

Development of a Two-Layer Movable Sweating Thermal Manikin

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Received March 3, 2006 and accepted April 12, 2006

Abstract: A thermal manikin is a useful tool to evaluate thermal environments such as clothing, houses and others. A manikin needs to have the following properties: shape and size, heat production, skin temperature, sweat rate, physiological responses and others. So far, no manikin satisfying all these criteria has been available. In the present study, a two-layer movable sweating thermal manikin was newly developed as a trial to compensate for the differences between conventional thermal manikins and the human body. The manikin consisted of two layers, a core section in the trunk and a shell section divided into 17 parts over the whole body, the temperature and heat supply of which could be independently controlled. The manikin is possible to change the posture and to walk. The sweat rate from 180 pores on the skin was controlled by peristaltic pumps. The temperature performance of the manikin was investigated using thermograph. As a result, the surface temperature of the manikin decreased more in the extremities than in the trunk when the manikin was exposed to 18°C after being exposed to 28°C for 20 min. This is analogous to the skin temperature decline in the extremities of the human body.

Key words: Sweating thermal manikin, Movable, Two layer model, Core, Shell

Introduction

Protective clothing is of great importance for the safety and health of industrial workers in hazardous fields involving fire, cold pathogenic microorganisms, etc. Clothing must protect the worker's body against environmental hazards as well as minimize possible detrimental effects on their thermo regulatory system. In order to develop high-quality protective clothing, precise evaluation of the heat and moisture transport properties of clothing is important.

A thermal manikin is a useful tool which can be used to realistically and objectively assess the environmental thermal impact on the human body, accurately measure heat exchange with reproducible results, and take cost-effective and comparative measurements. Many kinds of thermal manikins have been developed in the world¹⁻⁷⁾ and have been used to evaluate the protective qualities, performance and comfort of cold-weather, fire-protection, and biohazard-protection wear, as well as hats, gloves, footwear, and sleeping bags⁸⁻¹¹⁾. The development and improvement of thermal manikins as

an evaluating system of clothing is significant from the standpoint of industrial health.

A thermal manikin needs to have the following properties in order to accurately simulate the human body: (1) correct body shape and size; (2) control of heat emission; (3) control of the distribution of heat across the skin surface; (4) emission of the skin; (5) control of the distribution of perspiration across the skin surface; (6) control of pose and movement; (7) control of core and shell differently to simulate the physiological responses of the human body. So far, no manikin meeting all these criteria has been available. Recently manikins have been developed where perspiration across the skin surface and walking speed can be controlled in some laboratories. However, a two-layer model consisting of a core layer and a shell layer whose temperatures can be independently controlled by a computer has, until now never been developed or tested. Depending on some situation, for example, in the case when wearing cold-weather gear in cold conditions, existing thermal manikins are limited to a uniform temperature distribution across the skin surface

even though the human body's extremities experience large drops in skin temperature. This inevitably leads to an overestimation of heat loss from the extremities in the result obtained using the thermal manikin. The object of this research is to develop the two-layer movable sweating thermal manikins and bring the measurements into closer agreement with what an actual human body would be experiencing.

Development of the Manikin

The manikin developed was named "JUN." Figure 1 shows JUN's construction. The manikin's body is made of FRP plastic with a flesh-toned matte finish. The emissivity of the skin surface is approximately 0.9. The body's exterior dimensions are based on those of an average adult Japanese male (Table 1), divided into 17 segments: head, chest, back, abdomen, buttocks, left and right upper arms, left and right forearms, left and right hands, left and right thighs, left and right calves, and left and right feet. The manikin is articulated at both shoulders, both hips and both knees, enabling it to walk and sit. Heater wires are used to generate heat, and nickel wires are used to measure the average surface temperature. The core layer is made up of the head, chest, abdomen and buttock components, while the shell components correspond to the 17 segments noted above. Each can be independently controlled for fixed heat input or fixed temperature.

There is one sweat nozzle per 100 cm² of surface area. Each is fed with 36°C distilled water through tubes by peristaltic pumps outside of the manikin's body. Each nozzle can generate sweat at a rate of between 0.02 g/min and 0.15 g/min (20 g/m²h to 900 g/m²h). The manikin surface is tightly covered by a knit skin that disperses the water/moisture from the nozzle over the skin. The manikin's control cable and water supply tube emerge from the back of the manikin's head. A separate head unit was built for measurements. The amount of water vapor emitted is measured by a scale placed beneath the manikin. The manikin is made to walk by an external motorized apparatus connected to the arms and legs as shown in Fig. 2. A monitor displays times series data on changes in surface temperature, heat emission, ambient temperature and humidity, rate of heat flow, and clothing insulation (clo value). The total control system is summarized in Fig. 3.

Particulars of JUN's Control System

Figure 4 shows a graph of the total quantity of heat supplied



Fig. 1. JUN's construction and characteristic.

Table 1. Body surface area of each segment

Body Segments	Surface Area(m ²)
1 Head	0.156
2 Chest(F)	0.172
3 Chest(B)	0.176
4 Abdomen(F)	0.094
5 Abdomen(B)	0.116
6 Upperarm (R)	0.082
7 Fore arm (R)	0.060
8 Hand (R)	0.042
9 Upperarm (L)	0.086
10 Fore arm (L)	0.060
11 Hand (L)	0.042
12 Thigh (R)	0.146
13 Leg (R)	0.080
14 Foot (R)	0.062
15 Thigh (L)	0.142
16 Leg (L)	0.080
17 Foot (L)	0.062
Total	1.658



Fig. 2. Photograph during walking.

against skin temperature control under moderate ambient air conditions of 28°C and 50% humidity. After approximately 20 min, steady conditions are reached, and subsequently maintained, demonstrating good control. Figure 5 is a thermograph showing changes in the temperature of each segment as the room temperature is changed from 28°C to 18°C, while the core is controlled at a constant temperature and the shell is controlled with constant heat input. The falling air temperature is accompanied by a rapid decline in the surface temperature of the extremities. This is analogous to the skin temperature decline in the extremities of the human body due to vaso-constrictive response. This method resolves the problem of previous methods which overestimated the heat loss from extremities in cold conditions, and should make it possible to simulate the temperature changes in the

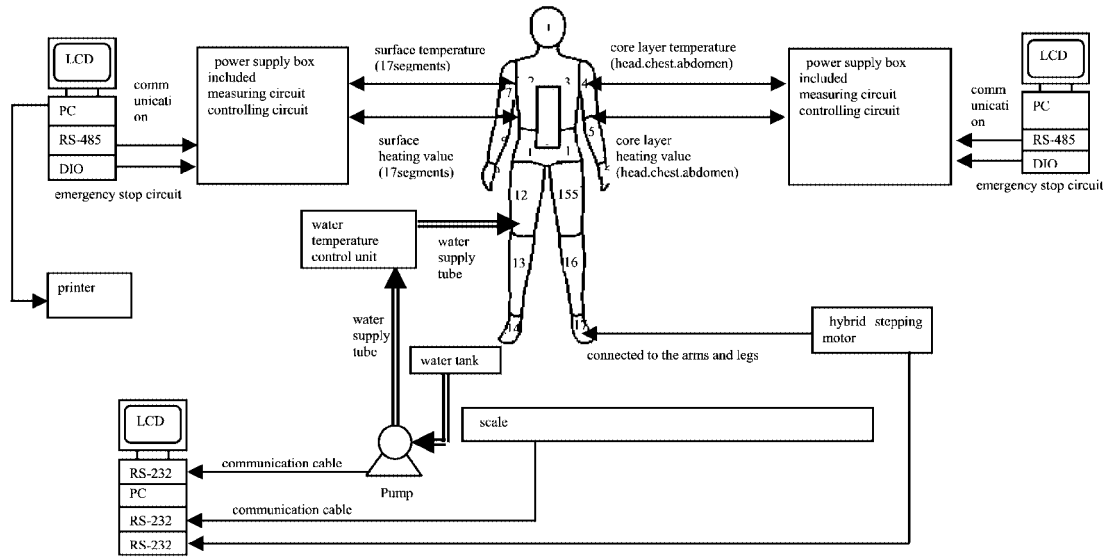


Fig. 3. The total control system.

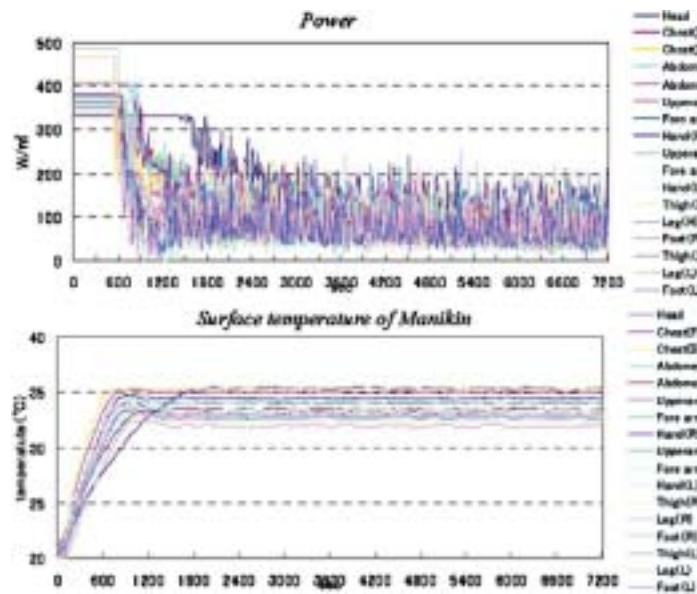


Fig. 4. Graph of total quantity of heat supplied against skin temperature control.

torso and limb, in exposed and covered parts of the body more accurately and to measure the effects of the shape and construction of garments on the wearer’s sensation more precisely.

The focus of this research project was the development of the manikin itself. We have not progressed to the point of incorporating a control system for heat quantity, skin temperature and sweat quantity based on an integrated body

temperature regulation model incorporating metabolism, blood flow and perspiration as means of evaluating environmental conditions. That is the next challenge.

Acknowledgements

This research was supported by a Grant-in-Aid for Scientific Research (No.152000530) by the Japanese Society

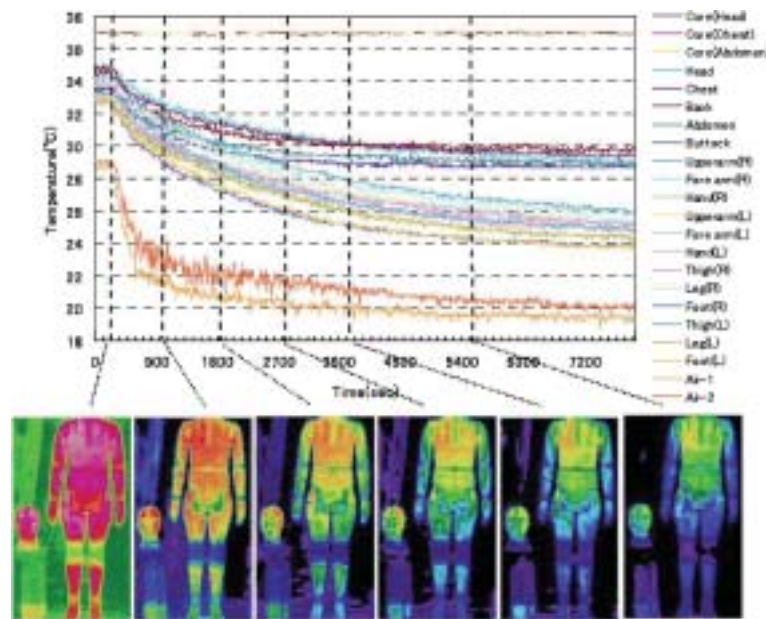


Fig. 5. Thermograph.

The room temperature is cooled from 28°C to 18°C degrees while the core is controlled at 37°C constant and the shell is controlled with constant heat input.

for the Promotion of Science. The author thanks to Ms. Iwasaki, Dr. Koshiba, Dr. N. Maruta and Mr. T. Yamada for their assistance of the experiments.

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