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USING 3D WHOLE BODY SCANNING TO DETERMINE CLOTHING AREA FACTOR

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Introduction

To determine the intrinsic/basic clothing thermal insulation, a thermal manikin is used in climatic chamber to measure the total thermal insulation of clothing, which is dependent on the intrinsic clothing insulation and surrounding air layer insulation (1). The latter is usually measured using a nude thermal manikin. However, the surface area of a clothed body is larger than nude body area. Increased surface area increases also the dry heat transfer from the surface to the surrounding environment. Therefore, a correction using clothing area factor is needed.

Clothing area factor (f_{cl}) is the surface area of the clothed body (A_{cl}) divided by the surface area of the nude body (A_D) (1). For manikin, clothing area factor (f_{cl}) is the surface of the clothed manikin (A_{cl}) divided by the surface area of the nude manikin (A) (2).

$f_{cl} = A_{cl}/A_D$ (for clothed body)
$f_{cl} = A_{cl}/A$ (for clothed manikin)

However, so far there has been no accurate and valid method to determine f_{cl} even for a standing manikin (1). ISO standard (2) recommends a photographic method to measure f_{cl}. Pictures of the projected area of the nude manikin are compared with pictures of the projected area of the clothed manikin from the same directions. Pictures of the projected area are taken from six directions. Another method using computer aided anthropometric scanners was cited by Parsons (1).

The objective of this investigation was to use a new 3D whole body scanning method to determine f_{cl} using human subjects, and to compare the results with those obtained by photographic method (2 photos, front and side) on manikin (3).

Method

Clothing

Nine types of clothing were worn by the subjects (Table 1 and 2). “Nude” subjects only wore briefs.

Subjects

Four male subjects participated in the 3D whole body scanning (Table 3).

3D body scanner and software

VITUS/smart 3D whole body scanner (Human Solutions, Germany) was used, which is a modular system and consists of four thin columns (standing in the four corners of the scanning cubicle). The

Table 1. Clothing type and weight

Clothing	Garment (see Table 2)	Weight (g)
U1 (HH1)	*Underwear 1, socks 1*	337
U2 (Ulf 1)	*Underwear 2, socks 1*	912
M1 (HH1+HH2)	*Underwear 1, intermediate, socks 1*	1562
M2 (Ulf1+ HH2)	*Underwear 2, intermediate, socks 1&2*	2137
Winter clothes A	*Underwear 1, outer garment 1, footwear 1, socks 1, handwear 1, headgear 1*	2996
Winter clothes B	*Underwear 1, intermediate, outer garment 1, footwear 2, socks 1, handwear 2, headgear 1*	5541
Winter clothes C	*Underwear 2, intermediate, outer garment 2, footwear 2, socks 1&2, handwear 2, headgear 2*	7146
Winter clothes D	*Underwear 2, intermediate, outer garment 3, footwear 2, socks 1&2, handwear 1, handwear 2, headgear 2, headgear 3*	8075
V (office clothes)	*Subjects' own office clothes for summer use (shirts with short or long sleeves, trousers, and socks)*	

Table 2. Garment

Underwear 1	HellyHansen no. 75007 poloshirt, no. 75401 pants w/fly
Underwear 2	Ullfrotté 400 g/m^2 no. 962 men's jacket, no. 965 men's pants
Intermediate:	HellyHansen no. 06266 jacket, no. 06501 trousers w/fly
Outer garment 1	Leijona no. 336320-076-74 jacket and no. 339001-0076-74 trousers
Outer garment 2	Tempex no. 390 2201 jacket and no. 392 0201 trousers
Outer garment 3	Taiga no. 21006 jacket (Eskimo Point) and no. 22317 trousers (Snowhill)
Socks 1	Ullfrotté no. 976 (400 g/m^2)
Socks 2	HellyHansen no. 06464 socks
Footwear 1	Arbesko no.3099 sport shoes
Footwear 2	Tempex no.730 8880 safety boots
Handwear 1	Hestra no. 3128 gloves
Handwear 2	Tempex no. 413 1290 (Low temperature mittens)
Headgear 1	Taiga no. 25928 Rohn
Headgear 2	Tempex no. 310 1030 Alaskan Hood
Headgear 3	HellyHansen no. 75702 balaclava
Office clothes	Subjects' own office clothes for summer including shirts with short or long sleeves, trousers, socks)

total base is 200 x 180 cm, it is 275 cm high. Each column is equipped with two CCD cameras and a laser. The scanner operates by laser triangulation. VITUS/smart's software is based on Windows NT. The body only needs to be scanned once for nude and for each clothed condition by optically lasers in about 15 seconds for each scanning, the standing still position and posture remained the same for each scanning, which measures 100,000 points from 43 tailor's measurements. This high resolution scan produces digital 3 D images (Figure 1).

Using Adobe Photoshop program, the pixels (used to estimate the area ratio between clothed and nude images) of the digital 3D images can be calculated at any angle and direction**.** In this investigation, pixels were calculated by manipulating the image into four azimuth angles: 0^o (front), 30^o, 60^o and 90^o (profile), and four altitudes angles: 0^o (horizontal), 30^o, 60^o and 90^o (vertical) at 0^o azimuth angle. Therefore totally 8 (4+4) images were used for the area calculation of each clothing condition for each subject.

Table 3. Subject's information

Subject	Height (m)	Weight (nude, kg)	Body surface area* (A_D, m^2, nude)
C	1.74	60.5	1.73
I	1.79	86.0	2.05
K	1.71	90.5	2.02
M	1.83	82.0	2.04

* DuBois surface area (4)

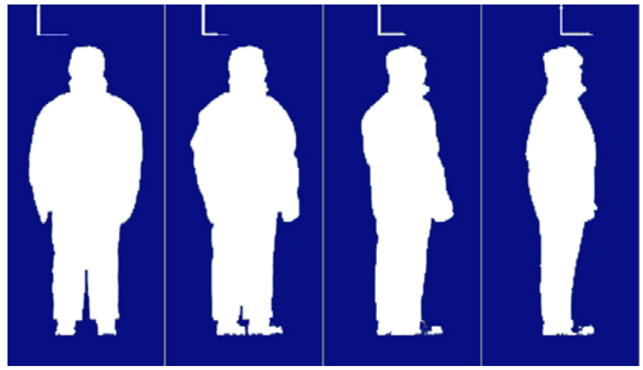

Figure 1. Scanned sample images, viewed from four azimuth angles: 0^o(front), 30^o, 60^o and 90^o (profile).

Calculation

Clothing area factor for each subject and each type of clothing and nude condition was estimated according to the following formula.

$$f_{cl} = \frac{\sum_{i=1}^{8} p_{cli}}{\sum_{i=1}^{8} p_{ni}}$$

where *i* designates the angle, p_{cli} is the pixels of angle *i* of the clothed image, p_{ni} is the pixels of angle *i* of the nude image.

Results and discussion

The analysis of variance (ANOVA) of the results showed that clothing area factors are significantly different among the nine types of clothing ($p< 0.01$) and among four subjects ($p<0.01$) (Figure 2). Clothing area factor estimated on subjects is probably more realistic to be used in IREQ calculation for real work environments than that estimated on manikin.

T-test showed that the estimated f_{cl} values are significantly lower by 3D body scanning method than by picture (2 pictures, front and profile) method on manikin (3) among the 4 types of winter clothing ($p<0.01$) (Figure 3). This difference might be attributed to the body shape difference between the subjects and manikin used and the number of photos used in the pixel calculations.

The regression analysis showed that the clothing area factor is significantly correlated with clothes weight for the 4 types of underwear and 4 types of winter clothing ($p<0.01$) (Figure 4) although

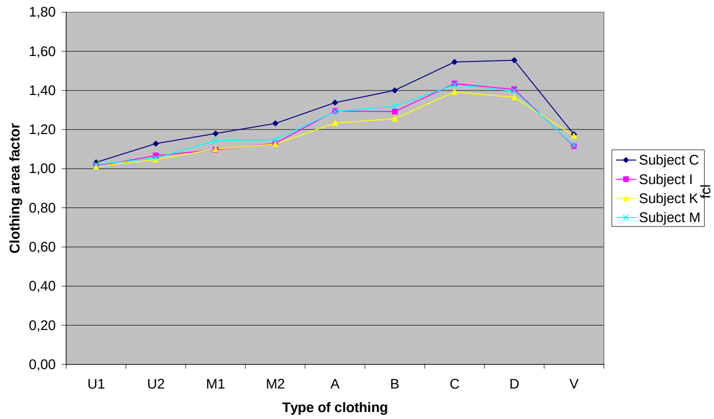

Figure 2. Clothing area factors (f_{cl}) of 9 types of clothing worn by four subjects

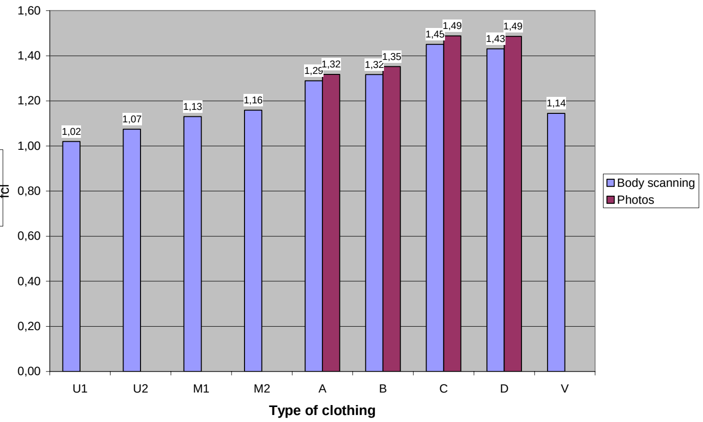

Figure 3. Comparison of estimated clothing area factor using 3D whole body scanning and photographic (2 photos, front and side) methods

scattering points can be seen. This may be used as a simple and quick method to roughly estimate winter clothing area factor. But it may not apply to other type of clothing.

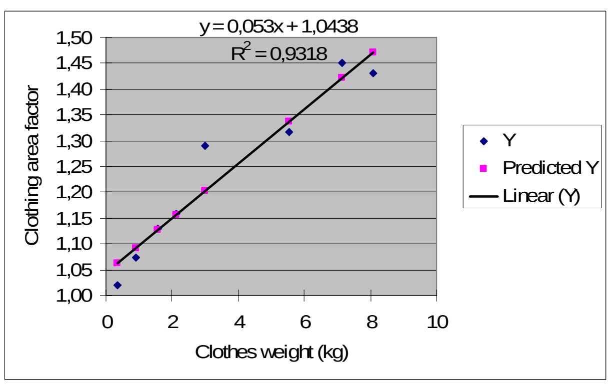

Figure 4. Simple estimation of clothing area factor by clothes weight

In addition to clothes weight, clothes size and subject's body shape and their match also affect f_{cl}. As an example, the body surface area A_D of subject C (Table 3) was smallest, which resulted in the f_{cl} as the highest among the subjects (Figure 2).

Conclusions

3D whole body scanning showed that clothing area factors differs among different subjects as well as among the nine types of clothing. 3D body scanning on the subjects generated in general lower clothing area factors than photographic method on a manikin. Clothes weight may be considered as a simple, quick and rough way to estimate winter clothing area factor.

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