Title

Thermal adaptation and insulation opportunities provided by different drapes of Indian saris

Journal

Architectural Science Review, 58(1)

ISSN

0003-8628 1758-9622

Authors

Indraganti, Madhavi
Lee, Juyoun
Zhang, Hui
et al.

Publication Date

2014-11-21

DOI

10.1080/00038628.2014.976540

Peer reviewed

Unique thermal adaptation in Indian Saris: Clothing insulation with different drapes

Madhavi Indraganti+, Juyoun Lee*, Hui Zhang** , Edward A. Arens**

+ Prince Sultan University, Riyadh, Saudi Arabia

maindraganti@gmail.com

Madhavi.indraganti@fulbrightmail.org

Phone: +966533422141

* HAE R&D Center, LG Electronics, South Korea

** Center for the Built Environment (CBE), University of California, Berkeley, CA

Abstract

Women across South-Asia wear the sari. It is versatile as the drape modifies the clothing insulation, for a given ensemble. We tested three Indian ensembles of saris (for four drapes) with a thermal manikin following ISO: 9920 protocols. The insulation on all the sixteen body parts and the whole-body were recorded. This provides information for advanced thermal comfort modeling needing clothing insulation at segmentation level. The sari offered a wide range of insulation (0.94 to 0.62) for a given set of garments. Winter ensembles provided 1.11 – 1.39 clo while the summer and monsoon ensembles had 0.62 – 0.96 clo. We noted the clothing insulation varying by about 48 - 51 % due to the changes in drape on the upper body alone. The findings of this research are more than a correction of clo value of saris.

Keywords

India; Sari; Clothing Insulation; Thermal Comfort standards; Thermal Manikin; Thermal Comfort Simulation; Clothing Adaptation

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Introduction

The sari is in use since the Indus valley civilization (circa 3000 BC). Only women wear saris across South-Asia and elsewhere and one size fits all. A recent field study in Indian offices identified that 99% women were in Indian ensembles (Indraganti et al. 2014). However, knowledge on the sari's clothing insulation is very limited in the current codes (ASHRAE 2010; BIS 2005; ISO:9920 2004). Recent literature features information on the Arabian-gulf clothing and Asian and African clothing (Al-ajmi et al. 2008; Mitsuzawa & Tanabe 2001) and some data on sari. Havenith et al. tested non-western clothing, including two sari ensembles (Havenith et al. 2014). These studies do not address the sari as an ensemble with its various drapes, as are worn by most women in Indian offices and homes.

Clothing adaptation through the change of sari drape was evident in Indian women (Indraganti 2010). The summation relationships of western clothing may not be applicable for the Indian sari, as the drape, body coverage, material, and fit are very different. Therefore, the sari is best tested as an ensemble.

Previous human physiology and thermal comfort models treated the human body surface as one segment (Gagge, Fobelets & Berglund 1986). However, recent human physiology and comfort models divide the human body into multiple body parts (such as head, hand, chest etc.), in order to accurately simulate skin and core temperatures and thermal comfort (Huizenga, Zhang & Arens 2001; Zhang et al. 2010).

These comfort models require clothing insulation of the occupants at segmental level. Unfortunately, existing clothing insulation databases only characterize the clothing insulation for the whole body, and not for individual body parts (McCullough & Jones 1983; Havenith, Holmer & Parsons 2002; ISO:9920 2004). With these aspects in mind, we conducted a climate chamber study on a segmented thermal manikin, draped in different sari ensembles. This paper illustrates its findings.

Methods

Modern sari is a single piece of unstitched rectangular cloth: 5 to 8.1 m x 1.15 – 1.25 m. (Figure1 A). It has a relatively ornate 'pallu' that hangs freely over the shoulder. The bodice is a body-hugging stitched single piece of garment (Figure 1 C, D) covering the upper body, up to a few inches above the navel. We draped the female manikin 'Monica' in 'nivi' style using two different handloom saris and a shawl (Table 1) along with two deep and wide necked bodices with sleeves up to the middle of the upper arm.

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Table 1. Weights and material composition of the garments tested

Clothing	Weight (g)	Material
Bra	40	Shell: 100% Cotton: Trims: 100% Elastin
Panty	34.99	100% Cotton
Mauve cotton bodice	78	100% Cotton
Petticoat	205	100% Cotton
Silk yellow bodice	78	Shell: 100% Silk, Lining: 100% cotton
Silk yellow sari	450	100% Silk
Polyester green sari	665	50% Cotton 50% Polyester
Shawl	220	100% Acrylic

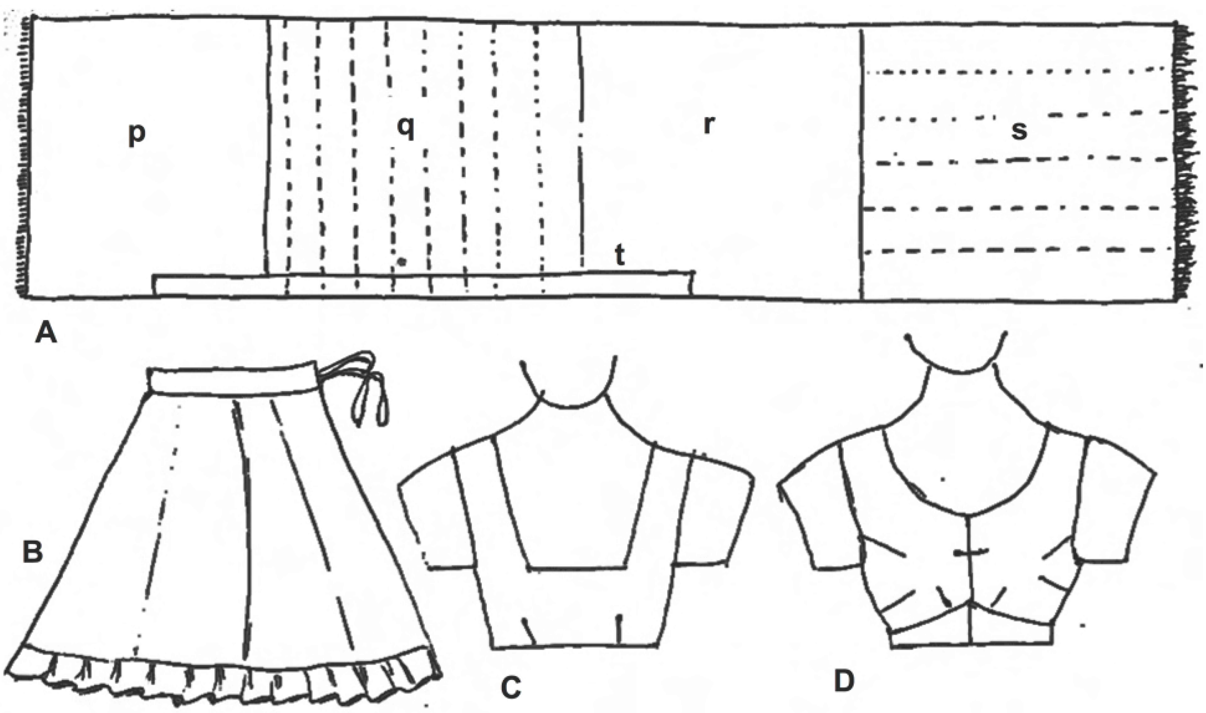


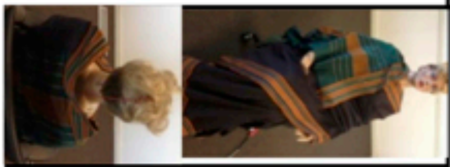
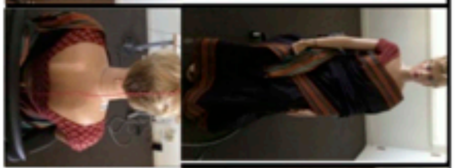
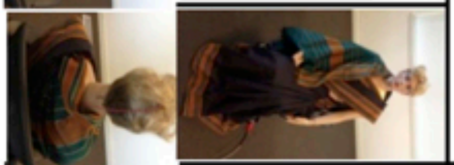
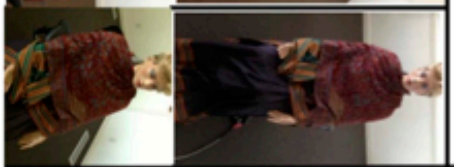
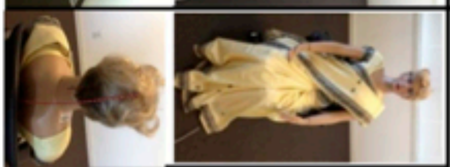
Figure 1. Parts of the ensemble 'sari.' A: Sari, B: Petticoat, C and D: Bodice back and front, p: inner layer of the sari, q: lower center-front pleats, r: front and rear cover, s: pleats of the pallu on the upper body, t: a strip of underlining.

Draping of a sari

The draping style of sari varies with geographical area and the activity of the female. The 'nivi' style has the sari draped in two layers from right to the left over a drawstring petticoat (Figure 1B) and a short tight fitting bodice (Figure 1C, D) (Boulanger 1997). Sometimes the 'pallu' covers one or both the upper arms and back (Table 2). Alternately, it can be pleated and pinned to the bodice on either of the shoulders. The petticoat and lower pleats offer fullness at the ankle, and improve the wearer's mobility. The number of pleats depends on the waist size of the wearer, desired length of the pallu and eventually the sari's length.

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Table 2. Description of the ensembles tested

Front/ rear views		Ensemble description	No.
	Summer/ monsoon	Sari pallu unpleated covering both arms	En1
		Sari pallu unpleated covering one arm	En2
		Sari pallu pleated both arms exposed	En3
		Sari pallu pleated covering one arm and back	En4
	Winter	Sari pallu pleated covering one arm and with shawl	En5
		Sari pallu pleated covering both arms and with shawl	En6
	Summer/ monsoon	Silk sari pallu pleated, both arms exposed	En7
		Silk sari pallu unpleated covering one arm	En8
		Silk sari pallu unpleated covering both arms	En9

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

The ensembles tested and the experimental setup

Figure 2. (Left to right) The test conditions of the climate chamber showing the data-logger setup; manikin with petticoat, panty, bra and bodice; a rear view of a sari and bodice on a human subject; manikin in a sari ensemble; the manikin control screen

Table 3. Body segments and respective areas of the manikin

Name of Part	**Area (m^2)**	**Name of Part**	**Area (m^2)**
Left Foot	0.043	Left Hand	0.038
Right Foot	0.041	Right Hand	0.037
Left Leg	0.089	Left Arm	0.052
Right Leg	0.089	Right Arm	0.052
Left Thigh	0.160	Left Shoulder	0.073
Right Thigh	0.165	Right Shoulder	0.073
Pelvis	0.182	Chest	0.144
Head	0.100	Back	0.133
Total	1.471		

Table 4. Experimental test conditions

Ambient temp. (ºC)	**Manikin skin temp. (ºC)**	**RH (%)**	**Air velocity (m/s)**	**Posture**	**Chair**
20.09 ±0.29	34	51.18	0.1	Seated on a chair	Mesh arm Chair

Three sari ensembles were tested and about four ways of draping are included. All together, we tested nine combinations of ensemble/drapes commonly observed in office buildings in both winter and summer. These are named EN1 to EN9 as listed in Table 2. We tested with a

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Danish adult female manikin in the climate chamber in September 2013 (Figure 2). The manikin's 16-segment body parts can be controlled and measured independently (Table 3).

The climate chamber measuring 5.5m x 5.5m x 2.5 m, with windows on the southern and western sides, at University of California Berkeley (Figure 2) is used. Fixed external shading devices shade its windows. A dedicated system controls the temperature of these windows. The levels of temperature, humidity, ventilation and lighting in the chamber can be controlled precisely. It has accuracies of 0.5 °C and 3% for temperature and humidity respectively. About eight floor grill diffusers control the temperature and ventilate the room air, while the air is exhausted through a ceiling return grill. The air temperature in the chamber was maintained at 20 ºC (Table 4). The data loggers (HOBO- U12-03) measured the wall temperature and ambient temperatures at 0.1 m, 0.6 m and 1.1 m heights and the relative humidity at the center of the chamber (Figure 2). The data logger has the measurement accuracy of ± 0.35 K at 0 ~ 50 °C range of temperatures and ±2.5% relative humidity (RH) at 10- 90% range of RH. The ambient temperature was also measured using a high precision mercury thermometer.

The skin temperature of the manikin was set to 34 ºC, following all the protocols of ASTM (ASTM-F1291-10 n.d.), and ISO (ISO:9920 2004) for testing. We seated the manikin in a mesh armchair and tested all the ensembles for a minimum of two hours or longer, until the manikin stabilized. When stable, we averaged the heat loss measurements over a 10 min period. The insulation level of the mesh chair was also measured. We subtracted the insulation of the chair and nude manikin from the total insulation obtained with a particular ensemble for all the body parts, thus eliminating the effect of the chair and nude insulations.

Results

Analysis of test data and evaluation of clothing insulation

Nude condition, and the one with cotton undergarments are also tested. We estimated the total insulation using the Eq. (1), given the manikin skin temperatures ($T_{s,i}$) and heat fluxes ($Q_{t,i}$).

$$\mathbf{I_{t,i} = (T_{s,i} - T_a) / (0.155 * Q_{t,i}) \qquad (1)}$$

Where, T_a is the ambient air temperature, I_{cl} = Clothing Insulation (clo)and 1 clo = 0.155 m^2 °C/W. The intrinsic insulation of the clothing itself was calculated by Eq. (2):

$$\mathbf{I_{cl,i} = I_{t,i} – I_a / f_{cl} = I_{t,i} – I_a/(1+0.3\ I_{cl,i}) \qquad (2)}$$

Architectural Science Review
http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

We found the thermal resistance of the nude body sitting on the mesh chair was measured as 0.78 clo. The insulation values for each of the sixteen body parts and the whole-body are tabulated in Table 5. Values for left and right extremities are averaged and combined. The winter ensembles tested had 1.11 – 1.39 clo as the whole-body clothing insulation, while the summer and monsoon ensembles tested ranged from 0.62 – 0.96 clo.

Table 5. Clothing insulation values of the ensembles tested (BP: Bra+panty, BSAC: Body surface area covered (%))

Clothing ensemble	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
Mesh Chair		0.03	0	0.05	0.14	0.01	0.03	0.01	0.03	0	0.02	0.11	0	0
BP	20	0.03	0	0.23	0	0	0	0.01	0.02	0	0.19	0.02	0	0
En1	81	0.96	0	1.9	1.23	1.58	1.07	0.56	0.4	0	2.01	0.75	0.98	0.33
En2	73	0.74	0	1.06	0.29	1.14	0.22	0.55	0.13	0	2.05	0.75	1.08	0.26
En3	65	0.65	0	1.5	0.45	0.73	0.17	0	0	0	1.8	1.91	1.12	0.41
En4	73	0.81	0	1.83	1.21	0.78	0.84	0	0.51	0	1.47	1.72	1.11	0.38
En5	81	1.11	0	2.71	1.94	1.75	1.29	0.84	0.69	0	1.99	1.92	1.09	0.38
En6	81	1.39	0	3.98	2.35	2.76	1.96	1.79	1.05	0	2.35	2.24	1.18	0.41
En7	65	0.62	0	1.32	0.51	0.85	0.25	0	0	0	1.58	1.62	0.95	0.25
En8	73	0.87	0	1.76	1.31	0.78	1.18	0	0.47	0	1.88	1.99	0.99	0.31
En9	81	0.94	0	1.58	1.35	1.15	1.08	0.57	0.49	0	1.83	1.84	0.97	0.27

Discussion

The body surface area covered (BSAC) by a garment relates to the clothing insulation value of an ensemble. In this study we noted that the BSAC varied from 65 % to 81%, while the whole-body insulation varied from 0.65 clo to 1.11 clo for summer ensemble (Table 5). The change in BSAC vis a vis the clothing insulation is obtained primarily by draping the sari around the upper body differently.

The results show that the sari is a versatile clothing ensemble with the possibility of a wide range of comfort conditions and clothing insulation, for the same pieces of garments used. Clothing insulation was increased by as much as 48 - 51 % just by changing the drape on the upper body alone using the same set of garments. For example, for En1 to En3 we used the same pieces of garments (Poly-cotton sari, cotton bodice and a cotton petticoat). By covering

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

the pallu around the torso/back and arms alone, we increased the BSAC from 65% to 81%. It meant that the clothing insulation increased from 0.65 to 0.96 clo (by 48%). Similar variation in clo value was noted between ensembles En7 – En9, by as much as 0.32 clo.

The summer and monsoon clothing insulation values matched closely with the clothing insulation of sari as reported by others (Mitsuzawa & Tanabe 2001; Havenith et al. 2014). Mitsuzawa and Tanabe reported the basic clothing insulation for cotton sari with cotton petticoat and bodice as 0.65 clo. Havenith et al. reported a basic clothing insulation of 0.74 clo for polyester sari with cotton bodice and cotton petticoat and 0.96 clo for the same ensemble worn along with an acetate shirt and a cotton towel worn as a head cover.

Table 6. Clothing insulation of the ensembles tested and as compared to Hanada et al. (1983)

Ensemble	**Weight* (g)**	**Clo Value measured**	**Clo (Hanada)**	**Havenith (clo)**
En1	1022.99	0.96	1.03	
En2	1022.99	0.74	1.03	
En3	1022.99	0.65	1.03	0.74+
En4	1022.99	0.81	1.03	
En5	1242.99	1.11	1.25	0.96++
En6	1242.99	1.39	1.25	
En7	807.99	0.62	0.81	
En8	807.99	0.87	0.81	
En9	807.99	0.94	0.81	

(*: includes the weight of the under garments) (+ a near equivalent drape without lower center pleats; ++ a near equivalent drape of the sari along with an acetate shirt and a cotton towel head cover)

Interestingly the summer clothing of the Middle Eastern women wearing summer *daraa* (a full-sleeved loose fitting long gown), *shiala* (fully covering long head scarf), bra, panty and sandals with a clothing insulation of 1.20 clo (Al-ajmi et al. 2008) was noted to be a near equivalent to the winter ensembles tested in this study. Lee et al. noted Western summer ensembles (e.g.: bra, panty, turtleneck blouse, skirt and socks with formal shoes) offering similar clothing insulation (0.65 clo) (Lee, Zhang & Arens 2013), to that of the light Indian

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

summer ensembles as found in this study. The Middle eastern ensembles offered higher clothing insulation, perhaps as the *daraa* covered the arms and legs fully while, the *shiala* covered the neck and head completely, leaving only the face exposed.

Field study evidence points to further possibility of change in the BSAC and thus the clo value of a sari ensemble. Indraganti (Indraganti, 2010), noted in a residential building study in India that the subjects have modified BSAC by raising the sari pleats up to the calves, while at heavy work in warm environments. This adaptability of the sari could have further reduced the clo value, for the same pieces of garments. However, due to logistic constraints we could not test the variations with the sari ensemble in the lower portion of the body.

Some other researchers found a linear relationship between the clothing insulation of an ensemble and its weight (Hanada, Mihira & Sato 1983) as,

$$\mathbf{I_{cl} = 0.00103\ W - 0.0253} \qquad \mathbf{(3)}$$

where, I_{cl} = Clothing Insulation (clo) and W = weight of the ensemble in grams (g).

While most of the clo values in this study matched closely with those from the above Eq., it overestimated the clothing value when the BSAC was low (Table 6). This observation renders support to the evidence that the sari is a versatile ensemble with a wide range of clothing insulation values within a given set of pieces of garments.

Conclusions

Unlike the western outfits, the sari was found to be a unique ensemble offering a range of clothing insulation depending on the drape, rather than a single value for a given set of garments of an ensemble. We noted the clothing insulation varying by about 48 - 51 % due to the changes in drape on the upper body alone.

It is important that the designers should consider a broader range of clothing among a building's female occupants. More pertinently, in multi-cultural environments coupled with adaptive behavior, questions on dress habits may be included in the thermal questionnaires and the options on various drapes in the clothing checklists during the thermal comfort surveys. Information on various drapes and materials could be built into the future version of the standard. The findings of this research are more than a correction of clo value of saris.

Acknowledgements

The manikin and climate chamber facilities of the Centre for the Built Environment, University of California Berkeley are made available through the Fulbright Grant and the support of HAE, R&D Center, LG Electronics, South Korea. Padma Indraganti of Los

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Angeles provided us the garments. The authors acknowledge all their financial and logistic support.

References

Al-ajmi, FF, Loveday, DL, Bedwell, KH & Havenith, G 2008, 'Thermal insulation and clothing area factors of typical Arabian Gulf clothing ensembles for males and females: Measurements using thermal manikins', *Applied Ergonomics*, pp. 39 (2008) 407–414.

ASHRAE 2010, 'ANSI/ ASHRAE Standard 55-2010, Thermal environmental conditions for human occupancy', Standard, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta.

ASTM-F1291-10, 'Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin', ASTM International.

BIS 2005, *National Building Code 2005*, Bureau of Indian Standards.

Boulanger, C 1997, *Saris: An Illustrated Guide to the Indian Art of Draping*, Chantal Boulanger Publishing, 78 Hammersmith Bridge Road, London W6 9DB Great Britan.

Gagge, F, Fobelets, A & Berglund, L 1986, 'A standard predictive index of human response to the thermal environment', *ASHRAE Transactions*, vol 86, no. 2, pp. 709-731.

Hanada, K, Mihira, K & Sato, Y 1983, 'Studies on the thermal resistance of men's underwear', *Journal of Japan Research Association for Textile End-Users*, vol 24, no. 8, pp. 363-9, [in Japanese with English summary].

Havenith, G, Hodder, S, Ouzzahra, Y, Loveday, D, Kuklane, K, Lundgren, K, Fan, J & Au, Y 2014, 'Extension of the Clothing Insulation Database for Standard 55 and ISO 7730 to provide data for Non-Western Clothing Ensembles, including data on the effect of posture and air movement on that insulation.', American Society of Heating Refrigerating and Air Conditioning Engineers, Inc., Universities of Loughborough, Lund, Cornell and Hong Kong.

Havenith, G, Holmer, I & Parsons, K 2002, 'Personal factors in thermal comfort assessment:clothing properties and metabolic heat production', *Energy and Buildings*, vol 34, pp. 581 - 591.

Huizenga, C, Zhang, H & Arens, E 2001, 'A Model of human physiology and comfort for assessing complex thermal environments', *Building and Environment*, vol 36, pp. 691 - 699.

Indraganti, M 2010, 'Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India', *Applied Energy*, vol 87, no. 3, pp. 866-883.

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d

Indraganti, M, Ooka, R, Rijal, HB & Brager, GS 2014, 'Adaptive model of thermal comfort for offices in hot and humid climates of India ', *Building and Environment*, vol 74, pp. 39-53.
ISO:9920 2004, 'Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble', International Standards Organization.
Lee, J, Zhang, H & Arens, E 2013, 'Typical clothing ensemble insulation levels for 16 body parts ', *CLIMA 2013 and 11th REHVA World Congress and the 8th Int Conf on IAQVEC, June 16 – 19*, Prague, Czech Republic.
McCullough, EA & Jones, BW 1983, 'Measuring and estimating the clothing area factor', Technical report: 83-02, Institute for Environmental Research, Kansas State University, Manhattan KS.
Mitsuzawa, S & Tanabe, S 2001, 'Effect of air movement on thermal comfort under hot and humid conditions while wearing traditional clothing', *Proceedings of Moving Thermal Comfort standards into the 21st Century*, Windsor.
Zhang, H, Arens, E, Huizenga, C & Han, T 2010, 'Thermal sensation and comfort models for non-uniform and transient environments, part III: Whole-body sensation and comfort', *Building and Environment*, vol 45, no. 2, pp. 399-410.

http://dx.doi.org/10.1080/00038628.2014.976540
www.escholarship.org/uc/item/8f10n38d