

Influence of Fabric Structure and Properties on Thermal Comfort of Medical Protective Clothing

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Abstract

Medical protective clothing is an important personal protective equipment for medical staffs, especially in the pandemic. This research paper studied the effect of structure properties (material, yarn linear density and fabric thread density) of cotton and polyester fabrics on human thermal comfort. The main methodology entails using a CAD software to simulate the thermal comfort value of the individual when they wear a medical protective clothing made of 10 plain-woven fabric types. The normal effective temperature formula is used to simulate the clothing microclimate for evaluating the thermal comfort value. Three environment settings, indoor hospital conditions, outdoor environment of Manchester, UK in July and the outdoor environment of Hong Kong in July, are used in the simulation. Then analysis was conducted on the simulation results. The results indicate that yarn linear density has the biggest effect on the thermal comfort value. The cotton fabric with a yarn linear density of 131 Denier and thread density of 209/inch has the best thermal comfort performance. It also meets the physical strength requirements of surgical gown son EN 13795-1:2019. The result demonstrates that the moisture management capability of the fabric that affects dampness sensation of human body, is the most important ability to improve the thermal comfort value, and the influence of the yarn structure needs to be taken into consideration in the future studies.

Keywords: Personal protective equipment; Textile CAD technology; Mathematical modelling; Mathematical analysis

1 Introduction

Medical protective clothing (MPC) is a personal protective equipment (PPE) for medical staffs. MPC also refers to medical gown, protective coverall, procedure gown, medical scrub etc. MPC can reduce the transmission risk between patients and medical staffs^[1].

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Covid-19 pandemic is the cause of worldwide shortage of medical PPE in 2022. Until June of 2022, only 20% of primary care facilities and 27% of healthcare facilities can provide the full PPE outfit^[2]. Moreover, in less developed countries, only one third of healthcare facilities are able to correctly dispose used PPE^[2]. Compared with disposal medical protective clothing (DMPC), reusable medical protective clothing (RMPC) can relieve the shortage of PPE, it can also save 28% energy and 41% water, while reducing 30% greenhouse gas and 93% solid waste^[3].

On top of the safety and public trust requirements, the comfort performance of RMPC for wearers is a critical consideration^[4]. Thermal comfort is an important part of clothing comfort and is essential for medical staffs due to their long working hours. Poor thermal comfort performance RMPC will result in physiological stress build-up as well as working efficiency of medical staff.

Compared to the variety DMPC material and fabric structure, RMPC is typically made of cotton, polyester or a mixture of cotton-polyester^[5] with a plain weaving structure. The main factors of fabric structure that affect medical protective level are material, yarn linear density and fabric thread density. These three factors also affect the thermal comfort value.

Several studies have been conducted on the relationship between fabric structure and thermal comfort value. Shaker K et al studied thermal comfort of puckered fabrics and core spun yarn, found the relationship between thermal resistance and fabric thickness/core spun yarn^[6]. Stankovic S et al studied the thermal comfort value of different yarn twist level and knitted fabrics for making thermal insulation textile product^[7]. Aslan S et al studied the comfort value and the protective ability of four kinds of fabrics used in MPC^[8]: the fibre types and fabric structures of four fabrics are all different, and two of them are used in DMPC. They found that disposal non-woven fabric has better microbial protection, but woven fabric has better thermal comfort performance; Maqsood M, et al studied the influence of fabric thread density and the weave structure on barrier performance and air permeability^[9]. As all woven RMPCs use plain weave structure, the contribution to the study of RPMC fabric is limited to the area of thread density. Guo YP et al compared the tactile and thermal comfort value between 5 different kinds of MPC^[10], which are made of different materials and/or fabric structures. They pay more attention to the influence of the clothing structure on the thermal comfort value but not the fabric material and structure. In conclusion, these studies did not consider the relationship between the fabric structure properties and the thermal comfort value in the plain weave structure systematically for the functional design of RMPC's.

Effective temperature (ET) is a subjective index of human body to the comfort value under a set of temperature and humidity. Missenard created a formula that uses air temperature and relative humidity to calculate ET through analysing people's subjective feeling on temperature when they wear clothes, with soft activity under a low wind speed environment^[11]. This index was initially used in the indoor environment, Gregorczyk used this formula to evaluate the whole earth's climate^[11]. ET can be further divided into two types: normal effective temperature (NET) and basic effective temperature (BET)^[12]. NET is for the clothed person who does the light work, BET is applicable to unclothed persons. For calculating negative NET, Gregorczyk modified Missenard's formula, added wind speed into it to calculate NET^[13]:

$$NET = 37 - \frac{37 - T}{0.68 - 0.0014\gamma + \frac{1}{1.76 + 1.4v^{0.75}}} - 0.29T \left(1 - \frac{\gamma}{100}\right) \quad (1)$$

T: air temperature, °C; wind speed, m/sec; γ : relative humidity.

Li PW and Chan ST used NET formula to define the extreme weather condition in Hong

Kong^[14]: they calculate NET of each day, and define the 2.5% days that are colder or hotter than the other 97.5% days as extreme weather. To evaluate the heat stress index of fireman, Cheng CM used NET formula to simulate the clothing microclimate (CMC) of the firefighter uniform^[15]. CMC is the climate between the underwear and the skin. As Firefighter uniform is a highly insulated clothing, the CMC differs from the external environment. To more accurately reflect heat stress from the firefighter clothing, Chen CM used CMC temperature and CMC relative humidity with a wind speed of 0 to simulate the NET CMC.

This research analyses 9 kinds of fabrics sold in the market, through measuring their three fabric structure factors: yarn material, yarn linear density and fabric thread density, simulating their thermal comfort value, and comparing them with a fabric used by National Health Service (NHS). It aims to find how fabric structures influence thermal comfort value, and whether they can meet the requirement of medical clothing in physical strength while providing suggestions for fabric selection of RMPC.

2 Methodology

2.1 Fabric Specimen

The US4822667A patent uses polyester filament yarn to weave RMPC fabric^[16]. The number of yarn denier is from 50 to 150, and the total number of ends and picks is no less than 100 per inch. In this article's experiment, 9 kinds of fabric are selected. They are bought from the market and are without hydrophobic treatment. These 9 kinds of fabrics are pure cotton or pure polyester, and their yarn linear density and fabric thread density range are within the regulation of US4822667A. Beside these 9 fabrics, a polycotton fabric used by NHS and bought from Michael Abakhan Ltd, is set as the control group. Figures 1 shows the fabric specimens and their size. Fabric 0 is NHS-used fabric. The fabric specimens have "L" shape, which is for the thickness testing.

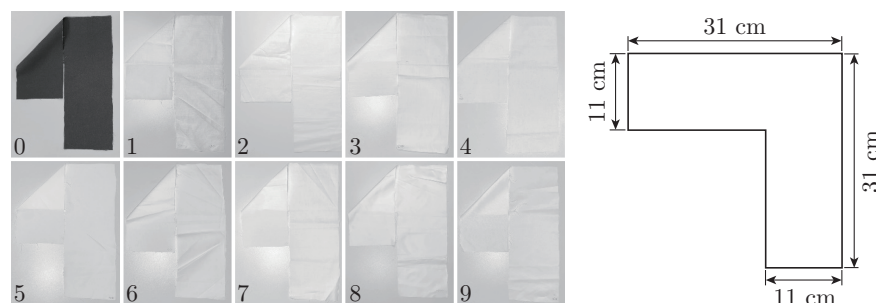


Fig. 1: The fabric specimens (left) and their size (right)

The fabric structure data is listed in Table 1, and the standard deviation of the fabric thread density is also listed. The fabric thread density is counted by Projectina CCD-1300PQC, whereby the warp and weft yarns within 0.8 cm long are counted. The counts were conducted six times on different places of each fabric. Fibre material and yarn linear density data are acquired from the seller. The supplier of fabric 0 did not provide the data for yarn linear density. 2 sets of warp yarns and 2 sets of weft yarns 5m long were extracted for weight measurement with the analytical balance. The fabric density is weighted by analytical balance. 5 pieces of 10 cm × 10 cm specimens

per fabric were cut and weighed. Besides fabric material data, the yarn linear density is divided into 2 levels for the DoE simulation: 50-87.5 and 131; the fabric thread density is also divided into 2 levels: 160.0 ± 0.3 to 216.4 ± 0.6 and 232.1 ± 0.8 to 287.4 ± 0.5 . The yarn linear density of fabric 0 is far greater than 131 D, and it is the only fabric which is made of polyester-cotton-blended fabric. Therefore, it is only used for comparing comfort value and physical strength, but not in the analysis of the fabric structures' influence.

Table 1: The fabric structures of fabric samples

ID	Material	Yarn linear density (Warp*Weft/Denier)	Linear density level	Fabric thread density with standard deviation (Warp*Weft/inch)		Fabric thread density level	Fabric weight (g/m ²)
0	65% Polyester 35% Cotton	174±4	N/A	119.1±0.3	61.1±0.3	N/A	155.6±3.7
1	Cotton	87	1	90.6±0.2	69.4±0.1	1	61.8±0.6
2	Cotton	131	2	141.6±0.3	67.2±0.2	1	113.6±1.5
3	Cotton	131	2	138.9±0.3	77.5±0.3	1	116.2±0.7
4	Cotton	87	1	119.9±0.4	112.2±0.4	2	88.2±1.0
5	Polyester	50	1	123.9±0.1	112±0.2	2	56.5±0.5
6	Cotton	131	2	143.4±0.4	94.7±0.2	2	132.5±1.4
7	Cotton	87	1	153.7±0.3	103.2±0.4	2	92.1±0.6
8	Polyester	50	1	183.6±0.5	102.9±0.3	2	58.4±0.4
9	Polyester	50	1	177.6±0.1	109.8±0.4	2	59.6±0.5

Note: I. Yarn linear density is provided by the suppliers. II. Yarn linear density data is divided into 2 levels, level 1 is from 50 to 87, level 2 is 131. III. Fabric thread density (warp + weft) level is divided into 2 levels, level 1 is from 160.0 ± 0.3 to 216.4 ± 0.6 , level 2 is from 232.1 ± 0.8 to 287.4 ± 0.5 . IV. The yarn linear density of fabric 0 is calculated by 2 sets of warp yarns and 2 sets of weft yarns of 5m long. V. Fabric 0 is not included in the DoE simulation, so it does not take part in the level division of linear density and thread density.

2.2 Test Method

The thermal comfort value is simulated by “s-smart” software and “e-thermal CAD” website, which is a clothing thermal CAD system^[17]. Huang QH et al used the system to simulate 6 kinds of fabrics' thermal comfort value^[18], this experiment uses the same procedure.

S-smart database contains the physical properties of some commonly used fabrics. For a more realistic simulation result, the fabrics physical properties were all tested. For simulating the fabrics that do not contain membrane, the s-smart needs 10 physical factors: (1) fibre material, (2) thickness (cm), (3) porosity, (4) tortuous gas, (5) spreading speed at top surface (SST) (mm/s), (6) spreading speed at bottom surface (SSB) (mm/s), (7) accumulative one-way transport capacity (R) (%), (8) overall moisture management capability (OMMC), (9) top water contact angle (WCA) (deg.), (10) bottom water contact angle (deg.).

Rubber gloves were worn when handling the fabrics. Only the clean parts of the fabrics were used while excluding the edges. Except for water contact angle testing, other tests are done at

20±1°C.

SDLATLAS MMT M290 were used to test the moisture management performance of the fabric. For each fabric type, the test was conducted 5 times with different samples. The moisture management ability includes SST, SSB, R and OMMC.

Kruss DSA100S was used to measure top WCA and bottom WCA. 5 different water drops of both top and bottom surface per fabric were tested. If the fabric absorbs the water droplet immediately, the WCA is 0. If the fabric absorbs the drop slowly, then the captive bubble method is used to measure WCA.

SDLATLAS Fabric touch tester M293 was used to test fabric thickness. For each fabric type, the test was conducted 4 times with different fabric samples. The method to calculate fabric porosity and gas tortuosity is described below, the fibre density is from s-smart database:

$$\text{Fabric density in g/cm}^3 = D_{\text{fabric}} = \text{Weight}_{\text{fabric}} / \text{Thickness}_{\text{fabric}} \quad (2)$$

$$\text{Fabric Porosity} = 1 - (D_{\text{fabric}} / D_{\text{fibre}}) \quad (3)$$

$$\text{Fabric gas tortuosity} = 1 / \text{Porosity} \quad (4)$$

Following the thermal comfort simulations, choose the fabrics from fabric ID 1 to 9, which have best comfort performance or their performances are better than the fabric ID 0, do the physical strength test and make the comparison. According to BS EN 13795-1^[19], the physical strength requirement to surgical gown contains bursting strength and tensile strength. The bursting strength is tested by SDLATLAS PnuBurst M229P, based on BS EN ISO 13923. Test three times per fabric on both dry and wet condition, and record the mean value and standard deviation. The tensile strength is tested by 5 kN-loaded Instron universal testing system, based on BS EN ISO 13934-1 but not BS EN ISO 29073-3 required in 13795-1, because 29073-3 is for non-woven fabric. Test twice on both warp direction and weft direction per fabric on both dry and wet condition, and record the mean value and standard deviation of total 4 times test results.

2.3 Computer Simulation Method

2.3.1 Simulation Data Preparation

Table 2 is the test result of the fabric physical properties.

2.3.2 Simulation Setting

According to the NHS Digital^[20], the mean weight and height of England men are 85.4 kg, 175.5 cm and for women 77.5 kg, 161.7 cm. This human body data is used for simulation in this experiment.

For garment setting, garment coverage for male is set to 90% and for female (95%) in the s-smart database, and the garment fitting is loose fit.

The environmental condition setting has two types: One is set as the internal condition, which contains the operation room, hospital office and inpatient ward. According to the standard of ASHRAE^[21], the temperature of the operating room should remain between 20 to 24 °C, and the relative humidity should remain between 20 to 60%. The temperature of the patient room and

Table 2: The test result (the mean value and the standard deviation) of fabric specimens

ID	Thickness (cm)	Porosity	Tortuous gas	SST (mm/s)	SSB (mm/s)	R(%)	OMMC	Θ_{top} (Deg)	Θ_{bottom} (Deg)
0	0.035±0.002	0.69	1.45	1.07±0.16	0.88±0.19	292.2±92.5	0.59±0.14	38.0±1.9	37.6±2.7
1	0.031±0.001	0.87	1.15	0	0.49±0.07	994.3±22.7	0.73±0.03	31.4±1.0	33.0±0.5
2	0.032±0.001	0.76	1.31	5.08±0.26	4.82±0.25	67.4±69.6	0.50±0.09	0	0
3	0.031±0.002	0.75	1.33	0.02±0.02	0.45±0.04	967.9±99.0	0.75±0.01	0	0
4	0.033±0.002	0.83	1.21	0	0.5±0.02	1029.2±13.1	0.73±0.02	40.6±4.3	37.8±2.2
5	0.025±0.000	0.84	1.19	0	0.45±0.08	1010.3±31.8	0.73±0.03	141.2±3.3	145.7±1.6
6	0.029±0.001	0.70	1.42	0.31±0.07	0	−993.5±53.8	0	137±4.0	139.3±3.5
7	0.027±0.001	0.78	1.29	0	0.44±0.06	968.3±34.7	0.73±0.02	138.1±2.2	135.5±2.0
8	0.015±0.001	0.72	1.38	1.15±0.05	1.16±0.04	−228.8±95.95	0.12±0.03	0	0
9	0.022±0.002	0.81	1.24	5.39±0.67	5.21±0.45	−10.8±96.21	0.43±0.12	0	0

common outpatient room should remain between 21 to 24 °C, and the relative humidity should be no higher than 60%. Based on the research of Sánchez-Barroso Moreno G et al^[22], the wind speed can be set as 0.15 m/s. Therefore, in the environmental condition setting of simulation, The place is indoor, the temperature is 22 °C, the relative humidity is 40% and the wind speed is 0.15 m/s.

Another environmental condition settings are outside work in Summer, Manchester, UK and Hong Kong are set as reference^{[23][24]}. In July of Manchester, the mean temperature is 16 °C, the relative humidity is 78%, and the wind speed is 3.58 m/s^[23], which is a cool outdoor environment. In July of Hong Kong, the mean temperature is 30 °C, the relative humidity is 76%, and the wind speed is 4.02 m/s^[24], which is a hot outdoor environment.

The activity setting is 60 minutes standing activity, 30 minutes sitting activity and 30 minutes moving activity.

2.3.3 Computational Software and Simulation Processes

E-Thermal is a computational portal that can simulate the thermal comfort value when wearing different kinds of clothing^[25]. Figure 2 is the operation interface of “Fabric Design” section of S-smart software that is downloaded from the E-Thermal website. After inputting simulation setting and simulation data, the software will generate a document. The document is uploaded to the e-thermal CAD website^[26], after the completing the simulation, the result can be downloaded.

2.3.4 The NET_{CMC} Formula

The distributions of the temperature and relative humidity from the inner side to the outer side of the fabric are also simulated and can be downloaded from E-Thermal portal. As the RMPC’s

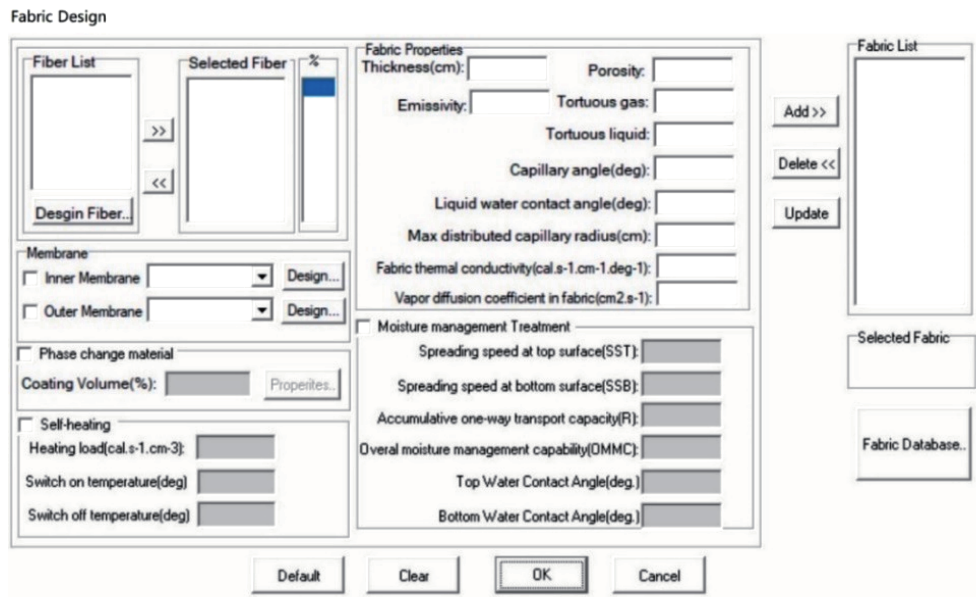


Fig. 2: The fabric design page of S-smart software

coverage rate to the human body is high, using the near-skin relative humidity and the near-skin temperature, NET formula can act as a reference for clothing microclimate of RMPC, which is the climate between the RMPC and human body.

$$NET_{CMC} = 37 - \frac{37 - T_{NS}}{0.68 - 0.0014Y_{NS} + 0.56818} - 0.29T_{NS} \left(1 - \frac{Y_{NS}}{100}\right) \quad (5)$$

T_{NS} : air temperature of near-skin, °C; Y_{NS} : relative humidity of near-skin; Wind speed is set as 0.

3 Result

Figure 3 is the simulation results of the fabric 0 and 2 worn by the male in the indoor hospital environment. As the figure shows, a set of simulation results contains 6 graphs: comfort value, dampness sensation, thermal sensation, relative humidity of skin, temperature of core and temperature of skin.

These graphs show how the thermal indexes change over time and with different types of exercise. The general trends of thermal indexes of fabric 0 and 2 are the same. The comfort value and dampness sensation of fabric 2 are better than fabric 0, and the skin relative humidity, core temperature and skin temperature of fabric 2 are also lower than fabric 0. For the influence of the activity type, all indexes go up during the standing and moving period, and the increasing speed is higher in the moving period. In the sitting period, all indexes go down. More detailed analysis will be done on Section 4.

Figure 4 is the comfort value, dampness sensation and thermal sensation graphs of fabric 3, when it is worn by the male in the indoor hospital, outdoor Manchester and outdoor Hong Kong environment. It is clear that the thermal indexes of human body are influenced by the

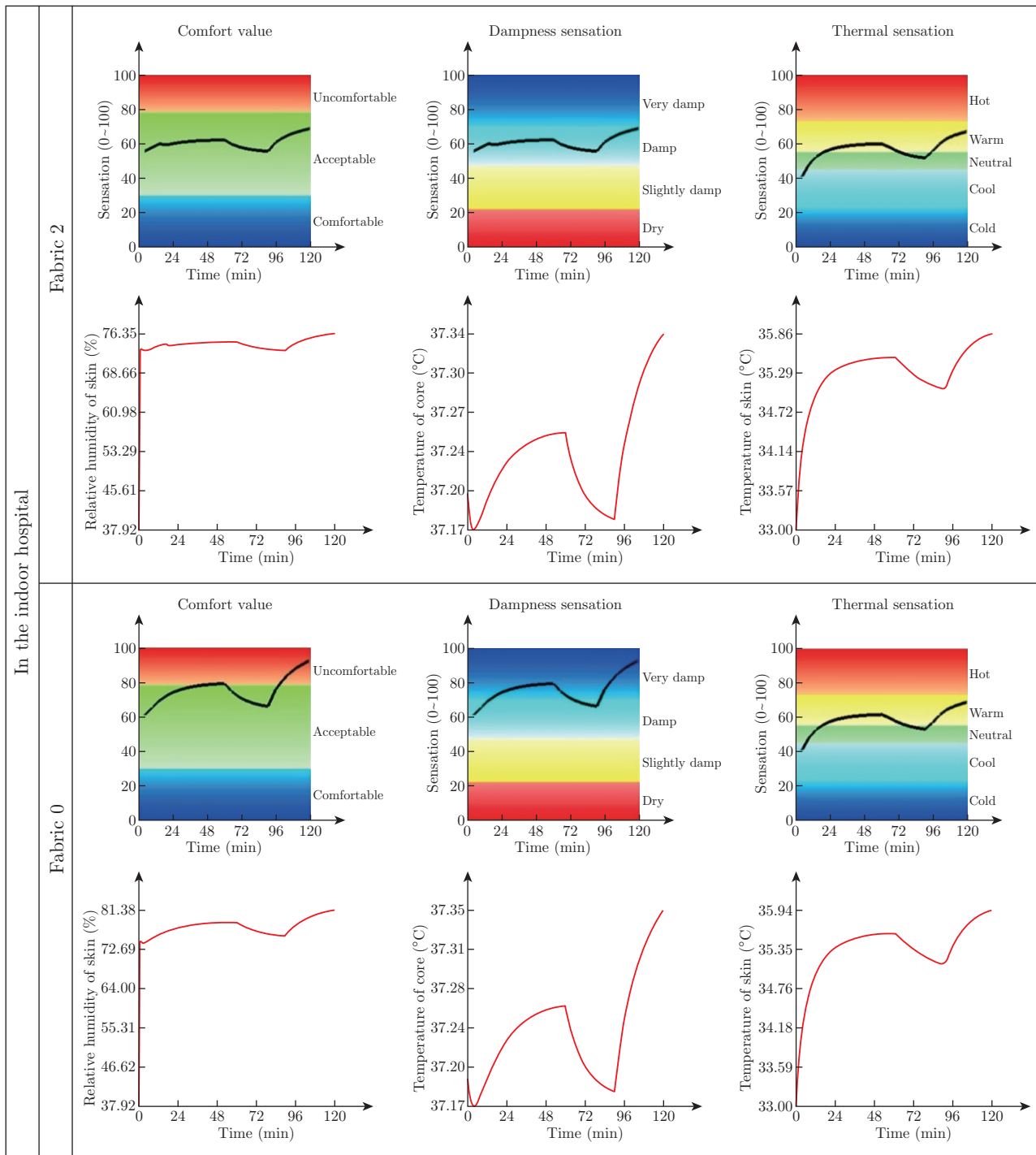


Fig. 3: The simulation result of fabric 2 and 0 worn by the male in the indoor hospital environment

Note: A set of simulation results contains 6 graphs: comfort value, dampness sensation, thermal sensation, relative humidity of skin, temperature of core and temperature of skin.

environment. In a colder environment, these three sensations are lower; in a hotter environment, the sensations are higher. More detailed analysis will be done on Section 4.

Figure 5 is the temperature distribution (left) and relative humidity distribution (right) within fabric 2 when it is worn by the male in the indoor hospital environment. The temperature and

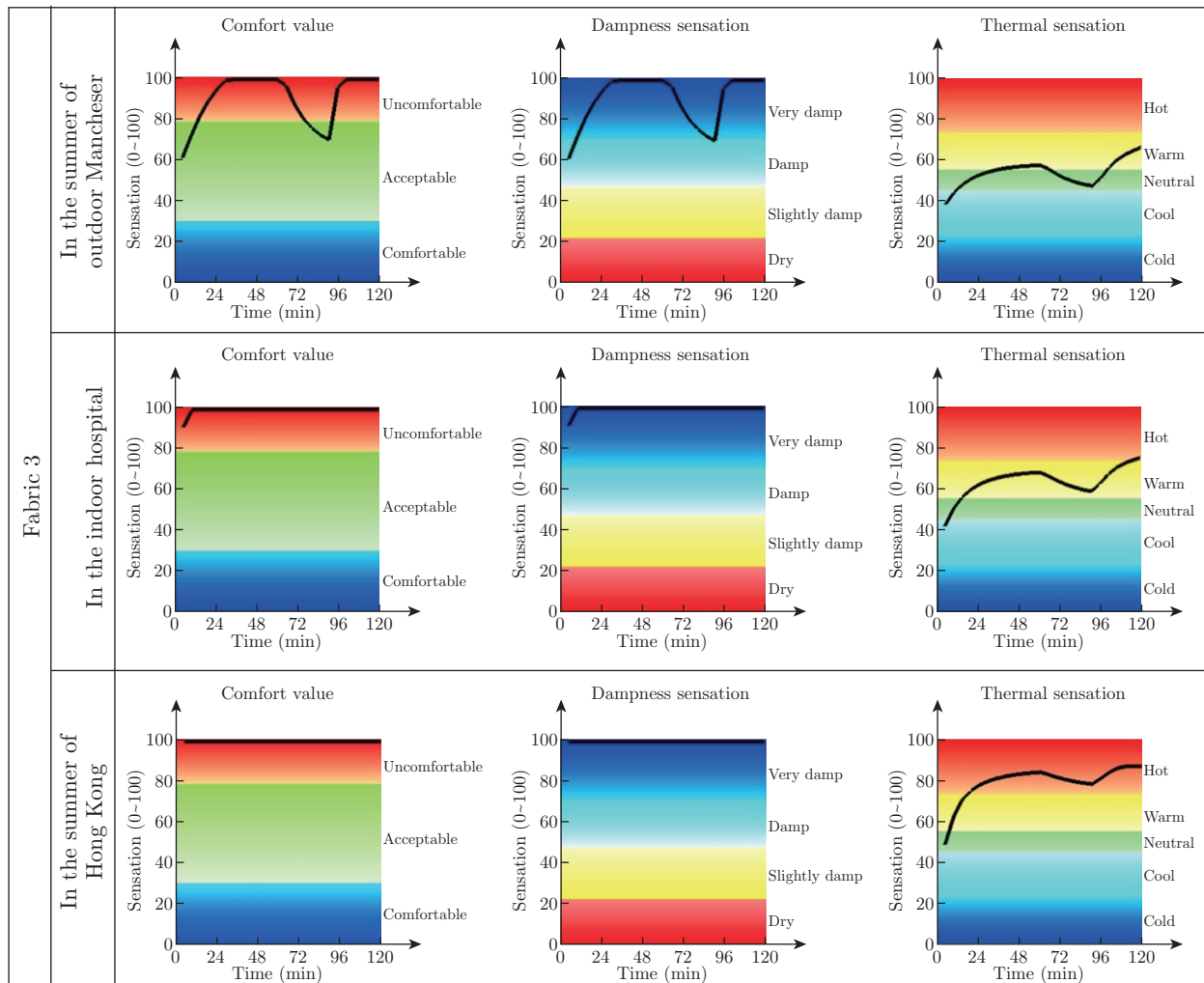


Fig. 4: Some parts of simulation results of fabric 3 worn by male in the indoor hospital, outdoor Manchester and outdoor Hong Kong environment

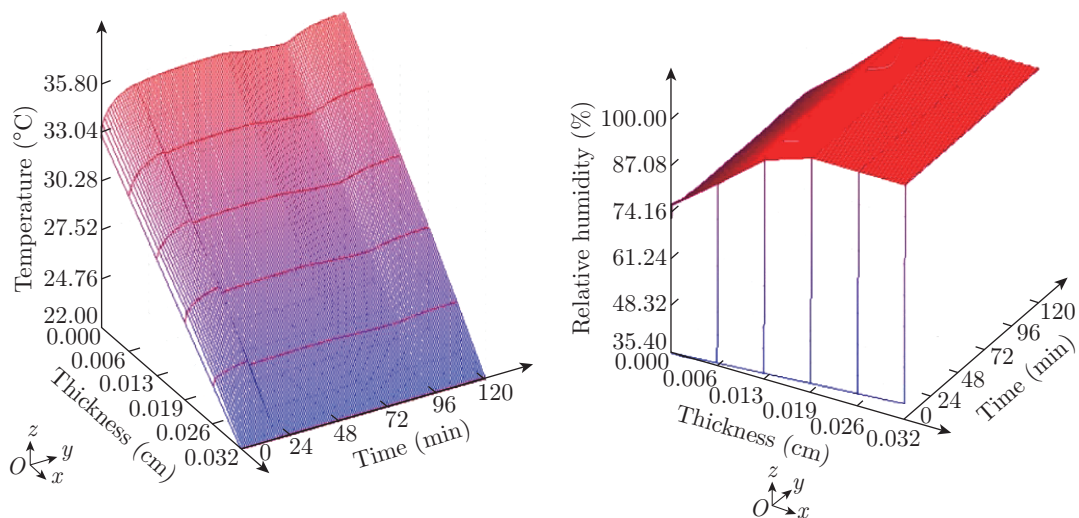


Fig. 5: The temperature distribution (left) and relative humidity distribution (right) within the fabric 2 when it is worn by the male in the indoor hospital environment

Note: X axis: the thickness of fabric; Y axis: the activity time; Z axis: the temperature of fabric.

relative humidity data within the fabric is divided into 6 layers. The x axis is the thickness of the fabric, the layer on the thickness 0 is near the skin surface. The larger the X coordinate, the further this layer is away from skin. As the distance of the layer from the skin increases, the temperature decreases, and the relative humidity increases. At the layer of the outside surface of the fabric, which is the end of the X axis, the temperature is equal to the environment temperature, and the relative humidity goes up to 100%.

4 Discussion

4.1 The Analysis to e-thermal CAD Simulation Result

4.1.1 Core Temperature

Core temperature of human body should remain at 36.5–37.5 °C for normal human physiological function and must be within the range of 35–39 °C for avoiding impairment to the human body^[26].

All core temperature changes of the 9 fabrics are similar. During the standing activity, the core temperature goes up. When the person is sitting, the core temperature goes down, and after 30 minutes of sitting activity, the core temperature reaches the lowest core temperature during standing activity. When the person is doing moving work, the core temperature increases quickly, and in most cases, the highest core temperature during the whole process is at the end of simulation. Meanwhile, the lowest core temperature of all fabrics does not go lower than 37.15 °C in both indoor and outdoor environments.

The left graph of Fig. 6 is the box plot of the male and female's mean highest core temperatures when they are wearing clothes made of fabric 0 to 9 in indoor and outdoor environments. The right graph of Fig. 6 is the box plot of the highest core temperature of fabric 0 to 9 in indoor and outdoor environments.

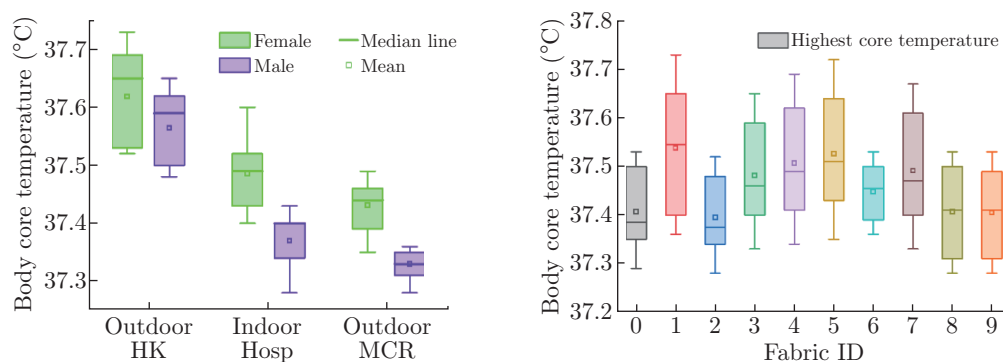


Fig. 6: Left: the box plot of the highest core temperature of male and female when they are wearing clothes made of fabric 1 to 9 in indoor and outdoor environments. Right: the box plot of the highest core temperature of fabric 0 to 9 in indoor and outdoor environments

Note: HK means Hong Kong, Hosp means hospital, MCR means Manchester.

In general, under the same environment and gender condition, the difference between different fabric types is small, the biggest difference is only 0.08. Besides, the core temperature of female is always higher than the male, which could be attributed to the fact that clothing coverage rate of the female is higher than the male.

In Fig. 4, during the whole movement period, the core temperature does not exceed 37.5 °C or exceed 37.5 °C within a short period. In conclusion, the core temperature is within the acceptable range throughout the whole activity time and all environments. The highest core temperature under all fabric and environment settings is not higher than 37.8 °C, and the period that the core temperature is higher than 37.5 °C do not last very long. Therefore, core temperature is not the key concern when selecting the fabric.

4.1.2 Comfort Value, Dampness Sensation and Thermal Sensation

Comfort value is decided by dampness sensation and thermal sensation. Figure 7 shows the box

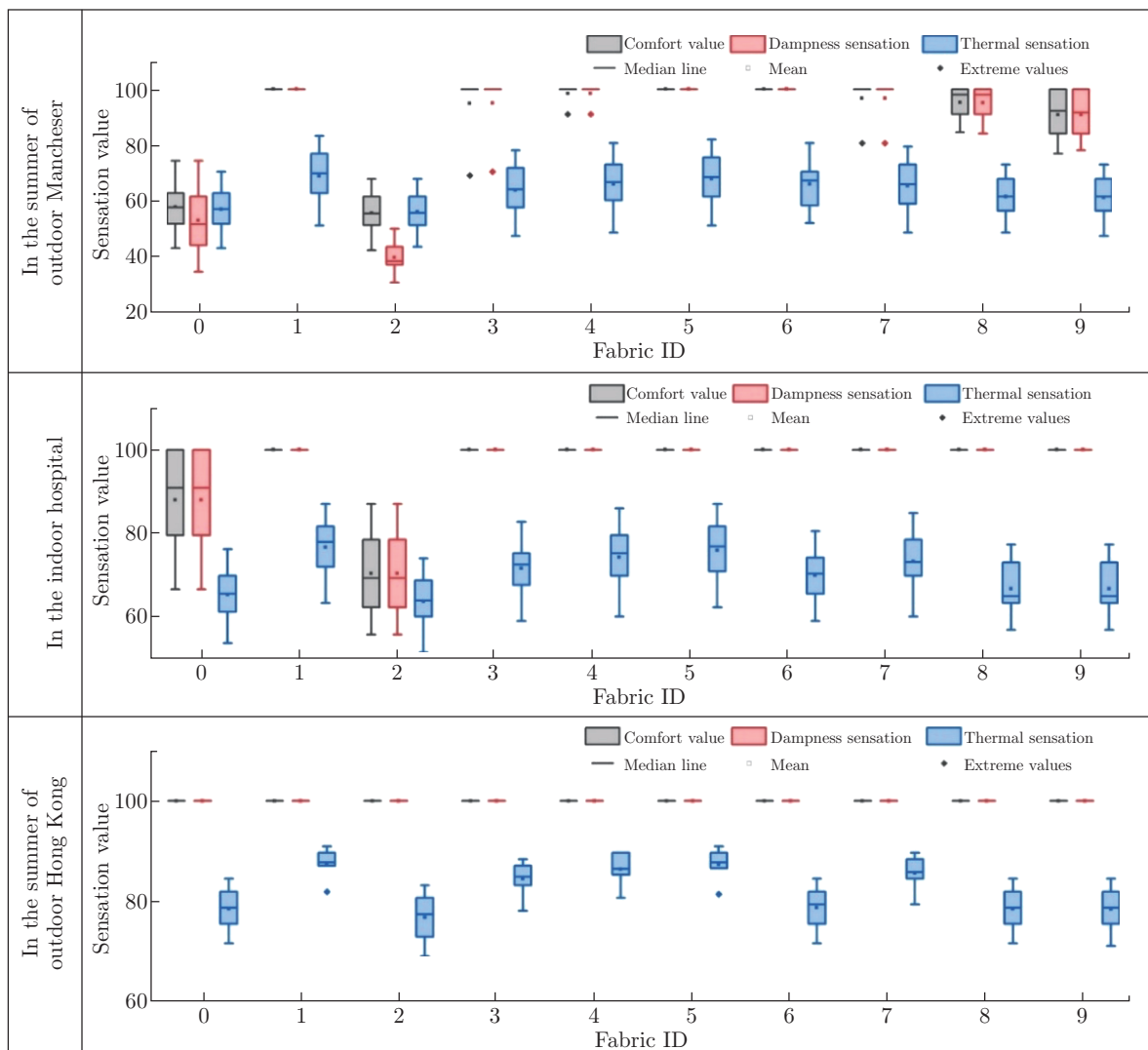


Fig. 7: The box plot of the comfort value, dampness sensation and thermal sensation of both male and female when wearing different fabrics in the outdoor Manchester, indoor hospital and outdoor Hong Kong environment

Note: I. Each comfort value, dampness sensation and thermal sensation data includes both male and female. II. Each comfort value, dampness sensation and thermal sensation data includes the numerical value at the 1 hour, 90 minutes and 120 minutes of the activity simulation.

plot of the comfort value, dampness sensation and thermal sensation of both male and female when wearing different fabrics in the hospital indoor environment. Each comfort value, dampness sensation and thermal sensation data includes the numerical values at the 1 hour, 90 minutes and 120 minutes of the activity simulation.

For outdoor Manchester, fabric 3, 4 and 7 show “extreme values” on the comfort and dampness sensation, which are the male’s comfort and dampness sensation at the 90th minute, the end of sitting activity. This phenomenon shows that comfort and dampness sensation go down significantly during sitting activity when wearing clothes of these fabrics, and the male’s comfort value is deeply affected by the dampness sensation, which may be caused by the high wind speed in the outdoor environment. Under some environment settings, some fabrics may have better breathability. Similar situation appears on the fabric 1 and 5 for outdoor Hong Kong. The male’s thermal sensation on the 90th minute is shown as “error data”. However, their comfort values are always 100, which means that the decreasing thermal sensation has no significant influence on the comfort sensation.

In conclusion, under all three environment conditions, on the simulation results of fabric 1 to 9, only fabric 2 has better thermal comfort value than fabric 0. For making a comfortable RMPC, the dampness sensation takes precedence over the thermal sensation.

4.1.3 The Influence of Three Fabric Structure Factors on NET_{CMC}

As Fig. 5 demonstrates, the simulation results from e-thermal CAD includes the temperature and relative humidity within the fabric, the detailed data is in the DAT documents “Fabric0_RH” and “Fabric0_Temperature”. The temperature and relative humidity on thickness 0 is set to act as the near-skin temperature and near-skin relative humidity. Formula (5) is used to calculate NET_{CMC} of different fabrics.

The left graphs of Fig. 8 are the NET box plot of different fabrics, which are calculated by the skin relative humidity and skin temperature at the 1 hour, 90 minutes and 120 minutes of the activity simulation. It is clearly seen that only the NET of fabric 2 is lower than the NET of fabric 0 in all environmental conditions.

The right graphs of Fig. 7 are Pareto charts of Spearman correlation between NET and fabric structure factors, which are generated by Minitab. The NET data used in Pareto charts are the data of fabric 1 to 9, and the terms of the Pareto charts that cannot be estimated are removed. For outdoor Manchester, the combining effect of yarn linear density is the biggest one followed by yarn linear density. For indoor hospital and outdoor Hong Kong, the yarn linear density has the largest effect, and the second one is the material.

To sum up, the yarn linear density has significant effect in all three environmental conditions, the material has significant effect in the indoor hospital condition and outdoor Hong Kong, and the combining effect of yarn linear density influences NET only in the outdoor Manchester.

4.2 The Relationship between OMMC and NET, and OMMC of Fabric 2 and 3

Dampness sensation is decided by skin relative humidity. The skin relative humidity is affected by the moisture management ability of fabric.

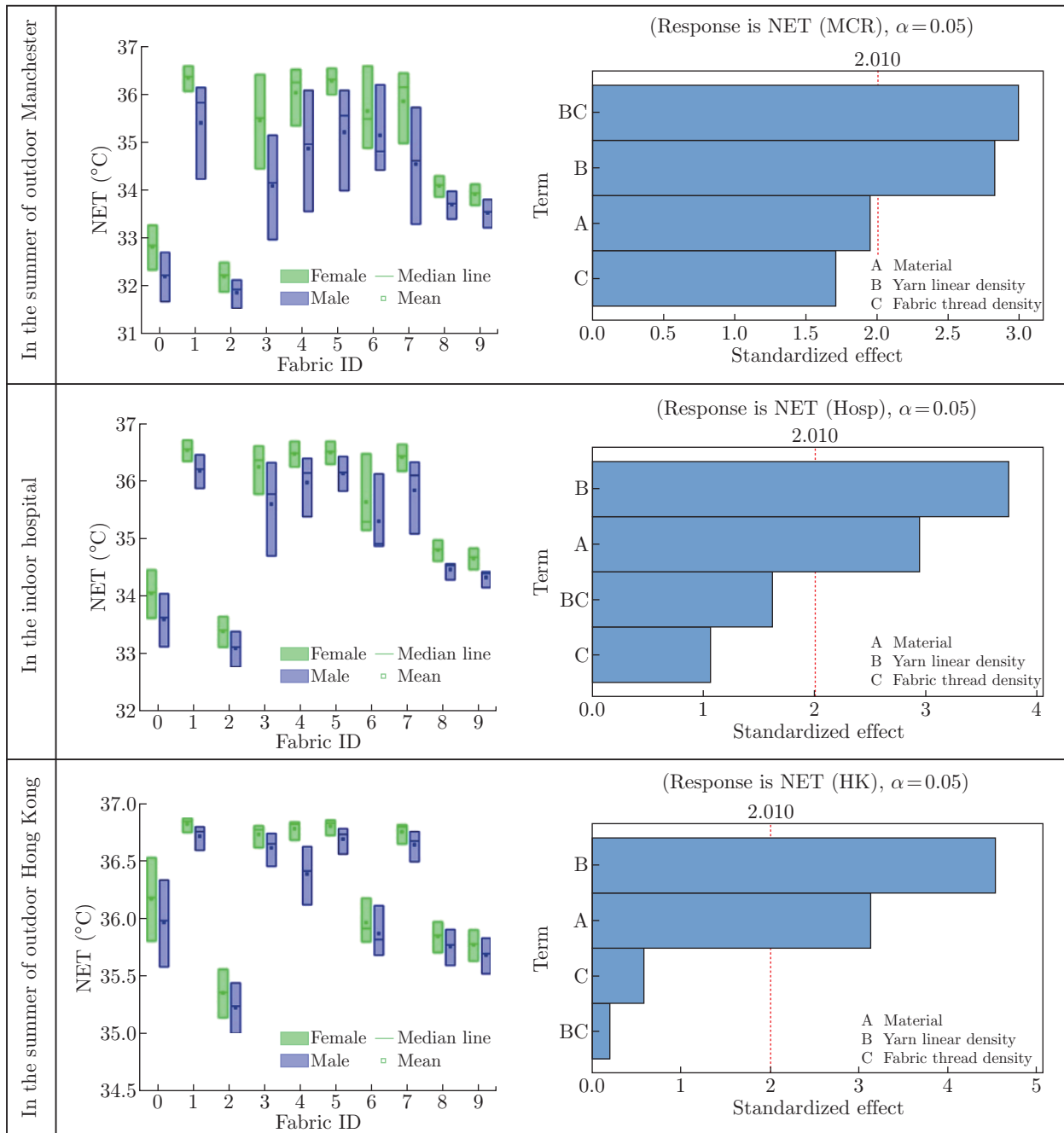


Fig. 8: The box plots of different fabrics NET (left) and Pareto charts of Spearman correlation between NET and fabric structure factors (right)

Note I: NET data of Pareto charts are the data of fabric 1 to 9.

The graphs a to c of Fig. 9 are the Spearman correlation between OMMC and NET in three environments. As demonstrated in the graphs, in all three environments, when the OMMC is near 0.5, NET decreases; when the OMMC is away from 0.5, NET increases. Besides, the P value is smaller than 0.05 in all environments, which means that OMMC has a big influence on NET.

As shown on the Table 1, fabric 2 and 3 are both made of cotton, they have same yarn linear density and similar thread density. However, the graphs of core temperature in Fig. 3 show that the skin relative humidity indexes of the man who wears fabric 2 and 3 are very different.

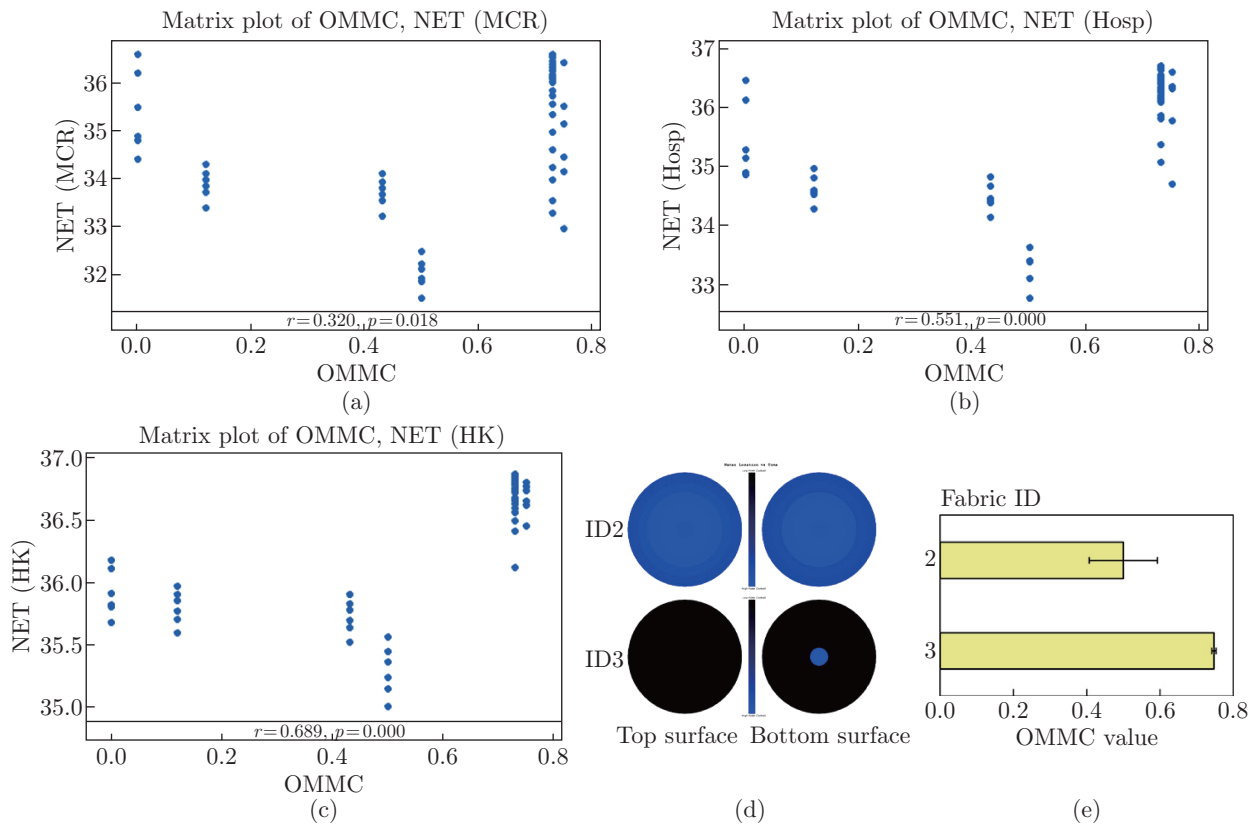


Fig. 9: The water permeabilities of fabrics 2 and 3

The graph d of Fig. 9 is the water permeabilities of fabric 2, 3 tested by MMT. As shown on the graph d, the water spreading ability of fabric 2 and 3 are very different, which are also reflected by the moisture management data of fabric 2 and 3 listed on Table 2. The graph e of Fig. 9 is the mean OMMC values and their standard deviation of fabric 2 and 3, this graph also shows that OMMC values of fabric 2 and 3 are different. This phenomenon may be caused by the difference in yarn structures for fabrics 2 and 3.

4.3 The Bursting Strength and Tensile Strength of Fabric 0 and 2

As shown in Fig. 6 and Fig. 7, only fabric 2 has the better thermal comfort value than the fabric 0. Therefore, only fabric 2 will be tested on physical strength and compared with fabric 0.

Table 3 shows the burst and tensile strength testing results of fabric 2 and 0. The results

Table 3: The bursting strength and tensile strength of fabric 2 and a with the standard deviation

ID	Bursting strength (kPa)	Bursting strength-wet (kPa)	Strength growth of wet condition (%)	Tensile strength (N)	Tensile strength-wet (N)	Strength growth of wet condition (%)
2	303.97±2.337	388.70±9.51	28	435.35±151.49	478.73±182.16	10
0	539.73±5.08	511.93±24.15	-5	687.70±267.92	722.83±264.07	5

show that fabric 0 has the better performance on both bursting strength and tensile strength than fabric 2. On BS EN 13795-1:2019^[19], the bursting strength need to be no less than 40 kPa on both dry and wet condition, and the tensile strength needs to be no less than 20 N on dry condition. For high performance surgical gown, the tensile strength also needs to be no less than 20 N when wet. Both fabric 2 and 0 exceed the requirement of the standard.

It is worth noting that the wet condition improves the fabric 2 strength, but has fewer influence on fabric 0, which could be because fabric 0 is mainly woven by polyester.

5 Conclusion and Future Works

In all three environment conditions, the thermal comfort value of RMPC is mainly affected by the skin relative humidity of the human body. Among three fabric structure factors, material, yarn linear density and fabric thread density, yarn linear density has the most apparent effect in all environment conditions, the material significantly influence the thermal comfort value when in the indoor hospital and outdoor hot environment, and the fabric thread density affect thermal comfort only when it is combined with yarn linear density in the cool outdoor environment.

9 kinds of plain weave fabrics were tested in the experiment, the cotton fabric whose yarn linear density is 131 Denier and thread density is 209/inch has best comfort value. Although its physical strength is lower than the fabric used by NHS, it can still easily meet the physical strength of surgical gown on EN 13795-1:2019^[19].

In this article, the cotton fabrics that have same yarn linear density and similar thread density have very different moisture management ability, which may be caused by the use of different structures of cotton yarns. In future works, yarn structure needs to be taken into consideration together with fabric structure properties. Besides, based on EN 13795-1:2019^[19], two protective performance, liquid penetration resistance and biosafety requirements also need to be considered.

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