation peak values of participants wearing clothing A and clothing B were very wet and wet respectively.

The analysis results of temperature are summarized in Table 5. The table shows that clothing and time had a significant influence on temperatures of different locations with $p < 0.001$. The interaction between clothing and time also had significant influences on temperatures with $p < 0.001$.

Figure 7 shows that the error bar charts of temperatures listed in Table 5. In Figures 7(a) and 7(b), the temperature of the back skin and the temperature of the outside of the underwear were higher when clothing A was worn than when clothing B was worn. In Figures 7(c) and 7(d), the temperatures of the outside of the vest and the coat were higher when participants wore clothing B than when participants wore clothing A. During the walking period, the temperatures increased sharply due to the higher activity level. During the recovery period, the temperatures of the back skin and the outside of the underwear decreased. The temperature change rates for those participants that wore clothing B were higher than for those who wore clothing A in Figure 7.

Figure 8 shows the error bar chart of the thermal sensation. Clothing and stage have significant influences on body thermal sensation ($p < 0.001$). Clothing and stage once again interact with each other and the impact of clothing on the thermal sensation differs as a function of time in the experiment ($p < 0.001$).

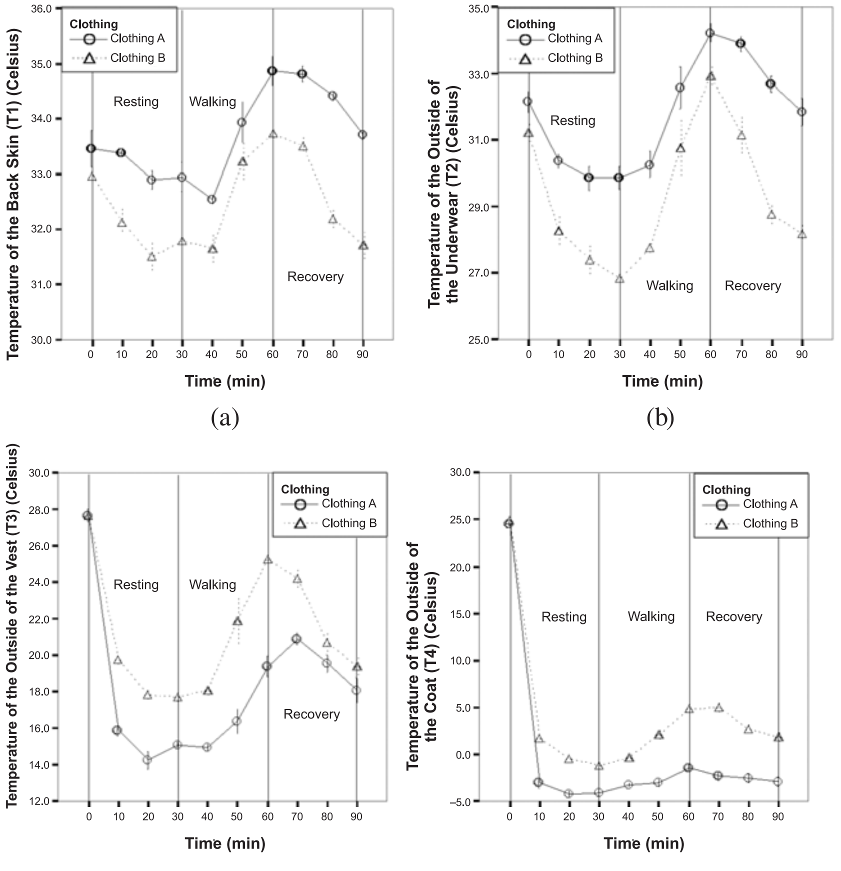
Figure 8 shows that, in the experimental period, participants felt warmer when wearing clothing A than when wearing clothing B. After 30 minutes walking, participants felt hot when wearing clothing A but felt warm when wearing clothing B.

Discussions

As shown above, the moisture and temperature distributions in clothing A and B were significantly different because of the use of different fabrics in the two clothing systems. It is of great interest to reveal why they are so different.

Figure 9 shows that the underwear in clothing A has no moisture management function, and the first and the third sub-layers of the vest, and the first sub-layer of the coat have poor water vapor permeability and poor moisture management capability. Before sweating, most of the moisture (water vapor) released from the body accumulated in the space between the skin and the inner side of the vest. When liquid sweat occurred, the liquid water was absorbed by the underwear and could not be transferred from the inner layers to the outer layers. The underwear was wetted. When participants stopped sweating, the microclimate of the clothing system became saturated.

As shown in Figure 10, the underwear in clothing B has a moisture management function. The first and the third sub-layers of the vest, and the first sub-layer of the coat have good water vapor permeability and good moisture management capabilities. The moisture in the clothing system can be easily transferred from the inner layer to the outer layers. When liquid sweat appeared, the liquid water was quickly absorbed by the underwear with the moisture management function and transferred to the outer layer. In the recovery period, the moisture in the clothing system continued to diffuse out, so that the humidity of the clothing system did not reach saturation.



(a) (b)

(c) (d)

Figure 7 The error bar charts of temperatures: (a) the temperature of the back skin; (b) the temperature of the outside of the underwear; (c) the temperature of the outside of the vest; and (d) the temperature of the outside of the coat.

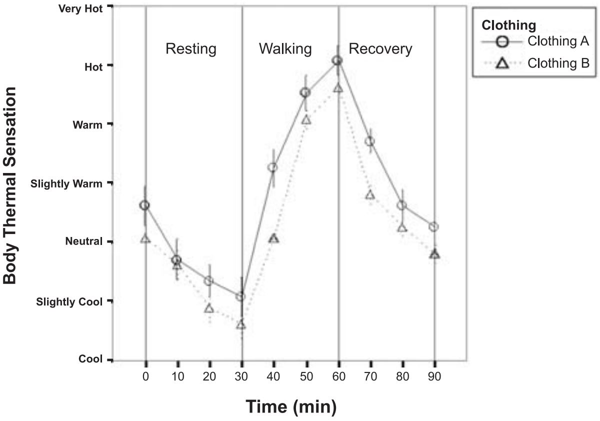


Figure 8 The error bar chart of the body thermal sensation.

A comparison of the water vapor permeability of each layer between the two clothing systems is shown in Figure 11. As shown in the figure, the water vapor permeability of each layer in clothing B was high, while the water vapor permeability of the second layer, the fourth, and the fifth layers in clothing A were very low. The moisture (water vapor) in clothing B could much more easily diffuse out and the absolute humidity decreased during the first 30 minute resting period. However, the moisture in clothing A was blocked by the second layer and accumulated in the space between the skin and the inner side of the vest, as shown in Figure 2(a).

A comparison of the overall moisture management capability (OMMC) of each layer between two kinds of the clothing system is shown in Figure 12. The figure shows that the OMMC values of the underwear and the first sub-layer of the vest, coat, and jacket (with values of 2, 5, and 7 respectively) in clothing B are high. When liquid sweat occurred, the liquid water in the clothing system was quickly absorbed and transferred to the outer layers. The inner layers of the clothing system were kept relatively dry. The water vapor zone [9] of the clothing system was not effected significantly by liquid sweat. However, the OMMC values of the underwear and the first sub-layer of the vest and coat (with values of 2 and 5 respectively) in clothing A were very low. The underwear was quickly wet-

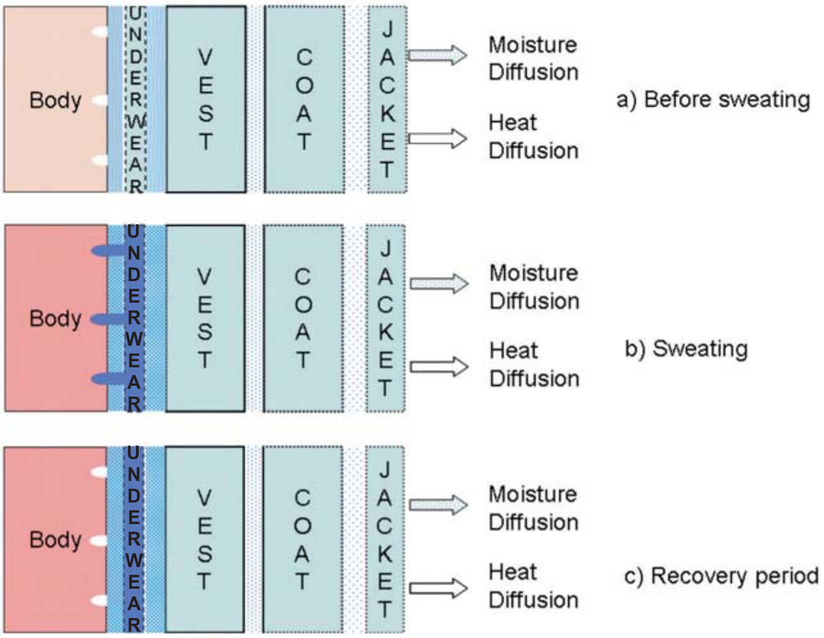


Figure 9 Moisture transfer in clothing A.

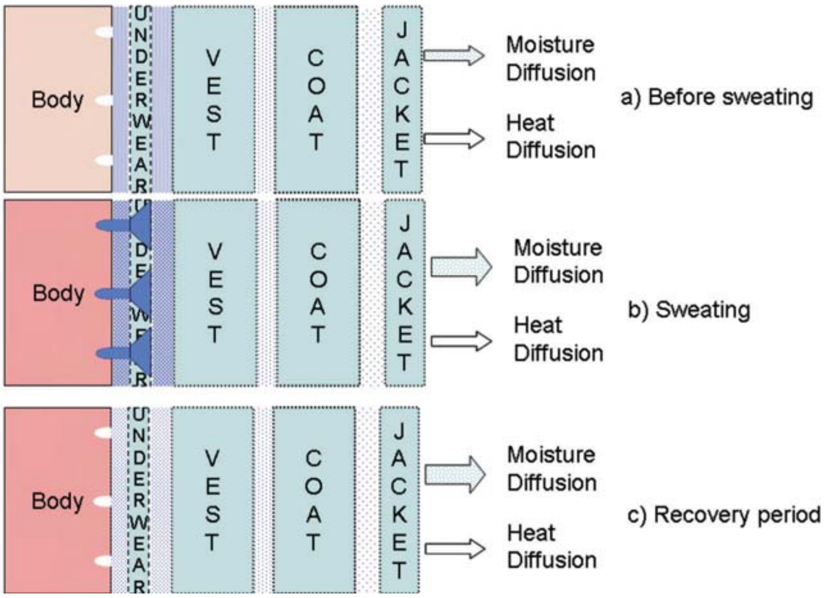


Figure 10 Moisture transfer in clothing B.

ted when liquid water appeared. The liquid sweat was blocked by the poor OMMC sub-layers. The water vapor zone of the clothing system decreased and the liquid water zone increased due to sweating and/or condensation, as shown in Figure 2(b).

The most important finding in the experiments was that the humidity of the skin surface and the outside of the underwear was significantly lower in clothing B than in clothing A (Figures 2, 3(a), and 3(b)). In contrast, the absolute humidity value was significantly higher in the outside of the vest and the outside of the coat in clothing B than in clothing A (Figures 3(c) and 3(d)). These results suggest strongly that the sweat produced during exercise was transferred through the skin surface and underwear to the outside of the vest and the coat more quickly in clothing B than in clothing A.

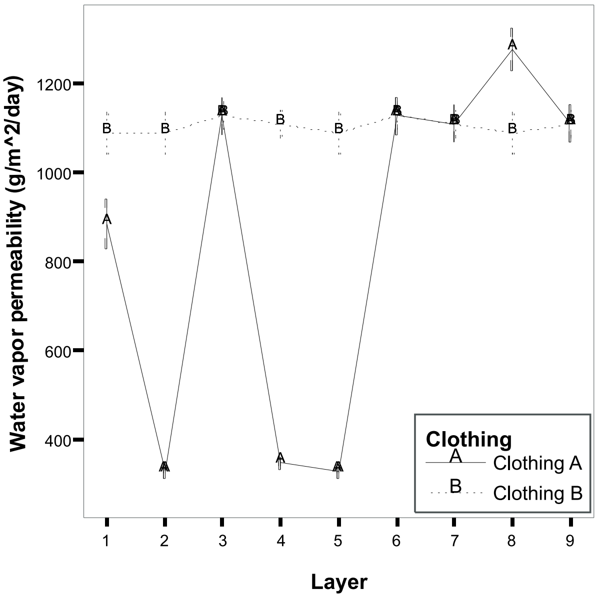


Figure 11 A comparison of the water vapor permeability of each layer between the two kinds of clothing system.

Body moisture sensation was perceived to be significantly higher in clothing A than in clothing B (Figure 6), implying that the findings observed above had a direct impact on sensory comfort. The subjects felt significantly hotter in clothing A than in clothing B (Figure 8), suggesting that heat was accumulated during exercise within the body. The humidity outside the vest and the coat was significantly higher in clothing B than in clothing A, showing that latent heat loss was more efficient in clothing B than in clothing A.

Conclusion

The experimental results showed that the fabric properties of clothing systems could significantly affect the humidity and temperature distributions and comfort of clothing. The moisture management functional design of a clothing system can allow effective transfer of moisture and latent heat loss to keep the clothing microclimate dry and comfortable. Thus the performance of protective clothing can be greatly improved if it is systematically designed. The water vapor permeability and moisture management of fabrics are indeed very important to prevent water condensation in the clothing and ultimately ensure improved superior thermal functional and comfort performance.

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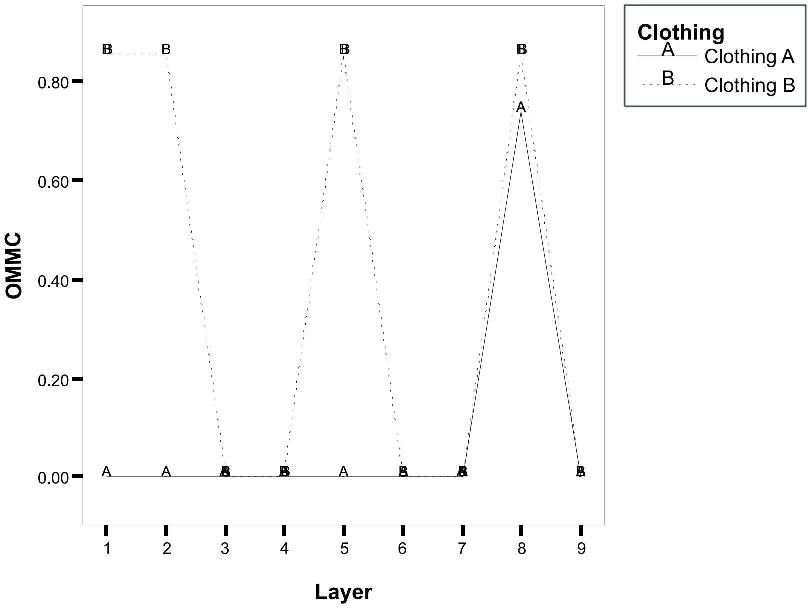

Figure 12 A comparison of the OMMC of each layer between the two kinds of clothing system.

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