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COMPARISON BETWEEN LOCAL TEMPERATURE DISTRIBUTION UNDER CLOTHING AND ON CLOTHING

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ABSTRACT

We measured temperature distributions under a garment using a measurement garment made of a textile instrumented with multiple thermocouple temperature sensors. We also measured the surface temperature of the garment using an infrared thermography camera. Comparing these separate temperature measurements enabled measurement of the increased temperature and its distribution under the clothing when wearing a shirt, which the infrared thermography camera does not measure. The places where the temperature increased were also confirmed. The local temperature distribution under the garment was also evaluated, which is not available from the surface temperature of the thermal manikin. Therefore, it was shown that the developed measurement garment can be used to measure temperature distribution in microclimate spaces and is useful for evaluating the thermal performance of garments.

KEYWORDS

Thermocouple temperature sensors, local temperature distribution, temperature under clothing, shirt.

INTRODUCTION

Clothing protects the skin and body from the inevitable changes of the natural environment, such as heat, cold, and ultraviolet rays, and also contributes to controlling human body temperature. The micro space between clothing and the skin is important for clothing comfort. One method to evaluate the thermal comfort of clothing is to measure skin temperature because it varies with changes in environmental temperature due to the human body's thermoregulatory response to maintain a 37°C core temperature. In general, skin temperature is measured by attaching a thermocouple temperature sensor or the temperature-sensitive part of a thermistor thermometer to the skin with a breathable surgical tape to measure the temperature by contact. However, this method can only provide temperature information for one location at a time [1].

By contrast, non-contact temperature measurement methods, such as radiation thermometers or thermography cameras, measure the radiant energy emitted from an object's surface. In thermography, the entire temperature distribution is captured using an image, which can be processed in various formats. However, because it can only measure surface temperature, it cannot measure the skin temperature under clothing. In addition, any change in the object's surface emissivity will result in

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measurement errors. Furthermore, if the angle between the object surface and the camera is greater than 60°, errors due to radiant energy attenuation will occur [1].

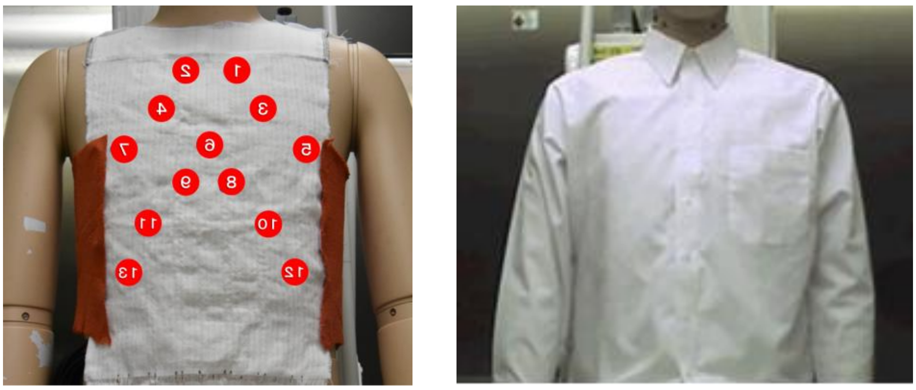
This study focused on the temperature distribution under clothing and on the skin surface. There have been many studies on the relationship between air layer thickness and heat transfer in clothing [2–4]. In most of these studies, experiments were conducted using a device incorporating a concentric cylinder model with a heating plate and clothing layers. Yamazaki et al. [5] measured the airflow and temperature inside a garment on an actual human body, but the temperature inside the garment was measured only at one point on the chest. Based on these studies, if a method can be established to continuously measure the microclimate space under a garment at multiple points, it will be possible to obtain a more detailed temperature distribution inside a garment and evaluate the local thermal comfort.

Takatera et al. [6] fabricated a textile incorporating thermocouple temperature sensors that can continuously measure the temperature inside a garment at multiple points, measured the upper garment temperature, and investigated the possibility of using the textile to measure the temperature inside the garment. Kim et al. [7] also fabricated a textile with a built-in temperature sensor and measured the temperature distribution inside the lower garment. This study clarifies the effectiveness of the textiles developed in those previous studies [6,7] by comparing temperatures measured under a garment using the developed textile with its surface temperature measured using an infrared (IR) thermography camera.

EXPERIMENT

To measure the temperature under a garment, we made a textile instrumented with multiple thermocouple temperature sensors. We made a measurement garment using this textile (Figure 1a) that can be worn by a thermal manikin (THM117S/217S, Kyoto Electronics Industry, Japan). The sides of the measurement garment were sewn together with elastic rib knit (60% acrylic, 40% wool) for the thermal manikin to wear. Thirteen thermocouples were installed on the front chest of the measurement garment (Figure 1a).

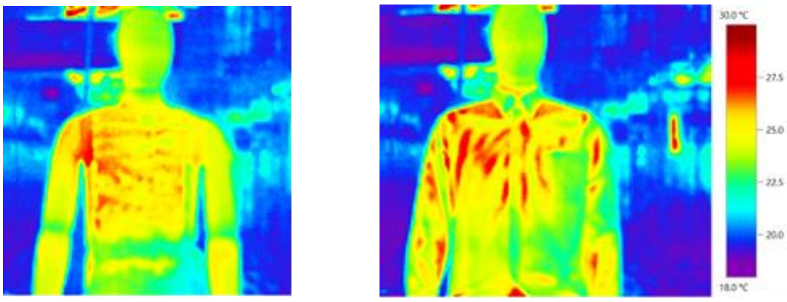
The thermal manikin was dressed in the measurement garment and a dress shirt (55% cotton, 45% polyester) in a climate chamber, as shown in Figure 1(b). The temperature under the shirt was measured three times using the measurement garment with the shirt worn over it. The temperatures of the measurement garment without the shirt were also measured three times. The temperature measurement using the measurement garment was performed for 20 minutes with a 20-second cycle, and the average value of the data obtained at each measurement point was calculated.



(a) measurement garment **(b) dress shirt**

Figure 1. A thermal manikin wearing the measurement garment (a), and dress shirt over it (b).

The shirt surface temperature was measured three times using an infrared (IR) thermography camera (875i, Testor Co., Ltd.). The measurement garment surface was also measured. The average value of each measurement was calculated using dedicated software (testo IRSoft). The measurement accuracy of the IR thermography is ±2°C, and its resolution is 0.1°C.



(a) measurement garment **(b) dress shirt**

Figure 2. Thermography images of measurement garment (a), and a dress shirt over it (b).

The thermal manikin is maintained at a constant power of 58.2 W/m^2, the metabolic rate when a person sits at rest on a chair to produce a state close to the human body's. The thermal manikin surface temperature is recorded in 20-second cycles. The environmental temperature and humidity in the chamber are set to 20°C and 65% RH, respectively.

RESULTS AND DISCUSSION

Figure 2 shows thermography images of the measurement garment surface with and without the dress shirt over the garment. Figure 3 compares the undergarment temperatures measured using the measurement garment to the IR thermography surface temperatures corresponding to the measurement points. The measured temperature distribution differed at each measurement point. The mean measurement garment temperature was 24.4°C when only the measurement garment was worn, and 30.1°C when a shirt was worn over it, a 5.7°C increase. The garment's temperature increased for all measurement points when wearing the shirt, with different temperature increases among the measurement points due to the varying air gaps between the garment and shirt. The increases in mean temperatures were 5.2°C at Nos. 1–4 near the collar, 6.0°C at Nos. 5–9 near the center, and 5.7°C at Nos. 10–13 near the hem.

The mean surface temperature measured by the IR thermography camera for the measurement garment only was 25.6°C. When the shirt was on the measurement garment, the mean garment surface temperature was 25.5°C. In contrast to the temperature results for the measurement garment, the measurement points where the temperature increased after the shirt was worn were Nos. 1–4, 8, and 9, mainly near the collar. The temperature decreased at other measurement points, possibly due to the influence of heat conduction because of a small air gap near the collar with the garment and shirt in contact with each other. However, the area near the hem had a larger air gap, and the heat conduction from the surface of the thermal manikin was smaller. No. 7 had the lowest garment surface temperature, coinciding with the shirt pocket and also indicating that the heat conduction effect is small.

The mean shirt surface temperature from the thermography was 25.9°C for Nos. 1–9 and 24.8°C for Nos. 10–13. By contrast, the mean temperature from the measurement garment with the shirt on was 29.9°C for Nos. 1–9 and 30.5°C for Nos. 10–13. The garment surface temperature is higher for a small air gap when the garment is worn and vice versa. However, the heat retention rate inside the garment increases when a certain air gap is reached [6], and the same result was obtained in this experiment. Therefore, it was found that a high clothing surface temperature does not necessarily mean a high temperature under clothing.

The surface temperature of the thermal manikin increased by 4.4°C when the shirt was worn, as shown in Figure 3. By contrast, the increased mean temperature measured by the measurement garment when wearing the shirt was 5.7°C. Thus, there was a 1.3°C temperature difference between the skin temperatures of the thermal manikin and measuring garment. In addition to this difference, the measurement garment provided localized temperature distributions that cannot be measured with the thermal manikin. Therefore, the developed measurement garment can measure the temperature distribution of microclimates like the inside of a garment that cannot be easily measured by the IR thermography camera or the thermal manikin.

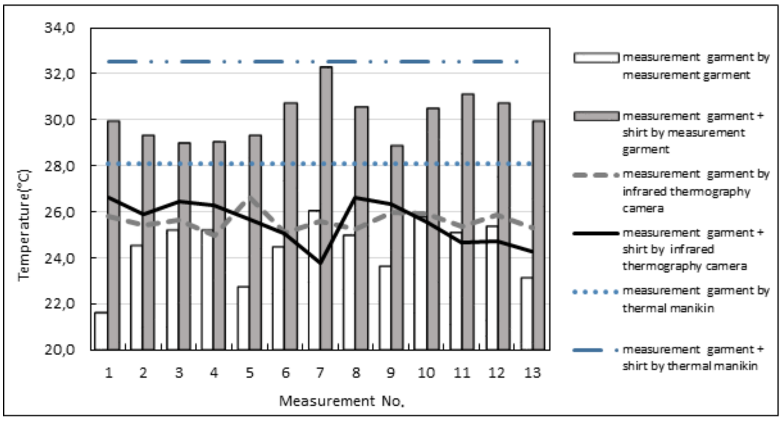


Figure 3. Temperatures measured by measurement garment, infrared thermography camera, and thermal manikin.

CONCLUSION

We measured the temperature under a garment using measurement garment made of a textile instrumented with multiple thermocouple temperature sensors. We compared the measured temperatures under the garment with surface temperatures measured using an IR thermography camera. By comparing the temperature under the clothing measured by the measurement garment with the surface temperature measured by the IR thermography camera, the increased temperature under the clothing when wearing a shirt was determined. The IR thermography camera cannot measure this temperature change. The locations where the temperature increased were also confirmed. The temperature distribution under the garment was also evaluated, which cannot be determined using the surface temperature of the thermal manikin. Therefore, the developed measurement garment can measure microclimate space temperature distributions and help evaluate and improve the garment thermal performance.

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