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Publication Date

2014-04-01

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Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world*** Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Versatile Indian sari: Clothing insulation with different drapes of typical sari ensembles

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Abstract

The sari is everyday attire for most women throughout the year all across South-Asia. It is a versatile ensemble because, a single set of garments can provide different levels of insulation just by changing the drape.

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 modelling 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.

Keywords: India; Sari; Clothing Insulation; Thermal Comfort standards; Thermal Manikin

1 Introduction

1.1 The sari

Derived from its Sanskrit origin 'śāṭī', the word 'sari' means a strip of cloth. Historic literature points towards the use of this garment even during the Indus Valley civilization in circa 3000 BC. India has a very long and rich textile tradition. The saris vary in style, material and embellishment across the regions and cultures (Fig. 1). Unlike the western outfits, only women wear the saris.

1.2 Review of literature

Clothing is one of the six primary variables that affect human thermal comfort in any environment. Evaluation of human thermal comfort using simulation models requires information on the clothing insulation of the occupants. The sari is an important ensemble worn regularly by most women in South Asia and in some other parts of the world (Fig. 1).

A recent large-scale yearlong field study in 28 Indian offices has shown that 99% of Indian women are dressed in Indian ensembles (Indraganti, et al., 2013; Indraganti, et al., 2014) (Fig. 2). However, knowledge on the sari's clothing insulation is very limited in the current codes (ASHRAE, 2010; BIS, 2005; ISO:9920, 2004). ASHRAE standards carry the clo values of many western-style ensembles only. 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 the Indian sari.

The recent experiments conducted by Havenith et al. focus on non-western clothing, including two sari ensembles. They provide data on the two ensembles tested (Havenith, et al., 2014). A study in Japan also reported the clo value of the sari (Mitsuzawa & Tanabe, 2001). Havenith et al., (Havenith, et al., 2002) noted looser fit of the Middle Eastern clothing promoting air movement around the body, affecting the thermal comfort. These studies do not focus much on the sari as an ensemble with its various drapes, as are worn by most women in Indian offices and homes.

Figure 1. Indian workingwomen in sari ensembles draped in 'nivi' style with pleats in the lower center front (Left to right: Alternate women displaying pleated and un-pleated pallus, with the drape changing the body surface area exposed).

Figure 2. Typical office women employees dressed in the sari ensemble draped in 'nivi' style with pleated and un-pleated pallu as found in a field study in summer and monsoon seasons in India.

A unique feature of sari is that it changes the insulation level significantly just by adjusting the drapes, and there are many ways to drape the upper body and lower body. The drape of the ensemble depends on several factors including, weather, occasion, and activity of the person and it alters the microclimate around various body parts (Fig.1, 2). Indraganti (Indraganti, 2010) observed the subjects in a field study adjusting their saris in several ways to accommodate the changing thermal regimes and metabolic activities, there by adjusting the clothing insulation. It may be worthwhile to know about the dress habits observed in the same space, as it may affect the design decisions.

The summation relationships for the pieces of an ensemble observed for western clothing may not be applicable for the Indian sari, as the material, fit, body coverage and drape and design are very different.

Moreover, the design of appropriate indoor environmental control systems mandates the knowledge and accurate estimation of clothing insulation of the building users. These design decisions in turn influence not only the thermal acceptability of the users but also the energy consumption on the whole.

Therefore, it is essential to obtain clothing insulation of the sari as an ensemble in a systematic manner. This information would also add value to the indoor environmental design of buildings, aircrafts, passenger railway coaches, and automobiles in addition.

Clothing insulation research in the past provided data only for the body as a whole (McCullough & Jones, 1983; Havenith, et al., 2002; ISO:9920, 2004). Human physiology and thermal comfort models treated the human body surface as one segment earlier (Gagge, et al., 1986).

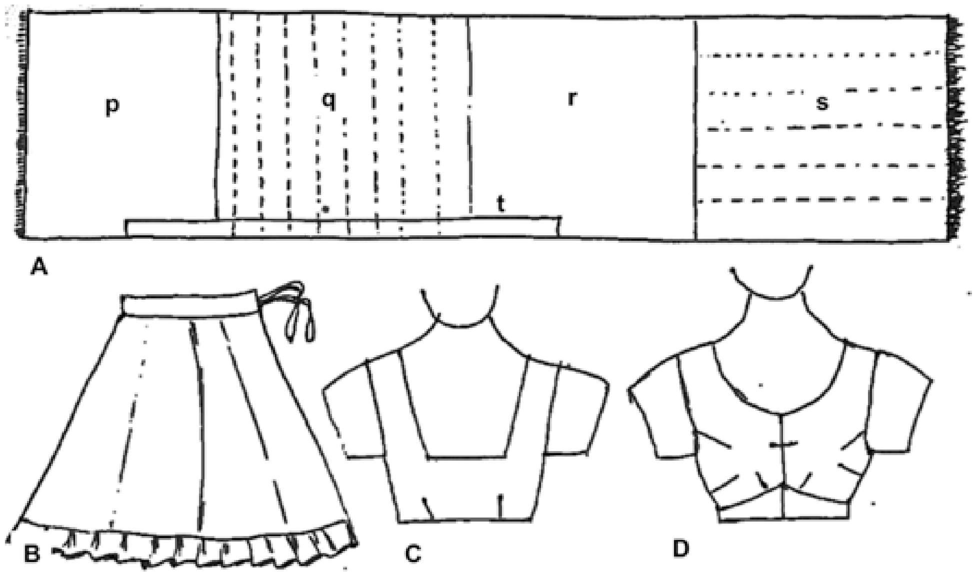


Figure 3. Parts of the ensemble 'sari.' A: Sari, B: Petticoat, C and D: Back and front sides of a bodice, p: inner layer of the sari, q: lower center-front pleats, r: front and rear cover, s: pleats of the pallu on the upper body, t: underlining.

However, some human physiology and comfort models divide the human body into multiple body parts (such as head, hand, chest etc., (Huizenga, et al., 2001; Zhang, et al., 2010) in order to accurately simulate skin and core temperatures and thermal comfort.

Most of these parts are normally covered with clothing insulation, which needs to be quantified in the simulation. Unfortunately, existing clothing insulation databases only characterize the clothing insulation for the whole body, and not for individual body parts. That means, every body part has the same clothing insulation level, even over the head and the hands.

With these aspects in mind, we conducted a climate chamber study on a sixteen-body segment female thermal manikin, draped in three different ensembles of saris (two saris and four drapes). The present paper presents the insulation values for each body part, as well as for the whole body for these ensembles.

2 Methods

2.1 The material

The sari in its modern day *avatar* is a single rectangular piece of unstitched cloth: 1.15 – 1.25 m wide and 5 to 8.1 m (5.5 yards to 9 yards) long (Fig.3 A). The more ornate, freely hanging end of the sari is called as 'pallu,' (Fig 3: s, Fig. 4 G)

Figure 4. Indian sari ensemble draped in 'nivi' style on a human subject and the manikin with (A –C) pleated pallu and (D, E) un-pleated pallu. A: Front view; B: Rear view; C: Seated manikin; D: Un-pleated pallu covering one shoulder; E: Un-pleated pallu covering both the shoulders; G: Pallu; H: Pleats of the pallu on the upper body; J: Lower center front pleats

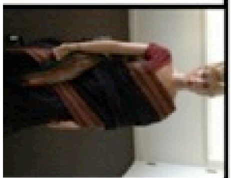
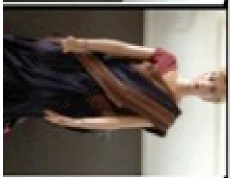
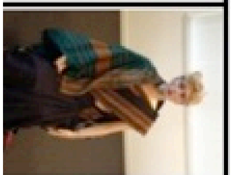
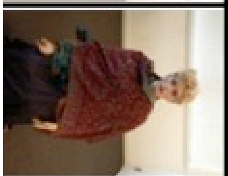
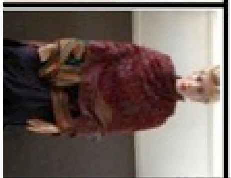
The draping style of sari varies with geographical area and the activity of the female, while there are more than a hundred known styles of draping. Sometimes the 'pallu' is used to cover one or both the upper arms and back (Fig. 4: D, E). Alternately, it can be pleated and pinned to the bodice on either of the shoulders (Fig. 4: A-C)

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

For this study we used the most popular 'nivi' style of draping along with its four sub-variations using two 5.75 m long saris. We draped the female manikin 'Monica' in two different saris. These are (1) a heavy weight poly-cotton handloom sari, and (2) a lightweight pure silk sari made in the Indian States of Karnataka and Tamilnadu respectively. In addition, we have also used an acrylic shawl from Uttar Pradesh. The weights and material composition of these garments are listed in Table. 1. The descriptions of sari and ways of draping are described in Table 2.

Table 2. Description of the ensembles tested.

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

2.2 Draping of a sari

Figure 5 shows the stepwise procedure of wearing a sari. In its modern style, the sari is draped in two layers from right to the left over a petticoat and a short tight fitting bodice. Five to eight flat pleats (each about 0.1 m wide) are clustered at the navel/ centre-front using fingers, on the outer layer. These are inserted into the first layer of the sari, which is being tightly held by the petticoat. Sometimes safety pins are used to hold the pleats in position (Fig. 4).

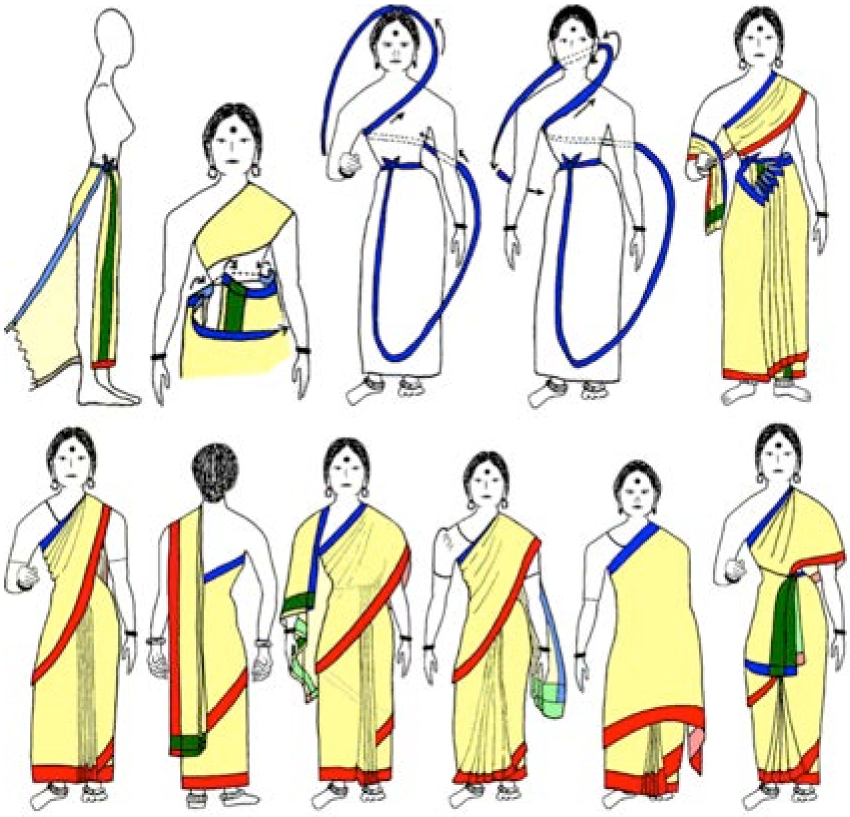


Figure 5. The steps of sari draping in 'nivi' style (Boulanger, 1997)

The pleats offer fullness at the ankle, and improve the wearer's mobility. Their number depends on the waist size of the wearer, desired length of the pallu and eventually the length of the sari. A long strip of cotton or polyester underlining (0.1 x 2.4 m) is often hemmed at the bottom selvage line of the sari (Fig. 3: t), where the pleats are formed, to add to the drape/ fall and fullness the garment.

2.3 The petticoat

A petticoat (Fig. 3B) is a stitched loose fitting conical shaped drawstring full skirt, usually in cotton/ polyester/ satin, worn around the waist. Most women wear a petticoat under a sari, although the sari can be draped without one. It adds fullness to the ensemble, and prevents the exposure of the silhouette of the legs, if the sari is thin/ transparent, while improving the walking and working convenience of the wearer. Some petticoats worn under saris made of sheer fabrics are heavily embellished at the hemline. We used a simple cotton petticoat without pleats at the bottom in this test.

2.4 The bodice or blouse

The bodice, or 'blouse' as it is called in India, is a body-hugging stitched single piece of garment (Fig. 3 C, D) covering the upper body, up to a few inches above the navel. The bodice's material, sleeve length and the size of the neck are matters of choice, season and style. It can be very highly embellished at the back/ front and on the sleeves. Some women wear bodices up to the navel and with full sleeves for cultural and religious reasons. We used two deep and wide necked bodices with sleeves up to the middle of the upper arm in this study.

2.5 The shawl

A shawl is a rectangular piece of unstitched cloth usually two to two and half meters long. Both men and women usually drape shawls over the dress/ sari in winters. Men's shawls are slightly bigger in size. Shawls are made of a wide variety of materials ranging from pure wool, acrylic, polyester, chiffon, cotton and silk. The choice of the material depends mainly on the season, style and wearers' taste. In this study we used a medium-sized acrylic women's shawl (2.05 m x 0.72 m), usually used in winters. The ensembles EN5 and EN6 as shown in Table 2 feature the shawl used in this test.

2.6 The ensembles tested

The manikin was draped in 'nivi' style. Three sari ensembles were tested and about four ways of drapes 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 and are listed in Table 2.

2.7 The experimental setup

Figure 6. (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

Table 3. 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

We conducted the tests in 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 (Fig. 6). Its windows are shaded by fixed external shading devices. 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. Table 3 features the experimental conditions.

The air temperature in the chamber was maintained at 20 ºC. 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 (Fig.7). 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.

We tested with a Danish adult female manikin in the climate chamber in September 2013 (Fig. 6). The manikin’s 16-segment body parts can be controlled and measured independently (Fig.7). Its body parts and their surface areas are listed in Table 4.

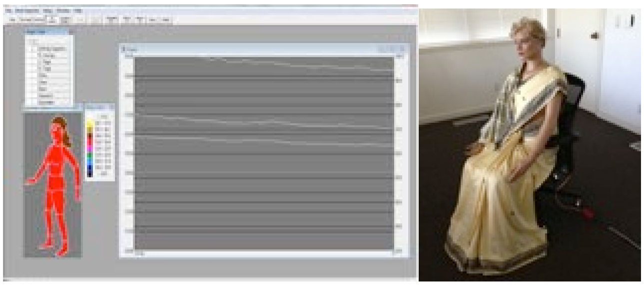


Figure 7. The manikin control screen (left), climate chamber and thermal manikin ‘Monica,’ in a sari

Table 4. Body segments and respective areas of the manikin

SNo.	**Name of Part**	**Area (m^2)**
1	Left Foot	0.043
2	Right Foot	0.041
3	Left Leg	0.089
4	Right Leg	0.089
5	Left Thigh	0.160
6	Right Thigh	0.165
7	Pelvis	0.182
8	Head	0.100
9	Left Hand	0.038
10	Right Hand	0.037
11	Left Arm	0.052
12	Right Arm	0.052
13	Left Shoulder	0.073
14	Right Shoulder	0.073
15	Chest	0.144
16	Back	0.133
Total		1.471

We set the skin temperature of the manikin to 34 ºC, and followed the protocols of ASTM (ASTM-F1291-10, n.d.), and ISO (ISO:9920, 2004) for testing with the manikin. The ISO uses individual pieces of garments for testing and the clothing insulation of the ensemble is obtained through the summation of individual pieces of the ensemble. However, we tested the sari as a whole ensemble, as the individual pieces of garments are seldom used separately (Fig. 7).

We seated the manikin in a mesh armchair and tested all the ensembles for a minimum of two hours or longer, until the manikin is stabilized. When stable, the heat loss measurements were averaged 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 the a particular ensemble for all the body parts, thus eliminating the effect of the chair and nude insulations.

3 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 ($Q_{t,i}$).

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

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

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

The thermal resistance of the nude body sitting on the mesh chair was measured as 0.78 clo during this experiment.

The insulation values for each of 16 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

4 Discussion and comparison with others' results

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. This changed the exposed body surface area of the manikin.

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 35% 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 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. 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 Mitsuzawa and Tanabe and Havenith et al. (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.

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, et al., 2013), to that of the light Indian 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.

Table 6. Clothing insulation values 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, used by factory workers)

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, et al., 1983) as,

$$I_{cl} = 0.00103\ W - 0.0253 \qquad [3]$$

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

We compared our results with those obtained through the above relationship and noticed interesting observations. While most of our clothing insulation values obtained through the laboratory study matched closely with Hanada et al., 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.

5 Conclusions

We measured and calculated the clothing insulation for the sixteen body parts for nine typical ensembles using two saris draped in the most common 'nivi' style. The values are useful for multi-segmented models of thermo-physiology and comfort. Unlike the western outfits, the sari was found to be a unique ensemble offering a range of clothing insulation, rather than a single value for a given set of garments of the ensemble depending on the drape. We noted the clothing insulation varying by about 35% due to the changes in drape on the upper body alone.

The winter ensembles had a clothing insulation of 1.11 – 1.39 clo, while the summer and monsoon ensembles provided 0.62 – 0.96 clo as clothing insulation. These values obtained using standard protocols of ISO: 9920 can be used in the design of indoor environments in the sub-continent and advanced comfort models which need clothing insulation at segmentation level.

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 behaviour, 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

For the manikin testing and analysis, we used the climate chamber facilities at the Centre for the Built Environment, University of California Berkeley. The test facility is made available through the Fulbright Grant and the support of HAE, R&D Center, LG Electronics, South Korea. Padma Indraganti of Los Angeles, USA provided us the garments. The authors appreciate their financial and logistic support.

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