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# A dynamic tester to evaluate the thermal and moisture behaviour of the surface of textiles

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ABSTRACT

The thermal and moisture behaviour of the microclimate of textiles is crucial in determining the physiological comfort of apparel, but it has not been investigated sufficiently due to the lack of particular evaluation techniques. Based on sensing, temperature controlling and wireless communicating technology, a specially designed tester has been developed in this study to evaluate the thermal and moisture behaviour of the surface of textiles in moving status. A temperature acquisition system and a temperature controllable hotplate have been established to test temperature and simulate the heat of human body, respectively. Relative humidity of the surface of fabric in the dynamic process has been successfully tested through sensing. Meanwhile, wireless communication technology was applied to transport the acquired data of temperature and humidity to computer for further processing. Continuous power supply was achieved by intensive contact between an elastic copper plate and copper ring on the rotating shaft. This tester provides the platform to evaluate the thermal and moisture behaviour of textiles. It enables users to conduct a dynamic analysis on the temperature and humidity together with the thermal and moisture transport behaviour of the surface of fabric in moving condition. Development of this tester opens the door of investigation on the micro-climate of textiles in real time service, and eventually benefits the understanding of the sensation comfort and wellbeing of apparel wearers.


## 1. Introduction

Textiles provide decoration and protection to human being through a complicated system. In the system, the human body, the clothing and the environment work together to maintain the wellbeing of the wearers. However, these three parts may affect each other due to the different attributes of clothing, physiology of human body and change of environment. Design of clothing is thus very important to maintain the comfort of wearers in this complicated system. In terms of protection function, garments are used to keep the body warm and transport sweat to maintain comfort. Thermal and moisture behaviour of clothing has been regarded as the determining factors that affect the comfort of clothing, and thus continuous attention from researchers have been putting on the thermal and moisture comfort (Song, 2011; Pan and Gibson, 2006). Previous research effort has developed evaluation methods such as thermal and moisture resistance tester (hotplate method) and simulated manikin (Huang, 2006; AATCC, 2010; Fan and Qian, 2004). However, it is very limited to evaluate the thermal and moisture behaviour of fabric on hotplate as clothing is usually subject to dynamic moving conditions in real application. Thermal manikin focuses on the thermal and moisture behaviour of whole apparel, the results vary evidently due to slight change from environment due to the complex mechanism of the apparatus.

Microclimate is defined to describe the environmental parameters that influence heat exchanges such as the temperature, humidity, and micro-space airstream between the skin and clothing (Zhong et al., 2006). Clothing has been served to keep body comfortable by maintaining the microclimate into a proper temperature and humidity level. Static assessment has found that the temperature and humidity of the microclimate of fabric changed evidently during a moisture liberation process (Cui et al., 2009; Li et al., 2008). Slight changes of the microclimate may cause uncomfortable sensation to wearers, thus it is of great importance to focus on the microclimate in a dynamic process in

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which the fabric is subject to movement. Static assessment can just characterise the thermal and moisture behaviour to some extent, it is not applicable in a dynamic process since clothing is moving in the process. Previous work has simulated the moving condition of textiles by putting the rotating arm in a cylinder (Lamb, 1992). Surface properties have also been found to affect the thermal and moisture behaviour of the microclimate of textiles (Wang et al., 2015). Microclimate can only be investigated thoroughly by varying the attributes of textiles, environment and body system. There is a lack of proper evaluation technique to characterise the changes of microclimate in a dynamic sweating or heat exchange process, which has greatly postponed the development of knowledge and limited the understanding of comfort.

Previous research work has focused on evaluating the thermal and moisture behaviour of the microclimate of a fabric using a specially designed tester (Li et al., 2013; Wang et al., 2014). This work will introduce the development of the dynamic tester and detail the established testing techniques. It opens the door to study the thermal and moisture behaviour of microclimate of textiles, and it will benefit the designing of clothing based on the thorough understanding of the thermal and moisture behaviour of textiles.

## 2. Setup

The setup provides a rotating testing platform as shown in Fig. 1. A testing unit is mounted on a motor to generate rotation during the test, simulating active movement of textiles in real service. The testing unit contains a central controlling panel and a rotating arm/shaft with a length of 250 mm from the panel. The testing platform is mounted on one end of the shaft while a balancer is mounted on the other end. Sensors and hotplate have been mounted on the platform to perform thermal and moisture testing. The motor together with the testing unit are mounted on the bracket. A computer is used to acquire data from the testing platform through wireless communication. The setup is thus able to evaluate the thermal and moisture index together with thermal and moisture transfer of textiles dynamically.

### 2.1. Rotation generation

Driven by the motor *1*, the central controlling panel *3* rotates in the testing. A circular movement of the testing platform *2* is thus generated through the shaft that connects the platform with the panel (as shown in Fig. 1). Different rotating speeds can be obtained by tuning the motor, and the simulated moving speed of the testing platform can thus be calculated according to the following formula:

$$V = 2\pi\omega r \tag{1}$$

Where, $\omega$ is the rotating speed of the motor, $d$ is the length of the shaft and $V$ refers to the simulated moving speed.

### 2.2. Testing platform

The testing platform *2* in Fig. 1 is depicted in detail in Fig. 2. It contains a bracket (as part of the rotating arm) on which a hotplate and different sensors are mounted. Samples are mounted tightly on the surface of the hotplate with a distance of 5 mm from the sensors during testing, as enlarged shown in Fig. 2. The hotplate contains a carbon fabric as the heating element, a PET jacket as insulation and protection element and two electrodes as power supply, with details illustrated in the inset of Fig. 2. Temperature sensors are located on both sides of the hotplate to monitor the temperature of the hotplate and to obtain the data of temperature in the test. High porous polyethylene is filled underneath the hotplate as an insulation layer.

### 2.3. Central controlling panel

The central controlling panel commands the whole testing process including setting the moving speed, acquiring of data from the sensors and regulating the temperature of the hotplate. The operating flowchart of the central controlling panel is depicted in Fig. 3. The rotating speed can be pre-set on the panel before the testing begins. Data of temperature and humidity will be processed through A/D transmission in the panel. The processed data, with °C and % as units, will be then transported to the computer afterwards via wireless communication. A proportional–integral–derivative (PID) controller has been successfully applied for the central controlling panel to control the temperature of hotplate.

### 2.4. Powering and mechanical transmission

The power of the motor is provided by electricity source through wiring and socketing. Another battery is mounted to power the central controlling panel for controlling of the temperature of hotplate. However, the central controlling panel is subject to rotating during the test, making the wiring of the rotating shaft impossible. A dedicated powering and mechanical transmission design is applied to the setup, as shown in Fig. 4. The coupling *3* joins the central controlling panel *4* with the shaft *1* that is inserted into the motor. There is an insulation jacket sheath *2* around the coupling *3* which prevents electricity leakage to the shaft. The jacket *2* is coated with copper film to conduct electricity from the conductive unit *6*. Contacting conduction is applied to provide electricity from the unit *6* to the copper film on *2*. This is done by a tightly contact between elastic conductive copper chips *7* on the conductive unit *6* and the copper film on the jacket *2*. A wire penetrates the hole on *2* and *3*, and passes along the inner wall of *3*, and goes through the nozzle *5* to reach the central controlling panel *4*. The electricity is then conducted by the wire from the copper film to the panel *4*. Thus the electricity has conducted to the panel *4* during the test when *1*, *2*, *3* and *4* are all subject to rotating. Digital power supply (PPS3005S) is used to provide electricity to unit *6*, with maximum voltage 35 V and maximum current 5 A.

## 3. Theory and methodology

### 3.1. Temperature and humidity sensing

In order to eliminate sensing error and to ensure the precisely controlling of hotplate, sensor for temperature must be small in size, precise, waterproof, sensitive and responsive, and versatile. The selected sensor is negative temperature coefficient (NTC) thermistor temperature sensor (NTC-MFB, Physics Research Centre of Chinese Academy of Science, Xinjiang). The temperature coupling unit of the sensor is 0.2 mm and the sensor is jacketed by epoxy resin to prevent water. A/D convertor is used to process the tested voltage into temperature from the voltage–temperature curve of the sensor.

Capacitive humidity sensor SHT11 is used to obtain the humidity in the test. With A/D convertor embedded, the digital sensor can sense RH humidity between 20% and 99% with a responsive time of 2 s.