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Authors

Indraganti, Madhavi

Lee, Juyoun

Zhang, Hui

et al.

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Why is the Indian Sari an all-weather gear? Clothing insulation of Sari, Salwar-Kurti, Pancha, Lungi, and Dhoti

Madhavi Indraganti¹, Juyoun Lee², Hui Zhang^{3,4} and Edward A. Arens^{3,5}

¹Department of Architecture & Urban Planning, Qatar University, Doha, Qatar
(Communicating author)

Madhavi.indraganti@fulbrightmail.org

²HAE R&D Center, LG Electronics, South Korea,

juyoun.comfort@gmail.com

³Center for the Built Environment (CBE), University of California, Berkeley, CA

⁴zhanghui@berkeley.edu, ⁵earens@berkeley.edu

Abstract

Barring a few reports on the clothing insulation of sari and salwar-Kurti, little is known about the other traditional ensembles men use in South Asia and beyond. To accurately account for the thermal insulation on the human body, simulation studies necessitate insulation on various body parts. This study reports the segmental level insulation of 52 traditional ensembles of both genders recorded in a climate chamber.

Indian garments are worn as ensembles. We focused on the drape, as traditional ensembles offer great opportunities for thermal adaptation through changing drape. We researched on 41 sari ensembles, four salwar-kurti and seven men's' ensembles, such as *dhoti*, *pancha* and *lungi*. More than the material, drape has a significant effect on the clothing insulation. For the same pieces of garments, the clo value of the ensemble varied by as much as 3.1 to 32 %, through changing drape in saris, the lower values being associated with lighter saris. A similar trend but somewhat lower variation was noticed in men's' ensembles. This makes the sari an all weather ensemble. Interestingly in the *pancha* ensemble, men can achieve 47% reduction in the clo value with minor variations. The adaptation possibility in traditional ensembles is enormous.

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

1 Introduction

Sari is a single piece of unstitched strip of cloth. Only women wear saris mostly in South Asia and in other places across the globe. It is used since millennia, circa 3000 BC. Indian women mostly used traditional ensembles at work ([CITATION Mad14 \l 1033]). Unlike western wear the sari is worn as an ensemble and not as different pieces of garments assembled together.

HVAC system design necessitates the insulation offered by many varieties of clothing to estimate the thermal comfort of occupants in buildings. Data on Indian traditional ensembles is not fully represented in the present building standards [CITATION ANS \l 1033 \m Placeholder2 \m ISO]. More over detailed comfort analysis requires segmental level information on clothing insulation to understand local discomfort of occupants[CITATION Cha01 \l 1033 \m Zha10 \m Zha10]. Being a 'one-size-fits -all' ensemble, it lends itself to a high degree of customisation and acclimatization at wearer's

level. However, the present codes and published information on sari and similar ensembles do not address the importance of drapes on clothing insulation [CITATION Mit01 \l 1033 \m FFA08].

We have reported earlier on the versatility of the sari in climate adaptation using different drapes. [CITATION Mad151 \l 1033]. This report presented nine ensembles used in summer and winter/ monsoon seasons. Extending this work, we report the segmental level and whole body insulation of 41 different sari ensembles in this paper. In addition, we also present these values for eleven different traditional ensembles for both the genders. These are women's Salwar-Kurti, and men's Lungi and Pancha used by men.

2 Methods

2.1 The sari ensemble

The sari ensemble has three pieces of garments essentially: a sari, a short blouse or bodice and a petticoat. Sari measures 5.0 – 8.1 m in length and 1.15 to 1.25 m in width. The length usually depends on the draping style. The most common type of sari measures 5.0 - 6.0 m, width being the same, used in this study. A strip of underlining (2 -2.5 m long and 75 – 100 mm wide) is usually attached at the bottom boarder of the sari to improve the drape and durability of the sari.

India has rich and varied textile tradition and saris can be found in very diverse fabrics, designs and embellishments. In this study we used saris in silk, silk chiffon, handloom and milled cotton and polyester and nylon fabrics, common to the normal sari stock.

A bodice or blouse as is referred to in India is a stitched tight fitting garment few inches above the navel. It is usually made in fine cotton or in the same fabric as that of the sari. Some bodices have cotton underlining. The necklines and shoulder lengths are a matter of fashion and user's choice. In this study we tested the blouses with deep and medium depth necklines and short and medium shoulder lengths. The blouse fabrics are cotton, silk, polyester in this study, with the non-cotton blouses being provided with thin cotton interlining.

A petticoat is a conical shaped, drawstring ankle length skirt worn under the sari. Stitched in cotton, polyester or satin, it holds the sari in place, provides fullness and mobility to the wearer. We used cotton, polyester and satin petticoats in this study. Indraganti et al. [CITATION Mad151 \n \t \l 1033] described the articles used in the typical sari ensemble in greater detail.

2.2 The sari drape

The sari can be draped in over a hundred different ways, the most common one being the 'nivi' style of draping. In this study we used the *nivi* style of draping for all the ensembles. This essentially has the sari wrapped around the petticoat in two layers. The second layer has frills or folds at the centre front, which gives the attire fullness. The second layer also covers the belly and the chest in a diagonal manner, the other end of which is the *pullu*. A detailed pictorial description of draping of sari can be found in Boulanger [CITATION Bou97 \n \t \l 1033].

2.3 The Salwar- Kurti

The salwar is a loose fitting baggy style trouser that tightens at the ankles. Historical evidence points to its use since Mauryan Period (322–185 BCE)[CITATION Vis93 \l 1033]. A stitched garment, it is worn generally as part of a three-piece ensemble, which consists of

salwar, *kameez*, *kurta* or *kurti* (stitched top) and *dupatta* (thin shawl). It is traditionally worn in northern parts of India and all over Pakistan and in some parts of Afghanistan. For the last few decades a majority of women across India have been using *salwar-Kurta/ Kurtis* as their everyday attire.

A *kurti* is a loose fitting short top up to hip length or slightly below worn traditionally along with the *salwar*. The shoulder length varies and some women also wear it with the trousers. A *dupatta* is a rectangular piece of cloth (2.25 - 2.5m in length and 0.9 - 1.14 m in width). In this test we used a fine cotton full-sleeved *kurti* along with a cotton loose fitting *salwar* and a cotton *dupatta*.

2.4 The Dhoti

Bas-reliefs dating back to 1st century AD point to the use of Dhotis by men [CITATION Bis \l 1033]. Traditionally worn predominantly in South Asia, the dhoti is a single piece of rectangular unstitched fabric, synonymous to the women's sari [CITATION Gov95 \l 1033]. It measures around 4 m x 1.5 m. Similar to Sari, it is knotted around the waist and is wrapped around the waist and legs. There is a major difference between a sari and a dhoti. The former covers both the upper and lower bodies and worn over a petticoat, while the latter covers only the lower body and is worn on the naked body directly.



Figure 1 Front, rear and side view of a dhoti ensemble on a human subject

A dhoti is usually passed through legs, tucked at the back and covers the legs loosely, and then it flows into long pleats at front of the legs. Historically its draping method hasn't changed much over time. Dhotis nowadays are usually in white, beige or light colours in plain handloom cotton, silk, or poly-cotton fabrics with or without gold thread borders in contrasting colours. Men wear either full-sleeved or half-sleeved *kurtis* along with the dhotis to cover the upper body. This is the traditional outdoor and indoor attire for several men in

rural and sub-urban parts of India and home-wear garment in cities as well. In this test we studied a dhoti as the nether garment with a half sleeved handloom cotton men's kurti.

2.5 The Lungi

Similar to the sari and dhoti, the Lungi or sarong is a single piece unstitched piece of cloth draped around the waist as a nether garment. It is a traditional garment worn in South Asian regions and beyond, stretching as far as Southeast Asia, Northern Arabian Peninsula and Somali Peninsula. It is everyday attire for men especially in warmer parts of Asia where the climate is unsuitable for western trousers. In some areas the shorter ends or the fabric are sewn together to form a tube like structure. A lungi usually measures 2 m x 1.15 m. Most common fabrics are handloom cotton, silk, and poly-cotton. In certain socio-political sections of the society, men in South India wear lungis as their everyday formal attire. On the other hand, in modern offices men in India usually wear western trousers and shirts [CITATION Mad \t \l 1033]. In some parts of Kerala, India even women use lungis as a nether garment.

The lungi is tied around the waist forming a double layer in the front in a double twist knot. This layering provides fullness to the wearer. It is worn over the naked body, unlike the sari. The draping style and length of body coverage are region and activity/ occasion specific. We tested a handloom cotton lungi with a cotton kurti in two ensembles of two different drapes.

2.5 The Pancha

In some parts of India, a very fine cotton dhoti (4m X 1.50 m) is folded into two layers and is draped as a lungi. This type of ensembles is traditionally referred to as 'pancha.' In this experiment we tested four ensembles with a Pancha and two of these with Kurti. In two of the drapes we folded the pancha up to a few inches above the knees, as is usually done by men at work or in summer. All the garments tested along with their weights are listed in Table 1.

Table 1. Weights, dimensions and the material characteristics of the garments tested

SNo	Code	Clothing	Weight (g)	Length (mm)	Width (mm)	Material
1	UG01	Bra	40			Shell: 100% Cotton: Trims: 100% Elastin
2	UG02	Panty	34.99			100% Cotton
3	UG03	Vest	50			100% Cotton
4	SA01	White and Indigo Sari	180	5817	1168	100% Polyester (without the fall attached)
5	SA02	Light Printed Kashmiri Sari	220	5131	1092	Sari: 100% Silk, Sari boarder underlining: 100% nylon
6	SA03	Orange Chanderi Sari	230	5400	1200	Sari: 100% Silk, Boarder: 50% silk, 25% copper -polyester blended wire, 25%: polyester; Sari boarder underlining: 100% cotton
7	SA04	Blue green Khadi Sari	240	5500	1150	Sari 100% Silk, Sari boarder underlining: 100% cotton
8	SA05	Kota supernet Sari	300	5258	1130	50% Rajasthani Cotton, 50% silk; Sari boarder underlining: 100% cotton
9	SA06	Brown printed voile Sari	300	5283	1054	100 % Cotton
10	SA07	Guntur Jari Sari	330	5029	1092	Sari: 100% Hand loom cotton; Sari

						boarder: 75% copper -polyester blended wire
11	SA08	White embroidered Sari	430	5800	1200	Sari: 100 % Silk Chiffon, Embroidery: 100% rayon and plastic crystals
12	SA10	Pochampalli blue Sari	460	5359	1130	Sari: 100% Mercirised cotton, Boarder underlining: 100% Polyester
13	SA11	Mauve KSIC Crepe Sari	490	5410	1168	Sari: 100% silk, Boarder: 50% silk, 50% gold-silver -polyester blended wire; Boarder underlining: 100% polyester
14	SA12	Red embellished Sari	500	5258	1092	Sari: 100% Polyester; Sari boarder under lining:100% cotton; Embellishment: 100% White-metal foil and plastic beads
15	SA13	Ochere Kanchi Sari	500	4851	1168	Sari: 100% Kanchi Silk; Boarder: 70% silk, 25% gold-silver -polyester blended yarn; Sari boarder underlining: 100% Polyester
16	SA15	Benaras Yellow Golden Sari	800	5588	1118	Sari: 100 % Silk satin; underlining on boarder and pallu: 100% polyester
17	DH01	Dhoti	310	3277	1295	100% hand loom Cotton
18	DH02	Pancha	240	3353	1270	100% hand loom Cotton
19	LU01	Lungi	210	1930	1168	100% hand loom Cotton
20	B1	Blue bodice	20			100% Polyester
21	B2	Orange Rubia bodice	40			100% Cotton
22	B3	Orange Pochampalli bodice	55			100% hand loom Cotton
23	B4	Cream Yellow Gurjari bodice	60			100% hand loom Cotton
24	B5	Mauve bodice	78			100% Cotton
25	B6	Yellow bodice	78			Shell: 100% Silk, Lining: 100% cotton
26	B7	Banaras Satin blouse	98			Shell: 100% Satin silk: Underlining: 100% cotton
27	P1	Orange Petticoat	120			100% hand loom Cotton
28	P2	White Petticoat	196			100% Polyester satin
29	P3	Green petticoat	200			100% Cotton
30	P4	Pink Petticoat	205			100% Cotton
31	SK01	White patiyala Salwar	155			100% Cotton
32	K2	Black short kurti	120			100% Cotton
33	K3	Khadi Pink Kurti	140			100% Khadi (hand spun) Cotton
34	C1	White Dupatta	160	2250	1120	Dupatta: 100% cotton,

embellishment: glass beads

2.6 The experimental setup

Table 2. Experimental test conditions

Ambient temp. (°C)	Manikin skin temp. (°C)	RH (%)	Air velocity (m/s)	Posture	Chair
20.09 ±0.29	34	51.1 8	0.1	Seated on a chair	Mesh arm Chair

Table 2 shows the environmental conditions of the climate chamber used for the experiment. We used the 5.5m x 5.5m x 2.5 m climate chamber facility at the University of California, Berkeley for this testing. It has windows on the southern and western sides, which are shaded by fixed external shading devices.

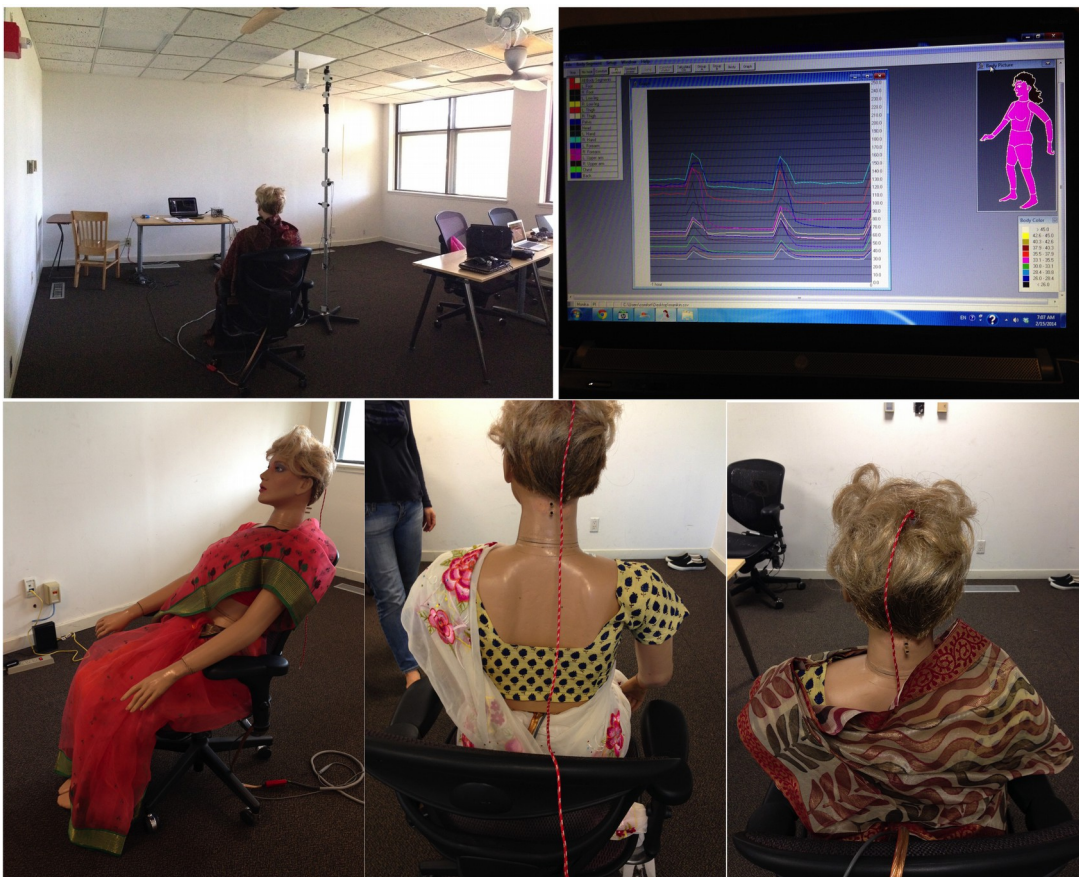


Figure 2 The experimental setup, manikin control, and the sample features of some of the drapes tested

A separate system controlled the temperature of the exterior openings. The chamber has eight floor grill diffusers to precisely control the temperature, humidity, and ventilate the space while the air is exhausted through a ceiling return grill. Even the lighting can be controlled. It has accuracies of 0.5 °C and 3% for temperature and humidity respectively. Table 2 features the experimental conditions. We set the air temperature to be at 20 °C. 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. 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 (Fig 2).

We used the same 16 segments Dansih female manikin in this experiment also, that was conducted during February 2014. It has temperature control to maneuverer different body segments. Its surface areas of various body segments are shown in Table 3.

Table 3. Body segments and their 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

The skin temperature setting of the manikin was 34 °C following the protocols of ASTM [CITATION AST \ 1033], and ISO [CITATION ISO \ 1033] 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, dhoti, lungi, pancha and chudidar as a whole ensemble, as the individual pieces of garments are seldom used separately (Fig. 2).

With a manikin draped in the designated ensemble seated on a mesh chair, we had run the experiment for nearly two hours till its heat exchange with the chamber got stabilized. When stable, we noted down the last 10 minute readings and averaged them. The insulation of the mesh chair and the nude body manikin were also estimated separately. We then 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. The experiment was repeated for all the ensembles one after the other.

3 Data analysis

Given the manikin skin temperatures ($T_{s,i}$) and heat fluxes ($Q_{t,i}$), we calculated the total insulation using the Eq (1),




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

Where, T_a is the ambient air temperature, I_{cl} = Clothing Insulation (clo) and,

1 clo = 0.155 m² °C/W. The intrinsic insulation of the clothing itself was calculated by Equation (2):










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

Table 4. Clothing Insulation of mesh chair, nude and with undergarments for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
1		Mesh Chair		0.02	0.00	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.03	0.02	0.00
2		Nude		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3		Panty		0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.05	0.00	0.05	0.03	0.00
4		Panty Bra	20	0.05	0.00	0.22	0.00	0.00	0.00	0.00	0.18	0.03	0.03	0.08	0.05	0.00

The nude body recorded a thermal resistance of 0.78 clo in this experiment (Table 4). We measured the insulation values of the 41 sari ensembles as shown in Table 5. In addition we tested four salwar-kurti ensembles for women, four Pancha ensembles, two lungi ensembles and one Dhoti ensemble for men (Table 6). These show the description of an ensemble along with the body surface area covered (BSAC) and insulation values. The insulation values for the right and left extremities are averaged and combined.

Table 5. Clothing Insulation of saris for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
1		E 201 (SA01, B1, P3) Polyester Georgette, both arms uncovered	65	0.76	0.28	1.57	0.71	0.65	0.21	0.04	0.03	0.03	1.79	2.01	0.80	0.20
2		E202, (SA01,B1,P3) Polyester Georgette, Right arm covered, pleated pallu	73	0.82	0.27	2.04	0.99	0.52	0.55	0.03	0.19	0.04	1.78	2.32	0.85	0.12
3		E203 (SA02,B4,P1) Light Printed Kashmir, both arms uncovered	65	0.77	0.36	1.51	0.48	0.83	0.24	0.01	0.04	0.04	2.33	2.45	0.84	0.16
4		E204 (SA02, B4, P1) Light Printed Kashmir, Right arm covered, pleated pallu	73	0.88	0.30	2.41	1.06	0.87	1.06	0.01	0.37	0.02	2.24	2.35	0.85	0.16
5		E205 (SA03, B2,P1) Orange Chanderi silk, both arms uncovered	65	0.71	0.28	1.44	0.83	0.51	0.18	0.02	0.01	0.06	1.75	1.53	0.65	0.06
6		E206 (SA03, B2, P1) Orange Chanderi silk, Sari Right arm covered, pleated pallu	73	0.77	0.16	2.06	0.84	0.42	0.66	0.03	0.19	0.06	1.86	1.59	0.55	0.18
7		E207 (SA04, B4, P1) Light Khadi Silk, both arms uncovered	65	0.78	0.29	1.37	0.89	0.79	0.30	0.08	0.03	0.02	2.12	1.87	0.64	0.22
8		E208 (SA04, B4, P1) Light Khadi Silk, Left arm covered unpleated pallu	73	0.83	0.25	1.25	0.77	0.93	0.17	0.64	0.03	0.07	2.69	2.38	0.71	0.23
9		E209 (SA04, B4, P1) Light Khadi Silk, Right arm covered, Pleated pallu	73	0.86	0.23	2.15	1.27	0.40	1.18	0.06	0.49	0.01	2.19	1.94	0.63	0.24











10		E210 (SA04, B4, P1) Light Khadi Silk, both arms covered	81	0.92	0.13	1.86	1.35	0.82	0.96	0.48	0.52	0.07	2.39	2.10	0.67	0.23
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Table 5. (Contd) Clothing Insulation of saris for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
11		E211S (A05, B4, P4) Kota Supernet, both arms uncovered	65	0.75	0.31	1.52	0.65	0.70	0.30	0.05	0.06	0.02	1.78	2.30	0.66	0.11
12		E212 (SA05, B4, P4) Kota Supernet, Right arm covered, pleated pallu	73	0.79	0.29	1.87	0.96	0.60	0.74	0.04	0.16	0.11	1.87	2.08	0.64	0.13
13		E213(SA06, B4, P4) Printed Cotton Voile, both arms uncovered	65	0.77	0.33	1.71	0.59	0.71	0.31	0.01	0.09	0.11	1.87	1.74	0.74	0.16
14		E214 (SA06, B4, P4) Printed Cotton Voile, Left arm covered unpleated pallu	73	0.78	0.29	1.24	0.44	0.77	0.34	0.43	0.06	0.11	2.08	1.81	0.77	0.07
15		E215 (SA06, B4, P4) Printed Cotton Voile, Right arm covered, pleated pallu	73	0.79	0.19	2.05	0.64	0.57	0.73	0.00	0.09	0.12	1.82	1.66	0.73	0.15
16		E216 (SA07, B4, P1) Handloom Guntur Zari both arms uncovered	65	0.74	0.33	1.54	0.41	0.65	0.22	0.03	0.05	0.05	1.53	2.27	0.79	0.19
17		E217 (SA07, B4, P1) Handloom Guntur Zari, Right arm covered, pleated pallu	73	0.85	0.33	2.15	1.00	0.63	0.98	0.02	0.37	0.06	1.58	2.26	0.81	0.19
18		E218 (SA07, B4, P1) Handloom Guntur Zari, both arms covered	81	0.91	0.31	1.85	1.25	1.17	0.96	0.43	0.32	0.07	1.84	2.44	0.83	0.19
19		E219 (SA08, B4, P2) White Silk Chiffon, both arms uncovered	65	0.74	0.32	1.44	0.47	0.75	0.18	0.05	0.06	0.02	2.15	1.83	0.79	0.18






20		E220 (SA08, B4, P2) White Silk Chiffon, right arm covered, pleated pallu	73	0.81	0.35	1.61	1.02	0.63	0.72	0.04	0.29	0.02	2.12	1.85	0.82	0.19
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Table 5. (Contd) Clothing Insulation of saris for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
21		E221 (SA10, B3, P4) Pochampalli Handloom cotton, both arms uncovered, pleated pallu	65	0.78	0.31	1.29	0.68	0.83	0.18	0.04	0.01	0.02	1.99	2.13	1.13	0.08
22		E222 (SA10, B3, P4) Pochampalli handloom cotton Left arm covered unpleated pallu	73	0.81	0.28	1.13	0.38	0.89	0.18	0.72	0.04	0.10	2.40	2.21	1.12	0.18
23		E223 (SA10, B3, P4) Pochampalli Handloom Cotton, Right arm covered, pleated pallu	73	0.89	0.26	1.77	0.86	0.68	1.21	0.04	0.74	0.03	1.93	2.26	1.13	0.19
24		E224 (SA10, B3, P4) Pochampalli Handloom cotton, both arms covered	81	0.96	0.30	1.61	1.42	1.03	1.09	0.71	0.49	0.07	2.35	2.14	1.19	0.20
25		E225 (SA11, B7,P3) Heavy Crepe Silk, both arms uncovered	65	0.72	0.27	1.32	0.56	0.86	0.22	0.03	0.05	0.03	1.01	1.45	1.18	0.25
26		E226 (SA11, B7, P3) Heavy Crepe Silk, Left arm covered, unpleated pallu	73	0.81	0.28	1.06	0.33	0.81	0.22	0.65	0.04	0.03	2.05	2.09	1.32	0.29
27		E227 (SA11, B7, P3) Heavy Crepe Silk, Right arm covered, Pleated pallu	73	0.82	0.33	2.02	0.98	0.56	1.06	0.02	0.44	0.02	1.31	1.40	1.14	0.24
28		E228 (SA11, B7, P3) Heavy Crepe Silk, both arms covered	81	0.95	0.21	2.24	1.18	0.87	1.20	0.61	0.45	0.12	1.93	1.99	1.21	0.26





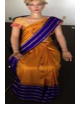





29		E229 (SA12, B3,P3) Red Polyester Nylex, both arms uncovered	65	0.78	0.28	1.39	0.65	0.67	0.13	0.04	0.02	0.01	1.75	2.13	1.01	0.28
30		E230 (SA12, B3, P3) Red Polyester Nylex, Left arm covered unpleated pallu	73	0.81	0.26	1.16	0.64	0.86	0.11	0.51	0.05	0.05	1.96	2.43	0.93	0.25

Table 5. (Contd) Clothing Insulation of saris for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
31		E231 (SA12, B3, P3) Red Polyester Nylex, Right arm covered, pleated pallu	73	0.86	0.27	1.95	1.11	0.75	0.73	0.05	0.38	0.02	1.83	2.12	0.96	0.18
32		E232 (SA12, B3, P3) Red Polyester Nylex, both arms covered	81	0.91	0.27	1.47	1.15	1.09	0.60	0.49	0.36	0.09	2.10	2.29	0.90	0.26
33		E233 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, both arms uncovered	65	0.79	0.25	1.38	0.33	0.65	0.19	0.04	0.05	0.02	1.93	2.38	1.41	0.48
34		E234 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, Left arm covered, unpleated pallu	73	0.88	0.17	1.22	0.54	0.87	0.19	0.87	0.04	0.13	2.23	2.71	1.41	0.43
35		E235 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, Right arm covered pleated pallu	73	0.91	0.25	2.15	1.06	0.43	1.28	0.03	0.55	0.03	1.99	1.95	1.44	0.43
36		E236 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, both arms covered	81	1.03	0.16	1.86	1.31	0.98	1.18	0.84	0.53	0.09	1.98	2.69	1.69	0.44
37		E237 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, right arm covered Pleated pallu with Shawl	81	0.90	0.39	1.98	1.01	1.55	1.18	1.28	0.68	0.11	0.82	1.50	1.29	0.43
38		E238 (SA13, B7, P4) Ochere Kanchi Silk Gold Zari, both arms covered with Shawl	81	1.17	0.10	3.32	2.07	2.31	1.51	1.96	0.67	0.20	2.18	2.60	1.56	0.49



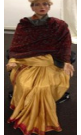



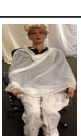
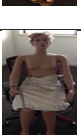



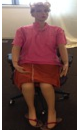
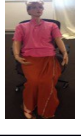

39		E239 (SA15, B7, P4) Benaras satin silk both arms uncovered	65	0.86	0.31	1.52	1.00	1.18	0.22	0.04	0.01	0.02	2.25	2.54	1.42	0.37
40		E240 (SA15, B7, P4) Benaras satin silk Right arm covered, pleated pallu	73	0.94	0.29	1.99	1.30	1.22	1.20	0.02	0.50	0.06	2.13	2.21	1.43	0.28
41		E241 (SA15, B7, P4) Banaras Silk Right arm covered Pleated pallu with Shawl	81	1.20	0.09	5.24	2.32	3.40	1.66	1.07	0.84	0.06	2.63	2.85	1.38	0.27

Table 6. Clothing Insulation of Salwar-kurti, Pancha, Lungi and Dhoti for whole body and sixteen segments

SNo.	Clothing ensemble	Codes of Ensemble sari, bodice, petticoat and details of drape	BSAC (%)	Whole-body	Head	Chest	Back	Shoulder_L	Shoulder_R	Lower arm_L	Lower arm_R	Hand	Pelvis	Thigh	Lower leg	Foot
1		E301 (SK01, K2) Light Cotton Loose fit Salwar, full sleeve kurti	81	0.76	0.27	1.17	0.87	0.64	0.69	0.47	0.45	0.07	1.40	1.22	0.58	0.20
2		E302 (SK01, K2, C1) Light Cotton Loose fit Salwar, kurti, Voile Dupatta multi folded into V shape	81	0.80	0.29	1.90	1.32	0.76	0.90	0.56	0.43	0.05	1.60	1.28	0.44	0.17
3		E303 (SK01, K2, C1) Light Cotton Loose fit Salwar, Kurti, half folded Voile Dupatta covering chest, arms	81	0.86	0.21	2.41	1.09	1.55	1.68	0.72	0.63	0.07	1.65	1.25	0.50	0.17
4		E303 (SK01, K2, C1) Light Cotton Loose fit Salwar, Kurti, single layered Voile Dupatta fully covering arms	81	0.91	0.29	2.42	1.30	1.39	1.22	1.04	1.09	0.15	1.95	1.54	0.60	0.16
5		E401 (DH 02) Handloom Pancha, Panty, Folded up		0.53	0.22	0.03	0.05	0.03	0.04	0.04	0.03	0.02	1.52	1.72	0.07	0.10
6		E402 (DH02) Handloom Pancha, Panty, Ankle length		0.58	0.24	0.06	0.04	0.02	0.02	0.01	0.00	0.05	1.07	1.40	0.92	0.32
7		E403 (DH02, K3, UG3) Handloom Pancha, Vest, Kurti, Panty, Folded up		0.70	0.27	1.46	1.35	0.67	0.73	0.05	0.07	0.02	1.87	1.71	0.10	0.11
8		E404 (DH02, K3, UG3) Handloom Pancha, Vest, Kurti, Panty, Ankle length		0.78	0.28	1.32	1.10	0.73	0.72	0.04	0.04	0.02	1.82	1.42	0.93	0.35

9		E405 (LU102, K3, UG3) Handloom Lungi, Vest, Kurty panty, Ankle length	0.75	0.24	1.37	1.06	0.67	0.54	0.03	0.05	0.01	1.52	1.70	0.64	0.23
10		E406 (LU102, K3, UG3) Handloom Lungi, Vest, Kurty panty, Folded up	0.69	0.27	1.52	1.11	0.68	0.64	0.06	0.05	0.01	1.52	1.46	0.13	0.13
11		E407 (DH01, K3, UG3) Handloom Dhoti, Vest, Kurty, Panty,	0.73	0.33	1.35	1.07	0.75	0.72	0.06	0.04	0.00	1.88	1.68	0.45	0.14

4 Discussion

We tested the saris in four weight categories: Super light (180 – 240 g), light (300 – 330 g), medium (430 -500 g) and heavy (500 -800 g). As can be noted in the above tables each sari ensemble is tested for two to four different variations of drape in the upper body keeping the nether garment ensemble unaltered. These drapes are: Pleated pallu with both hands exposed, unpleated pallu with left arm exposed, pleated pallu with right arm covered and left arm exposed, unpleated pallu with both arms covered. For a heavy sari generally used in winter we also tested with an acrylic shawl.

4.1 Effect of drape

Heavy weight saris generally had higher insulation, for a given drape. For example, in a drape with pleated pallu having both arms exposed, the clo value variation was as much as 21% between super lightweight and heavy category saris (E205 and E239). Similarly when both the arms are covered, the clo value varied a bit lesser: by 13% between lightweight and medium weight saris tested in this experiment.

However, for a given sari, blouse, petticoat ensemble drape in the upper body alone had a substantial effect on the clothing insulation value of the total ensemble. The variation due to drape in a given garment combination was noted to be varying from 7.7% to 40.1%. Understandable, the lower variation was in lightweight saris, generally used in summer.

Similar variations in clo value due to the drape are noted in other three attires tested: Salwar-kurty, Pancha and Lungi.

4.2 Comparison with other's results

The clothing insulation offered by an ensemble directly relates to the surface area of the body enveloped by the garments. This area is referred to as body surface area covered (BSAC)[CITATION McC83 \l 1033]. The BSAC varied from 65% to 81% while the clo value varied between 0.71 clo to 1.20 clo.

For example, the clo value varied between 0.71 clo and 0.91 clo for summer ensembles (very light and lightweight saris, (i.e., weight within 180 – 330 g range) giving 28% variation. With winter ensembles, we recorded an increase in clo value from 0.72 clo to 1.26 clo (67 % variation). These are typically medium to heavy weight saris (weight range: 430 – 800 g), and lightweight shawls.

The wearers can achieve this variation without adding any new pieces of garments to the ensembles, just by changing the drape. Indraganti [CITATION Mad \n \t \l 1033] 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.

These values matched closely with the values obtained in our previous experiment and others [CITATION Mad151 \l 1033 \m Mit01 \m Hav13]. 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 [CITATION FFA08 \l 1033] 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) [CITATION July13 \l 1033], 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.

5 Conclusions

In a climate chamber study using a Danish manikin we measured the traditional ensembles both women and men use in the South Asia and elsewhere. This paper presented these results. We measured 41 sari ensembles in nivi style of draping using very light weight, lightweight medium weight and heavy weight saris. These saris were in typical fabrics that women wear typically to work, such as: light cotton, voile, georgette, handloom fine cotton, Khadi silk, crepe silk, polyester, nylon, Kota Super-net and Kanchi silk (heavy mulberry silk). We testing using four types of drapes commonly noted in offices: pleated pally with both arms exposed, pleated pallu with right arm exposed, unpleated pallu with left arm exposed, both arms covered.

Clothing insulation of lighter weight saris used in summer varied between 0.71 clo and 0.91 clo and medium to heavy weight saris generally used in monsoon and winter varied from 0.72 - 1.20 clo, with the higher insulation being achieved by additional acrylic shawl. It means that the sari ensemble can effortlessly offer 28 - 67% change in insulation by draping differently and by simple addition of a light shawl. Similar improvement of 14 -20 % is possible in the other traditional ensemble, Salwar-kurti by draping the dupatta, a thin accouterment worn on the upper body.

The possibility of clothing insulation adaptation in the Pancha was found to be much higher, from 0.53 clo to 0.78 clo among the four drapes tested. It means that men can alter their clothing insulation by as much as 47% in this traditional ensemble. By folding the lungi up to the knee length, we noted the clo value reducing by 9%. The Dohti, another traditional ensemble was found to have a clo value of 0.73, similar to a light sari ensemble.

The values obtained in this study are a valuable addition to the clothing insulation databases, as these are frequently used simulation studies for HVAC systems design. Accommodating appropriate clothing insulation values in the design ensures higher

acceptability of the thermal environments and reduced energy use. Therefore, the fundamental data provided in study assumes great significance.

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