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Evaluation of Adjustable Thermal Insulations of Tibetan Clothing by Manikin Testing

Abstract
The thermal insulation of clothing needs to be easily adjusted in an unsteady environment, but this is extremely difficult for most clothing. To reveal the effect of different styles of Tibetan clothing on their thermal property, the total thermal insulations of Tibetan clothing in three typical styles were measured using a thermal manikin. The clothing area factors (f_{cl}) of the Tibetan clothing and body surface area covered by a Tibetan robe were tested with a photographic method. The results showed the following: 1) For similar insulation, f_{cl} of Tibetan clothing is about 0.23 bigger than that of western clothing, estimated from ISO 11079; 2)the style of Tibetan clothing significantly affects the f_{cl} ($p < 0.05$, $f_{cl} = 1.229 + 0.007$ BSAC) and the intrinsic thermal insulation ($p < 0.05$, $I_{cl} = 0.166 + 0.016$ BSAC); 3)the adjustable thermal insulation of Tibetan clothing proved its adaptability to the large air temperature difference environment on the Tibetan plateau ,which should be valuable for the product development of clothing used in a unsteady environment.

Key words: *Tibetan clothing, style, thermal insulation, clothing area factor, thermal manikin.*

Introduction

The 'Human-clothing-environment' is regarded as a uniform whole in research of heat transfer between the human body and the environment. Thermal comfort of the human body can be kept only if these three factors are well balanced [1] and maintain a proper relationship between body heat production and loss [2]. We all know that the weather is always changeable when people are working outdoors and the physical activity level of the human body is also diverse when people are doing exercise [3] or some indoor work [4]. Therefore to maintain the thermal comfort of the human body, the thermal insulation of the clothing ensemble may vary accordingly. However, the thermal insulation of western clothing is difficult or impossible to be adjusted according to changes in the air temperature and physical activity level of the human body. Thus the heat strain of the human body may develop in such conditions, which in cold is equally or even more hazardous than that in a warm environment. Therefore facilitation of heat loss is very important and clothing design with easy adjustment of thermal insulation is extremely urgent [5].

Tibetan clothing is developed by local people in a long-term practice in the unsteady environment of the Tibetan plateau. The average difference in air temperature in this area is near 15 °C in a day because of its high altitude and strong solar radiation. Based on the wearer's thermal sensation, Tibetan clothing can be adjusted into several styles. Three typical styles are the regular, one shoulder exposed and the upper body exposed (***Figure 1***) [6]. Practice has proved that Tibetan clothing has excellent adaptability to the unsteady environment on the Tibetan plateau [7].

Thermal properties of traditional clothing are very different from those of western garments. This had been demonstrated by earlier researches on the thermal comfort properties of Inuit caribou skin clothing [8], Korean clothing [9] and Arabian Gulf clothing [10]. But up to now there has been a lack of description and research of Tibetan clothing in China, except for some cultural and aesthetic information.

The aim of this research was to investigate the thermal insulation and clothing area factor of Tibetan clothing in China by means of manikin testing and the photographic method, and reveal the effects of different styles of Tibetan clothing on their thermal property. This research hopes to be valuable for the product development of clothing used in an unsteady environment and contribute to the database of collecting and documenting information about traditional and western garments and clothing ensembles developed by the American Society of Heating Refrigerating and Air conditioning Engineering (ASHRAE) and the International Standard Organization (ISO) [10].

Materials and methods

Clothing ensembles

Eight typical Tibetan robes were sampled in Lhasa city, China. Specifications of the Tibetan robes are shown in ***Table 1***.

Table 1. *Descriptions of Tibetan robes.*

Code	Fabric type	Colour	Fiber content	Weight, kg
1#	Fur-lined robe	Dark Olive	100% polyester + fur	3.20
2#	Synthetic robe	Purplish Blue	100% polyester	1.19
3#		Black	70% polyester 30%viscose	1.53
4#	Pulu robe	Black	100% wool	3.70
5#		Dark Red		3.82
6#		Maroon		3.42
7#		White		2.77
8#	Wool robe	Black		1.89

Table 2. Descriptions of garments in the inner ensemble.

Code	Color	Fibre content	Weight, g
Briefs	Dark Cyan	100% Cotton	50
Sleeveless Shirts	Dark Gray		50
Long-legged Pants		48% Modal / 47% Cotton / 5% Spandex	185
Trousers	Dark Khaki	70% Polyester / 30% Viscose	410
Socks	White	85% Cotton / 15% Spandex	40

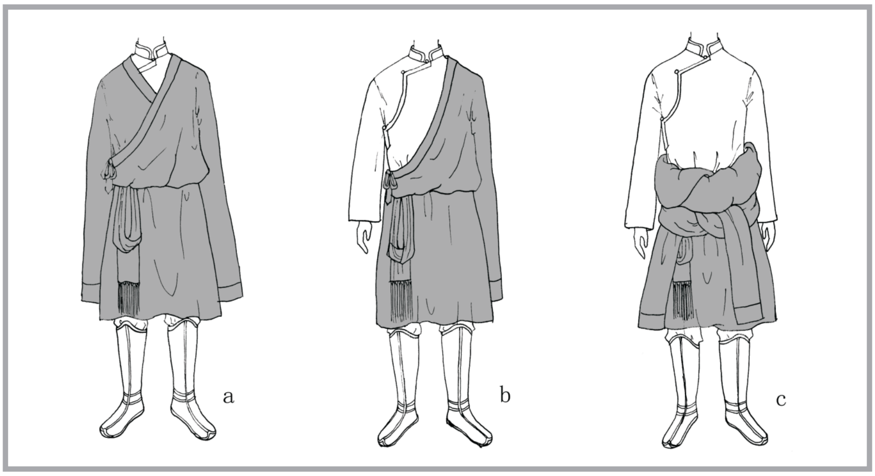

Figure 1. *Three typical styles of Tibetan clothing; a) regular, b) one shoulder exposed, and c) upper body exposed.*

***Figure** 2. Thermal manikin clothed in Tibetan clothing in three typical styles.*

On the Tibetan plateau, a thick and heavy fur-lined robe (#1) is worn in winter, Pulu robes (#4 ~ #7)and wool robe (#8) are worn in the transitional seasons, and light and thin synthetic robes (#2 ~ #3) are worn in summer generally. Pulu is a hand woven fabric and usually used to make Tibetan garments.

Eight Tibetan clothing ensembles were used in this research. They consisted of different Tibetan robes and the same inner ensemble (***Table 2***).

According to Tibetan custom, three typical styles of Tibetan clothing were chosen in this research (***Figure 1***). In Tibet, Tibetan clothing is always worn in the regular style when the weather is much colder and in the other two unconventional styles when people work or in a warmer environment.

Thermal manikin

In this research, experiments were performed using a dry and copper thermal manikin of the FTD17 type (developed by Donghua University), which can simulate dry heat loss from the human body. The height of the manikin is 168 cm and the body surface area 1.68 m^2. There are a total of 11 electrically independent heating segments about the manikin: in the head, chest-back, abdomen, buttocks, left and right arms, thighs, legs and feet. Each segment is individually controlled by a computer. LabView software was used to operate the thermal manikin.

Environmental conditions

Measurements were performed in a climatic chamber of about 6 m^3 volume according to the requirements of ISO 15831 [11], in which the ambient condition was maintained at a constant level: the air temperature at 14 ± 0.1 °C, the air velocity at 0.4 ± 0.1 m/s, the relative humidity of air at 50 ± 5% and no radiation.

Thermal manikin experiments

The thermal manikin was clothed with the inner ensemble first, then one Tibetan robe was chosen and clothed in the regular style. The average manikin surface temperature of each segment of the manikin was maintained at 34 °C (uniform surface temperature operation model). According to the requirements of ISO 15831 [11], the total thermal insulations of 8 clothing ensembles in three styles were measured (***Figure 2***). The parallel method, recommended by ISO 9920 [12], was used to calculate the total thermal insulation (I_T) of the clothing ensembles according to local thermal insulations of 11 segments of the manikin. Each measurement was taken twice, and the thermal insulation of the naked manikin (I_a) was also tested in the same air conditions.

Clothing area factor (f_{cl}) of Tibetan clothing measurements

There are two methods to determine the clothing area factor of a clothing ensemble: an estimated equation and the photographic method. Related researches [13, 14] had showed that existing regression equations developed for determining the f_{cl} of western clothing ensembles were not suitable to predict the f_{cl} of traditional clothing. Thus a more complicated photographic method with a digital camera was used in this research. According to related information [15], photographs of the clothed manikin and naked manikin were taken by digital camera from three azimuth angles (0, 45, and 90°) of two altitudes.

Then f_{cl} values of the clothing ensembles were calculated by the average method (***Equation 1***) based on projected areas according to Photoshop treatments of the digital pictures:

$$f_{cl} = \sum_{i=1}^{6} A_{cli} \Big/ \sum_{i=1}^{6} A_{ni} \qquad (1)$$

In ***Equation 1***, f_{cl} is the clothing area factor; A_{cli} is the projected area of each clothing ensemble at the i^{th} angle (3 azimuths of 2 altitudes); A_{ni} is the projected area of the nude manikin at the i^{th} angle (3 azimuths of 2 altitudes); i = 1, 2, 3, 4, 5 and 6.

There were total three clothing area factors (f_{cla}, f_{clb} and f_{clc}) for each Tibetan clothing ensemble in different styles.

Measurements of the body surface area enclosed by a Tibetan robe

The body surface area enclosed by a Tibetan robe (*BSAC*) can indicate the difference between different styles of Tibetan clothing. Thus three *BSAC* values of 8 Tibetan robes were tested in the same experiment of determining the f_{cl} of Tibetan clothing. Then the *BSAC* value of the Tibetan robe was calculated by ***Equation 2***.

$$BSAC = 100 * A_r / A_{n1} \quad (2)$$

In ***Equation 2***, *BSAC* is the body surface area clothed by the Tibetan robe in %; A_r is the projected area of the thermal manikin clothed by the Tibetan robe from the front view; A_{n1} is the projected area of the whole nude manikin from the front view.

There were a total of three *BSAC* values ($BSAC_a$, $BSAC_b$ and $BSAC_c$) for each Tibetan robe in different styles.

Calculation of the intrinsic thermal insulation of Tibetan clothing

Based on the clothing area factor and total thermal insulation, the intrinsic thermal insulation of Tibetan clothing was calculated as follows [1]:

$$I_{cl} = I_T - I_a / f_{cl} \quad (3)$$

There were a total of three intrinsic thermal insulations (I_{cla}, I_{clb} and I_{clc}) for each Tibetan clothing ensemble in different styles.

Results and discussion

The total thermal insulations of the 8 samples of Tibetan clothing tested on the thermal manikin are shown in ***Table 3.*** The clothing area factors of the Tibetan clothing tested by the photographic method and calculated from ***Equation 1*** are also shown in ***Table 3***. The thermal insulation of the nude manikin (I_a) was determined as 0.74 clo in the same conditions.

Table 3 shows that both the total thermal insulations and clothing area factors of the Tibetan clothing gradually decreased according to the style: regular, one shoulder exposed, and upper body exposed.

The intrinsic thermal insulations of the Tibetan clothing calculated from ***Equation 3*** and the *BSAC* values of the Tibetan robes calculated from ***Equation 2*** are shown in ***Table 4***.

Table 3. *Total thermal insulations and clothing area factors of Tibetan clothing.*

Code	I_{Ta}, clo	I_{Tb}, clo	I_{Tc}, clo	f_{cla}	f_{clb}	f_{clc}
1#	2.50 ± 0.09	2.01 ± 0.05	1.48 ± 0.04	1.90 ± 0.04	1.75 ± 0.05	1.68 ± 0.07
2#	1.68 ± 0.04	1.48 ± 0.05	1.27 ± 0.05	1.75 ± 0.06	1.51 ± 0.08	1.44 ± 0.04
3#	1.67 ± 0.07	1.50 ± 0.04	1.28 ± 0.05	1.74 ± 0.06	1.52 ± 0.05	1.43 ± 0.09
4#	1.78 ± 0.06	1.58 ± 0.07	1.31 ± 0.03	1.86 ± 0.03	1.72 ± 0.04	1.59 ± 0.05
5#	1.73 ± 0.06	1.54 ± 0.07	1.29 ± 0.04	1.84 ± 0.07	1.69 ± 0.06	1.58 ± 0.03
6#	1.77 ± 0.08	1.53 ± 0.06	1.30 ± 0.06	1.82 ± 0.08	1.67 ± 0.05	1.55 ± 0.04
7#	1.80 ± 0.09	1.66 ± 0.02	1.32 ± 0.04	1.76 ± 0.07	1.61 ± 0.04	1.49 ± 0.06
8#	1.79 ± 0.10	1.54 ± 0.08	1.30 ± 0.03	1.73 ± 0.04	1.59 ± 0.05	1.51 ± 0.09

Table 4. *I_{cl} of Tibetan clothing and BSAC of Tibetan robe in three typical styles.*

Code	I_{cla}, clo	I_{clb}, clo	I_{clc}, clo	$BSAC_a$, %	$BSAC_b$, %	$BSAC_c$, %
1#	2.11	1.58	1.04	78 ± 0.54	63 ± 0.67	42 ± 0.50
2#	1.26	0.99	0.75	76 ± 0.44	61 ± 0.69	40 ± 0.46
3#	1.24	1.01	0.76	78 ± 0.63	61 ± 0.56	40 ± 0.78
4#	1.39	1.15	0.84	77 ± 0.54	61 ± 0.56	40 ± 0.76
5#	1.33	1.11	0.82	77 ± 0.45	61 ± 0.65	40 ± 0.38
6#	1.36	1.09	0.82	77 ± 0.73	61 ± 0.45	40 ± 0.74
7#	1.38	1.20	0.82	76 ± 0.56	60 ± 0.38	38 ± 0.47
8#	1.36	1.08	0.81	76 ± 0.63	61 ± 0.56	40 ± 0.76

Effect of different styles on f_{cl} of Tibetan clothing

For western clothing, the f_{cl} can be estimated from the I_{cl} according to some regression equations [12, 14, 15]. A similar estimated equation was obtained for traditional Tibetan clothing. According to ***Tables 3*** and ***4***, three prediction models were deduced by linear regression analysis of f_{cl} values and I_{cl} values of the Tibetan clothing in different styles (***Figure 3***).

Figure 3 shows that by changing the style from regular to one shoulder exposed and to the upper body exposed, the intercepts of these models were decreased; however, the slopes were increased gradually. This means that for a similar change in I_{cl}, the change in f_{cl} increased in the unconventional styles more than in the regular style.

A united model was deduced by linear regression analysis of f_{cl} values and I_{cl} values of the Tibetan clothing in all styles (***Figure 4***).

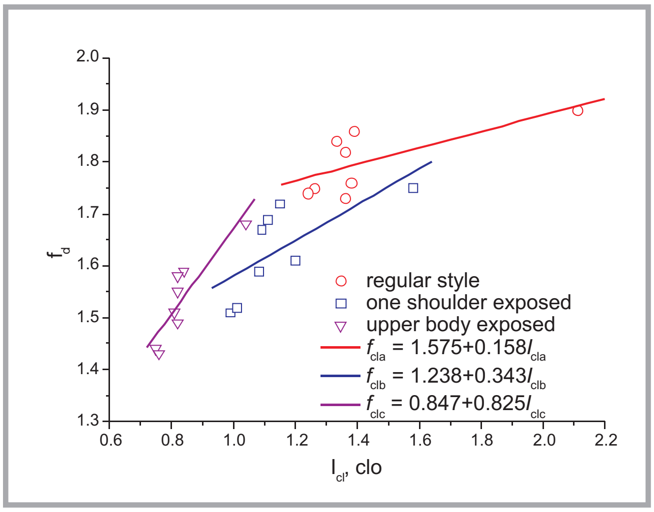

Figure 3. *Three models of the f_{cl} of Tibetan clothing in different styles.*

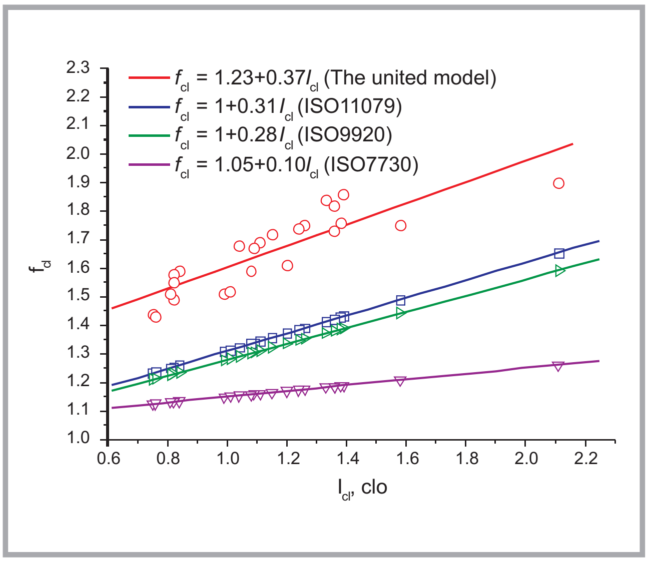

Figure 4. *United model of the f_{cl} of Tibetan clothing and present models.*

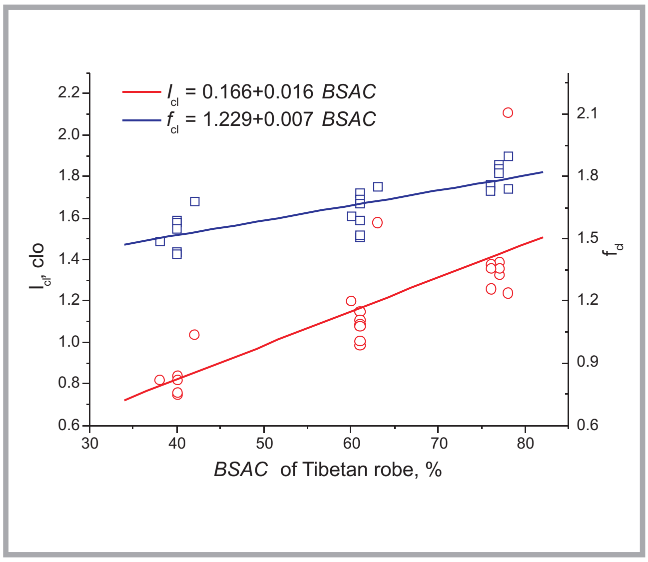

Figure 5. *Relationship between I_{cl}, f_{cl} and BSAC.*

Figure 4 shows that the f_{cl} of the Tibetan clothing in this research were more than that of western clothing according to ISO standards. The slope of the united model is similar to that of the model from ISO 11079 [15]; however, the intercepts of the two models are different. For similar insulation, the f_{cl} of Tibetan clothing is about 0.23 bigger than that of western clothing estimated from ISO 11079.

One-way ANOVA analysis was used to reveal the effect of different styles on the f_{cl} of the Tibetan clothing. Multiple comparison results of the LSD testing method showed that there are significant differences among the three f_{cl} values of the Tibetan clothing in different styles ($p < 0.05$). One predicting model was deduced by linear regression analysis of f_{cl} values of the Tibetan clothing and *BSAC* values of the Tibetan robes (***Figure 5***).

Figure 5 shows that the influence of the *BSAC* of the Tibetan robe on the f_{cl} of Tibetan clothing is significant, and the f_{cl} will increase by 0.007 with an increase of 1 percent in the *BSAC*. From the regular to the upper body exposed style, the *BSAC* value of the Tibetan robe decreased by about 40%; hence the f_{cl} decreased by nearly 0.28.

This means that the style of Tibetan robe has a significant effect on the f_{cl} values of the Tibetan clothing. The looser fitting of traditional clothing than western clothing results in greater f_{cl} values, which is in agreement with the conclusion of Arab Gulf clothing [10]. Therefore the photographic method is recommended to determine the f_{cl} of traditional clothing, and the estimated equation is more suitable to predict that of western clothing.

Effect of different styles on the I_{cl} of Tibetan clothing

One-way ANOVA analysis was used to reveal the effect of different styles on the intrinsic thermal insulations of Tibetan clothing. Multiple comparison results of the LSD testing method showed there were significant differences among the three intrinsic thermal insulations of the Tibetan clothing in different styles ($p < 0.05$).

One prediction model was deduced by linear regression analysis of I_{cl} values of the Tibetan clothing and *BSAC* values of the Tibetan robes, shown in ***Figure 5***.

Figure 5 shows that there was a significant influence of the *BSAC* of the Tibetan robe on the I_{cl} of Tibetan clothing. The I_{cl} increased by 0.016 clo with an increase of 1 percent in the *BSAC*. From the regular to the upper body exposed style, the *BSAC* values of the Tibetan robes changed by about 40%, hence the I_{cl} was nearly regulated at 0.64 clo, which proved that the adjustable extent of intrinsic thermal insulations of Tibetan clothing by their styles was big enough to influence heat transfer between the human body and the environment.

The adjustable thermal insulation of Tibetan clothing revealed its adaptability to the large air temperature difference environment of the Tibetan plateau, which should be valuable for the product development of clothing used in such an unsteady environment and contribute to the database of collecting and documenting information about traditional and western garments and clothing ensembles.

Conclusion

Thermal manikin testing and the photographic method were used to test the intrinsic thermal insulation and clothing area factor of Tibetan clothing. The *BSAC* of a Tibetan robe was also tested to indicate the difference between styles of Tibetan clothing. The effects of different styles on the clothing area factor and intrinsic thermal insulation of Tibetan clothing were revealed.

Experimental results showed the following: 1) For a clothing ensemble of similar insulation, the f_{cl} of Tibetan clothing is about 0.23 bigger than that of western clothing estimated from ISO11079; 2) the style of Tibetan clothing significantly affects the f_{cl} ($p = 0.05$, $f_{cl} = 1.229 + 0.007$ *BSAC*) and I_{cl} ($p = 0.05$, $I_{cl} = 0.166 + 0.016$ *BSAC*) of Tibetan clothing; 3) the adjustable thermal insulations of Tibetan clothing prove its adaptability to the large air temperature differences of the environment of the Tibetan plateau, which should be valuable for the product development of clothing used in an unsteady environment and contribute to the database of collecting and documenting information about traditional and western garments and clothing ensembles.

Acknowledgments

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