The Evaluation of Thermal Comfort for CB Protective Garments

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Abstract

The purpose of the study is attempted to evaluate thermal comfort properties of Chemical and Biological (CB) protective garments dressed in condition like Taiwan climate. Understanding the thermal comfort properties of protective clothing can help us understand the threat of heat strain. Furthermore, the heat stress we suffer can even be predicted. The study focused on the utilization of skin model system, sweating torso, sweat manikin to understand the difference of three types of CB protective garments. All three of the measurements showed that JLIST owned the best of thermal comfort performance while emergency CB suit was obviously the worst one among the comparison of 3 CB types of protective clothing.

Key words: CB Protective Garment, Skin Model System, Sweating Torso, Sweating Thermal Manikin

1. Introduction

CB protective garment is a type of protective suit giving protection inclusively against direct contact with and contamination by biological and chemical substances. Ideally, In consideration of military operations, CB protective clothing must be lightweight and flexible, with limited thermo-insulating properties to ensure that the soldier can move without over-heating. Recently, JSLIST (Joint Service Lightweight Integrated Suit Technology) garment has been widely adopted by US Army, Navy, Air Force, Marine Corps. The state-of-the-art of JSLIST garment features not only chemical protection improvement, but also more mobility, and heat stress reduction for the wearer.[1] In order to understand whether there was some difference among thermal comfort property which could be described in objective way for JSLIST garment, indigenous BDO (Battle Dress Overgarment) and a emergency type CB suit in Taiwan climate, The evaluation with skin model system, sweating torso and sweating manikin were arranged.

2. Material

The JSLIST garment is a 4 color Woodland camouflage consisted of 2 layers. The outer shell is a 50/50 nylon/cotton poplin ripstop with a durable finish. The liner layer consists of a nonwoven front laminated to activated carbon spheres and bonded to a tricot knit back. The BDO is 3 layers consisted of polyester/cotton twill out shell, a nonwoven middle layer laminated with activated charcoal cloth and bonded to woven fabric, and a cotton inner layer. The emergency type CB suit is a transparent plastic material.

3. Testing Method

3.1 Skin Model System

The system also called sweating guarded hotplate was used to determine the water-vapor resistance (Ret) in this study. According to ISO 11092 standard, the test set the measuring plate at 35 ℃ and the air condition at 35 ℃, 40% R.H. The air velocity was controlled at 1 m/s.[2]

3.2 Sweating Torso System

The sweating Torso system developed by EMPA Switzerland is a cylinder with the dimension of a human trunk. The torso contains a total of 54 independently controlled sweating nuzzled. The torso can either be run with constant surface temperature or with constant heating power. The whole torso is placed on a precision scale to assess the condensation within the clothing.[3] The study analyzed the wearing temperature on torso surface with constant heating power way. The analysis conducted in 3 phase, starting an acclimatization phase (35℃), then crossing sweating phase and recreational phase in final. The condition of the set on the torso was described in Table 1. In the sweating phase, personnel wearing CB suit in moderate metabolic and high metabolic rate were considered. The state of sweating torso set at 82W heating power, 100g/hr sweating rate simulated a person in moderate metabolic state to 360W, 415 g/hr perspiration while 118W heating power and 300 g/hr sweating rate was set to imitate a person in high metabolic state to 520W, 1250g/hr perspiration. The recreational phase of the torso was set at 23.5W, no sweat was assumed as the person in metabolic state to 100W, no perspiration.

In order to understand the thermal comfort of these clothing in Taiwan area, we measured with Sweating Torso System under the condition similar to the summer and winter environment of Taiwan e.g. The average of temperature and humidity in Taiwan were individually 28℃, 75%R.H. in summer and 15℃, 75%R.H. in winter.[4]

Table 1 Phase profile of sweating torso evaluation

Phase and Period	Moderate metabolic rate	High metabolic rate
1hour acclimatization	Surface 35℃	Surface 35℃
1hour sweating	82W, 100g/hr	118W, 300g/hr
1hour recreational	23.5W	23.5W

3.3 Sweating thermal manikin

3.3.1 Measurement system

The thermal manikin called Huey was made by MTNW Company, designed with 1.75m^2 surface area, 1.7m height. This designation is referred to a 50th percentile US Army male. It is divided into 17 thermally isolated zones, and the skin surface has a matrix of 119 pores, which provide fluid for sweating. A fitting fabric was dressed on the manikin to even the fluid distribution. Water supplied through the pores wicks over the entire surface of the manikin simulating human perspiration.[5]

In this study, the skin temperature and the fluid rate of the manikin was set at 33℃, 600g/hr, which was the maximum capability of Huey running consecutively to reach equilibrium state. In this state, we analyzed thermal resistance (R, clo) and the permeability index (im) of the 3 CB suits without consideration of the hands and face part of the manikin because there is no protective equipment on these areas in this study. The condition where the manikin stood was set to 28℃, 75% R.H. as summer condition and 15℃, and 75% R.H. as winter one.

3.3.2 Evaluation method

According to Woodcock, A.H. works [6], dry heat transfer (H_D) and evaporative heat transfer (H_E) could be calculated by the following equations:

$$H_D = \frac{6.45(T_S - T_a)}{R}\left(\mathrm{W/m^2}\right) \quad ....(1)$$

$$H_E = \frac{14.3 \times im \times (P_S - P_a)}{R}\left(W/m^2\right) \quad ....(2)$$

Here Ta and Pa were air temperature (℃) and water vapor pressure (mmHg), Ts and Ps were the temperature and water vapor pressure on the skin surface.

In order to develop an indicative unit which made us have more sense, we tried to calculate how long a person could endure such wearing condition which he can suffer. Despite many factors affect the wearing time mentioned in some study,[7] our calculation were based on the following assumptions. This index was called "Endurable Wearing Time Index".

(1) Metabolic heat only could dissipate to environment through human skin, ignoring the work of respiration.

(2) Once the metabolic heat could not totally dissipate the heat only cumulate in the internal human body. The work of heat accumulation in clothing system is neglected.

(3) The maximum heat storage of a person was 330kJ which was derived from Goldman work [8] concluding that this kind of body heat storage enough made a number of persons stop working.

(4) The calculation of endurable wearing time at the condition of 360W regarded as moderate metabolic state and 520 W as high metabolic state.

(5) The total surface area of the skin for a person was assumed 1.8m^2, and the skin temperature was set to 35℃, without consideration of temperature different disturbed on different parts of human body.

Under the above assumptions, we could calculate easily, and, we certainly understood that the real endurable wearing time would be severely underestimated. However, it seemed to be a valuable information that made us more sense how the wearing condition we suffered.

4. Result

4.1 Water Vapor Resistance (Ret)

Table 2 Testing result of Ret

Sample Type	Ret (Pa.m^2/W)	Method
JSLIST	6.1	
BDO	8.6	ISO 11092
Emergency CB	346.2	

According to Hohenstein classification of breathable fabric with Ret value, the value below 6 is belong to very good level while between 6 and 13 is considered as good level. If the Ret value was beyond 20, the fabric could be thought unsatisfactory for people from clothing physiological point of view.[9] Table 2 showed the Ret value of the 3 CB clothing. Despite JSLIST has lower water vapor resistance than indigenous BDO, both were still on the same level of breathable property. Emergency BDO could be considered as a suit without breathable property.

4.2 Temperature Response of sweating torso in summer condition

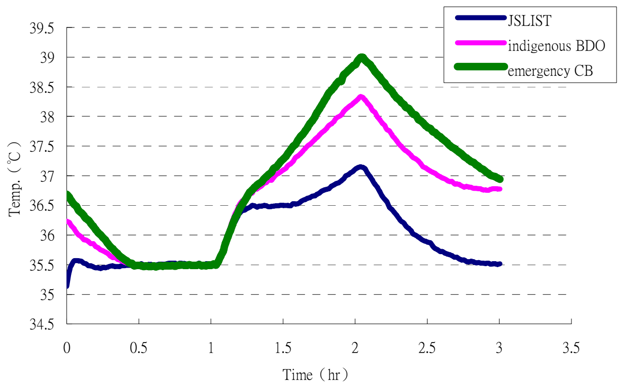

Fig.1. Wearing temperature of 3 CB suits in moderate metabolic state and summer condition

Fig.1. showed that, under the summer condition, wearing temperature of 3 CB suit increased because the heat generated form torso could not totally dissipate to outside environment. After 1 hour sweating phase, the emergency CB suit with 39℃ appeared to be highest temperature, and indigenous BDO was the second with 38.3℃. The JSLIST was the lowest one with 37.1℃. Until the creational phase completed, the temperature of the emergency CB, indigenous BDO and JSLIST were 36.9℃, 36.8℃ and 35.5℃ individually.

The tendency of the curves in Fig.1 showed that the JSLIST seemed to be the best structure for dissipating heat produced by a person in moderate metabolic during the summer condition.

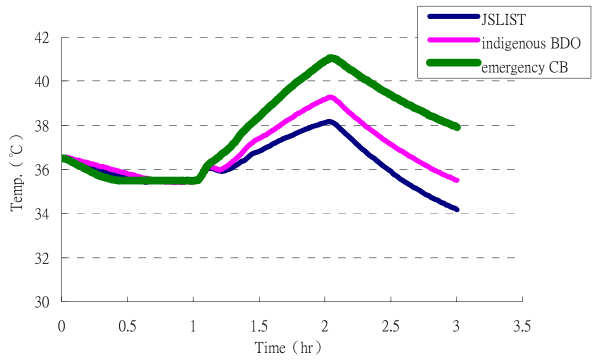

Fig.2. Wearing temperature of 3 CB suits in high metabolic state and summer condition

Fig.2. showed that the same sequence of wearing temperature for the 3 CB suits in high metabolic state as that in moderate metabolic state. However, the temperature of those CB suits in high metabolic state was above 1℃ higher than those in moderate metabolic state, e.g. 38.1℃ for JSLIST and 39.3 for indigenous BDO. For emergency CB suit, the wearing temperature even rise 2℃ compared with that in moderate metabolic state, reaching to 41℃.

4.3 Temperature Response of sweating torso in winter condition

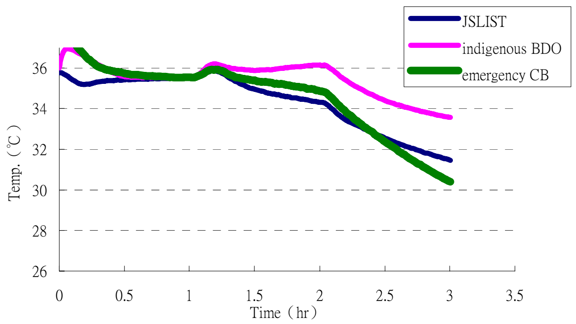

Fig.3. Wearing temperature of 3 CB suits in moderate metabolic state and winter condition

In moderate metabolic rate, the wearing temperature curves of JLST and emergency CB in the sweating phase of Fig. 3. didn't rise up, even the indigenous BDO can likely maintain the temperature until the sweating phase finished. The result indicated that the heat produced by the sweating torso in the moderate metabolic state could completely dissipate to outside environment. However, in high metabolic rate which described on Fig. 4. showed that, except JSLIST can keep the wearing temperature response not rise, the other two CB suits raised after the end of the sweating phase. Finally, indigenous BDO and emergency CB reached to 35.9℃ and 37.2℃ individually. This phenomenon indicated that, in winter and moderate metabolic state, dry heat loss which is due to the temperature difference almost dominated the heat loss mechanism of the 3 CB suits. In high metabolic state, the heat loss nevertheless still relied on moisture vapor dissipation to avoid heat cumulating inside of CB clothing system, and eliciting wearing temperature increase.

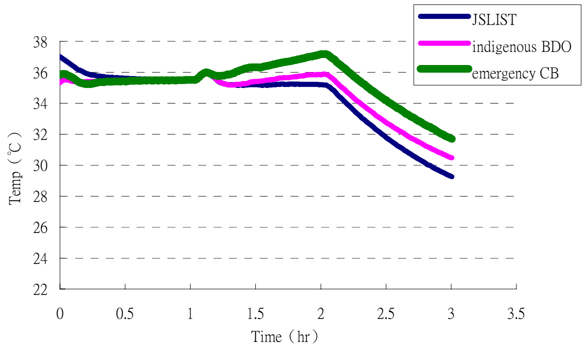

Fig.4. Wearing temperature response of 3 CB suits in high metabolic state and winter condition

4.4 Sweating manikin testing result

Table 3 The result of sweating manikin test in summer condition

Summer condition					
Sample Type	R (clo)	im	He +Hd (W/m^2)	EW t_i for med. MB state)	EW t_i for high MB state
JSLIST	1.49	0.32	185	31	16
indigenous BDO	1.71	0.36	177	30	16
emergency CB	1.76	0.13	94	21	13

Table 4 The result of sweating manikin test in winter condition

Winter condition					
Sample Type	R (clo)	im	He +Hd (W/m^2)	EW t_i for med. MB state)	EW t_i for high MB state
JSLIST	1.4	0.3	358	34	nil
indigenous BDO	1.84	0.44	338	30	nil
emergency CB	1.62	0.22	269	22	60

Table 3 and Table 4 showed the thermal insulation, moisture vapor index, total heat transfer (Hd+He) and endurable wearing time index (EW t_i). The result described the capability of heat dissipation for the 3 CB clothing system dressed in winter and summer condition. Under the metabolic rate of 360 W/㎡ and 520 W/㎡, the total heat transfer of JSLIST, BDO and emergency CB individually was just 185, 177, 94 W/㎡ in summer condition. Therefore, the 3 CB suits could not sufficiently get rid of metabolic heat completely, and the heat was gradually cumulated in human body. The endurable wearing time index would be 31, 30 and 21 minutes individually in 360 W/㎡ metabolic state. For 520 W/㎡ metabolic heat, the endurable wearing time index of JSLIST, BDO and emergency CB was 16, 16 and 13 minutes individually. However, in terms of winter condition, the total heat transfer of JSLIST, BDO could tackle the 360 W/㎡ metabolic state sufficiently. The heat accumulation problem did not take place. Moreover, the total heat transfer of JSLIST and BDO appreciably exceed that of emergency, there is obviously different from emergency CB for endurable wearing time index in winter condition.

5. Conclusion

(1) All three measurements showed the consistent result that JSLIST was the best thermal wearing performance; BDO was the second and emergency CB was the worst.

(2) Whether the skin model system or the sweating manikin was used, the result showed JSLIST was not significantly bettered than BDO, being different from the result derived from the sweating torso. This difference was caused by the control of sweating rate in the sweating torso because the perspiration of the torso started in the sweating phase which was dry on the surface initially. In the opposite, the surfaces of skin model system and sweat manikin were completely wet at the beginning.

(3) In order to have better prediction of endurable wearing time and real wearing condition, the measuring system might be achieved when the sweat rate and the surface temperature could response to the heat accumulation as human body response in real sweat rate.

Acknowledgements

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