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Dressing Poses in Relation to Clothing Thermal Insulation

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Abstract : By the movable thermal manikin developed by China Dong Hua university, the laws of clothing thermal insulation influenced by dressing poses are studied. It is found that I_a on nude thermal manikin has no relation to testing pose as a whole (notable level is 5%), while the change of testing pose influences I_a value on parts of body obviously. The testing result I_{cle} on clothed thermal manikin has relation to testing pose. The I_{cle} value of the whole body in seated pose decreases 20 percent compared with that in standing pose (notable level is 1%). In view of heat transmission theory, the reasons are pointed out based on the knowledge of heat transmission.

Key words : clothing, thermal insulation, thermal manikin, wearing pose, thermal manikin

PREFACE

On the aspect of heat properties of clothing, the clothing form and the dressing way are as important as the clothing material. Clothing form changes in different dressing way then the total heat insulation of clothing change. Clothing form is composed of clothing itself and wearer's body. Clothing function is influenced by its form and dressing way.

According to the outside environment clothing forms a non-equal temperature surface covering the human body. The means that clothing has a good thermal insulation property is to keep still air layer near wearer's body skin[1]. In order to probe reasonable rules of dressing and designing fashion, it is necessary to study the influence of dressing on how to distribute still air layer on each part of human body, and how to adjust its distribution on the aspect of dressing way.

Dressing way mainly includes dressing poses, clothes combination, dressing sequence and etc. In this paper the laws of clothing thermal insulation influenced by dressing poses are studied.

EXPERIMENT

By the movable thermal manikin used under the condition of simulate climate, in the state of nude and dressed, we test and note the skin temperature and consuming power of each part of body in the poses of sitting and standing, then study the changing laws of clothing thermal insulation(Fig. 1, Fig. 2).

Testing materials

Jump suit made of cotton medium plane with a little

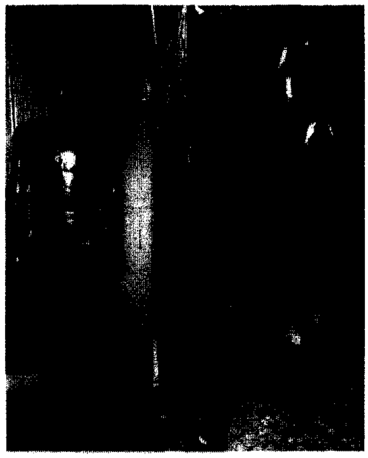

Fig. 1. The nude thermal manikin in standing/seated pose

Fig. 2. The clothed thermal manikin in standing/seated pose

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Table 1. Parameters of testing materials

Name	Material	Weave	Thickness/mm	Warp density/ pieces · (10^{-1})cm	Weft density/ pieces · (10^{-1})cm	Weight/g · m^{-2}
Medium plane	Cotton	Plain	0.7	236	236	129

Table 2. Parameters of testing suits

Item	Total length	Breast circumference	Sleeve length	Waist circumference	Hip circumference	Shoulder width
Size/cm	150	88	56	82	100	35

ease is skinny to a movable thermal manikin, which details are given in Table 1 and Table 2.

Methods

The movable thermal manikin : The movable thermal manikin system developed by China Dong Hua university is composed of two parts, the manikin body and computer smart controlling system. Manikin is built according to the anatomy of Chinese male adults, including 16 temperature-controlled parts. Each joint of manikin can do the movement in the similar range like human being and can make several poses, for example, standing without any support. Computer smart temperature controlling part has two kinds of controlling model, invariable skin temperature and invariable heating power by using separate controlling technology. By the means of simulating the process of heat changing of "human-clothing- environment" system, we can get the clothing thermal insulation value.

Simulate climatic environment : Using various sensors connected with the manikin system, we can make real-time controlling on simulate climate, keep surveillance and gather the environmental signals. In this study, the climatic room's temperature is controlled at(16.5±0.5)°C ,the relative humidity is(45±5)%, and the wind velocity is 0.1 m/s.

Testing indexes

The total insulation (I_t) : The total insulation (I_t) is the insulation from the skin surface to the environment, including the effect of increased surface area (f_{cl}) and the resistance at the surface of the clothed body (I_a).

$I_t=(t_s-t_a)/0.155Q$

Where I_t= total insulation, clo

Q=dry heat loss per m^2 skin area, W/m^2

T_s=mean skin temperature, °C

T_a=environment temperature, °C

The effective clothing insulation (I_{cle}) : The effective clothing insulation (I_{cle}) is the insulation from the skin to the clothing surface, excluding the effect of increased surface area of the clothed body (F_{cl}).

$I_{cle}= I_T - I_a=(t_s-t_a)/0.155Q-I_a$

Where I_{cle} =clothing effective heat insulation value, clo

I_a=resistance at the surface of clothed body, clo

RESULTS AND DISCUSSION

Testing results on nude thermal manikin

I_a in standing pose

I_a in standing pose is shown in Table 3.

I_a in seated pose : I_a in seated pose is shown in Table4.

Taking a nonparametric statistic method, sequences sum test, to analyze I_a among the whole body and each part of nude thermal manikin, we can tell whether the samples in seated pose and standing pose are from the same whole as well as whether the difference between the two kinds of poses are obvious[2] (Notable level a=5%).

For example, take the testing results (I_a) on the whole body of nude thermal manikin in seated pose and standing pose respectively and give statistical suppose Ho: there is no difference between I_a in these two poses, we

Table 3. Testing results (I_a/clo) on nude thermal manikin in standing pose (n=6)

	Chest	Back	Upper arm	Forearm	Thigh	Calf	Hip and Abdomen	Whole body
1	0.684	0.770	0.824	0.563	0.730	0.579	0.694	0.700
2	0.716	0.838	0.931	0.684	0.737	0.567	0.682	0.729
3	0.746	0.913	0.888	0.706	0.776	0.592	0.654	0.755
4	0.776	0.963	0.958	0.678	0.771	0.608	0.651	0.768
5	0.768	0.984	0.876	0.619	0.744	0.612	0.648	0.749
6	0.812	1.065	0.901	0.617	0.736	0.597	0.623	0.754
Average	0.750	0.922	0.896	0.645	0.749	0.592	0.659	0.743

Table 4. Testing results (I_a/clo) on nude thermal manikin in seated pose (n=4)

	Chest	Back	Upper arm	Forearm	Thigh	Calf	Hip and Abdomen	Whole body
1	0.86	0.852	0.762	0.551	0.792	0.661	0.653	0.757
2	0.83	0.848	0.79	0.6	0.8	0.635	0.61	0.753
3	0.856	0.87	0.813	0.612	0.81	0.616	0.578	0.757
4	0.782	0.818	0.794	0.627	0.806	0.622	0.598	0.745
Average	0.832	0.847	0.79	0.597	0.802	0.634	0.61	0.753

Table 5. Sequence value of testing results on nude thermal manikin in seated pose and standing pose

Sequence value	1	2	3	4	5	6	7	8	9	10
Whole (seated pose)			0.745		0.753			0.757	0.757	
Whole (standing pose)	0.7	0.729		0.749		0.754	0.755			0.768

can arrange these data in order from the smallest to the biggest and get sequence value.(Table 5)

To the sample having fewer data (the testing result in seated pose, $n_1=4$), add each sequence value and get the sum T, then calculate valve value $T_{1,a}$,$T_{2,a}$ (Notable level a=5%).

$T_{1,a}=12<T=25<T_{2,a}=32$

It means that there is no obvious difference to the testing result I_a on the whole body of nude thermal manikin between in seated pose and standing pose when the notable level is 5 percent.

Using the same method we can study the difference on testing results on each part of thermal manikin in seated pose and standing pose.

To the chest part: $T=33>T_{2,0.05}=32$; $T_{1,0.01}=10<T=33<T_{2,0.01}=34$. The conclusion is that there is no obvious difference to the testing result I_a on the chest of nude thermal manikin between seated pose and standing pose when the notable level is 5 percent, while the notable level is 1 percent there is no difference.

To the back part: $T_{1,0.05}=12<T=17<T_{2,0.05}=32$. There is no obvious difference to the testing result I_a on the back of nude thermal manikin between seated pose and standing pose when the notable level is 5 percent.

To the upper arm part: $T=10<T_{1,0.05}=12$;$T=10°\neg T_{1,0.025}=10$. There is obvious difference to the testing result I_a on the upper arm of nude thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the forearm part : $T_{1,0.05}=12<T=15<T_{2,0.05}=32$. There is no obvious difference to the testing result I_a on the forearm of nude thermal manikin between seated pose and standing pose when the notable level is 5 percent.

To the thigh part: $T=34\geq T_{2,0.05}=32.$; $T=34\geq T_{2,0.01}=34$. There is difference to the testing result I_a on the thigh of nude thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the calf part: $T=34\geq T_{2,0.05}=32.$; $T=34\geq T_{2,0.01}=34$. There is difference to the testing result I_a on the calf of the nude thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the hip and abdomen part: $T_{1,0.05}=12<T=13<T_{2,0.05}=32$. There is no difference to the testing result Ia on the hip and abdomen of the nude thermal manikin between seated pose and standing pose when the notable level is 5 percent.

Testing results on nude thermal manikin in different poses

Testing results I_{cle} on clothed thermal manikin in standing pose

Testing results I_{cle} on clothed thermal manikin in standing pose is shown in table 6.

Testing results I_{cle} on clothed thermal manikin in seated pose

Testing results I_{cle} on clothed thermal manikin in seated pose is shown in table 7.

Using the same method as before, we study the testing results on each part of clothed thermal manikin and tell whether the difference to the testing results I_{cle} in two kinds of poses is obvious.

To the whole body: $T=61>T_{2,0.05}=57$; $T=61>T_{2,0.01}=60$. There is obvious difference to the testing results I_{cle} on the whole body of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent and I percent.

To the chest part: $T=21<T_{1,0.05}=27$; $T=21<T_{2,0.01}=24$. There is obvious difference to the testing result I_{cle} on the chest of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the back part: $T_{1,0.05}=27<T=52<T_{2,0.05}=57$. There is no obvious difference to the testing result I_{cle} on the back of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent.

To the upper arm part: $T_{1,0.05}=27<T=43<T_{2,0.05}=57$.

Table 6. Testing results (Icle/clo) on clothed thermal manikin in standing pose (n=6)

	Chest	Back	Upper arm	Forearm	Thigh	Calf	Hip and Abdomen	Whole body
1	0.338	0.612	1.032	0.198	0.573	0.154	1.950	0.458
2	0.344	0.660	0.290	0.238	0.581	0.209	0.977	0.421
3	0.383	0.635	0.612	0.255	0.640	0.242	0.985	0.478
4	0.381	0.691	0.896	0.299	0.709	0.261	0.984	0.529
5	0.359	0.607	1.085	0.244	0.705	0.299	1.095	0.539
6	0.397	0.715	0.794	0.170	0.788	0.288	0.985	0.535
Average Value	0.367	0.653	0.785	0.234	0.666	0.242	1.163	0.493

Table 7. Testing results (I_{cle}/clo) on clothed thermal manikin in seated pose (n=7)

	Chest	Back	Upper arm	Forearm	Thigh	Calf	Hip and Abdomen	Whole body
1	0.469	0.579	1.149	0.254	0.557	0.165	0.535	0.449
2	0.478	0.596	0.828	0.211	0.544	0.176	0.624	0.438
3	0.502	0.614	0.589	0.217	0.427	0.148	0.530	0.383
4	0.536	0.647	0.904	0.262	0.317	0.119	0.497	0.374
5	0.510	0.623	0.628	0.262	0.375	0.159	0.416	0.3746
6	0.490	0.590	0.631	0.234	0.315	0.148	0.502	0.349
7	0.515	0.671	0.821	0.276	0.280	0.141	0.430	0.361
Average Value	0.469	0.579	1.149	0.254	0.557	0.165	0.535	0.449

There is no obvious difference to the testing result I_{cle} on the upper arm of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent.

To the forearm part: $T_{1,\ 0.05}=27<T=38<\ T_{2,\ 0.05}=57$. There is no obvious difference to the testing result I_{cle} on the forearm of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent.

To the thigh part: $T=63>T_{2,\ 0.05}=57$; $T=63>T_{2,\ 0.01}=60$. There is obvious difference to the testing result I_{cle} on the thigh of clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the calf part: $T=60\geq T_{2,\ 0.05}=57$; $T=60\geq T_{2,\ 0.01}=60$. There is obvious difference to the testing result I_{cle} on the calf of the clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent and 1 percent.

To the hip and abdomen part: $T=63>T_{2,\ 0.05}=57$; $T=63>T_{2,0.01}=60$. There is obvious difference to the testing result I_{cle} on the hip and abdomen of the clothed thermal manikin between seated pose and standing pose when the notable level is 5 percent.

Fig.3 shows these conclusions.

As a whole, there is no obvious difference to the testing results I_a on nude thermal manikin between seated pose and standing pose when the notable level is 5 percent. But testing results I_a (0.742) in standing pose is smaller than that in seated pose (0.753) and the change of pose results in the obvious change of testing result on each part of nude thermal manikin. For example when the notable level is 1 percent, there is obvious difference on the I_a of thigh, calf and upper arm between these two poses and when the notable level is 5 percent there is difference to the testing results on the chest of nude thermal manikin. It shows that the I_a of air layer is related to the pose of nude thermal manikin.

The change of testing results I_a on each part of nude thermal manikin is due to the change of heat transmission. In the condition of this experiment there are three kinds of heat transmission ways, radiation, convection and conduction. Among them the radiation is the main way. According to the Stefan-Boltzman law, the radiation of manikin surface towards the experimental environment can be shown by[3]:

$$R=A_{eff}xs[(t_{cl}+273)^4-(t_{mrt}+273)^4]$$

Where: R=the quantity of heat dissipation from the surface of clothed thermal manikin towards outside (kcal/h)

A_{eff}=effective radiation area of clothed thermal manikin (m^2)

s=Stefan constant;

t_{mrt}=average radiation temperature(°C)

t_{cl}=average temperature of dressed manikin surface(°C)

x=diffusion of clothed thermal manikin

In this experiment the thermal manikin is nude then the

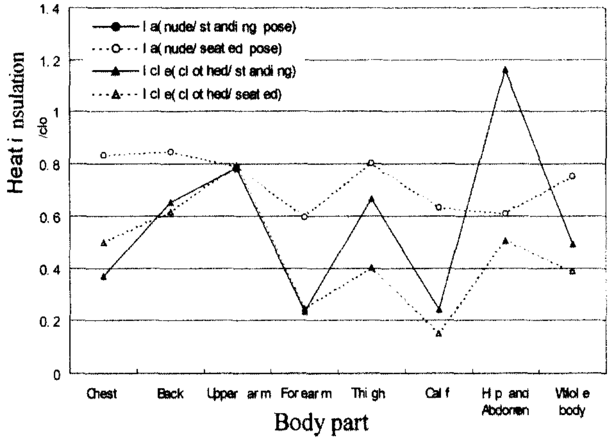

Fig. 3. Thermal insulation affected by manikin's pose

change of quantity of heat dissipation in the way of radiation is determined by the value of A_{eff} (x^a1, $t_{mrt}{}^at_a$, $t_{cl}{}^at_s$).

$A_{eff}=f_{eff}\times f_{cl}\times A_{Du}$
Where: A_{ef}=effective radiation area factor
f_{cl}=clothing area parameter
A_{Du}=nude body surface area (m^2)

Because in this experiment the A_{Du} is constant and $f_{cl}:=1$, the difference of I_a value in thermal manikin's different pose is due to the f_{eff}. According to the research of P.O.Fanger and ect, f_{eff} is 0.696 and 0.725 separately in seated pose and standing pose which is independent of sex, weight, height, nude body surface area, body structure and etc. This law is applicable to the thermal manikin with the Chinese male body form features in this study.

The testing I_a value in standing pose is smaller in some sort than that in seated pose because the f_{eff} is bigger and A_{eff}, R is bigger accordingly.

At the same time the relative space position of each part of body changes in seated pose. The distance between thigh and chest, calf and thigh becomes shorter, which makes heat radiation weak, then I_a value is increasing. On the other hand because the distance between arm and body is longer, and other part of body has little influence on it, the heat radiation is larger and I_a value is a little smaller accordingly.

The testing result I_{cle} on clothed thermal manikin is also influenced by the different pose but not as much as I_a on nude thermal manikin. When the notable level is 1 percent, the I_{cle} value of the clothing tested by thermal manikin in seated pose decreases 20 percent as to it in standing pose; In view of body part, I_{cle} value of thigh, calf, hip and abdomen decreases; I_{cle} value of chest increases. These show that wearing pose influence I_{cle} value greatly.

From the point of body heat dissipation, the wearing pose has influence in three aspects: f_{eff}, f_{cl}, the thickness of air layer under clothing. In seated pose, f_{eff}, and f_{cl}, decrease but the change of air layer thickness is the main factor. In this experiment the testing material is jump suit and it is found the spacing thickness in many body parts changes in seated pose. By using contacting needle method to measure thickness, we find the spacing thickness on the part of hip and abdomen, thigh, calf in seated pose decreases obviously. The reason is that clothing is under the pressure of hip and knee joints bending as well as touching between hip and seat. The spacing under clothing on the part of chest increases much but decreases on the part of back. In seated pose arm overhangs naturally so there is almost no change on the spacing thickness. The change of spacing thickness on parts of body results in the change of still air under clothing thus the clothing heat resistant value decreases greatly.

It is necessary to point out the changing pattern of heat insulation in clothed condition has relationship with clothing item and different body part.

CONCLUSIONS

(1) The testing result I_a on nude thermal manikin has no relation to testing pose as a whole (notable level is 5%). On the other hand the change of testing pose influences I_a value on parts of body obviously. For example, thigh and upper arm (notable level is 5 percent); chest, hip and abdomen and calf (notable level is 5 percent). The reason why pose changing has influence on I_a value is the change on heat dissipation according to different testing poses.

(2) The testing result I_{cle} on clothed thermal manikin has relation to testing pose. When the notable level is 1 percent, the I_{cle} value of the whole body in seated pose decreases 20 percent compared with that in standing pose; I_{cle} value of thigh, calf, hip and abdomen decreases; I_{cle} value of chest increases. From the point of body heat dissipation, the wearing pose has influence in three aspects: f_{eff}, f_{cl}, the thickness of air layer under clothing.

Dressing poses affect the clothing thermal insulation, and it is suggested that the testing pose should be limited when measuring clothing heat insulation by thermal manikin.

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