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EVALUATION OF THE EFFECT OF AIR FLOW ON CLOTHING INSULATION AND ON DRY HEAT TRANSFER COEFFICIENTS FOR EACH PART OF THE CLOTHED HUMAN BODY

気流が人体各部の着衣抵抗および総合熱伝達率におよぼす影響

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The effects of air flow on clothing insulation and on the dry heat transfer coefficients were evaluated for each part of the clothed and nude human body. This was done by measuring clothing surface temperature using an infrared imaging radiometer. The results showed that increasing wind speed causes a decrease in clothing insulation and an increase in the dry heat transfer coefficients. The effect of air penetration on dry heat transfer coefficients could be determined by comparing the heat transfer coefficients of the clothed manikin to those of the nude manikin. Lastly, by comparing clothing insulation results obtained by the conventional indirect method to those of the direct method in this study, one can demonstrate the limitation of the conventional method and the need for direct estimation.

Keywords : *dry heat transfer, clothing insulation, infra-red thermography, human body, thermal comfort, airflow*
総合伝達，着衣抵抗，熱画像，人体，熱的快適性，気流

1. INTRODUCTION

There are many situations where the evaluation of thermal environment under airflow is required. For example, the outdoor environments which usually have faster airflow than indoor environments, room environments controlled by personal air-conditioning systems that have air diffusers in the vicinity of occupants, room environment in buildings which employ natural ventilation, and so on. In those highly non-uniform environments, detailed analysis on thermal comfort would be required not only for the whole body but also for individual body parts. Concerning the nude human body, there are some studies for the effect of airflow on heat transfer at the body-part level (Wang, 1990, Ichihara, 1997, deDear, 1997). However there are few data for clothing insulation and dry heat transfer coefficients on clothing at the body part level.

In addition, there is a strong need for such empirical data for multi-node models of thermoregulation (Stolwijk, 1971, Tanabe, 1998). The completion of these models partly depends on those empirical data at the anatomical resolution of each part of the human body.

2. METHODOLOGY

Seppanen (1972) measured the effect of airflow on clothing insulation for the whole human body at the velocity of 0.1 to 1.5m/s by using a thermal manikin. Tanabe (1996) also measured clothing insulation of traditional thin Asian-style clothing for the whole human body at 0.08, 0.38, 0.87 and 1.53m/s by using a thermal manikin. The methodology they employed was based on the following equations.

$$I_{cl} = I_T - I_a/f_{cl} \quad \text{(clo)} \qquad (1)$$

$$I_a = 1/(0.155h_n) \quad \text{(clo)} \qquad (2)$$

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I_{cl}: intrinsic clothing insulation (clo)
I_T: total clothing insulation (clo)
I_a: insulation of boundary air layer for nude manikin (clo)
f_{cl}: clothing area factor (nd)
h_n: dry heat transfer coefficient for nude manikin (W/m^2/K)

This includes an assumption that the convective and radiant insulation of the boundary air layer over the clothed manikin is the same as that over the nude manikin. Although this assumption has not been proved we rely on it because of the difficulty of measuring the insulation of the boundary air layer for a clothed manikin, which means the difficulty of measuring the surface temperature on clothing. Griffith (1995) recently proposed a fairly accurate (± 0.5 °C) technique for measuring surface temperatures using infrared thermography. Using this approach, it is possible to directly estimate clothing insulation by measuring clothing surface temperature directly with an infrared imaging radiometer.

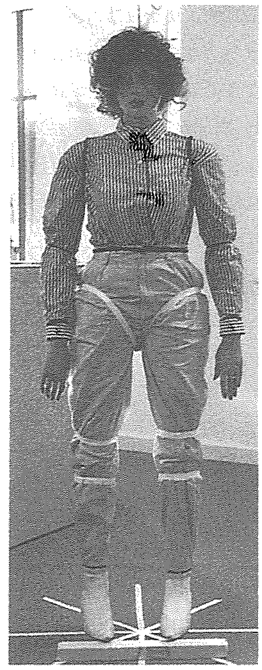


Figure 1 Thermal manikin

(1) Estimation of clothing insulation

Heat transfer between skin surface and the clothing for each part of the body can be described by the following equation, which is the same as for the whole body (ASHRAE, 1995, Handbook of fundamentals).

$$Q_t = [1/(0.155\ I_{cl})]\ (t_s - t_{cl})A_m \qquad (W) \qquad (3)$$

Where,
Q_t: dry heat loss for each clothed segment (W)
I_{cl}: intrinsic clothing insulation for each clothed segment (clo)
t_s: skin surface temperature of each nude segment (°C)
t_{cl}: clothing surface temperature of each clothed segment (°C)
A_m: skin surface area of each nude segment (m^2)

When one uses a thermal manikin which can automatically measure the skin surface temperature and the dry heat loss for each segment, by measuring the clothing surface temperature t_{cl}, using infrared thermography, one can estimate I_{cl} directly from Eq.(3).

Table 1 Surface areas of the nude manikin

Body Segment	Surface Area(m^2)
Back	0.128
Chest	0.138
Head	0.117
Left Arm	0.050
Left Foot	0.043
Left Hand	0.038
Left Leg	0.090
Left Upper Arm	0.076
Left Thigh	0.160
Right Arm	0.051
Right Foot	0.042
Right Hand	0.036
Right Leg	0.090
Right Upper Arm	0.073
Right Thigh	0.166
Pelvic Region	0.170
Whole Body	1.469

(2) Estimation of dry heat transfer coefficients

Assuming a uniform temperature field in which surrounding wall surface temperatures are the same as the ambient air temperature, the heat transfer between the clothing and its surrounding environment for each part of a manikin can be described by the following equation, which is the same as for the whole body.

$$Q_t = h_{cl}\ (t_{cl} - t_o) f_{cl} A_m \qquad (W) \qquad (4)$$

Where,
Q_t: dry heat loss for each clothed segment (W)
h_{cl}: dry heat transfer coefficient for each clothed segment (W/m^2/K)
t_o: ambient air temperature (°C)

Table 2 Measurement height for each body segment for standing posture

Body Segment	Measurement Height for Velocity (m)	Measurement Height for Temperature (m)
Back	0.92 1.05 1.18	0.90 1.20
Chest	0.92 1.05 1.18	0.90 1.20
Head	1.18	1.20
Left Arm	0.66 0.79	0.50 0.90
Left Upper Arm	0.92 1.05 1.18	0.90 1.20
Left Thigh	0.41 0.54 0.66	0.50
Right Arm	0.66 0.79	0.50 0.90
Right Upper Arm	0.92 1.05 1.18	0.90 1.20
Right Thigh	0.41 0.54 0.66	0.50
Pelvic Region	0.66 0.79	0.50 0.90

Using Eq.(4), by measuring clothing surface temperature and clothing area factor, the dry heat transfer coefficient on clothing for each clothed body part can be calculated.

3. MEASUREMENT PROCEDURE

(1)Thermal Manikin

A skin-temperature-controlled thermal manikin was used for measuring the clothing insulation and dry heat transfer coefficient for each body segment. This manikin was developed to evaluate asymmetric thermal environment by measuring the heat loss at each part of the body (Tanabe, 1994). The 16 body segments and their respective surface areas are listed in Table 1.

(2) Clothing

The clothing ensemble used in this study is a set of casual clothing items for mid season. These items are: panties and bra, 100% cotton shirt with long sleeves, 100% cotton trousers, socks and shoes. In addition, in this study a medium length hair wig for the head was employed and treated as a clothing item in order to clarify the difference between wig insulation and air layer insulation as well as the other clothing items.

To clearly define the heat loss from the clothing surface for each segment of the body we cinched down the clothing along the manikin segment boundaries using plastic tape. This was done to prevent lateral heat transfer between segments due to air movement underneath the clothing. Fig.1 shows a picture of the clothed thermal used in this study.

(3)Measurement of clothing area factor

Clothing area factor is usually measured as an average of projected area ratios between nude and clothed human body measured at several main angles (ISO9920). In this study, pictures were taken with a 35mm camera with a 50mm lens from 8 directions, i.e., horizontally every 45 degrees, around the manikin at the distance of 2m from the manikin. This was done for both the nude and clothed manikin. Angles and distances were held precisely constant during all of the measurements. The negatives were digitized at 1000 dots per inch resolution to analyze projected areas, with the number of pixels counted using computer software (SigmaScan 2.00) designed for image measurement. For each part of the body, eight ratios of projected area between the nude and clothed manikin were obtained. Those eight ratios were simply averaged and used as clothing area factors for each body part in subsequent analyses.

(4)Wind tunnel test procedure

The wind tunnel

The manikin was set in a wind tunnel with a test section 1.5m high and 2.1m wide. Seven meters upwind of the test section, a large cylindrical drum (1.0 m tall and 0.5m in diameter) was installed to generate some large-scale eddies in the airflow (This resulted in 2.3 to 13.1% turbulence intensity during across the range of wind speed measurements). The drum was also utilized for measuring the manikin surface temperatures. An infrared imaging radiometer was set on the drum when a picture of the manikin was to be taken from the up-wind direction and the operator hid up-wind of the drum to minimize his influence on the airflow and surface temperatures in the tunnel.

Wind tunnel anemometry

Wind speed was measured by a TSI (model 1266) heated element anemometer. The device has a measurement range from 0.15 to 66m/s with a specified error of ±10% at 0.2m/s and ±2% at 5.0m/s. The anemometer was attached to a sliding mount on a vertical mast, which was driven by a programmable stepper-motor enabling wind speed profile from floor to ceiling to be automatically determined during each experiment. The anemometer mast's stepper motor was programmed to pause for 10 seconds at equally spaced heights, and the arithmetic average of 150 instantaneous wind speeds recorded during each pause was sent out to the wind tunnel's data logger. These averages recorded during each manikin test were the basis of subsequent analyses. There were 10 separate anemometer measurements for a full sweep of the tunnel cross section. Their heights above the floor of the wind tunnel were: 0.02, 0.15, 0.28, 0.41, 0.54, 0.66, 0.79, 0.92, 1.05, and 1.18m. Table 2 indicates the anemometer heights associated with each of the manikin's 16 body segments during the experiment. Where more than one anemometer height is given in Table 2, the mean values obtained at adjacent measurement points were used.

Wind tunnel temperature sensors

Four temperature probes were mounted near the manikin at different heights within the wind tunnel's working section. They were continuously scanned and averaged by an automatic data logger for 3 minutes during the final stages of each experiment. The probes were thermistors mounted at the tips of 30-cm-long shafts. The four measuring heights were: 0.10, 0.50, 0.90, and 1.20m.

All subsequent analyses performed on each manikin body segment were based on measurements from the nearest of these temperature probes. Although the wind tunnel had no capability for temperature control, the variation of temperatures within the working section was found to be very small for the duration of a single manikin experiment (less than 0.2℃ for any experiment).

The surface temperature measurement

An infrared imaging radiometer (Inframetrics MODEL 760) was used to measure the temperature of the clothing surface on the manikin. The specified worst-case accuracy of this instrument is ±2℃ or ±2% of full scale. However according to Grifith(1997), the accuracy can be improved to about ±0.5℃ or better by using a reference emitter of known emissivity. A thin film with known emissivity of 0.90 was employed as a reference emitter and 4 pieces of the film were set near the air temperature sensors in the wind tunnel. We assumed the surface temperature of the film was very close to the air temperature that can be measured by the accurate thermistor probe. Then the surface temperatures measured by the radiometer were corrected by using the difference of the surface temperature of the film measured by the radiometer and the air temperature measured by the thermistor. Prior to the actual measurement, we measured the emissivity of the film and main clothing items by using a similar radiometer and putting the pieces of those material on a hot copper plate and comparing the measured temperature to the reference of known emissivity. The emissivity of the shirt and trousers used in this study were estimated as 0.87 and we assumed this value as emissivity for all the clothing items.

The thermographs were taken from the front and back. For the up-wind side in the wind tunnel the drum for turbulence was used to hide behind. For the downwind side a small chair covered with cloth was used to hide behind. The thermographs were analyzed by software for image measurement. The area average function in the software was used to estimate average temperature for each part of the body. The circumference of each body part on the thermograph image was traced for its area average temperature. For the chest and the back, the estimated surface temperature was directly used in subsequent analyses. For the head, the upper arms, the forearms, the waist and the thighs, two average temperatures for the front and back were simply averaged and used as the average surface temperature for those clothed body segment. The hands were not analyzed because they were almost naked and have no clothing insulation.

For the head, the circumferential area of the hair was somewhat transparent when seeing from the front or the back. Thus the temperature measured by the infrared radiometer might have included the effect of ambient air temperature.

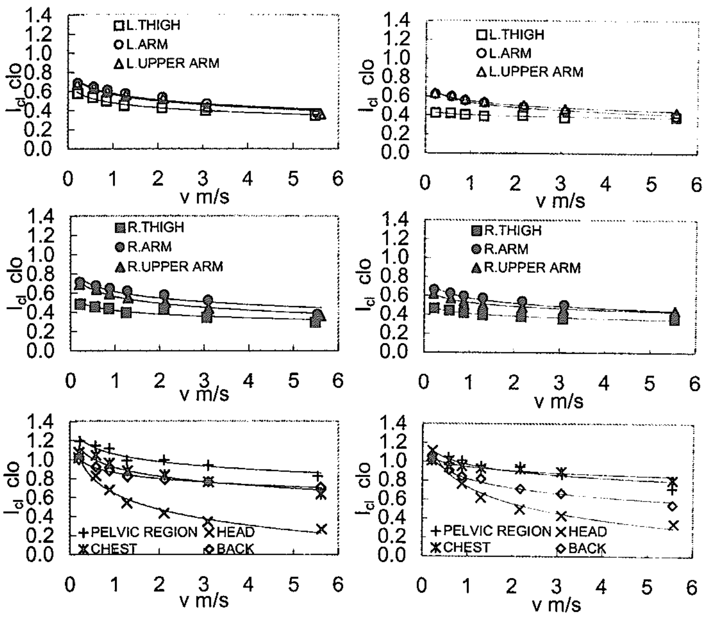
Table 3 Clothing area factor

Body Segment	Clothing Area Factor (nd)
Back	1.11
Chest	1.03
Head	1.51
Left Arm	1.21
Left Foot	1.41
Left Hand	1.00
Left Leg	1.25
Left Upper Arm	1.24
Left Thigh	1.08
Right Arm	1.21
Right Foot	1.31
Right Hand	1.00
Right Leg	1.28
Right Upper Arm	1.24
Right Thigh	1.14
Pelvic Region	1.03
Whole body	1.17

Test conditions

Measurements were carried out for the nude and clothed manikin for wind directed onto her front and back. The wind speed was set at 0.2, 0.5, 0.8, 1.2,2.0, 3.0 and 5.5m/s (only 0.8, 2.0, 5.5m/s for nude) for each case. Both standing and sitting postures were tested. (In this paper, the results for standing posture are presented.) Because the height of the wind tunnel was not enough for the manikin to stand fully erect, we did not measure the insulation of the lower legs in the standing posture and are using instead the lower leg results obtained from the sitting posture experiment. For the standing tests, we bent the knees of the manikin with her unheated lower legs trailing back in a kneeling position. (This paper does not include the results for legs and feet.)

Although the wind tunnel had no capability for temperature control, the variation of temperatures within the working section was found to be small for the duration of all the experiments. For the duration of measuring the clothed manikin, the air temperature was mostly between 21 and 22.5℃. For the duration of measuring the nude manikin, that was mostly between 20 and 21℃.



(a)Wind from the front (b)Wind from the back

Figure 2 Clothing insulation under airflow

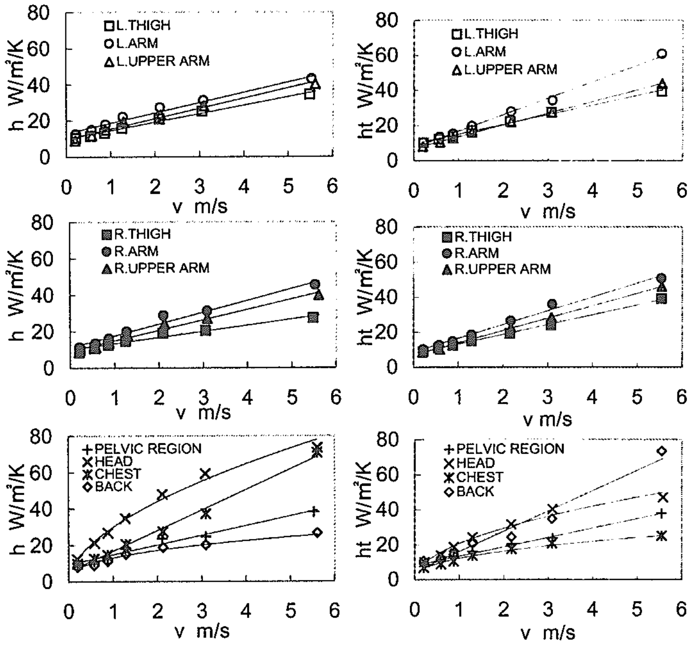
4. RESULTS AND DISCUSSION

(1) Clothing area factor

Table 3 shows the measured clothing area factors. It is reasonable that the head, with a wig, and the feet with shoes have large clothing area factors. There are many parts that have small clothing area factors such as the chest and the thighs. This is partly due to the binding of the clothing between segments as seen in Fig.1. In total, the clothing area factor is 1.17 and can be described as a relatively tight fit.

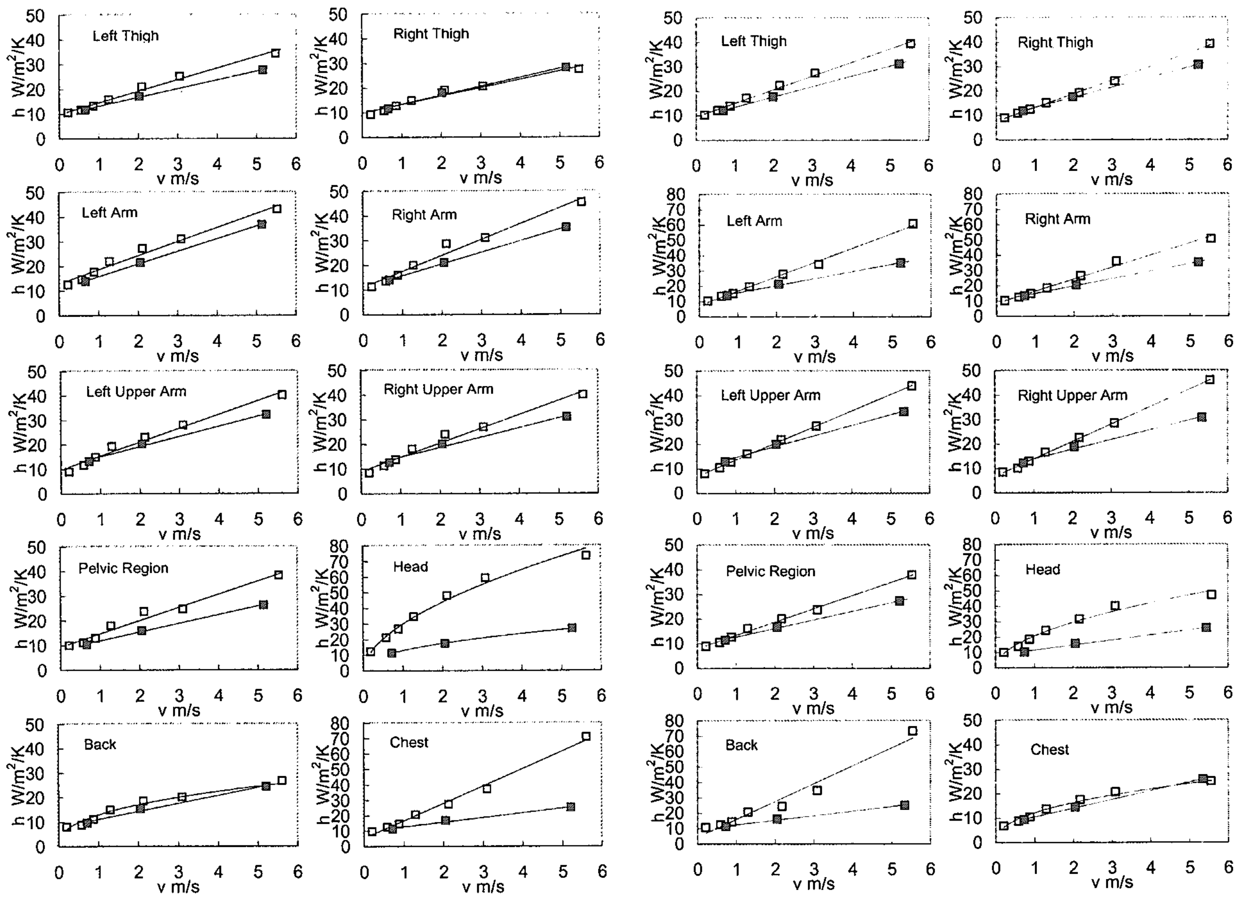
(2) Clothing insulation

Fig.2(a) shows clothing insulation for airflow from the front. Fig.2(b) shows clothing insulation for airflow from the back. For the low velocity of 0.2m/s, the insulation on limb parts such as thighs, forarms and upper arm is relatively small. In contrast, the head, chest, back and pelvic region have higher insulation values. This can be explained as follows. The limbs have low insulation values because they have no underwear beneath the cotton shirt or pants. The head has high insulation due to its wig, which due to its foundation layer is probably more insulating than natural hair. The pelvic region has very high insulation due to the



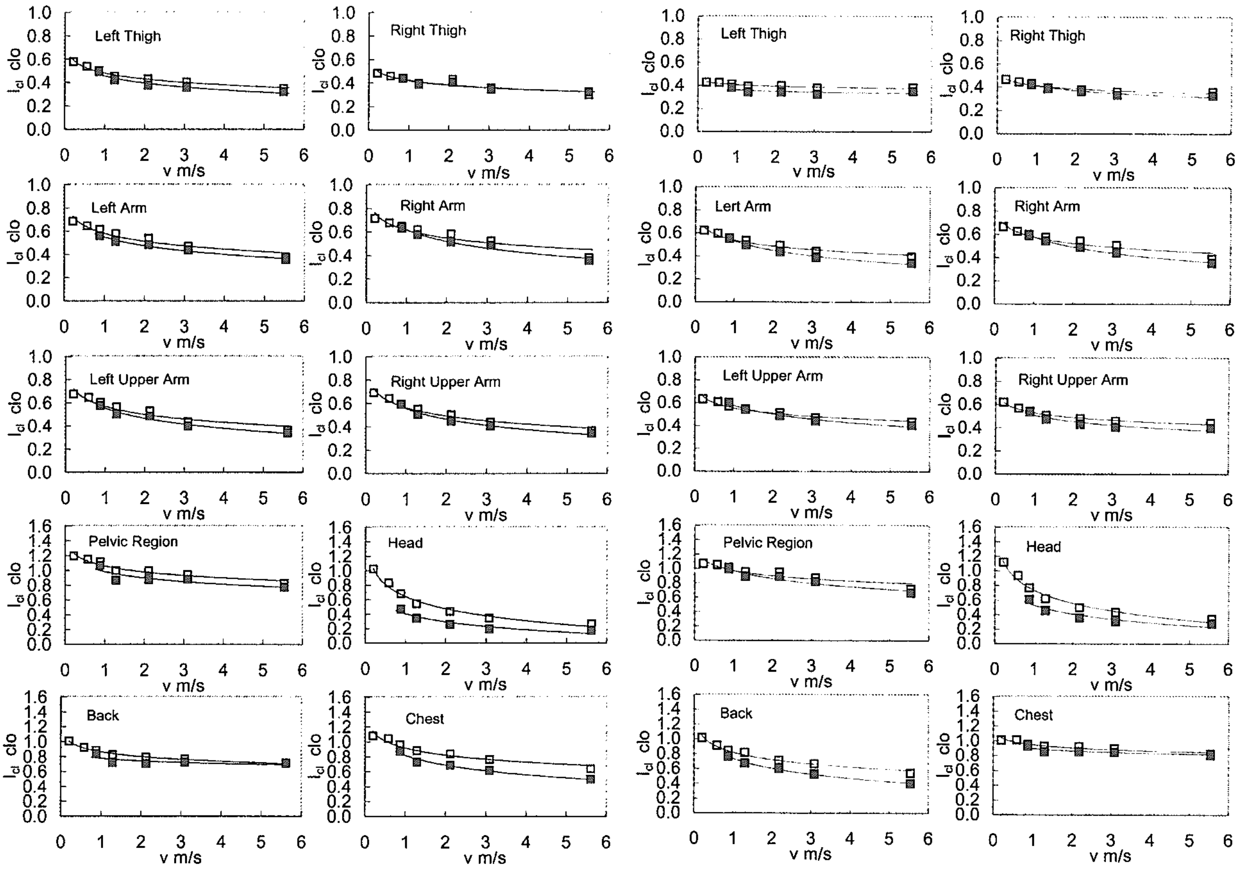
(a) Wind from the front (b) Wind from the back

Figure 3 Dry heat transfer coefficients under airflow



(a) Wind from the front (b) Wind from the back

Figure 4 Comparison with dry heat transfer for nude manikin
(Open square means the results from clothed manikin and solid square means those from nude manikin)



(a) Wind from the front **(b) Wind from the back**

Figure 5 Comparison with conventional method in clothing insulation
(Open square means the results from direct estimation and solid square means those from conventional method)

underwear and a part of the shirt tucked into the pants. The back and chest have high insulation due to the underwear and the large air space between the skin and the shirt.

For all the body parts, the higher the velocity, the lower the insulation. This is probably due to air penetration rather than decreasing air space by wind pressure, because even at the back/chest where there is negative pressure under airflow from the front/back, the clothing insulation decreases when the wind speed increases.

The decrease rate is highest at the head for two reasons: 1) the wig is porous and the wind penetrates it easily, and 2) the head is warmed under still air conditions by a thermal plume rising from the chest and back. This plume is easily disrupted by wind. This second effect may also explain the rapid decrease of insulation on the chest and back under increasing wind from the facing direction.

(3) Dry heat transfer coefficient

Fig.3(a) shows dry heat transfer coefficients under the airflow from the front. Fig.3(b) shows dry heat transfer coefficients under the airflow from the back. Because the dry heat transfer coefficients include radiative heat transfer, direct comparison can not be made with convective heat transfer coefficients from other studies. In addition, in this study the feet and legs, which often have rather large convective heat transfer coefficients in still air (Lee, 1990, deDear, 1997, Murakami, 1999, Ishii, 2000) were not studied. However, when looking at the heat transfer coefficients at low air velocity of about 0.2m/s, slightly larger values are observed at arms and head than those at chest and back. This is almost consistent with the results from some other studies for natural convection (Lee, 1990, Ichihara, 1997, deDear, 1997).

For all the body parts, the higher the velocity, the higher the dry heat transfer coefficients. This is basically due to the increase of convection heat transfer between the clothing and ambient air. According to other studies (Ichihara, 1997, deDear, 1997), convective heat transfer coefficients can be modeled by power function of wind speed (the power of around 0.5). However, in this study, we found better fits in linear regression model except for a few parts such as the head. The main reasons may be the followings: a) because dry heat transfer coefficients includes radiative heat transfer coefficients the dry heat transfer coefficients are far from zero even when wind speed approaches zero, and b) air penetration into the clothing enhances convective heat transfer more rapidly than the air movement on or along the nude surface or the surface of impermeable clothing.

The increase rate is highest at the head under the airflow from the front, because the face is naked and the wind also penetrates the wig. Also the dry heat transfer coefficient at the chest/back increases a bit more rapidly compared to the other body parts when they face upwind, probably as the wind removes the relatively thick boundary layer created by the body's thermal plume.

(4) Comparison with dry heat transfer coefficients for a nude manikin

Fig.4 (a) shows the comparison between nude and clothed dry heat transfer coefficients under airflow from the front. Fig.4(b) shows the comparison of those under airflow from the back. Here again, we used linear regressions for the nude manikin coefficients, both to allow clear comparison with the plots of clothed manikin coefficients, and because power regression does not fit well because dry heat transfer coefficients are far from zero when the wind speed approaches zero.

When looking at the dry heat transfer coefficients at the velocity of about 0.8m/s, the differences of those values between nude and clothed manikin, except for the head, are relatively small. This indicates that, except for the head, the dry heat transfer coefficients for the nude can be used also for clothed surfaces as long as the wind speeds are low. On the other hand, for the head, even at 0.8m/s, the dry heat transfer coefficients for the head with wig are larger than those for the head with no wig.

Except for a few cases such as the right thigh or the back under the airflow from the front, the higher the velocity, the higher the difference between clothed and nude dry heat transfer coefficients. The difference is largest at the head under the wind from the front. This is probably due to air penetration, because at the back/chest where it should have a relatively low velocity under airflow from the front/back, the difference is very small. Another special characteristic of the head that might affect the results is the transparency of the circumferential area of the hair. This might decrease the average temperature of the head and result in larger dry heat transfer coefficients. The reason for small differences at the right thigh under airflow from the front may be due to an observed tighter fit of the pants on the front side of the right thigh than on the left thigh.

(5) Comparison with conventional method in clothing insulation

Conventionally the clothing insulation has been estimated by the indirect method based on Eq. (1). Fig.5 shows clothing insulation under the airflow from the front/back both for the direct estimation in this study and the results from the conventional indirect method. When looking at the clothing insulation at the velocity of about 0.8m/s, as a natural result from small differences of the dry heat transfer coefficients between nude and clothed manikin, the differences of the clothing insulation between nude and clothed manikin, except for the head, are relatively small. This indicates that, except for the head, under relatively low wind speed, the conventional method based on Eq. (1) results in reasonable clothing insulation estimates.

On the other hand, for the head, even at 0.8m/s, clothing (wig) insulation from the conventional method resulted in less insulation value than that from the direct method. This may be because the air penetrates the wig very easily even at 0.8m/s. This implies that the conventional method cannot be used to estimate clothing insulation when clothing has a large permeability for air. This implication can be clearly seen at high velocity conditions. Except for a few cases such as the right thigh or the back under the airflow from the front, at the velocity higher than 0.8m/s, the conventional method underestimated the clothing insulation. This happens because the rapid increase of dry heat transfer coefficient on clothing surface due to air penetration is not taken into account in Eq. (1). As expected, for the back/chest which should have relatively low velocity under airflow from the front/back, the differences between conventional method and direct insulation measurement are very small.

All these results suggest that the conventional method can be used only for clothing which has low air permeability or under relatively slow airflow conditions, and that otherwise the direct estimation method, as described in this paper, is required to estimate clothing insulation.

4. SUMMARY

Direct evaluation of the effect of airflow on clothing insulation and dry heat transfer coefficients (or boundary air layer insulation) for each part of the body was carried out by measuring surface temperature, using an infrared image radiometer. Increasing wind speed caused decrease of clothing insulation and increase of dry heat transfer coefficient. Compared to the dry heat transfer coefficients for the nude manikin, those for clothed manikin more rapidly increase according to the increase of wind speed due to air penetration into clothing. Concerning clothing insulation of permeable clothing under relatively fast airflow, the conventional indirect method could underestimate clothing insulation and the direct method would be required.

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和文要約

1. はじめに

気流下において、不均一な温熱環境の評価を求められる状況は多く、このような状況では部位別の評価が必要である。同様の観点から裸体のサーマルマネキンを用いて部位別の熱伝達の研究が行われているが、部位別の着衣抵抗や、着衣時の総合熱伝達の研究は非常に少ない。

2. 研究方法

着衣抵抗を求めるに当たり、従来法は（1）、（2）式に基づいている。つまり、裸体表面における空気層抵抗をもって、着衣表面の空気層抵抗とする方法が取られているが、本研究では熱画像装置を用いて着衣表面の温度を計測し、着衣抵抗および着衣表面の総合熱伝達率を直接算出する。

（1）着衣熱抵抗の評価

人体各部の熱抵抗は（3）式で表され、サーマルマネキンで熱量と皮膚温度が解っていれば、着衣の表面温度を測定することにより、着衣抵抗が直接算出できる。

（2）総合熱伝達率

サーマルマネキンにおける人体各部の熱損失は（4）式で表され、着衣の表面温度および着衣面積率を測定することにより、総合熱伝達率が算出できる。

3. 計測方法

（1）サーマルマネキン

計測に用いたマネキンは皮膚温度可変型の女性体のサーマルマネキンで、主に室内の不均一温熱環境の評価用として開発されたものである。部位の分割数は 16 であり、表面積は表-1 のようになっている。

（2）着衣

計測に用いた着衣は下着、綿 100％の長ズボン、および綿 100％の長袖シャツ、靴下、靴である。頭にはセミロングのかつらを取りつけ、着衣の一つとして評価した。

また、人体各部の着衣からの熱損失量を明確にするため、マネキンの各部位の境界をビニールテープで縛り、着衣内での部位間の熱の移動がないよう配慮した。図-1 に写真を示す。

（3）着衣面積率の計測

立位マネキンを対象とし、2m離れた位置から、裸体、着衣時の双方について、水平方向に 45゜毎に 8 方位から撮影し、投影面積の比を平均することにより着衣面積率を算出した。

（4）風洞実験手順

風洞の測定部（高さ 1.5m、幅 2.1m）にマネキンを設置した。風洞上流側には、乱れをつくるための高さ 1m、直径 0.5mの円柱を測定部の上流 7mの位置に設置した。表面温度測定は、熱画像をマネキン正面と背面から測定した。熱画像を解析することにより、各部位の正面と背面の着衣表面温度を求め、それらを平均することにより各部位の着衣表面温度とした。実験条件としては、裸体および着衣のマネキンそれぞれについて、正面および背面から風を当てて測定した。ただし、風洞高さの制限で完全に立位にはできず、ひざで折り曲げ、ひざから上のみの測定とした。設定風速は 0.2、0.5、0.8、1.2、2.0、3.0、5.5m/s（裸体では 0.8、2.0、5.5m/s のみ）である。

4. 結果および考察

（1）着衣面積率

部位毎の着衣面積率を表-3 に示す。全身では 1.17 とややきつめの着衣状態であった。これは、人体各部の境界をテープで縛ったことによるものと考えられる。

（2）着衣抵抗

着衣抵抗の測定結果を図-2(a)～(b)に示す。すべての部位で風速が増大するに伴い、着衣抵抗が低下する。負圧領域の部位でも着衣抵抗が低下することから、その原因は、着衣内の空気層の厚みの変化というより、主に気流が着衣を貫通することによると考えられる。着衣抵抗の低下率は頭が正面、背後を問わず最も大きい。これは、主にかつらの通気性が大きいこと、および胴体からの熱プルームが風により壊されることによると考えられる。

（3）総合熱伝達率

着衣抵抗の測定結果を図-3(a)～(b)に示す。すべての部位で風速が増大するに伴い、総合熱伝達率が増加する。その増加率は正面からの風の時の頭が最も大きい。その他の部位では正面からの風の時の胸、および背後からの風の時の背中の増加率が他の部位に比べると増加率が大きい。

（4）裸体の総合熱伝達率との比較

図-4(a)～(b)に裸体時と着衣時の総合熱伝達率の比較を示す。0.8m/s 程度ではその差は小さいが、風速が大きくなるに従い、その差は大きくなる傾向にある。その差は正面からの風の時の頭が最も大きい。その他の部位では正面からの風の時の胸、および背後からの風の時の背中での差が他の部位に比べると大きい。

（5）着衣抵抗の算出方法の比較

図-5(a)～(b)に従来法と本研究の直接法の比較を示す。0.8m/s 程度ではその差は小さいが、一部の部位を除き、風速が大きい場合、従来法では着衣量を小さく見積もる傾向にある。また、0.8 m/s であっても、通気性の大きな頭ではその差が大きい。このことは、従来法は通気性の低い衣服や低風速下でのみ使用することができることを示している。

5.まとめ

有風化での部位別の着衣抵抗と着衣表面の総合熱伝達率を着衣の表面温度計測により求めた。裸体時との比較を行い、通気による総合熱伝達率の増大を示した。さらに、着衣抵抗の測定方法について従来法と比較し、従来法の限界を示した。

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