The Effects of Local Cooling on Thermophysiological Response in the Subjects Wearing Dust-free Garment

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1. Introduction

The dust-free garment used generally in semiconductor production factory is designed to prevent any of products from dust or static electricity. It consists of an enclosed type wear system combined with protective coveralls, hood, mask, gloves and boots for dust resistance and elimination of static electricity. Hood and mask are worn to wrap released particles because the head is a plentiful source of particles.
However, workers wearing hood and mask feel discomfortable due to accumulated heat, because 70-80% of the body-generated heat is released from the head (Siekmann, 1983).

Furthermore, workers wearing the dust-free garment also often suffer from general discomfortable feeling caused by impermeable properties of the clothing, indicating that an improvement of the dust-free garment is necessary.

Although a few studies have been carried out on the development of better dust-free garment (Webber and Wieckowski, 1982 ; Brinton and Swick, 1984 ; Swick and Vancho,1985), they are mainly based on the development of its superior materials, and control and method for evaluation of the dust-free garment without sufficient study concerned with its thermal physiology related to the wearing system of dust-free garment.

With these in mind, we endeavored to compare the effects of two kinds of dust-free garment with and without frozen gel strip (FGS) and half naked clothing (brassiere and shorts) on thermophysiological parameters and clothing microclimate (temperature and humidity).

2. Methods

Nine healthy females volunteered as subjects. Their characteristics (mean ± SD) were 19.4 ± 1 yrs in age, 159.4 ± 5.1 cm in height, 54.0 ± 5.4 kg in body mass and 1.4822 ± 0.08 m^2 in body surface area, calculated according to Fujimoto et al .(1968). The subjects arrived at laboratory at the same time of the day and in the same menstrual phase to avoid difference due to circadian and menstrual effects on thermal physiological parameters.

Two kinds of dust-free garment with (A) and without (B) FGS and half naked clothing (brassiere and shorts) (C) were used in this study. Dust-free garment ensemble were composed of hood, mask, boots, gloves, dust-free inner wear and coveralls garb.

The dust-free garment were made of a polyester/carbon conductive woven fabric with standard front zipper and snap closing at wrists and ankles. The dust-free garment with FGS was designed to have two pockets with the size of 9 x 6 cm in the inner chest part of dust-free garment. Those pockets were made of non-woven polyethylene materials with excellent air-keeping and bulkiness not only to maximize the cooling performance after inserting the FGS, but to minimize the infiltration of water into both inner wear and outwear by defreezing of FGS.

Rectal temperature (T_{re}) was measured with a thermistor probe. A rectal probe was inserted into the anus to a depth of 12 cm by the subjects themselves. Skin temperatures (T_{sk}) were measured at eight sites (forehead, forearm, hand, chest, back, thigh, leg, and foot) with adhesive surgical tape. Clothing microclimate (temperature and humidity) were measured using thermistor and humidity sensors at chest and back levels between the human body and inner wear (1st layer), and between the inner wear and outwear (2nd layer), respectively. Heart rate was recorded every minute by Sport Tester (Polar Electro Ky, Finland). The body mass of subjects and garments were measured at the beginning and at the end of the experimental protocol. The body weight loss was measured by using a balance (Sartorius) with an accuracy 1g. All parameters were recorded continuously by a recorder, and also sampled every one minute by a computer throughout a A/D converter. Inquires were also made into thermal sensation, humidity sensation and comfort sensation.

Tests were carried out in climatic a chamber at an air temperature of 23℃, a relative humidity of 50% and air velocity of 0.1 $m.sec^{-1}$. The measuring times were 140 minutes totally in such procedure. After a 20 minutes rest, 20 minutes simple work, 10 minutes walk (5 $km.h^{-1}$ on a tread-mill) and 5 minutes rest (20 minutes rest in the final trial) were three times repeated. Mean skin temperature (T_{sk}) was calculated by following modification of the Hardy-DuBois equation: $T_{sk} = 0.07\ T_{head} + 0.14\ T_{arm} + 0.05\ T_{hand} + 0.18\ T_{chest} + 0.17\ T_{back} + 0.19\ T_{thigh} + 0.13\ T_{leg} + 0.07\ T_{foot}$. The statistical significances between the parameters were assessed using a two-factor analysis of variance by F-test. A p-value less than 0.05 was considered statistically significant.

3. Results

Temporal changes in rectal temperature tended to slowly drop in the beginning after entry, and then to sharply rise after first walking in garb A and garb B. But rectal temperatures were clearly the lowest in garb C, intermediate in garb A and the highest in garb B. The rectal temperatures after first walking in among three kinds of garb were significantly different , $p<.01$).

The mean skin temperatures were significantly lowest in garb C, intermediate in garb A and the highest in garb B through the experiment ($p<.01$). The mean skin temperature during the 140 minutes experimental period was 35.9±0.04℃ in garb A, 36.4±0.04℃ in garb B and 31.7±0.02℃ in garb C.

There was no remarkable difference in the temperature of the limbs such as leg, foot, forearm and hand between garb A and garb B, while those in garb C were significantly lower than in garb A and garb B. Skin temperatures in leg, foot and hand were lowered or did not change during working in garb A, garb B and garb C, while those in forearm increased in garb A, garb B and garb C. Skin temperatures in forearm and hand were lowered during walking in garb A, garb B and garb C, while those in leg and foot increased mostly in garb A, garb B and garb C. Forehead and chest skin temperatures fell conspicuously during walking in garb C, while in garb A and garb B did not always fall during walking ($p<.01$).

The local skin temperature at chest and forehead were 34.4±0.02℃ and 34.5±0.01℃ in garb A, 35.0±0.03℃ and 35.0±0.01℃ in garb B, and 33.0±0.01℃ and 34.5±0.02℃ in garb C, respectively .

Heart rate as indications of cardic output tended to be sharply increased by walking and be returned by rest to its original condition, which was lower in garb A than in garb B for all subjects excluding one subject. The mean heart rate ($beats.min^{-1}$) during the 140 minutes experimental period were 80.5±11.4 in garb A, 88.9±13.6 in garb B and 77.6±17.8 in garb C. And also, it was significantly different among the three kinds of garb in accordance with walking and rest ($p<.01$).

The body mass losses by evaporation during the 140 minutes tests were 126.3±0.04 g in garb A, 145.4±1.11 g in garb B and 83.2±0.34 g in garb C, which were significantly different ($p<.05$).

The temperature and humidity were measured in chest level between skin and inner wear ($T_{micro-chest}$), and between the inner wear and outer wear ($T_{inner-chest}$). $T_{micro-chest}$ and $T_{inner-chest}$ were significantly lower in garb A than in garb B ($p<.01$). $T_{micro-chest}$ and $T_{inner-chest}$ were 32.6±0.09℃ and 30.4±0.1℃ in garb A and 33.3±0.06℃ and 30.8±0.07℃ in garb B, respectively.

The humidity within clothing showed that the garb A and garb B were about 1.5-1.7 kPa which equivalently and slowly rised in the beginning of walking, and then rapidly rised. After the third walking, the humidity in between skin and inner wear($H_{micro-chest}$) showed that both garb A and garb B rised up to about 4 kPa. But the humidity in between inner wear and outer wear ($H_{inner-chest}$) showed that both garb A and garb B rised up to about 3.1 kPa in chest level. In case of humidity in between skin and inner wear, $H_{micro-chest}$ was lower in garb A than in garb B. This condition similarly appeared in $H_{inner-chest}$ between inner wear and outer wear . There was significant difference in garb A as compared with garb B ($p<.05$). $H_{micro-chest}$ and $H_{inner-chest}$ were 2.52±0.56 kPa and 1.94±0.16 kPa in garb A and 2.67±0.59 kPa and 2.14

±0.24 kPa in garb B, respectively.

Although the humidity and thermal sensation of this study tend to be higher in garb A than in garb B, it was not significantly different for garb A vs. garb B. And also, comfort sensation was not significantly different in between garb A and garb B. However, most of the subjects (six-ninth of subjects) answered that they were more comfortable in garb A than in garb B, and were also cooler in thermal sensation when tested actually, they showed the reaction of 'wet' after the time of about one hour passed. It was shown, particularly, that the uncomfortable part in wearing included head and hands, of which the head was based on the wearing of hood and mask, and hands on the wearing of vinyl gloves of the dust-free fabrics gloves.

4. Discussion

The rectal temperature was significantly lower in garb A than in garb B. There was an initial dip following entry into the chamber. The time to be recovered to the first rectal temperature just before entry was about 60 minutes for garb B and 50 minutes for garb A. It continued to increase at an increasing rate until after approximately 70 to 80 minutes of tests. Then the rate of increase began to drop rapidly until by 120 minutes the temperature itself began to decline. Especially important is that rectal temperature after 140 minutes exposure has risen only 0.2℃ in both garb A and garb B. We hypothesize the reason for the initial drop in rectal temperature is the sudden increase in skin temperature. The heat to rise skin temperature comes from either the deep body, the environment, or both. Because heat transfer to the skin from the body is by conduction or convection by the blood and that from the environment is by convection or radiation. The removal of heat from the core would be reflected in a low rectal temperature.

Mean skin temperature and skin temperatures such as forehead and chest level were significantly lower in garb A as compared with garb B. Where the cooling effects were acceptable, and was particularly remarkable in forehead level. Although skin temperature was suggested that the local skin temperature in general wearing were regularly kept within 32-34℃ because it was not directly exposed to the temperature of outer air due to the microclimate formed by the clothing, its temperature was approximately 3℃ higher when wearing the dust-free garment . It seem to be caused by insufficient ventilation resulting from the structure and materials of the enclosed type coveralls, rather than the increase of heat production by kinetic load.

Heart rate and sweat rate during the experimental period were significantly lower in garb A than in garb B. Heart rate were the lowest in garb C, intermediate in garb A and the highest in garb B throughout the experiment. And sweat rates from the body mass loss were compared between garb A and garb B . The body mass loss by evaporation throughout the experiment was lower in garb A than in garb B. How would explain the means of difference between garb A and garb B ?

Heart rate and sweat rate are extremely sensitive to thermal stress as well as anxiety, work, and a host of others factors. These are an excellent general indicator of the presence of thermal stress when one can compare rates under given conditions with and without kinetic load. Heart rate data as indications of thermal stress are to be found in many papers, but such data in the context of individual cooling may be found in Webb(1968), Miura et al.(1971), Ran Rensburg(1972), Konz et al.(1973), Mihal(1981). In each of these papers, the heart rate data are shown for heat or heat plus work, cooled and uncooled, using air-ventilated clothing. And Kamon and Belding(1971) reported that core temperature is positively correlated with heart rate.

From the point of fact in described above, the effectiveness of the garb A has been proved by showing that the garb reduce physiological strain (rectal temperature and skin temperature, heart rate and sweat rate) and psychological distress substantially. In other words, these fact means that wearing of dust-free garment with FGS serves to maintain the rectal temperature and skin temperature at a lower level, so as to reduce the sweat rate.

Clothing microclimate temperature and humidity at chest level were significantly lower in garb A than in garb B . It is known that clothing microclimate temperature are closely correlated with the temperature of the adjacent skin surface (Natsume et al.,1988). Therefore it is easily conceivable that the lower clothing microclimate temperature in garb A were affected by lower chest skin temperature in garb A. In case of the garb A, the 1st layer humidity within clothing was higher in chest level than in back level, but it was rather higher in back level after walking. This condition similarly appeared in the garb B. It seemed, particularly, that high humidity in the chest level was caused by the opening in the head part where ventilation of clothing and vaporization of moisture from FGS occurred by defreezing. Why was humidity within clothing higher in back level during recovery than in chest level?

Which seemed to have been caused by the moving phenomenon of humidity from ventilations between chest level and back level when humidity moved within the enclosed clothing. In particular, the rise of humidity with the passage of time remarkably occurred in both garb A and garb B after the 1st walking. But after the 3rd walking when 120 minutes passed, rather, its rise of the garb A was higher than of the garb B. Which seemed to be caused by the phenomenon of moisture vaporization from FGS by defreezing with the passage of time.

As discussed above, these measurement are especially valuable during the early stages of the development of new type of dust-free garment or in the application of known FGS in a new situation. There results suggest that the usage of FGS could improve heat load in the lightly working and walking subjects wearing the dust-free garment. The reduction in physiological strain, although not ideal, would be of practical importance in many situations.