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LOCALIZED EVAPORATIVE RESISTANCE: CORRECTION FOR BODY AND AIR MOVEMENT

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INTRODUCTION

Clothing evaporative resistance determines how much sweat could be escaped through one's clothing to the surrounding environment (Wang et al. 2011). Although ISO 9920 (ISO 9920 2007) has considered effects of body and air movement on clothing total evaporative resistance $R_{e,T}$, the correction factor for $R_{e,T,r}$ (total resultant evaporative resistance) was made based on the reduction factor for $I_{T,r}$ (total resultant thermal insulation). In addition, a total dynamic value cannot always fully reflect the local evaporative transfer characteristics, for example, when considering inhomogeneous garments over the body. Thus it is meaningful to investigate local clothing thermal comfort.

METHODS

The Newton type sweating thermal manikins (MTNW, Seattle) was used in this study. The manikin surface temperature was controlled at 34.0 °C. The water was continuously supplied to fabric skin through embedded sweating glands. The fabric skin was fully saturated. Fourteen temperature sensors were attached on the wet skin surface to measure skin temperature. All experiments were conducted at an environmental temperature (34.0±0.5 °C) and relative humidity (38±5 %). Three levels of air velocity were selected: 0.18, 0.48 and 0.78 m/s. The reference air velocity was 0.18 m/s. Three walking speeds were chosen: 0, 45 and 55 dspm (double steps per minute). The corresponding walking speeds are 0, 0.96 and 1.17 in m/s, respectively.

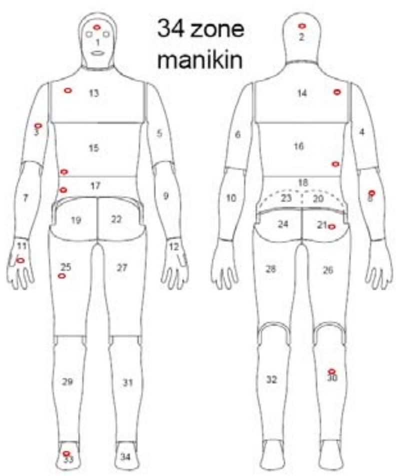


Fig 1. Sensor location on a 34-segment Newton sweating thermal manikin.

[†] These authors contribute equally to this work and order of authorship is listed alphabetically.

RESULTS

The local heat losses of 14 segments of a 34-segment Newton sweating manikin at different body and air movements are presented in Table 1.

Table 1. An example on local manikin segmental heat loss (in W/m^2) at different walking speeds and air velocities.

Zone	Test conditions					
	SL	SH	W45L	W45H	W55L	W55H
Face	186.4	202.3	188.3	192.5	183.5	212.1
Head	92.0	152.2	104.3	142.1	109.9	151.8
Chest	116.2	145.5	127.1	128.3	120.1	133.3
Shoulders	65.9	105.2	92.8	103.7	96.1	97.0
Upper arm	196.9	209.4	215.9	223.0	223.8	221.8
Forearm	154.8	197.7	452.6	465.0	556.7	430.9
Hand	202.6	343.5	424.5	465.3	531.5	604.6
Back	81.9	97.0	111.8	125.9	123.5	136.8
buttocks	62.0	76.8	122.2	123.9	152.3	153.6
thigh	187.4	244.4	245.5	294.9	279.7	295.5
Calf	140.3	167.0	249.0	368.1	544.4	554.1
Foot	228.7	246.1	396.0	280.2	479.8	542.5
Stomach	130.9	156.0	135.2	144.4	141.1	147.9
Waist	136.1	145.0	169.7	174.1	197.1	183.7

Note: S-standing manikin; L-low air velocity (0.18 m/s); H-high air velocity (0.48 m/s); W-walking manikin; 45-walking speed, 45 dspm; 55-walking speed, 55 dspm.

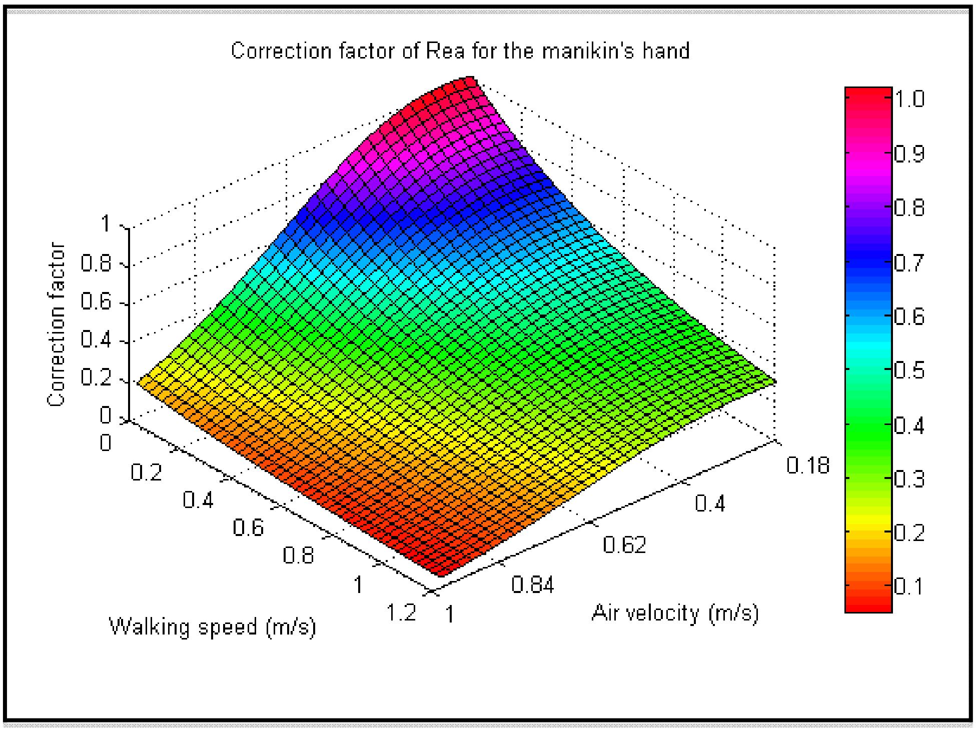
The data were analyzed with multiple nonlinear regression analysis using the XLSTAT software (Addinsoft Inc., NY, USA). Prediction parameters were air velocity and walking speed. The coefficient of determination (r^2) and standard errors of the estimate (SEE) were used to judge the prediction accuracy. The correction factor curves of the air boundary layer's resultant evaporative resistance at the manikin's right hand and stomach are displayed in Fig.2. The correction factor equations can be expressed as

$$R_{ear,Rhand} = e^{[(0.500\times(v_{ar}-0.18)-3.389\times(v_{ar}-0.18)^2-1.306\times v_w+0.247\times v_w^2)]}\cdot R_{ea,Rhand}$$

where, $0.18<v_{ar}<1.0$ m/s and $0<v_w<1.2$ m/s, r^2=0.987, SEE=0.048.

$$R_{ear,stomach} = e^{[(-0.232\times(v_{ar}-0.18)-2.433\times(v_{ar}-0.18)^2+0.011\times v_w-0.116\times v_w^2)]} \cdot R_{ea,stomach}$$

where, $0.18<v_{ar}<1.0$ m/s, $0<v_w<1.2$ m/s, $r^2=0.988$, SEE=0.031.



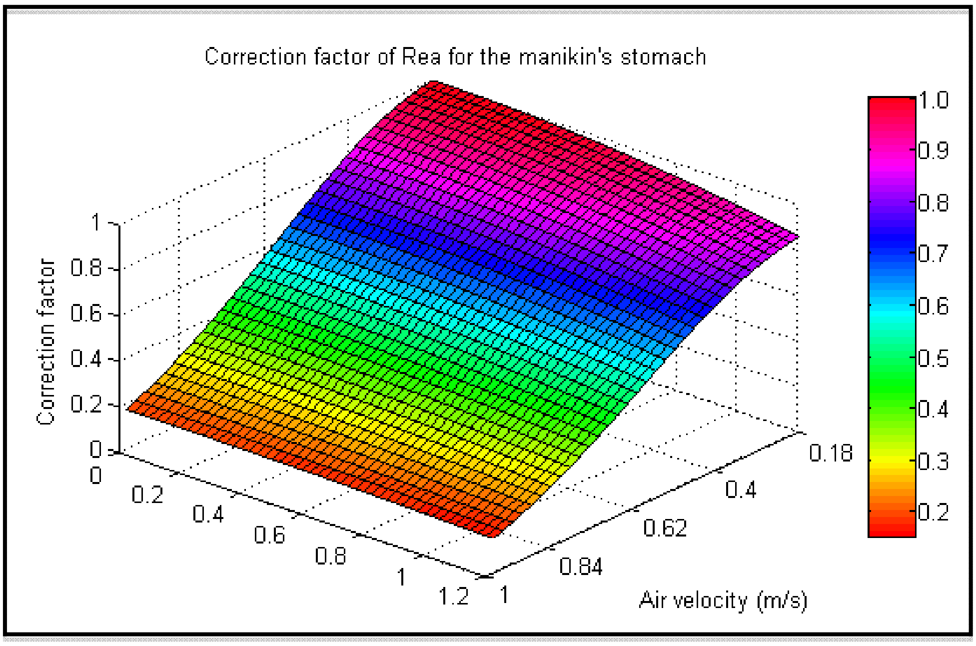


Fig 2. Correction/reduction factors of the boundary air layer's evaporative resistance (R_{ea}) for the manikin's right hand and stomach.

CONCLUSION

The body movement has more influence on the body extremity than on the torso. In contrast, the air velocity has more influence on the torso than that from walking speed. This is in good agreement with the results reported on dynamic clothing thermal insulation (Holmér et al. 1999; Havenith et al. 2004). By using correction factors developed for each local body segment, the local clothing moisture transfer property could be more clearly characterized.

REFERENCES

Havenith G. Nilsson H. (2004) Correction of clothing insulation for movement and wind effects, a meta-analysis. *Eur. J. Appl. Physiol.* **92:** 636-640.

Holmér I. Nilsson H. Havenith G. Parsons K. (1999). Clothing convective heat exchange-proposal for improved predictions in standards and models. *Ann. Occup. Hyg.* **43**: 329-337.

ISO 9920 (2007). Ergonomics of of the thermal environment-Estimation of thermal insulation and water vapour resistance of a clothing ensemble. Geneva: International Organization for Standardization.

Wang. F. Kuklane. K. Gao. C. & Holmér I. (2011). Effect of temperature difference between manikin and wet fabric skin surfaces on clothing evaporative resistance: how much error is there?. *Int. J. Biometeorol.* doi: 10.1007/s00484-011-0411-z

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